Health economic aspects of childhood excess weight

A thesis submitted for the degree of Doctor of Philosophy

Oluchukwu Onyimadu

Approximate word count: 59,800

Trinity 2024

This thesis is dedicated to my parents (Ajuluchukwu and Anthonia) and my brothers—Chimdi (along with Lila, Levi, and Nathan), Toto, Afam (together with Rebecca and Chiamaka), and Chukwu—with profound gratitude for their steadfast support and encouragement.

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Abstract

Background: Over the past four decades, the prevalence of childhood excess weight has risen significantly globally and remains high in many countries. In England, the prevalence of excess weight among Year 6 children (10–11-year-olds) increased from 31.6% in 2006/07 to 36.6% in 2022/23. Despite the increasing public health burden, substantial uncertainty persists regarding key economic parameters and outcomes necessary to guide research and inform policy for the efficient allocation of resources that target childhood excess weight.

Methods: This thesis presents a structured review of economic aspects of childhood excess weight as a foundation for further analyses. A systematic review of economic evaluations of interventions targeting childhood excess weight was conducted, followed by an analysis of data from the UK Millennium Cohort Study to estimate transitions in childhood weight status. Additionally, electronic health records extracted from the Clinical Practice Research Datalink (CPRD), linked with Hospital Episode Statistics (HES), were analysed to estimate direct healthcare costs attributable to childhood excess weight.

Results: The systematic review found that early prevention strategies for childhood excess weight are generally cost-effective. Analysis of data from the Millennium Cohort Study indicated that children aged 3 to 7 years had a significantly higher probability of transitioning from overweight or obesity to a healthy weight compared to older children, with more than twice the annual likelihood of such transitions. These movements between weight status categories were also influenced by child, maternal, and sociodemographic factors. My analyses of CPRD-HES data revealed that children living with overweight and obesity incurred significantly higher direct healthcare costs than their peers with a healthy weight. In comparison to children with healthy weight, those living with overweight generated additional costs of £133.93 and £66.32, on average, in the year preceding and following a BMI measurement, respectively, while children with obesity incurred additional costs of

£115.47 and £154.51, on average, during the same periods. The total annual healthcare cost attributable to childhood excess weight in England was estimated at £0.3 billion.

Conclusions: This thesis identifies critical areas for future economic research, offering insights for researchers and policymakers. It underscores the significance of investing early in cost-effective interventions to address childhood excess weight. The evidence presented in this thesis can serve as data inputs for future economic evaluations in this field.

Acknowledgements

I would like to express my sincere gratitude to all those who have accompanied me throughout this DPhil journey and thank them for their support. Foremost, I extend my deepest thanks to my four supervisors—Stavros, Mara, Nerys, and Alison—each of whom has been consistently available to offer guidance, support, and invaluable insights that have significantly enriched my work. I am incredibly grateful to Stavros, who encouraged me to pursue this National Institute for Health and Care Research (NIHR)-funded project and has continually motivated and challenged me to write and publish my research. I also thank the NIHR Applied Research Collaboration (ARC) Oxford and Thames Valley for its financial support.

I would like to acknowledge my colleagues and friends in the Health Economics and Policy Evaluation team and the broader Nuffield Department of Primary Care Health Sciences at the University of Oxford for fostering a supportive and collegial work environment. I would also like to thank Cynthia Drakesmith and the Clinical Practice Research Datalink (CPRD) team in the Department for facilitating my use of CPRD-Hospital Episode Statistics (HES)-linked data for this thesis.

Throughout my DPhil research and academic career, I have been fortunate to be mentored by esteemed senior researchers, including Prof Joanne Lord, Prof Ibrahim Abubakar, the late Prof Olajire A. Adegoke, Prof Subhash Pokhrel, Prof Nana Kwame Anokye, Prof Chimezie A.B. Osigweh, Prof Kunle Idowu, Prof Titilayo Fakeye and Prof Susan Jebb. Their guidance has been instrumental to my development.

Finally, I am deeply thankful to my family and friends, particularly Obinna Onyimadu (along with Sinmi, Zoe and Abigail), Maria K. Norton, Kene Diobi (together with Nneka, Zorina and Zina), Eugene Nwoke (Chimerem), Oluwole Bamgboye, Benneth Chukwuemeka, Idowu Akinwande, Ifeanyi Metuh, Ifeanyi Maduka, Roderick Delanougerede, Janneke, Chidera Awoh and many others for their unwavering love and encouragement.

Abbreviations

%OBMI: percent over BMI
AIC: Akaike Information Criterion
AQoL: Assessment of Quality of Life
BIC: Bayesian Information Criterion
BMI: body mass index
CBA: cost-benefit analysis
CCA: cost-consequences analysis
CDC: Centres for Disease Control and Prevention
CEA: cost-effectiveness analysis
CEAC: Cost-effectiveness acceptability curves
CHD: coronary heart disease
CHEERS: Consolidated Health Economic Evaluation Reporting Standards
CHU-9D: Child Health Utility-9 dimensions
CMA: cost-minimisation analysis
CPI: Child Poverty Index
CPRD: Clinical Practice Research Datalink
CUA: cost-utility analysis
DALY: disability-adjusted life year
DKK: Danish crowns
DSA: deterministic sensitivity analysis
EHR: Electronic Healthcare Record
EMR: Electronic Medical Record
EQ-5D: EuroQol-5 dimensions
EQ-5D-Y: EuroQol 5Dimension Youth version
ESPGHAN: European Society for Paediatric Gastroenterology, Hepatology and Nutrition
GBP: British pound sterling
GLM: generalised linear model
GP: general practice/practitioner
GPA: grade point average
GPBM: generic preference-based measures
HES: Hospital Episode Statistics
HFSS: high in fat, sugar and salt
HRQoL: health-related quality of life
HSUV: Health state utility values
HUI: Health Utilities Index
ICER: incremental cost-effectiveness ratio
IHME: Institute for Health Metrics and Evaluation
IMF: International Monetary Fund
IOTF: International Obesity Task Force
IWQOL-Kids: Impact of Weight on Quality of Life – Kids
LAGB: laparoscopic adjustable gastric banding
LMIC: low and middle-income countries
LSAC: Longitudinal Study of Australian Children

MAUI: multi-attribute utility instrument
MCS: Millennium Cohort Study
MET: metabolic equivalent
ML: maximum likelihood
MVPA: moderate-to-vigorous physical activity
NCD: non-communicable disease
NCMP: National Child Measurement Programme
NHANES: National Health and Nutrition Examination Surveys
NHS: National Health Service
NICE: National Institute for Health and Care Excellence
NIHR: National Institute for Health and Care Research
OECD: Organisation for Economic Co-operation and Development
OLS: ordinary least squares
PBAC: Pharmaceutical Benefits Advisory Committee
PedsQL: Paediatric Quality of Life Inventory
PHE: Public Health England
PIAT: Peabody Individual Achievement Test
PLN: Polish zloty
PPP: Purchasing power parity
PSA: probabilistic sensitivity analysis
QALY: quality-adjusted life years
RCT: randomised controlled trial
RUC: rural-urban classification
RYGB; laparoscopic Roux-en-Y gastric bypass
SD: standard deviation
SDI: sociodemographic index
SES: socioeconomic status
SG: laparoscopic Sleeve Gastrectomy
SII: slope index of inequality
SSB: sugar-sweetened beverage
SWiM: Synthesis Without Meta-analysis
TTO: time trade-off
UK: United Kingdom
US: United States
VAS: visual analogue scale (VAS)
WAItE: Weight-Specific Adolescent Instrument for Economic Evaluation
WC: waist circumference
WHO: World Health Organisation
WHtR: waist-to-height ratio
WTP: willingness to pay; SES: socioeconomic status
ZINB: zero-inflated negative binomial regression model
ZIP: zero-inflated Poisson regression model

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Chapter 1 Introduction

1.1 Background

Excess weight results from an imbalance between energy intake and expenditure, leading to adiposity or the accumulation of body fat to levels that detrimentally impact metabolic function and psychosocial outcomes.[1-3] Childhood excess weight, encompassing both childhood overweight and childhood obesity (defined in clinical assessments through UK-WHO growth charts as a Body Mass Index above the 91st and 98th centiles, respectively[4,5]) is a significant public health issue with far-reaching consequences. In the short term, children with excess weight are at a higher risk of developing mental health disorders compared to their healthy-weight peers.[6] Adolescents with obesity tend to report poorer outcomes in education with potential knock-on effects on human capital development and societal costs.[7] In the long term, childhood excess weight increases the likelihood of adult obesity[8-10], which imposes substantial healthcare and indirect costs on society.[11] Several highly prevalent noncommunicable diseases in adult populations have been linked to chronic childhood excess weight, making it a top public health priority for high-income countries and emerging economies.[6]

Amid these health and economic concerns, numerous countries have experienced significant increases in the prevalence of childhood excess weight. Between 1990 and 2022, the age-standardised prevalence of obesity among children and adolescents aged 5 to 19 years across 200 countries rose sharply.[12] In the majority of the surveyed countries, the prevalence of obesity more than doubled, and many nations witnessed a significant shift from underweight dominance to obesity dominance. This transition underscores a critical change in the global health landscape. In England, data from the National Child Measurement Programme (NCMP) reveal that the prevalence of excess weight among Year 6 children (10-11-year-olds) increased from 31.6% in 2006/07 to 36.6% in 2022/23.[13] Globally, an estimated 37 million children under the age of 5 were classified as overweight in 2022.[14]

Intervention strategies for managing excess weight, whether aimed at maintaining optimal energy balance through prevention or reversing energy imbalance through treatment, are increasingly reflecting the multi-faceted nature of this complex chronic condition.[15] Health economics and related disciplines provide robust approaches and tools for exploring determinants, quantifying consequences, and assessing the benefits and value of interventions spanning the natural history and management pathways of overweight and obesity in childhood.[16-18]

1.2 Weight status classifications, references, and body composition assessment in children

Body mass index (BMI), a person's weight in kilograms divided by the square of their height in metres (kg/m^2), is generally accepted as a proxy measure for adiposity[19], and fixed cut-off points are used to define overweight or obesity in adults.[20] Due to the ongoing growth in height among children, age- and sex-specific thresholds—expressed as centiles (or percentiles) or BMI standard deviation (BMI z-scores)—are employed to categorise weight status during childhood. These weight status classifications place the child in a relative position compared with other children of the same age and sex. To determine a child's weight category, their BMI centile is looked up on a reference chart of BMI by age and sex.

The United Kingdom and several other countries have developed their references using local data (growth curves), and BMI interpretations (cut-off points) vary considerably across countries. For instance, using the UK-WHO growth charts, BMIs above the 91st and 98th centiles suggest overweight and obesity in clinical assessment, respectively[4,5], while for population monitoring, the 85th and 95th centile cut-offs are indicative of overweight and obesity, respectively.[21,22] The Centres for Disease Control and Prevention (CDC) definition (above the 85th and 95th centiles for overweight and obesity, respectively) is the preferred reference in the United States.[23]

In addition to country-specific references, a few standards are recommended for international use, such as those developed by the World Health Organization (WHO) [24,25] and the International Obesity

Task Force (IOTF).[26] The application and challenges involved in applying international references are well documented in the literature.[4,27-30] For example, the WHO references and cut-off points take a cautious approach when classifying children under five years old, aiming to avoid the imposition of restrictive diets on young children.[29] However, when this global standard is applied to the UK childhood population, it results in a lower percentage of children under five being classified as overweight or obese. International charts are often implemented for children between 0-4 years of age in the United States and most European countries. However, many countries revert to national references for children five years and above because growth patterns during mid and late childhood vary significantly across countries. For consistency, the primary analyses in this thesis are based on the British 1990 growth reference (UK90) and UK cut-offs for population monitoring, which are used for most published studies on obesity and overweight among children in the UK.[22] Childhood weight status classifications based of these UK cut-offs are: less than or equal to the 2nd centile (underweight), greater than the 2nd and less than the 85th centile (healthy weight), greater than or equal to the 85th and less than the 95th centile (overweight), and greater than or equal to the 95th centile (obesity).[22]

Other anthropometric measures of adiposity include skinfold thicknesses and arm, waist, hip, or thigh circumferences. These measures generally correlate with BMI and do not offer significant performance improvements over BMI due to measurement and reproducibility challenges.[31,32] While BMI is typically used to assess body fat in children over two years of age[2,33-35], anthropometric measures such as weight-for-age, height (or length)-for-age and weight-for-height are reserved for young children aged less than two years old.[36] A recent study indicated that waist circumference-to-height ratio could be a better measure of excess fat mass than BMI and should be considered an additional metric for central adiposity in future population studies.[37] Sophisticated methods of measuring adiposity and body composition, such as hydrometry, bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry (DXA) and magnetic resonance imaging (MRI), offer

improvements in terms of precision but are more expensive than measuring BMI or require more rigorous technical training for implementation.[38,39]

While BMI has gained wide acceptance among health practitioners, children, and parents, parental and self-reported measures are prone to biases and uncertainties, and researchers are advised to be cautious when analysing data reporting such measures.[40] Other body fat assessment methods will continue to complement BMI, but given its cost advantage, BMI will likely remain the first choice in routine practice for the foreseeable future.

1.3 Epidemiological aspects of childhood excess weight

Trends and subpopulation disparities in the prevalence of childhood excess weight

While the prevalence of underweight has declined in many countries[12,41], the prevalence of childhood excess weight has shown sharp upward trends over the past 40 years.[42] Globally, the prevalence of children and adolescents aged 5 to 19 with excess weight has surged from 8% in 1990 to 20% in 2022.[14] The WHO estimated that 37 million children under 5 were overweight in 2022.[14]

There are variations in obesity prevalence by sex, age, ethnicity, and socioeconomic status (SES). In a 2014 study among European children between ages 2 and 10, a higher prevalence was observed among girls than boys (21.1% vs. 18.6%) and children in population groups with low SES.[43] In a Portuguese study conducted in 2021 that used parents' education as a proxy for SES, children with parents in the highest education level had a lower prevalence of excess weight than their counterparts from low and medium education levels.[44] Similarly, a Spanish study conducted in 2020 reported an increase in the prevalence of overweight and obesity among children from the most deprived areas and with non-Spanish nationalities.[45] In the United States, analyses of 2013-2016 National Health and Nutrition Examination Surveys (NHANES) data showed significant increases in the prevalence of obesity and severe obesity among children with lower educational attainment of household head.[46]

In England and Wales, the National Child Measurement Programme (NCMP), a mandated annual programme that measures the height and weight of school children in Reception (4-5-year-olds) and year 6 (10-11-year-olds), reported a decrease in the prevalence of excess weight for all Reception-aged pupils except in the most deprived areas between 2006/07 and 2019/20.[47] Ethnic variations in prevalence were also reported. Year 6 boys and girls saw an upward trend in the prevalence of excess weight due to increases amongst pupils from the more deprived neighbourhoods.[47] These SES disparities mirror those across Europe and the United States, with widening socioeconomic inequalities in excess weight across all age groups and both sexes. Figure 1 and Figure 2 show sharp upward trends in excess weight for ethnic minorities across most weight categories.

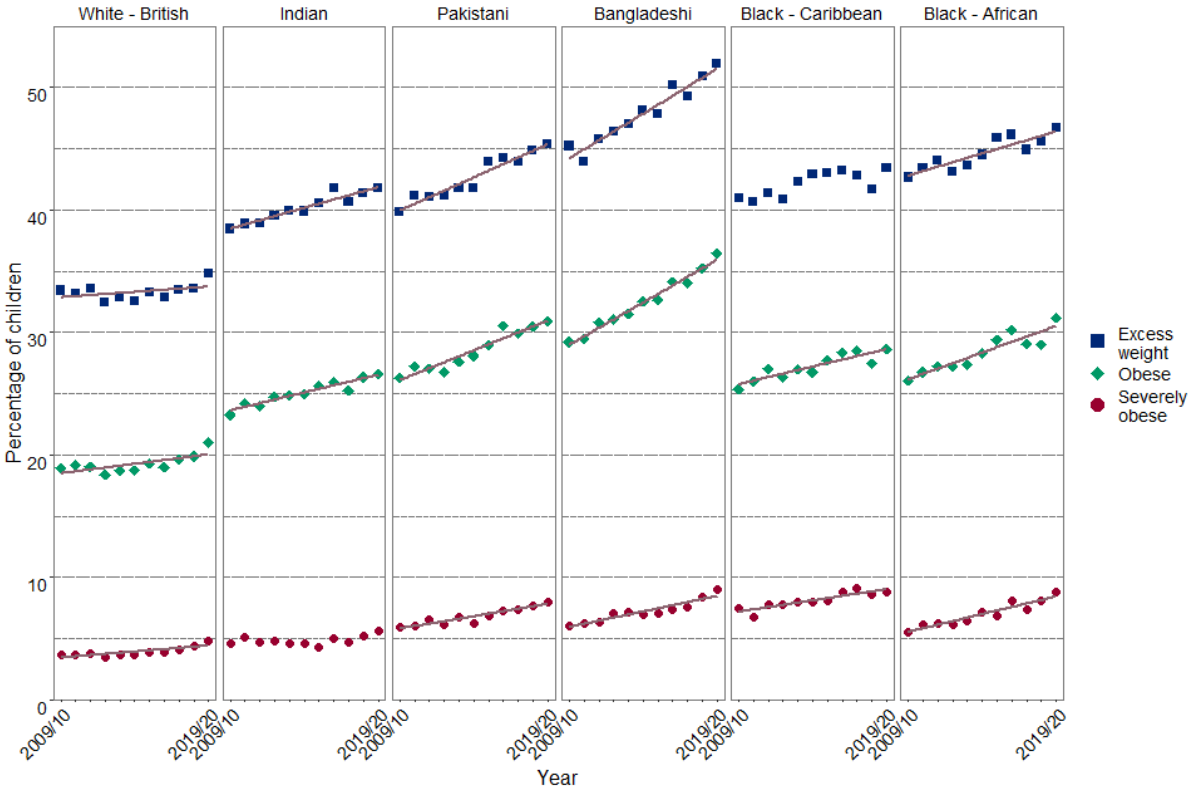

Figure 1 Prevalence of excess weight by weight classification and ethnicity for year 6 boys

(Source: PHE[47]). Significant upward linear trends are indicated with a red line.

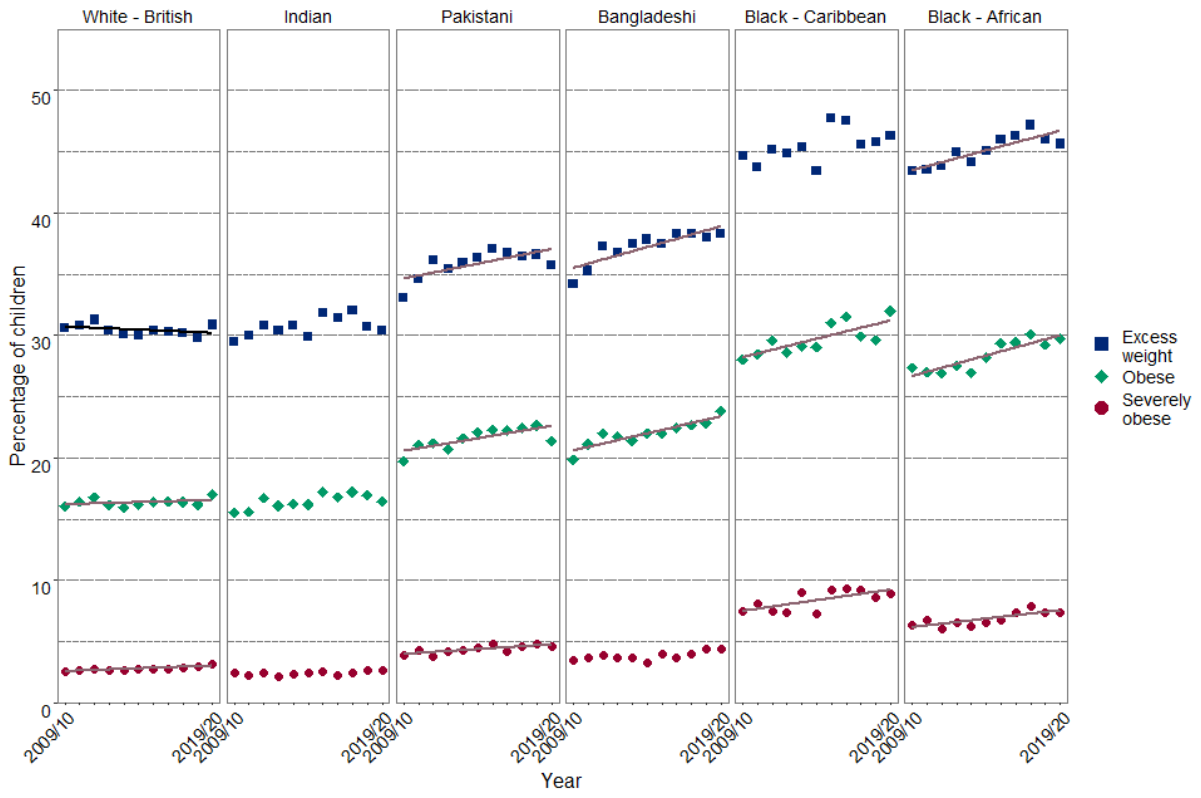

Figure 2 Prevalence of excess weight by weight classification and ethnicity for year 6 girls

(Source: PHE[47]). Significant upward linear trends are indicated with a red line, and downward linear trends are indicated with a black line (White-British and excess weight).

Risk factors for childhood excess weight

It is well established that excess weight results from a prolonged imbalance between energy intake and expenditure.[1-3] However, despite the extensive body of research exploring the epidemiological determinants of childhood obesity, there remains significant uncertainty regarding its specific risk factors. The main challenges with linking risk factors to childhood excess weight arise from the inherent limitations of cross-sectional studies, and insufficient sample sizes as well as measurement errors in prospective studies exploring dietary intake, physical activity and obesogenic environments.[48]

First 1,000 days - from conception to age 2

A systematic review examining 282 studies on risk factors for childhood obesity from conception to age 2 years categorised epidemiological determinants as biological, community, family,

environmental, infant behavioural risk factors and infant feeding practices.[49] The review identified several risk factors consistently associated with childhood obesity, including higher maternal pre-pregnancy body mass index (BMI), prenatal tobacco exposure, excessive maternal gestational weight gain, high infant birth weight, and accelerated infant weight gain. Additionally, the review found that other potential risk factors, such as gestational diabetes, childcare attendance, weak maternal–infant relationships, low socioeconomic status (SES), reduced infant sleep duration, inappropriate bottle use, early introduction of solid foods before four months of age, and infant antibiotic exposure, were supported by a more limited number of studies.

A position paper evaluated systematic reviews, randomised controlled trials (RCTs) and large observational studies published between 2011 and 2020, which investigated the role of dietary patterns, food habits and lifestyle risk factors in the prevention of excess weight in children aged 0-18.[50] In general, the study found that parental eating behaviours are strongly associated with childhood obesity and recommended a multi-component approach for the prevention of childhood excess weight. Key findings and recommendations of this position paper are summarised below separately for the first 2 years of life and from 2 to 18 years.

First 2 Years of Life - breastfeeding and post-weaning

Compared with breastfeeding, formula feeding and not breastfeeding were associated with altered body composition in infancy and later excess weight, respectively. Breastfeeding for 6 months versus 4 months was associated with slower infancy growth rates in high-income countries. The effect on growth rate was more pronounced with exclusive breastfeeding. High protein intake during complementary feeding was associated with an increased risk of later excess weight.

The study did not find sufficient evidence to recommend a baby-led weaning approach. No evidence was found that reduced-fat cow's milk prevented childhood excess weight. Breastfeeding for extended durations was highly recommended. The study further recommended including an early

response parenting intervention as part of the multi-component childhood excess weight prevention approach.

From 2-18 Years

Sugar sweetened beverages (SSBs) were found to be positively associated with obesity, but the evidence around Mediterranean, Nordic, and vegetarian diets was insufficient. For eating behaviour, skipping breakfast was positively associated with obesity, while regular family meals were associated with excess weight gain prevention. Higher daily meal frequency was negatively associated with obesity. The consumption of high-density foods during snacking and larger portions, particularly energy-dense foods, was associated with excess weight. A negative link was deemed plausible between childhood obesity and a combination of increased physical activity and decreased sedentary time.

Water was recommended as a healthy alternative to SSBs. The consumption of breakfast and family meals were both recommended, but the evidence around the benefits of pro-, pre-, or synbiotics for obesity prevention was not sufficient to recommend their use. Children under 12 years were encouraged to eat at least five meals daily, and fruits and vegetables were considered healthy snack options. An average of 60 minutes of moderate-vigorous physical activity (MVPA) per day was recommended for children above the age of 3 years. The use of screen devices during mealtimes was discouraged. Screen time and sedentary behaviour were also discouraged.

The increasing prevalence of childhood excess weight and the widening inequalities in childhood excess weight across all ages of childhood necessitate the development of efficacious and cost-effective obesity interventions. These interventions should be informed by evidence on the individual risk factors previously discussed and should focus on either preventing excess weight (by maintaining appropriate energy balance) or treating it (by correcting caloric imbalance). However, uncertainties regarding many potential risk factors for childhood obesity continue to present significant challenges in the formulation of weight management guidelines. Further epidemiological

studies targeting specific subpopulations, including those defined by ethnicity, socioeconomic status, and other relevant factors, are essential to enhance the current understanding of causality and intervention efficacy.

Consequences of childhood excess weight

There is a growing prevalence of cardiometabolic complications typically observed in adults, such as Type 2 Diabetes Mellitus, Non-alcoholic Fatty Liver Disease (NAFLD), Obstructive Sleep Apnoea (OSA), and Dyslipidaemia, now emerging during adolescence.[2,51] In the short term, children with excess weight are also vulnerable to a range of psychosocial problems, such as depression, bullying, social isolation, low self-esteem, dissatisfaction with body image, suicidal ideation, and a diminished quality of life[2,3,52,53], as well as poorer educational outcomes.[7,54] There exists a potential for reverse causality between childhood obesity or interventions aimed at addressing excess weight in children and their subsequent effects. For example, dietary restriction interventions, though initially successful, may cause adolescents to develop unhealthy eating habits.[2]

Progress and challenges in approaches to childhood excess weight management

Contemporary lifestyle interventions typically target dietary habits and physical exercise to sustain a healthy caloric balance or address energy imbalance. Recent research has examined the shift of various lifestyle interventions from conventional, in-person settings to digital platforms and mobile applications.[55,56] These adaptations are linked with unique complexities and challenges, such as data ownership, protection, and cost uncertainties, which present a knowledge gap in assessing their value.[57,58] Overall, lifestyle approaches show only modest effects on weight loss[2] and methodological limitations in studies evaluating the effectiveness of interventions for childhood excess weight hinder the formulation of definitive recommendations.[59] Invasive procedures, including bariatric surgery, have demonstrated potential effectiveness; however, they are presently restricted to children experiencing severe obesity. Policy-driven strategies focused on altering obesogenic

environments, along with groundbreaking pharmaceutical interventions such as GLP-1 agonists, offer significant promise but require thorough and rigorous evaluation.[2]

1.4 The imperative for economic research on childhood excess weight

Excess weight during childhood is linked to broader societal consequences, including diminished academic performance, lower educational attainment, reduced economic productivity, and increased pressure on healthcare systems. The economic burden incurred by the public, whether through health insurance or taxation, underscores the necessity for government intervention. Economic research on childhood excess weight plays a pivotal role in healthcare policy development by providing evidence-based insights that enhance access to care, improve service quality, and ensure a favourable return on investment. This research encompasses various economic considerations, such as the economic evaluation of interventions targeting childhood excess weight and the estimation of costs associated with childhood excess weight. Economic evaluations are essential for assessing the cost-effectiveness of both current and prospective interventions, thereby assisting policymakers and healthcare providers in prioritising those interventions that offer the greatest health benefits relative to their costs. Additionally, cost-of-illness studies contribute to understanding the financial implications of childhood excess weight, guiding the efficient allocation of limited healthcare resources, including funding, medical personnel, and technologies, to effectively address the population's health needs.

1.5 Research objectives

This thesis aims to inform and guide the allocation of resources channelled towards preventing and treating childhood excess weight by quantifying associated resource use and costs and estimating parameters crucial for conducting studies that evaluate the cost-effectiveness of interventions targeting childhood excess weight. Therefore, my first objective in this thesis was to delineate and investigate four strands of research evidence underpinning health economic aspects of excess

weight among children. I conducted structured reviews of the identified research strands **(Chapter 2)**. The reviews revealed several knowledge gaps. A key finding was the paucity of studies that assessed the association between childhood weight status and the cost of healthcare services in many countries. In particular, estimates of the cost of illness associated with childhood excess weight, based on data extracted from electronic health records, are currently unavailable in the United Kingdom. Outdated systematic reviews of economic evaluations of interventions targeting childhood excess weight and uncertainties surrounding transitions between childhood weight status categories constituted further disparities of information on health economic aspects of childhood excess weight. Given these findings, the next objectives of this thesis are to:

- Undertake a systematic review, critically appraising and synthesising evidence from economic evaluations of interventions targeting childhood excess weight **(Chapter 3)**.
- Estimate the hazards of transitioning between childhood weight status categories and explore the impact of child, maternal, and sociodemographic characteristics on the aforementioned transition hazards **(Chapter 4)**.
- Estimate the economic costs associated with childhood excess weight from a health service perspective, using data within the Clinical Practice Research Datalink (CPRD)[60], an anonymised primary care database representative of the UK population, and linked Hospital Episode Statistics (HES) data **(Chapters 5, 6 and 7)**.

1.6 Structure of the Thesis

In Chapter 2, I delineate four research strands that underpin health economic aspects of excess weight among children, namely: economic costs associated with childhood excess weight; health utility values associated with childhood excess weight; economic evaluations of preventive and treatment interventions for children with excess weight; and economic determinants and broader consequences of childhood excess weight. The Chapter consists of scoping and narrative literature reviews based on my updated targeted searches of the most relevant and recent systematic reviews

focusing on the four individual research strands listed above. I conclude Chapter 2 by drawing summative conclusions across the four strands of evidence.

Chapter 3 presents a systematic review of economic evaluations of interventions targeting childhood overweight and obesity. This Chapter critically appraises and synthesises evidence based on systematic searches conducted in 11 databases, where interventions targeted children up to 18 years to prevent or treat childhood excess weight. Studies included in this review were also eligible if they aimed to improve diet or physical activity, regardless of the type of economic evaluation or study design.

In Chapter 4, I use the Millennium Cohort Study (MCS), a longitudinal survey of around 19,000 children born in the UK between 2000 and 2002[61], to develop Markov multistate transition models that estimate transition probabilities and hazard ratios for transitioning between childhood weight status categories and the impact of child, maternal, and sociodemographic characteristics on these transition parameters.

Chapters 5, 6 and 7 are based on my analyses of CPRD-HES-linked data.[60,62-66] Chapter 5 describes the methods and results of analyses for disaggregated primary healthcare services (primary care consultations, prescription items, and monitoring and diagnostic tests) in relation to childhood excess weight. Similarly, Chapter 6 reports methods and results of analyses for disaggregated secondary care health services (admitted patient care, outpatients, and accident and emergency) as they relate to childhood weight status. In Chapter 7, I present the analysis results of aggregated healthcare service costs and discuss the overarching findings covering Chapters 5 and 6, as well as the results of Chapter 7.

Finally, in Chapter 8, I summarise the findings from the work undertaken in this thesis and interpret them in the context of other relevant studies. Additionally, I identify the novel contributions of the work, considering policy implications and healthcare planning, and describe the limitations of the work and potential areas for future research.

1.7 Role of the author in the preparation of this Thesis

I was awarded a National Institute for Health and Care Research (NIHR) Applied Research Collaboration (ARC) Oxford and Thames Valley Doctoral Research Fellowship in October 2020 to undertake the research presented in this thesis. I led the research presented in this thesis, developing research questions, devising study designs and analysis plans, performing analyses, and preparing manuscripts and thesis chapters. My supervisors (Professor Stavros Petrou, Associate Professor Mara Violato, Associate Professor Nerys Astbury and Professor Alison Hayes) contributed to each aspect of this process for all research presented in this thesis. Professor Susan Jebb offered guidance in a supervisory capacity during the preparation of the initial chapters of this thesis and contributed as a co-author to two papers arising from my DPhil research.

Three health economists at the Nuffield Department of Primary Care Health Sciences (NDPCHS) (Dr Felix Achana, Dr May Ee Png and Dr Patrick Fahr) contributed to the research presented in Chapters 4-7. Specifically, Dr Felix Achana validated the MCS analysis I conducted in Chapter 4, while Dr May Ee Png and Dr Patrick Fahr provided expert advice on the CPRD-HES-linked analyses conducted in Chapters 5-7. Associate Professor José Leal at the Health Economics Research Centre, Nuffield Department of Population Health (NDPH), also gave expert advice on my CPRD-HES-linked analyses. Medical students from the University of Oxford and The Technical University Munich, Germany, constituted a "second reviewer" team that assisted with the systematic review I conducted in Chapter 3. I am the first author of the three papers published based on the research listed in this thesis (see Appendix A). The abstracts related to my DPhil research that were presented at conferences are also listed in Appendix A.

Chapter 2: Systematic Narrative Review of Studies on the Health Economic Aspects of Childhood Excess Weight

2.1 Introduction

This chapter provides a comprehensive summary of the evidence surrounding four key areas of research on health economic aspects of childhood excess weight. These areas include the economic costs associated with childhood excess weight, health utility values related to childhood excess weight, economic evaluations of interventions aimed at preventing and treating childhood excess weight, and the economic determinants and broader consequences of childhood excess weight. Sections 2.2, 2.3, 2.4 and 2.5 present narrative reviews based on updated targeted searches of the most pertinent and recent systematic reviews within each research area. Section 2.6 draws summative conclusions across the four strands of evidence. The work described in this chapter has been published in a peer-reviewed journal (Onyimadu, O., Violato, M., Astbury, N. M., Jebb, S. A., & Petrou, S. (2022). Health economic aspects of childhood excess weight: a structured review. Children, 9(4), 461.).[67]

2.2 Economic costs associated with childhood excess weight

2.2.1 Background and rationale for literature review

The economic burden of diseases linked to excess weight is substantial, often imposing significant costs on taxpayers and society.[18,68,69] Therefore, it is crucial for policymakers to comprehend the costs of childhood excess weight in relation to the value of prevention or treatment. For instance, decision-makers may be interested in estimating the impact on costs of hypothetical reductions in the prevalence of childhood excess weight[70], or the potential lifetime cost savings accrued from scenarios of varying intervention costs and effect sizes.[71] These potential cost savings, along with the

enhanced health outcomes that may result from reducing childhood excess weight, present a promising outlook.

A recent systematic review by Hamilton et al. 2018 included 13 studies and quantified the mean incremental lifetime direct and indirect costs of childhood overweight and obesity in high-income countries in Euros.[72] The review expanded upon the scope of a previous review[73] that focused only on studies in the United States and excluded indirect costs. Hamilton et al. reported considerable heterogeneity in methodological approaches and large inter-study differences in the cost estimates across the studies included in their review. However, they estimated the mean total lifetime incremental cost of a child with obesity to be €149,206 and €148,196 in Irish 2014 Euros for boys and girls, respectively. Productivity losses, specifically income penalties (employment-related financial disadvantages or reductions in income), were the major contributors to the estimated mean total incremental costs. The review by Hamilton and colleagues supports the findings of a previous systematic review[74], which concluded that for overweight and obesity in the general population, incremental costs associated with lost production exceed those associated with direct healthcare spending.

Several methodological issues and limitations in the review by Hamilton and colleagues raise fundamental concerns about the applicability of the derived mean costs. Firstly, some included studies do not meet the inclusion criteria stated by the authors in their review. In three of the included studies[75-77], the baseline age for weight measurement was 20 years, thus indicating that the studies did not estimate economic costs in adulthood attributable to childhood excess weight but rather excess weight in early adulthood. In another included study, the baseline age was 19 years.[78]

Secondly, the substantial heterogeneity between included studies arising from differences in populations, cost outcomes, and healthcare models presents doubts about the generalisability of the mean incremental costs estimated in the review. The estimated income penalties were driven by two studies conducted in the United States and Sweden[79,80], which reported percentage income loss.

These percentages were multiplied by the average annual earnings in Ireland to estimate the loss of earnings. The resulting cost estimates (€97,118 and €126,108 per capita for boys and girls, respectively) significantly exceeded those reported in another included study for the German population, which estimated discounted lifetime indirect incremental costs of €4,209 and €2,445 per boy and girl, respectively.[70] Finally, although the systematic review estimates are projected for all high-income countries, the reviewed studies covered only four countries: the US, Sweden, Germany, and the Netherlands.

Given the issues discussed above and the time elapsed (February 2016) since the searches conducted by Hamilton et al., a new systematic review is justified. Future reviews should strive for a broadened scope that includes both lifetime costs and studies covering a broad spectrum of time horizons. Given the time constraints associated with this DPhil, I conducted a focused literature search limited to Medline via Ovid, adapting the search strategy reported in the systematic review by Hamilton and colleagues. The search strategy was adapted from the systematic review by Hamilton and colleagues. The methods and results of this search, along with a discussion of the key findings, are presented below. Since the completion and publication of my searches, a more recent systematic review and meta-analysis by Ling and colleagues has been published.[81] However, due to the time limitations of this DPhil, it was not possible to evaluate this new review within this chapter. A comprehensive assessment is deferred to Chapters 7 and 8, where I estimate the costs attributable to childhood excess weight and contextualise my findings within the broader literature. It is important to note that some of the limitations discussed herein, such as concerns regarding generalisability, remain relevant to the systematic review by Ling and colleagues.

2.2.2 Methods

Search strategy

Details of the search strategy can be found in Appendix B (Table B 1). I adapted the PubMed search strategy used by the authors and additionally searched Medline via Ovid, covering studies published from 2016 to 14 January 2021. The eligibility criteria included studies where the age upon body

weight assessment fell during childhood, that compared children of different weight categories, e.g., healthy weight children versus children with obesity, and that reported economic costs across any time horizon. I excluded studies if the age at study entry exceeded 18 years; outcomes were not expressed in terms of economic costs, expenditures, or charges; or were not published in English.

In this narrative review, I identified and extracted key assessment items from the individual studies identified by my de novo searches as well as studies identified by the original review by Hamilton and colleagues[72] that met my refined inclusion criteria. To facilitate comparisons between studies, I extracted cost outcomes from individual studies and updated them using a web-based tool for adjusting cost estimates (the CCEMG—EPPI-Centre Cost Converter), expressing cost values in 2020 prices and British pounds sterling (GBP). The CCEMG— EPPI-Centre Cost Converter uses national price indices to inflate costs to a common price date and purchasing power parities (PPPs) provided by the International Monetary Fund (IMF) for currency conversions.[82] I assessed the quality of the included economic cost studies using 19 relevant items in the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement.[83] To ensure that the reviewed studies were scored fairly, I estimated separate denominators for the individual studies based on the relevance of individual CHEERS checklist items to each study design.

2.2.3 Results

Selection and inclusion of studies

My searches identified 1042 papers. After screening titles and abstracts and removing duplicates, 12 potentially relevant papers were identified. Six of them were excluded because they did not meet the eligibility criteria. I applied the same eligibility criteria to the 13 studies included in the systematic review by Hamilton et al.[72] I excluded seven of them[75-80,84] because they did not meet my eligibility criteria on baseline exposure age, estimated outcomes, or language in the full-text publication. I included 12 studies in my structured review, comprising six from the review by Hamilton et al.[70,85-89]and six from my de novo searches.[90-95]

Table 1 aggregates studies based on shared characteristics. All the studies identified in this review were conducted in high-income countries: seven in the United States (U.S.)[85-88,93-95], two in Germany [70,89], two in Australia[90,92], and one in The Netherlands.[91] Six of the economic cost studies[70,85-87,89,95] were based on decision-analytic models such as microsimulation models or state transition models, whilst five studies[88,90,92-94] were based on regression modelling of longitudinal datasets or panel data analysis. Only three studies[70,86,93] estimated indirect costs, and the study time horizon ranged from one year to a lifetime across all studies.

Table 1 Aggregate descriptive summary of economic cost studies

Study Characteristics	Number of Studies Identified
Year of publication	
2006–2010	3[85-87]
2011–2015	2[88,89]
2016–2020	7[70,90-95]
Country/Jurisdiction	
High-income	All
Low- and middle-income	None
Type of study design (or decision-analytic model, if applicable)	
Decision-analytical models	2[88,90-94]
Longitudinal study/panel data analysis	6[70,85-87,89,95]
Study perspective	
Direct costs	11[85-95]
Indirect costs	2[70,86]
Study time horizon	
Lifetime	5[70,85,87,89,95]
30 years	1[86]

10 years	1[94]
3 years	1[90]
1 year	4[88,91-93]

In Table 2, I report 12 key assessment items for individual studies, including type of study design, age range upon study entry, study time horizon, compared weight status groups, type of economic costs estimated, discount rates, estimated economic costs, and the overall quality score (%). The quality of studies ranged from 81% to 100% for the included studies, based on relevant items of the CHEERS checklist.[83]

Summary of Study Results— incremental Direct Costs

The studies estimating direct costs (resources consumed in the treatment or management of children with excess weight) associated with childhood excess weight differed in terms of the age at which weight status was measured and the study time horizon for cost estimation. The age ranges at study entry varied between 2 and 18 years. Hayes et al.[90] and Lightwood et al.[86] estimated direct costs between 2 and 5 years and 2 and 19 years, respectively. The baseline age for children in the study by Schell et al.[95] was 18 years. A discount rate of 3% was applied in most of the 11 studies that estimated direct costs where the study or model time horizon exceeded 1 year. Two studies[90,94] with time horizons of 3 years and 10 years of follow-up did not report any discount rates.

Statistical methods for cost estimation broadly followed either an econometric/regression analysis approach or a decision-analytic modelling approach. However, these approaches are umbrella terms that describe a collection of methodological approaches. The use of regression-based analyses to estimate costs was predominantly applied in studies with a time horizon of three years or less.[88,90,92-94] Among these studies, the two-part model specification, recommended as the choice statistical

model for handling the substantial skewness and mass of zeros often seen in health care cost data[96,97], was mostly applied or, when not applied, duly justified.[90] Two recent studies used an instrumental variable (IV) approach to assess the economic burden in Australia and the U.S.[92,93] Both studies utilised the BMI of biological parents as instruments for child BMI. Decision-analytic studies were conducted mostly through state-transition modelling[98] and tended to estimate costs over a lifetime horizon[85,87,89,95], except for the study by Lightwood et al.[86], where the time horizon adopted was 30 years.

There was marked variation in the type of economic outcomes estimated with a preponderance of studies that reported expenditures or charges rather than costs among studies conducted in the U.S. Four U.S.-based studies[87,88,93,95] reported various types of expenditure, whilst one[94] reported charges and costs. With the exception of the study by Kompaniyets et al.[94] that used the National Inpatient Sample (NIS) longitudinal database, all U.S.-based studies relied on expenditures from the Medical Expenditures Panel Survey (MEPS). A study conducted in The Netherlands by Wijga et al.[91] also estimated health care expenditures.

A further source of methodological heterogeneity between the reviewed studies involved direct cost components and time horizon. Estimated costs were primarily direct health care costs, but direct non-medical costs were sometimes estimated. For instance, Biener et al.[93] investigated the incremental annual out-of-pocket expenditure by families related to children aged 11 to 17. incremental lifetime health care costs were estimated at an individual level in three studies[85,88,95] or at a population level in one study.[87] Mean individual-level incremental lifetime costs relative to healthy weight ranged from GBP 1494 (pounds sterling, 2020 prices) for an 18-year-old black female with obesity in the study by Schell et al.[95] to GBP 13,260 (pounds sterling, 2020 prices) for a 9-year-old girl with obesity in the study by Fernandes.[85] Schell et al.[95] also estimated mean lifetime costs for white males, black males, and white females, which were GBP 16,525, GBP 10,970, and GBP 27,644, respectively (pounds sterling, 2020 prices), for children in the U.S. Fernandes[85] estimated a mean excess weight cost of GBP 10,214 for boys in the U.S., while Sonntag et al.[89] estimated a mean

lifetime excess weight cost of GBP 7432 and GBP 4507 per girl and boy, respectively, in Germany (pounds sterling, 2020 prices).

Trasande[87] estimated the total direct medical expenditures accrued in childhood and adulthood attributable to childhood overweight and obesity for boys and girls at GBP 2.69 billion and GBP 3.02 billion, respectively, in the U.S. population (pounds sterling, 2020 prices).[87] These lifetime values are not comparable to the mean annual direct cost of obesity of GBP 5.88 billion in the U.S. childhood population estimated by Biener et al.[93] or the GBP 40 billion cumulative incremental direct cost projected over 30 years from 2020 to 2050 by Lightwood et al.[86] (pounds sterling, 2020 prices).

Individual-level incremental mean annual direct costs were assessed in four studies and ranged from GBP 89[92] to GBP 1829[93] for excess weight (pounds sterling, 2020 prices). Ma and Frick[88] estimated incremental annual medical expenditure due to childhood obesity in the U.S. as GBP 234, while Wijga et al.[91] estimated mean incremental annual health care expenditure due to childhood excess weight in The Netherlands as GBP 217 (pounds sterling, 2020 prices). Black et al.[92] assessed incremental annual non-hospital Medicare costs per child in Australia of GBP 89 for excess weight, while Biener et al.[93] estimated incremental annual expenditure per child in the U.S. of GBP 1829 for obesity or severe obesity (pounds sterling, 2020 prices).

Summary of Study Results— incremental Indirect Costs

Only two of the included studies estimated indirect costs (i.e., the values of the time and resources of the children and/or their families taken up in the treatment or management of childhood excess weight, often in the form of work disability or loss of productivity). The age ranges at study entry varied between 3 and 18 years.

Sonntag et al.[70] estimated indirect costs associated with childhood excess weight, including the economic value of sickness absence and early retirement over a lifetime horizon in a baseline German population of children aged 3 years to 17 years. Per girl and boy, these projections were GBP 2586 and GBP 4451, respectively (pounds sterling, 2020 prices). While for boys, the estimated

incremental indirect costs were similar in magnitude to incremental direct costs, for girls, the incremental direct costs were nearly three times the incremental indirect costs, potentially due to lower lifetime earnings.

Lightwood et al.[86] investigated lost productivity due to morbidity or premature death associated with children and youths in the U.S. aged 12 years to 19 years over 30 years. In contrast to the GBP 39 billion incremental direct costs projected over 2020–2050 associated with childhood obesity, the authors projected an incremental indirect cost of GBP 180 billion over the same period (pounds sterling, 2020 prices).

Table 2 Descriptive analysis of the key assessment items for individual economic cost studies

First Author and Year of Publication	Country	Type of Study Design (or Decision-Analytic Model if Applicable)	Age Range upon Study Entry	Study Time Horizon	Exposures/ Measures of Weight Status Compared	Type of Economic Cost(s) Estimated	Currency Unit (Price Year)	Discount Rates	Sensitivity Analyses (Further Analytical Approaches)	Estimated Economic Costs*	Quality Score (%)
Fernandes, M. M. 2009[85]	United States	Cohort (Monte Carlo) simulation model	9 years	Lifetime	Obese versus healthy weight	Direct costs	U.S. dollars (2008)	3% annually	DSA and PSA	incremental lifetime costs of USD 12,047 and USD 15,639 per boy and girl, respectively	18.5/19 (97%)
Lightwood, J. 2009[86]	United States	Markov model	12 to 19 years	30 years	Obese versus healthy weight	Direct and indirect costs	U.S. dollars (2007)	3% annually	DSA	Projected (2020–2050) cumulative incremental direct, indirect, and total costs: USD 46 billion, USD 208 billion, and USD 254 billion, respectively	17.5/19 (92%)
Trasande, L. 2010[87]	United States	Cohort simulation model	12 years	Lifetime	Obese and overweight versus healthy weight	Direct costs	U.S. dollars (2005)	3% annually	DSA	Total direct medical expenditures (child and adult) attributable to childhood overweight/obesity for male and female is USD 2.94 billion and USD 3.3 billion, respectively	16.5/19 (87%)
Ma, S., and Frick, K. D. 2011[88]	United States	Panel data analysis (two-part regression model)	6 to 17 years	1 year	Obese versus healthy weight	Direct costs	U.S. dollars (2006)	3% annually	DSA (Controlled for covariates)	incremental annual medical expenditure: USD 264 per capita	15/17 (88%)
Sonntag, D. 2015[89]	Germany	Markov model	3 to 17 years	Lifetime	Obese and overweight versus healthy weight	Direct costs	Euros (2010)	3% annually	DSA	incremental lifetime direct costs (excess weight): EUR 7028 and EUR 4262 per girl and boy, respectively	19/19 (100%)
Sonntag, D. 2016[70]	Germany	Markov model	3 to 17 years	Lifetime	Obese and overweight versus healthy weight	Indirect costs	Euros (2010)	3% annually	DSA and PSA	incremental lifetime indirect costs (excess weight): EUR 2445 and EUR 4209 per girl and boy, respectively	19/19 (100%)
Hayes A. 2016[90]	Australia	Longitudinal cohort analysis (multivariable regression analyses)	2 to ≤5 years	3 years	Obese and overweight versus healthy weight	Direct costs	Australian dollars (2014)	Not stated	DSA (Controlled for covariates)	incremental mean 3-year health care costs: AUD 1608 and AUD 93 for an obese and overweight child, respectively	16/17 (94%)
Wijga, A. H. 2018[91]	The Netherlands	Longitudinal birth cohort analysis (Wilcoxon–Mann–Whitney test for	14 to 15	1 year	Overweight (including obesity) and non-overweight	Direct costs	Euros (2011)	NA	None reported	Mean incremental annual health care expenditure: EUR 221	13/16 (81%)

First Author and Year of Publication	Country	Type of Study Design (or Decision-Analytic Model if Applicable)	Age Range upon Study Entry	Study Time Horizon	Exposures/ Measures of Weight Status Compared	Type of Economic Cost(s) Estimated	Currency Unit (Price Year)	Discount Rates	Sensitivity Analyses (Further Analytical Approaches)	Estimated Economic Costs*	Quality Score (%)
		statistical significance)									
Black, N. 2018[92]	Australia	Longitudinal panel analysis (two-part regression model with IV estimator as base case)	6 to 13 years	1 year	Obese and overweight versus healthy weight	Direct costs	Australian dollars (2015)	NA	DSA (Controlled for covariates)	Incremental annual non-hospital Medicare costs per child: AUD 63 and AUD 103 for overweight and obesity, respectively and annual medical cost due to excess weight was AUD 43 million in the full childhood population	14/16 (88%)
Biener, A.I. 2020[93]	United States	Panel data analysis (two-part regression model with IV estimator as base case)	11 to17 years	1 year	Obesity and severe obesity versus healthy weight	Direct costs	U.S. dollars (2015)	NA	DSA (Controlled for covariates)	Per child for obesity and severe obesity, respectively, incremental annual medical expenditure: USD 907 and USD 1491 and incremental annual out-of-pocket expenditure: USD 25.79 and 37.36. Mean annual direct cost of obesity of USD 7.71 billion in the full childhood population	15/16 (94%)
Kompaniyets, L. 2020[94]	United States	Longitudinal study (two-part regression model)	2 to 19 years	10 years	Primary obesity diagnosis and secondary obesity diagnosis versus no obesity diagnosis	Direct costs	U.S. dollars (2016)	Not stated	(Controlled for covariates)	Incremental primary obesity diagnosis charges and costs: USD 20,879 and USD 6049, respectively. Incremental secondary obesity diagnosis charges and costs: USD 3453 and USD 1359, respectively	14/17 (82%)
Schell, R. C. 2020[95]	United States	Markov model	18 years	Lifetime	Obese versus healthy weight	Direct costs	U.S. dollars (2017)	3% annually	None reported	Incremental lifetime costs: USD 22,315, USD 14,813, USD 37,329, and USD 2018 for white males, black males, white females, and black females, respectively	17/19 (89%)

DSA: deterministic sensitivity analysis; IV: instrumental variable; NA: not applicable; PSA: probabilistic sensitivity analysis. * Estimated costs are expressed in the original currency and price year.

2.2.4 Discussion

Between study methodological variations

This review demonstrated that childhood overweight and obesity lead to significant short- and long-term incremental direct and indirect costs in high-income countries. Furthermore, this review revealed a number of gaps in the evidence base in this area. First, most of the studies were conducted in the U.S., with the remaining conducted in Australia, Germany, and The Netherlands. There is a paucity of evidence surrounding the economic costs of childhood excess weight in low- and middle-income countries. Second, only two studies estimated indirect costs, and third, there was a lack of clarity regarding the methodological approaches adopted by many of the reviewed studies.

The studies included in my review estimated that, in high-income countries, the mean incremental annual direct costs of overweight and/or obesity per child ranged between GBP 89 and GBP 1829 (pounds sterling, 2020 prices). Over a lifetime, incremental direct costs per child ranged from GBP 1494 to GBP 13,260 (pounds sterling, 2020 prices) in the reviewed studies. I observe that the annual estimates do not correspond proportionally to the lifetime estimates. Van Baal et al.[77] argue that incremental costs due to diseases unrelated to obesity in adulthood could potentially offset costs from obesity prevention. It is possible that the incremental costs due to overweight and obesity exhibit a non-linear increase from childhood to old age. Considering the substantive methodological differences across the reviewed studies, these ranges should be considered with caution.

Only two studies investigated indirect costs, limiting the usefulness of presenting value ranges. It has been suggested that indirect costs account for a greater share of total economic costs compared to direct costs[74], but the current literature on childhood excess weight is insufficient to establish this. The lifetime indirect cost projections by Sonntag et al.[70] show significantly lower costs for girls than boys. They argue that this difference is due to lower rates of full-time employment and lower lifetime earnings among women during adulthood.

Meta-analyses of economic costs, as attempted in the systematic review by Hamilton et al.[72], are unlikely to yield estimates that are generalisable across different jurisdictions and countries due to the high level of between-study heterogeneity stemming from the type of outcome estimated, as well as variations in health care practices and relative prices of resource inputs across settings. Charges and expenditures reported in most U.S.-based studies have been shown to differ considerably for a given procedure.[99] Further inter-study variability stems from

the body weight status categories compared, the population subgroups investigated, and the type of costs included in the analysis of individual studies. The global mean total lifetime incremental cost calculated in the systematic review of 13 studies by Hamilton et al.[72] for boys (GBP 142,258—pounds sterling, 2020 prices) is an extreme departure from the estimate by Sonntag et al.[70,89] (GBP 8958—pounds sterling, 2020 prices) for males in the German population and demonstrates the challenge associated with synthesising cost outcomes across studies.

Two studies that examined the impact of childhood excess weight on healthcare utilisation using an IV estimator found elevated utilisation for excess weight relative to a healthy weight when endogeneity was accounted for.[100,101] Among the six regression-based studies I identified, two studies conducted in Australia[92] and the U.S.[93] applied an IV estimator to mitigate omitted variable bias. In both studies, IV estimates of economic burden were significantly larger than non-IV estimates within the studies, as well as earlier and contemporary non-IV estimates from other studies. The authors suggested that measurement errors in children's BMI and unobserved variables could be responsible for the underestimated economic cost outcomes from non-IV estimates. The IV estimator is not without limitations. Primarily, when only one instrument is used—as in the reviewed studies—its validity cannot be fully established.

Strengths and Limitations

My review identified six additional studies since the systematic review by Hamilton et al., some of which applied new statistical methods for estimating economic costs associated with childhood excess weight. The main strength of my study is the review methodology, which entailed the presentation of costs in a common currency and price date, thereby aiding comparisons across study estimates and the use of narrative and tabular synthesis methods. The major limitation of my approach is that only one database was searched, and some studies of economic costs may, therefore, have been missed.

My quality assessment of the studies using the CHEERS checklist identified several areas for improvement in studies aiming to estimate the economic burden of childhood excess weight. Generally, these include applying a discount rate when the study time horizon exceeds one year, performing robust deterministic and probabilistic sensitivity analyses where appropriate, accounting for the variation in results across subgroups of patients where possible, reporting funding sources, and describing conflicts of interest. Future studies in this strand specific to

childhood populations should consider Mendelian randomisation, an IV method that uses selected genetic variants.[102]

2.3 Health utility values associated with childhood excess weight

2.3.1 Background and rationale for literature review

The literature on childhood bodyweight distribution is replete with studies centred on measuring health-related quality of life. A greater number of these studies measure general health profiles using generic instruments such as the Paediatric Quality of Life Inventory (PedsQL), Kid-KINDL and KIDSCREEN[103,104] or weight-specific quality of life using instruments such as Sizing Me Up[105], Sizing Them Up[106] and Impact of Weight on Quality of Life – Kids (IWQOL-Kids).[107] Both generic and weight-specific measures have their advantages[108] and most of the above-mentioned instruments can be applied in healthy as well as unhealthy or excess weight populations.

However, these generic and obesity-specific instruments are unsuitable for performing economic evaluations in resource allocation decision-making for three main reasons.[99] First, in most cases, they generate multiple scores across several domains rather than a single quality of life score. Second, the generated scores do not reflect the preferences of children, their parents, or the general public, and as such, higher scores do not necessarily indicate greater preference. Third, unlike the quality-adjusted life-year (QALY) measure where the quality adjustment weight (or utility value) is bound between the numeric values of zero and one representing death and full health respectively, a single value that captures quality and length of life cannot be produced by merging the multiple scores obtained from the type of instruments listed above[99,109]

Cost-utility analysis (CUA) is the method recommended for carrying out economic evaluations for healthcare decision-making by the National Institute for Health and Care Excellence (NICE), the Pharmaceutical Benefits Advisory Committee (PBAC) and several other health technologies regulatory bodies around the world.[110-112] CUA consists of an incremental cost component and an incremental QALY component. Health state utility values (HSUVs) or utilities for short, crucial elements in the calculation of QALYs, are numeric values that capture an individual's perceptions of a health state along with their time preferences and potential trade-offs with respect to that health state or competing health states.[99,109]

Utility elicitation techniques are broadly described as direct or indirect. Direct methods implement the measurement and valuation of utilities in a single step.[99] Frequently used direct methods include the visual

analogue scale (VAS), time trade-off (TTO), and standard gamble. Utility estimates from these different direct methods may differ for the same individual.[113] Indirect elicitation methods follow two key steps. First, individuals describe their health state using generic preference-based measures (GPBM) or multi-attribute utility instruments (MAUIs). Typically, MAUIs are descriptive systems for defining health status with several dimensions or questions and multiple levels per dimension. The descriptive contents of some widely used MAUIs such as the EQ-5D[114], SF-6D[115] and Assessment of Quality of Life (AQoL)[116] and Health Utilities Index (HUI)[117] are summarised in an article by Brazier et al.[118] The last step in an indirect elicitation method involves calculating a utility score by applying a prespecified algorithm or value set of preference weights from a relevant population to responses from the MAUIs.

As with direct methods, the utility values generated by different MAUIs often vary for the same respondent. The reasons for these variations in adult populations have been explored in the literature.[109,118] In the subpopulation of children, further methodological challenges arise when measuring and valuing health states for CUA.[119] Among recognised contributing factors to these unique methodological concerns are the heterogeneous nature of the childhood subgroups, the developmental delays in younger children, and cognitive limitations in adolescents.[119-121] Current attempts at resolving these issues such as the use of parental proxy assessment of health states and adaptations of existing MAUIs like the EQ-5D Youth (EQ-5D-Y) or the development of entirely new paediatric-specific MAUIs like the Child Health Utility 9-Dimensions (CHU-9D) still bear potential sources of bias and age restrictions.[120,122,123]

In the following subsections, I aim to review the literature on health-related quality-of-life studies that report preference-based values or utilities for cost-utility analyses of childhood excess weight interventions. Methods and results of an updated search of a recently conducted systematic review and meta-analysis[124] are presented, and key findings, limitations and recommendations are discussed.

2.3.2 Methods

Search strategy

I adopted the search strategies developed in the systematic review by Brown et al.[124] Due to time constraints, I searched only Medline via Ovid for studies published from 2017 to 19 January 2021. The contents of these search strategies and the search outputs can be found in Appendix B **Table B 2** and **Table B 3**, respectively.

I used the same eligibility criteria applied in the original review by Brown et al.[124], namely, studies published in peer-reviewed journals reporting primary data collection of utility values, with results reported by weight status; studies conducted in childhood populations; and studies reported in the English language.

I identified and extracted assessment items from the individual studies in my de novo search as well as studies in the original review by Brown and colleagues[124] that met the inclusion criteria. I assessed the quality of the studies using the key items recommended by the checklist developed by Papaioannou et al.[125] for assessing studies reporting HSUVs. These included reporting of response rates to the instrument used, loss to follow-up, missing data, and the potential effects of these items on the validity of the estimates; sample size; respondent selection and recruitment; study inclusion and exclusion criteria; and appropriateness of measure for the population or patient group.

2.3.3 Results

In my updated searches (Appendix B **Table B 3**), I identified 1066 papers. After de-duplication and title and abstract screening, 155 papers remained. I then screened the full texts and identified five studies based on my eligibility criteria. Table 3 summarises nine assessment items for 14 studies: nine health state valuation studies that elicited primary utility values identified by the systematic review by Brown et al.[124] and five studies identified by my updated searches.

The overall quality score of the individual studies, as measured using the key assessment criteria outlined by Papaioannou et al. 2013[125], ranged from 67% to 100%. The number of relevant items for the reviewed studies was either six for cross-sectional studies or seven for longitudinal studies. Response rates were not explicitly reported in four studies[126-129], while two studies by Boyle et al.[130] and Keating et al.[131] reported low response rates (33% and 50%, respectively). Details on the levels of missing data and how they were dealt with were scantily reported in many studies.

Six of the reviewed studies were conducted in Australia[127,131-135], four in the United Kingdom (U.K.) [128-130,136], two in the U.S.[137,138], and two in The Netherlands.[126,139] The targeted childhood age groups varied widely across studies but mostly encompassed teenage age groups. The youngest age considered was 5 years in three studies.[129,133,137] All nine studies identified in the systematic review by Brown et al.[124] were cross-sectional, but three of the five

newly identified studies from my search were longitudinal.[135,136,139] The setting of the studies was diverse, but most of them were conducted in school settings. Other settings included clinical settings and multi-setting scenarios. Study sample sizes varied vastly, ranging from as few as 76 children[137] to 4979 children.[138] Similarly, a wide range of utility instruments was used across the studies. Six studies used the Child Health Utility 9D (CHU-9D), making it the most frequently used instrument [128,129,132,134-136]. Other instruments used include the EuroQol 5D Youth (EQ-5D-Y)[128,130], EQ-5D-3L[126,139], Assessment of Quality of Life 6D (AQoL-6D)[127,131], and various versions of the Health Utilities Index (HUI).[133,137,138] Two studies that applied the HUI3 used parental proxy reports for utility assessment.[133,137] The choice of valuation method across studies was roughly evenly distributed between time trade-off and standard gamble, but the choice of preference weights tended to derive from adult populations of the country where the study was conducted. The exception was Australia, where the preference weights were generated from adolescent populations for five studies.[127,131,132,134,135]

The highest estimates of utilities associated with healthy weight were 0.90 for children aged 11 to 15 years in the U.K.[130], 0.87 for children aged six to seven years in the U.K.[132], 0.89 for children aged 11 and above in Australia[127], and 0.96 for children at age five years in Australia.[133] The lowest utility estimates were 0.83 for children aged five and six years in the U.K.[129] and 0.81 for children aged five to 18 years in the U.S.[137] The highest estimates of utilities associated with overweight and obesity at five years were estimated in Australia at 0.96 and 0.95, respectively.[133] Killedar et al.[135] disaggregated their estimates by gender for children aged 10 to 17 in Australia. They found that the association between BMI z-score and utilities was affected by age and was statistically significant in girls but weak in boys at all ages.

Table 3 Descriptive analysis of the key items on health utility values associated with childhood excess weight

First Author and Year of Publication	Country	Population and Age	Sample Size(s)	Type of Study	Utility Instrument (Proxy Assessment)	Preference/ Valuation Method	Estimated Utility Values (or Coefficients) and Corresponding Health States	Quality Score (%)
Boyle, S. E., et al. 2010[130]	United Kingdom	Children aged 11 to 15 years: two groups who either achieved the recommended PA guidelines or did not	*n* = 1771 (achieved recommended PA: Yes *n* = 446; No *n* = 1325)	Cross-sectional study	EQ-5D-Y/VAS	United Kingdom adult general population/TTO	Healthy weight: 0.9 (s.d. 0.18); Overweight or obese: 0.87 (s.d. 0.14)	4.5/6 (75%)
Belfort, M. B., et al. 2011[137]	United States	Children aged 5 to 18 years	*n* = 76 (Healthy weight *n* = 34; Overweight or obese *n* = 42)	Cross-sectional study	HUI3 (and proxy parent version for all)	Canadian general population (>16 years of age)/SG	Healthy weight: 0.81 (95% CI 0.76–0.86); Overweight or obese: 0.78 (95% CI 0.72–0.83)	4.5/6 (75%)
Keating, C. L., et al. 2011[131]	Australia	Secondary school children aged 12 to 15 years	*n* = 2890 (Thin *n* = 16; Healthy weight n = 1960; Overweight *n* = 642; Obese *n* = 272)	Cross-sectional study	AQoL-6D	Recalibrated for Australian adolescents/TTO	Healthy weight: 0.86 (s.d. 0.16); Overweight: 0.842 (s.d. 0.17); Obese: 0.805 (s.d. 0.18)	4.5/6 (75%)
Makkes, S., et al. 2013[126]	The Netherlands	Children aged 8 to 13 years and 13 to 19 with severe obesity	8 to 13 years old (*n* = 16) and 13 to 19 years old (*n* = 64)	Cross-sectional estimations from the HELIOS trial	EQ-5D-3L VAS	Dutch general population/TTO	Severely obese: 0.79 (s.d. 0.22)	4/6 (67%)
Trevino, R. P., et al. 2013[138]	United States	Sixth grade students (aged under 13 years and approximate average age 11 years)	*n* = 4979 (BMI%: <85 *n* = 2456; 85–94 *n* = 1003; 95–99 *n* = 1176; and 99+ *n* = 344)	Cross-sectional estimations from the HEALTHY trial	HUI2 and HUI3	Canadian general population (>16 years of age)/SG	HUI2 BMI%: <85 0.853 (s.d. 0.157); 85–94 0.848 (s.d. 0.157); 95–99 0.838 (s.d. 0.163); and 99+ 0.814 (s.d. 0.175) and HUI3 BMI%: <85 0.805 (s.d. 0.233); 85–94 0.795 (s.d. 0.236); 95–99 0.786 (s.d. 0.242); and 99+ 0.759 (s.d. 0.245)	6/6 (100%)
Bolton, K., et al. 2014[127]	Australia	Students aged 11 to 19.6 years	*n* = 1583 (Healthy weight *n* = 727 and Overweight/obese *n* = 243)	Cross-sectional study (baseline data only)	AQoL-6D	Recalibrated for Australian adolescents/TTO	Healthy weight: 0.89 (s.d. 0.14) and Overweight or obese: 0.87 (s.d. 0.14)	4.5/6 (75%)
Canaway, A. and E. Frew 2014[128]	United Kingdom	Children aged 6 to 7 years	*n* = 160 (Healthy weight *n* = 127; Overweight *n* = 13; Obese *n* = 20; and Overweight or obese *n* = 330	Cross-sectional study	CHU-9D and EQ-5D-Y	United Kingdom adult general population/CHU-9D: SG and EQ-5D-Y: TTO	CHU-9D: Healthy weight 0.87 (95% CI 0.84–0.89); Overweight 0.86 (95% CI 0.81–0.9); Obese 0.84 (95% CI 0.77–0.91); and Overweight or obese 0.85 (95% CI 0.8–0.89) and EQ-5D-Y: Healthy weight 0.73 (95% CI 0.66–0.8); Overweight 0.66 (95% CI 0.43–0.83); Obese 0.69 (95% CI 0.54–0.83); and Overweight or obese 0.67 (95% CI 0.56–0.78)	4.5/6 (75%)
Chen, G., et al. 2014[132]	Australia	Primary (7 to 13 years) and secondary (13 to 17) school children	Primary schools *n* = 2588 (Healthy-weight *n* = 1674; Overweight *n* = 396; Obese *n* = 107) and secondary schools *n* = 765 (Healthy-weight *n* = 520; and Overweight or obese *n* = 101)	Cross-sectional study (baseline data only)	CHU-9D	Recalibrated for Australian adolescents/SG	Primary schools: Healthy-weight 0.87 (s.d. 0.11); Overweight 0.86 (s.d. 0.12); Obese 0.83 (s.d. 0.16) and secondary schools: Healthy-weight 0.82 (s.d. 0.12); and Overweight or obese 0.81 (s.d. 0.12)	5/6 (83%)

First Author and Year of Publication	Country	Population and Age	Sample Size(s)	Type of Study	Utility Instrument (Proxy Assessment)	Preference/ Valuation Method	Estimated Utility Values (or Coefficients) and Corresponding Health States	Quality Score (%)
Frew, E. J., et al. 2015[129]	United Kingdom	Children aged 5 to 6 years	*n* = 1344 (Healthy weight 1012; Overweight 116; Obese 176)	Cross-sectional estimations from the WAVES trial	CHU-9D	United Kingdom adult general population/SG	Healthy weight 0.825 (s.d. 0.14); Overweight 0.811 (s.d. 0.14); Obese 0.827 (s.d. 0.13); and Overweight or obese 0.82 (s.d. 0.13)	4.5/6 (75%)
Eminson, K., et al. 2018[136]	United Kingdom	Children between 6 and 10 years old	The WAVES trial: 1350 children at baseline (Healthy weight *n* = 1022; Overweight *n* = 118; Obese *n* = 167)	Longitudinal study	CHU-9D	United Kingdom adult general population/SG	In the regression results from the analyses investigating the impact of weight status on health utility, the coefficients (*p*-values) for healthy weight, overweight, and obese are 0.000437 (0.968), −0.00126 (0.915), and 0.003166 (0.782), respectively	6/6 (100%)
Tan, E. J., et al. 2018[133]	Australia	Children aged 5 years	*n* = 368 (Healthy weight *n* = 224; Overweight *n* = 114; Obese *n* = 30)	Longitudinal study, but HRQoL data and analysis were cross-sectional	HUI3 (parent proxy version)	Canadian general population (>16 years of age)/SG	Healthy weight: 0.956 (*p* value 0.08); Overweight 0.956 (*p* value 0.09); Obese 0.952 (0.10). Utility estimates across the 3 weight status groups were similar.	6/6 (100%)
Hoedjes, M., et al. 2018[139]	The Netherlands	Children and adolescents ages 8 to 19 years with severe obesity: intensive lifestyle treatment	*n* = 120	Longitudinal study	EQ-5D-3L	Dutch general population/TTO	Utility scores at baseline, after 1 year of treatment, and 1 year of follow-up were 0.80 (*p*-value 0.02), 0.89 (*p*-value 0.02) and 0.88 (*p*-value 0.02), respectively.	5.5/7 (79%)
Bell, L., et al. 2019[134]	Australian	9–11-year-olds	*n* = 2611 at baseline (intervention *n* = 1373; 20 matched comparison *n* = 1238)	Quasi-experimental repeat cross-sectional design	CHU-9D	Recalibrated for Australian adolescents/SG	Utility values for the intervention at baseline and end of study were 0.82 and 0.77, respectively. Utility values for the comparator at baseline and end of study were 0.80 and 0.79, respectively. Utility values not reported by weight status.	7/7 (100%)
Killedar, A., et al. 2019[135]	Australian	Two cohorts (waves 6 and 7) of boys and girls 10–17 years from the LSAC study	Girls: between *n* = 1370 and *n* = 1714 across cohorts/waves. Boys: between *n* = 1464 and *n* = 1778 across cohorts/waves	Primary data collection from a longitudinal study	CHU-9D	The best–worst scaling study conducted in an Australian adolescent population/SG	Girls: BMI z-scores −2, 1, 2, and 3 from ages 10 to 17, respectively: [10 years: 0.818; 0.812; 0.809; 0.807], [11 years: 0.814; 0.799; 0.794; 0.789], [12 years: 0.811; 0.787; 0.779; 0.771], [13 years: 0.807; 0.775; 0.764; 0.753], [14 years: 0.804; 0.762; 0.748; 0.735], [15 years: 0.800; 0.750; 0.733; 0.717], [16 years: 0.796; 0.738; 0.718; 0.698], [17 years: 0.793; 0.725; 0.703; 0.680]. Boys: BMI z-scores −2, 1, 2, and 3 from ages 10 to 17, respectively: [10 years: 0.811; 0.799; 0.795; 0.792], [11 years: 0.817; 0.806; 0.802; 0.798], [12 years: 0.824; 0.812; 0.809; 0.805], [13 years: 0.830; 0.819; 0.815; 0.811], [14 years: 0.837; 0.825; 0.822; 0.818], [15 years: 0.843; 0.832; 0.828; 0.824], [16 years: 0.850; 0.838; 0.835; 0.831], [17 years: 0.856; 0.845; 0.841; 0.837]	7/7 (100%)

AQoL: Assessment of Quality of Life; BMI: body mass index; CHU-9D: Child Health Utility-9 dimensions; EQ-5D: EuroQol-5 dimensions; EQ-5D-Y: EQ-5D-Youth; EQ-5D-3L: EQ-5D-3 levels; HUI2 and HUI3: Health Utilities Index version 2 and 3; LSAC: Longitudinal Study of Australian Children SG: standard gamble; TTO: time trade-off; VAS: visual analogue scale.

2.3.4 Discussion

Summary of Results and Comparative Evidence

Several methodological challenges characterised chiefly by considerable variation in valuation protocol (utility instrument, population preferences for weight-related health states, and methods of valuation) and sample sizes (76 children[137] to 4979 children[138]) across studies may have impacted the quality of the estimated utilities. Inadequately powered sample sizes, the lack of sensitivity of the instruments used in children of young ages, or the weak relationship between BMI and utility could potentially have diminished the statistical significance of estimated utility values associated with a given weight status.[128,129,133]

In contrast to the studies from the original review by Brown et al.[124], which were all cross-sectional studies, three of the newly identified studies from my searches were based on longitudinal data analysis.[135,136,139] Longitudinal study designs offer an opportunity to investigate reverse causation[124], and these recent longitudinal studies suggest a growing interest in investigating theories about the potential relationships between childhood body weight status and HSUVs.

A recent systematic review that investigated the longitudinal association between weight change and health-related quality of life (HRQoL) in children did not include studies that assessed HSUVs from generic preference-based measures[140], and preference-based measures are often omitted in many clinical effectiveness studies on childhood weight gain. This exclusion underlines the need for mapping functions that predict HSUVs from a target preference-based measure using data obtained from non-preference-based HRQoL measures. Mapping functions or prediction equations are increasingly being developed for utility instruments. One example is the mapping of a weight measure called the Weight-Specific Adolescent Instrument for Economic Evaluation (WAItE) to the CHU-9D[141]. It is worth noting that mapped estimates of utilities are subject to greater uncertainty, and mapping may generate HSUVs with poor external validity.[142] Therefore, it is preferable to include utility instruments directly in RCTs, and where a preference-based measure is not included, the appropriateness of a mapping function should be considered rigorously.

The quality assessment of individual studies included in this updated review used the key criteria recommended by Papaioannou et al.[125] and represents an important step for assessing the rigour and reliability of the reviewed studies. However, further quality considerations may be worth exploring. For instance, in addition to the question

around the appropriateness of the measure, it may be worth considering if the population that valued the change in HRQoL is appropriate. A points-based checklist that gives additional weight to longitudinal studies may also add more rigour to the quality assessment procedure.

Strengths and Limitations

My review includes five new studies and similar to the systematic review by Brown and colleagues[124], revealed a dearth of evidence on HSUVs for childhood excess weight, with 14 included studies from only four high-income countries. While this study draws from a growing body of longitudinal studies and highlights the need for a fine-tuned quality assessment tool, it was not without weaknesses. One limitation of this study is that only one database was searched, and relevant studies on preference-based measures in childhood excess weight may have been missed. I also did not carry out an updated meta-analysis. Given the limited scope of my search, such an analysis may exclude key studies. Therefore, I recommend an exhaustive search and updated systematic review of this topic.

2.4 Economic evaluations of interventions targeting children with excess weight

2.4.1 Background and rationale for literature review

Economic evaluation, defined by Drummond et al.[99] as "the comparative analysis of alternative courses of action in terms of both their costs and consequences", is crucial for making healthcare investment decisions in the interest of the public. The decision regarding which childhood excess weight intervention to adopt fits within the purview of economic evaluation. Ideally, the type of economic evaluation applied will reflect the analytical perspective, institutional context, and geographical jurisdiction. However, evaluating childhood excess weight interventions is challenging because they comprise multiple interacting components with implementation, often outside the health sector.[143] A further complication arises from the uncertainty surrounding the assumptions of longer-term costs and consequences of interventions in early childhood. Economic modellers argue that these assumptions are necessary since all the perceived benefits and cost offsets may not be apparent within the timeframe of intervention implementation.[144]

A review conducted in 2009 found that, in contrast to the substantial literature on the clinical effectiveness of excess weight programmes in children, only a small number of peer-reviewed studies on the economic evaluation of childhood obesity interventions had been published.[145] Zanganeh et al.[146] identified several inadequacies in subsequent reviews[147-153] of childhood overweight and obesity economic evaluations published since 2009. Some of the identified gaps included omission of relevant databases; inadequately reported search strategies; absence of quality assessment for included studies; and exclusion of studies conducted in developing countries. Therefore, Zanganeh and colleagues[154] undertook a systematic search to address the existing lapses in May 2017. Zanganeh and colleagues searched 11 electronic health economics or biomedical databases for studies published between January 2001 and April 2017. They identified and summarised 35 papers, and the quality of the included studies was assessed using the Drummond checklist.[99]

In January 2021, I conducted an updated search from 2017 using the search strategy by Zanganeh and colleagues for Medline (Ovid) and extracted 31 additional economic evaluations for childhood excess weight interventions. With nearly as many new studies published within the past three years as between 2001 and 2017, my search points to massively expanding interest in the costs and benefits of childhood obesity interventions.

The systematic review by Zanganeh et al. excluded pharmacologic and surgical interventions. No rationale was provided for the exclusion of these classes of interventions, but it could be these are not routine treatments in children. My search identified a US-based study[155] published in 2017 on the cost-effectiveness of bariatric surgery in adolescents, and I identified a similar study[156] on UK-based adolescents. Both studies suggest that bariatric surgery may be a cost-effective treatment option for severe childhood obesity.[155-157] Furthermore, ongoing research on pharmacologic treatments for severe childhood obesity is expected to result in the approval of new competitive drugs, contingent upon the outcomes of studies evaluating their safety and efficacy.[2,158,159] There is, therefore, a need for a rigorous appraisal of the current literature on economic evaluations of childhood excess weight interventions in order to identify and summarise all potentially cost-effective innovations in the management, treatment, and prevention of excess weight among children. This review aims to provide an overview of the recent literature on the economic evaluation of childhood excess weight interventions. A systematic review that provides a comprehensive summary of the literature is reported in Chapter 3. In the succeeding subsections, I report the methods and results of my updated search and discuss key findings.

2.4.2 Methods

The previous review by Zanganeh and colleagues[154] searched for economic evaluations of interventions targeting childhood excess weight published between January 2001 and April 2017. I adapted their search strategy, targeting studies published from 2017 to 17 January 2021 and limiting my search to Medline via Ovid due to time constraints (Appendix B **Table B 4**). This review encompassed economic evaluations of interventions targeting childhood excess weight regardless of the type of economic evaluation or the approach underpinning the economic evaluation (e.g., randomised controlled trial (RCT), observational study with individual-level data, decision-analytic model, quasi-experimental design, etc.). My eligibility criteria included studies if they targeted children at the time of intervention; evaluated treatment, prevention, or management interventions targeting childhood excess weight, including behavioural (diet, physical activity), pharmacological or surgical; contained at least one comparator, such as usual care or 'no treatment' or 'no intervention'; and reported economic evaluation outcomes, such as incremental cost-effectiveness ratios (ICERs) expressed in metrics such as incremental cost per quality-adjusted life year (QALY) gained, incremental cost per unit change in health effect (e.g., incremental cost per change in BMI z-score), or net monetary benefits. Studies were excluded if they were not focused on tackling excess weight (overweight or obesity) in childhood; not an economic evaluation; the title and abstract were not published in English; a protocol study; or a review article not containing primary research evidence.

I identified and extracted assessment items from the individual studies in my de novo search and studies in the original review by Zanganeh and colleagues[154] that met my inclusion criteria. The quality of each study was assessed using the CHEERS statement.[83] I used only applicable CHEERS items in the assessment of individual studies. For instance, decision-analytic modelling items (item numbers 15 and 16) were not relevant for within-trial economic evaluations. To ensure that the reviewed economic evaluations were scored fairly, I estimated separate denominators for the individual studies based on the relevance of individual CHEERS checklist items to each study design.

Definitions and Taxonomies

Interventions were categorised as behavioural, environmental, pharmacological, surgical, policy-focused, or a combination. Behavioural interventions refer to procedures and practices to change the individual's behaviour.

Environmental interventions aim to modify or adapt the environment. Pharmacological interventions include prescribed or over-the-counter pharmaceutical drugs and medicines. Surgical interventions are medical and dental procedures that involve surgery. Interventions classified as policy interventions can be applied, proposed, or modelled at the population level through legislation or fiscal actions and may affect advertising, taxes, levies, and subsidies.

The study approaches were categorised as prevention, treatment, management-focused, or a combination of these categories. A preventive approach was an intervention targeted at healthy weight children or children with overweight to prevent progression to obesity. An approach was defined as management-based if the intervention aimed to control the excess weight condition but did not necessarily treat it.

An intervention was described as cost-effective if the authors of the study carried out cost-effectiveness or cost-utility analysis and deemed the intervention cost-effective with reference to the cost-effectiveness threshold in the country in which the study was conducted. An intervention was described as potentially cost-effective if the authors deemed the intervention cost-effective but did not make explicit reference to a cost-effectiveness threshold or performed a different type of economic evaluation (e.g., cost-benefit or cost-consequences analysis). An intervention was also described as potentially cost-effective if the authors expressed concerns about uncertainties, such as implementation, despite considering it cost-effective. Evidence was described as inconclusive if the authors could not conclude that it was cost-effective. An intervention was described as not cost-effective if the authors of the study carried out cost-effectiveness or cost-utility analysis and deemed the intervention not cost-effective with reference to the cost-effectiveness threshold in the country in which the study was conducted or if the costs exceeded the benefits in cost-benefit analyses. Generally, all statements about the cost-effectiveness of interventions in this review should be treated with caution, as I did not seek access to the contributing study data and models with the view of replicating or verifying study estimates.

2.4.3 Results

My searches identified 282 papers. After screening titles and abstracts and excluding duplicates, 52 potentially relevant papers were identified. I then reviewed the full-text versions of the screened papers and included 31 relevant papers. Of the 35 papers reported in the review by Zanganeh et al.[154], I excluded three papers[160-162] because they did not meet the inclusion criteria for this review. My review, therefore, includes results for 63

studies: 32 studies from the systematic review by Zanganeh et al. plus 31 studies extracted from my updated searches.

In Table 4, the studies identified by the review are described based on shared characteristics. Only two studies were conducted in low- or middle-income countries, specifically China.[163,164] The remaining studies were conducted in high-income countries, with more than half of them conducted in the U.S.[55,150,155,165-184] or Australia[185-199]. Seven studies were carried out in the U.K.[71,200-205] and three each in The Netherlands[206-208] and New Zealand.[209-211] Two studies were conducted in both Germany[212,213] and Spain[214,215], while one study each was conducted in Canada[216], Denmark[217], Sweden[218], Portugal[219], Finland[220], and Poland.[221]

Table 4 Aggregate descriptive summary of economic evaluation studies

Study Characteristics	Number of Studies Identified
Year of publication	
2001–2005	2[165,166]
2006–2010	11[167-170,185-189,210,220]
2011–2015	16[71,150,163,171-176,190-192,200,209,212,214]
2016–2020	34[55,155,164,177-184,193-199,201-208,211,213,215-219,221]
Jurisdiction	
High-income	61[55,71,150,155,165-221]
Low- and middle-income	2[163,164]
Intervention category	
Behavioural	26[71,163,165,166,170-172,180,181,185,186,191,192,200-202,204,210-212,214-216,218-220]
Environmental	2[169,213]
Policy	2[198,203]
Surgical	1[155]
Multiple categories	32[55,150,164,167,168,173-179,182-184,187-190,193-197,199,205-209,217,221]
Study approach	
Prevention	37[55,150,163,164,166,168,169,171,173-178,182,184,188-199,203,205,209,210,212-214,216,218]
Treatment	14[71,155,165,170,172,180,183,185,186,200,201,211,217,220]
Treatment and prevention	10[167,179,181,187,204,206-208,215,219]
Management	2[202,221]
Setting	
School-based	23[55,163,164,166,169,171,173,177,178,182,184,193,195,204,205,207-209,212,214-216,219]
Health care/clinical setting	5[155,172,206,218,220]
Family (not necessarily taking place at home)	3[165,185,186]
Home	2[175,192]
Community	5[170,196,201,202,217]
Population	3[168,197,203]
Multi-setting	22[71,150,167,174,176,179-181,183,187-191,194,198-200,210,211,213,221]
Study design	
Randomised controlled trial	27[55,163,165,169,170,172,177,180,181,186,192,193,195,200-202,204-206,210-212,214,215,217,218,220]
Decision-analytical	24[71,150,166,167,174-176,178,179,182,184,185,187-191,194,196-198,203,213,216]
Multiple design (studies with two main types of designs)	7[155,164,171,173,199,208,209]
Cross-sectional	1[168]
Quasi-experimental	1[207]
Non-randomised controlled trial	1[219]
Longitudinal	1[221]
Pilot	1[183]
Study Perspective	
Societal	45[150,163,164,166-182,184-191,193,194,196,198,204-208,210,212-214,217-220]
Health care	12[71,155,192,195,197,199-203,209,211]
Institutional or school system	2[215,216]

Study Characteristics	Number of Studies Identified
Provider	1[183]
Not stated/insufficient information	3[55,165,221]
Type of economic evaluation	
Cost-effectiveness	30[55,71,163,165,168-170,172,173,180,185,187-196,198,200,211,212,215,217,218,220,221]
Cost-utility	11[155,171,177,201,202,204,205,208,209,213,216]
Cost-consequence	8[179,181,183,186,197,203,214,219]
Cost-benefit	3[182,184,207]
Two or more types	11[150,164,166,167,174-176,178,199,206,210]

I report key descriptive characteristics for all 63 studies in Table 5. The quality of studies, as assessed by the CHEERS checklist, ranged from 52% to 100% for the included studies. Twenty-six studies evaluated behavioural interventions[71,163,165,166,170-172,180,181,185,186,191,192,200-202,204,210-212,214-216,218-220]. Purely environmental[169,213] or policy[198,203] interventions were analysed in two studies, while one evaluated a surgical intervention.[155] Thirty-two studies analysed interventions that belonged to multiple categories.[55,150,164,167,168,173-179,182-184,187-190,193-197,199,205-209,217,221] Schools were the most common settings for intervention evaluation, with 23 interventions conducted in different educational settings.[55,163,164,166,169,171,173,177,178,182,184,193,195,204,205,207-209,212,214-216,219] Twenty-two interventions met the criteria for multi-setting implementation[71,150,167,174,176,179-181,183,187-191,194,198-200,210,211,213,221]. Five[155,172,206,218,220], two[175,192] and three[165,185,186] interventions were conducted in clinical, home, and family (not necessarily taking place at home) settings, respectively. Five interventions were targeted at community settings[170,197,201,202,217], while three study interventions took a population-wide perspective.[168,197,203]

The underpinning study design was a solely trial-based economic evaluation for 27 studies.[55,163,165,169,170,172,177,180,181,186,192,193,195,200-202,204-206,210-212,214,215,217,218,220] Twenty-four studies involved decision-analytic modelling alone[71,150,174-176,178,179,182,184,187-191,194,196-198,203,213,216]. Six studies incorporated two types of study designs[155,164,171,173,199,208,209], which were predominantly a hybrid of trial-based and decision-analytic designs. The primary designs for the remaining studies were less common and incorporated cross-sectional[168], quasi-experimental[207], non-RCT[219], longitudinal[221], and pilot study[183] designs. Forty-five studies took a societal perspective[150,163,164,166-182,184-191,193,194,196,198,204-208,210,212-214,217-220], while 12 studies took a health care perspective.[71,155,192,195,197,199-203,209,211]

The baseline study populations in the reviewed studies spanned all ages of childhood. The predominant aim of the study was to prevent excess weight gain, with interventions targeting solely healthy-weight children in 37 studies.[55,150,163,164,166,168,169,171,173-178,182,184,188-199,203,205,209,210,212-214,216,218] Only two studies took a management approach

where interventions offered multidisciplinary supportive care.[202,221] Interventions in 14 studies took a treatment approach where the baseline childhood populations had excess weight.[71,155,165,170,172,180,183,185,186,200,201,211,217,220] Of these studies, one was conducted in a cohort of children with weight-related comorbidities[211] and another study cohort involved adolescents with obesity and signs of addictive eating[183] Interventions in 10 studies of children with mixed (healthy and excess weight) body weight status took a combined approach of prevention and treatment[167,179,181,187,204,206-208,215,219] Four studies were conducted in infant and preschool populations.[192,199,213,218] Two studies targeted female-only cohorts[166,171], and the interventions in two other studies focused on children in low-income communities.[55,193]

More than half of the studies were either cost-effectiveness analyses (CEAs) or CUAs. The most common measure of health consequence for the 30 CEAs in this review was change in BMI z-score or reduction in BMI units.[55,71,163,165,168-170,172,173,180,185,187-196,198,200,211,212,215,217,218,220,221] Other measures of health consequence included change in percentage body fat, waist circumference (WC), waist-to-height ratio (WHtR), number of obesity cases, percentage point change in the proportion of schools that adhered to the policy, minutes of moderate to vigorous physical activity (MVPA), and metabolic equivalent (MET). Eleven studies were exclusively CUAs with measures of consequences presented as QALYs, disability-adjusted life years (DALYs), or health-adjusted life years (HALYs).[155,171,177,201,202,204,205,208,209,213,216] Three studies were purely cost-benefit analyses (CBAs) with monetary valuation of consequences[182,184,207], two of which were school-based drinking water interventions.[182,184] Eight studies were cost-consequences analyses, where disaggregated costs and outcomes, such as change in dietary habits, percentage of body fat, MVPA, and dietary habits (fruits/vegetables intake, water, desserts, and sugar-sweetened beverages (SSBs) served) were reported [179,181,183,186,197,203,214,219]. Eleven studies reported two or more types of economic evaluation.[150,164,166,167,174-176,178,199,206,210]

There was a strong correlation between the time horizons of the economic evaluations and their study designs. Trial-based studies had follow-up periods ranging from 7 months[214] to 4 years.[55,210] Studies that featured decision-analytic modelling tended to have a lifetime horizon. However, shorter time horizons were modelled in some studies. Discounting future costs and consequences was not relevant to trial-based studies where the follow-up period did not exceed 1 year. Across most countries, the most frequently applied discount rate was 3%, but rates as high as 5% for both costs and consequences[192,199,210] and as low as 1.5% for consequences[206,208] were applied in

some studies. A few studies with follow-ups and time horizons exceeding 1 year did not apply discount rates, and no justification was provided for the omissions.[55,193,203,217,218,221]

Interventions in 50 of the reviewed studies were either cost-effective[163,165-168,177,185,187,191,196,199,206,212,213,215,216] or potentially cost-effective[55,71,150,155,164,169-176,178-184,192-195,197,198,200,203,208-211,214,217], while interventions in 13 studies were either not cost-effective[186,188-190,201,202] or inconclusive.[204,205,207,218-221] Some authors expressed concerns about the implementation of the intervention, even though they deemed the intervention cost-effective.[150,174,195] In relation to the study approach, I estimated that 86%, 79%, and 70% of the interventions for prevention, treatment, and prevention/treatment were either cost-effective or potentially cost-effective, respectively. Neither of the two management interventions I reviewed was cost-effective or potentially cost-effective. Three studies reported gender differences in the estimates of cost-effectiveness.[181,205,215] One study indicated that the intervention had shown greater health benefits and cost savings in those living in socioeconomically disadvantaged areas compared to those living in the least disadvantaged areas[194], and another study highlighted the uncertainties surrounding the persistence of effects beyond adolescence that could drive estimates of cost-effectiveness.[208]

Table 5 Descriptive analysis of the key assessment items for individual economic evaluations

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
Goldfield, G. S., et al. 2001[165]	United States	Mixed group treatment incorporating both group and individualised treatment versus group treatment only	PA, diet, and self-monitoring (Family-based)	Cost-effectiveness (Not stated/Provider perspective implied)	Families with obese 8- to 12-year-old children	1 year	U.S. dollars (not stated)	NA	Change in Z-BMI or change in percentage overweight	Both groups demonstrated equivalent weight control results; however, the mixed group was 2.8 times more expensive per family (USD 1390 vs. USD 491). The group treatment only was cost-effective	87%
Wang, L. Y., et al. 2003[166]	United States	Planet Health, a school-based intervention targeting obesity versus 'no intervention'	PA, diet, and television viewing (School-based)	Cost-utility, cost-effectiveness, and cost-benefit analyses (Societal perspective)	Girls 10 to 14 years with mixed-weight status	25 years (age 40 to 65 years)	U.S. dollars (1996)	3% discount rate on future costs and benefits	Averted costs associated with cases of adulthood overweight prevented and QALY saved	An ICER of USD 4305 per QALY saved and a net saving of USD 7313 to society was estimated for the Planet Health programme relative to 'no intervention'. Cost-saving and cost-effective	93%
Brown, H. S., et al. 2007[167]	United States	The CATCH[1] intervention versus control	PA, school curriculum/education, and modification to school food service (School-based with family- and home-based components)	Cost-utility and cost-benefit analyses (Societal perspective)	Children between the ages of 8 and 11 years across grades three, four, and five with mixed-weight status	25 years (age 40 to 65 years)	U.S. dollars (2004)	3% discount rate on future costs and benefits	QALY saved and averted medical and labour productivity costs	An ICER of USD 900 per QALY saved and a net benefit of USD 68,125 to society was estimated for the CATCH programme relative to control. Cost-effective	94%
Moodie, M., et al. 2008[185]	Australia	A behavioural intervention involving GP consultations at home (the LEAP trial) versus 'no intervention' control	Lifestyle, diet, PA, and GP consultations (Family-based and GP-mediated)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Children aged 5 to 9 years with a BMI z-score of ≥ 3.0 (overweight and moderately obese)	Lifetime	Australian dollars (2001)	3% discount rate on future costs and benefits	DALY saved	Compared to the control, the intervention resulted in a net cost per DALY saved of AUD 4670. Cost-effective	98%
Peterson, M., et al. 2008[168]	United States	State-wide social marketing:	PA, television, and billboard	Cost-effectiveness analysis (Societal	Children 12 to 17 years with	NA	U.S. dollars	NA	Increase in PA (measure not	Cost per person to become more active was lowest for	56%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
		(exposure to varying levels of advertisements) versus No advertisements	advertising (Population-based)	perspective)	mixed-weight status attending public schools		(not stated)		specified)	billboards alone at USD 5.11 but cost USD 8.87 per person for the entire campaign. Billboards were potentially more cost-effective than television advertisements in high traffic areas	
Wake, M., et al. 2008[186]	Australia	A behavioural intervention involving GP consultations at home (the LEAP trial) versus 'no intervention' control	Lifestyle, diet, PA, and GP consultations (Family-based and GP-mediated)	Cost-consequence analysis (Societal perspective)	Children aged 5 to 9 years with a BMI z-score of ≥ 3.0 (overweight and moderately obese)	15 months after randomisation	Australian dollars (2003)	NA	Children's change in BMI, PA, and dietary habits	Mean change in BMI z-score not statistically significant at 2 and 1.92 for the intervention and control, respectively. Daily dietary habits improved significantly in the intervention. The additional cost from the intervention was AUD 4094. Not cost-effective	89%
Wang, L. Y., et al. 2008[169]	United States	An after-school intervention (MCG FitKid) versus usual after-school care control	Diet, PA, and academic enrichment activities (School-based)	Cost-effectiveness analysis (Societal perspective)	Third-grade children with mean age of 8.7 years with mixed-weight status	1 year after randomisation	U.S. dollars (2003)	NA	Reduction in percent body fat (%BF)	The study found that students who attended at least 40% of the intervention reduced %BF by 0.76% at an additional cost of USD 317/student, compared with students in the control group. Potentially cost-effective	95%
Janicke, D. M., et al. 2009[170]	United States	Parent-only intervention versus family-based intervention	Diet and PA (Rural community setting)	Cost-effectiveness analysis (Societal perspective)	Overweight or obese children aged 8 to 14 years and their parent(s)	10-month follow-up after randomisation	U.S. dollars (not stated)	NA	BMI unit reduction	The total cost per child for the parent-only and family interventions were USD 521 and USD 872, respectively. No significant difference in weight status change at follow-up. Parent-only potentially cost-effective	75%
Kalavainen, M., et al. 2009[220]	Finland	Family-based group treatment (15 separate sessions	Diet and PA (Primary health	Cost-effectiveness analysis (Societal	Obese children 7 to 9 years old	12 months post-	Euros (2004)	NA	BMI unit reduction	The additional costs for a 0.1 reduction in BMI z-score for the family-based group	90%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
		for parents and children) versus routine counselling (two appointments for children)	care)	perspective)		baseline				treatment were EUR 266 compared with routine counselling. Inconclusive: family-based group treatment more effective but also costlier	
Magnus, A., et al. 2009[187]	Australia	A ban on television advertisements for EDNP foods and beverages versus current practice	Diet and legislation (Population-based, home-setting)	Cost-effectiveness and cost-utility analyses (Societal perspective)	All children aged 5 to 14 years	Lifetime	Australian dollars (2001)	3% discount rate on future costs and benefits	Changes in BMI and DALYs saved	The intervention had a gross ICER of AUD 3.70 per DALY saved and cost per BMI unit saved of AUD 0.33. Cost-effective	100%
Moodie, M., et al. 2009[188]	Australia	WSB programme versus 'current practice' defined as 'do nothing'	PA: increase the number of children walking to school (Population-based, school-based)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Primary school children aged 5 to 7 years with mean BMI (Kg/m2) 16.24, 16.47 for boys and girls, respectively	Lifetime	Australian dollars (2001)	3% discount rate on future costs and benefits	BMI unit saved and DALY saved	The ICER for the WSB intervention was estimated at a net cost per DALY saved of AUD 0.76 million but the evidence base underpinning the results was deemed weak by the authors. Not effective or cost-effective	100%
McAuley, K. A., et al. 2010[210]	New Zealand	The APPLE project: the provision of community activity coordinators at each intervention school versus usual care	Diet, PA, and lifestyle-based (School and Community-based)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Children aged 5 to 12 years representative of the wider population in this age group	4 years	New Zealand dollars (2006)	5% discount rate per annum for costs	Reduction in weight z-score and QALY gain (HUI values)	The implementation cost for the intervention was NZD 664–1708 per kg of weight gain prevented over 4 years with weight z-score reduction was 0.17 units relative to control, but mean utility values did not differ between the groups. Potentially cost-effective	93%
Moodie, M. L., et al. 2010[189]	Australia	The AASC programme: 2 to 3 sessions per week of PA programmes during the after-school period versus no	PA: after school period (Population-based, school-based)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Children aged 5 to 11 years (grade 4 to 6) of mixed weight status	Lifetime	Australian dollars (2001)	3% discount rate on future costs and benefits	BMI unit saved and DALY saved	The ICER for the intervention was estimated at a net cost per DALY saved of AUD 82,000. Not cost-effective	100%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
		intervention									
Moodie, M., et al. 2011[190]	Australia	TravelSMART Schools Curriculum programme versus current practice	PA (Population-based, school-based)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Children aged 10 to 11 years of mixed weight status	Lifetime	Australian dollars (2001)	3% discount rate on future costs and benefits	BMI unit saved and DALY saved	The ICER for the intervention was estimated at a net cost per DALY saved of AUD 117,000. Not cost-effective	100%
Martínez, P. M., et al. 2011[214]	Spain	Three 90-minutes sessions per week of recreational PA conducted after school hours on school premises versus usual afterschool care	PA (School-based)	Cost-consequence analysis (Societal perspective)	Children aged 9 to 10 years of mixed weight status	7 months from baseline	Euros (2005)	NA	Decrease in triceps skinfold thickness and decrease in the percentage of body fat	The intervention costs EUR 269.83/year/child while the usual afterschool care was estimated at EUR 844.56/year/child. The decrease in the percentage of body fat for the intervention group ranged from −0.59% to −0.67%. Potentially cost-effective	85%
Wang, L. Y., et al. 2011[171]	United States	Planet Health, a school-based intervention targeting obesity and DWCB versus 'no intervention'	PA, diet, DWCB prevention (purging or diet pill use), and television viewing (School-based)	Cost-utility analysis (Societal perspective)	Girls 10 to 14 years with mixed-weight status	10 years	U.S. dollars (2010)	3% discount rate on future costs and benefits	QALY gained (15D instrument)	With a net savings of USD 14,238 and a gain of 4.8 QALYs, the ICER for the intervention was estimated at USUSD 2966 per QALY gained. Potentially cost-effective	100%
Hollingworth, W., et al. 2012[71]	United Kingdom	Lifestyle interventions (identified in literature review of 10 RCTs) to treat overweight and obese children versus no intervention	Diet and PA (Hospital and community-based)	Cost-effectiveness analysis (UK National Health Service perspective)	Hypothetical cohorts of overweight or obese children aged 4 to 5 and 10 to 11 years in state schools	Lifetime	GBP (not stated)	3.5% discount rate on future costs and health outcomes	Life year gained	For children aged 10 to 11, the discounted cost per LYG was estimated at GBP 13,589. Similar results reported for children aged 4 to 5 years. Lifestyle interventions potentially cost-effective	91%
Kesztyüs, D., et al. 2013[212]	Germany	The URMEL-ICE intervention integrated into the usual school	Diet, PA, and media (School-based)	Cost-effectiveness analysis (Societal perspective)	Primary school children (second graders), mixed-weight group,	1 year	Euros (2008)	NA	WC gain prevented, WHtR gain prevented, and BMI difference between	The ICER was EUR 11.11 per cm WC and EUR 18.55 per unit WHtR gain prevented for the intervention group with	95%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
		curriculum consisting of teaching, activity breaks and homework assignments versus usual care			mean ages 7.64 and 7.53 in the intervention and control groups, respectively				groups	respect to the control group. Assuming a maximum WTP of EUR 35, cost-effective	
Meng, L., et al. 2013[163]	China	Four groups: nutrition education; PA; nutrition education and PA (comprehensive intervention); and control (usual care)	Diet and PA (School-based)	Cost-effectiveness analysis (Societal perspective)	Children 6 to 13 years of mixed-weight status	1 year from baseline	CNY/U.S. dollars (2010)	NA	BMI z-score avoided, overweight and obesity case avoided	The comprehensive intervention had an ICER of USD 120.3 per 1 kg/m2 BMI reduction, USD 249.3 per BMI z-score, and USD 1308.9 per one overweight and obesity case avoided compared with the control group. Comprehensive intervention cost-effective	76%
Moodie, M. L., et al. 2013[191]	Australia	BAEW: an intervention to increase PA and healthy eating versus usual practice	Reduction of television viewing, diet, and PA (Community-based, primary school setting)	Cost-effectiveness and cost-utility analyses (Societal perspective)	Children aged 4 to 12 years mixed-weight status	Lifetime	Australian dollars (2006)	3% discount rate on future costs and health outcomes	BMI units saved and DALYs averted	The BAEW yielded a net cost per DALY saved of AUD 29,798 in comparison with the comparator. Cost-effective	100%
Epstein, L. H., et al. 2014[172]	United States	Two assumptions of P&C treated separately: P&C-1 (P&C treated on separate days) and P&C-2 (P&C treated on same days) versus FBT obesity treatment.	Diet and PA (Medical school setting)	Cost-effectiveness analysis (Societal perspective)	Children 8 to 12 years old, at or above the 85th BMI percentile, and had an overweight/obese parent	1 year from baseline	U.S. dollars (not stated)	NA	Unit of weight loss (defined in children as % over BMI)	ICERs were not estimated: the costs per unit weight lost for children were USD 209.17 per % over BMI, USD 1036.50 per % over BMI and USD 973.98 per % over BMI for FBT PC-1 and PC-2 groups, respectively. FBT potentially cost-effective	87%
Hayes, A., et al. 2014[192]	Australia	Home-based early intervention: eight home visits by specially trained	Diet and PA (Home-based)	Cost-effectiveness analysis (Health care funder	Infants followed and received the intervention for the first 2	2 years from baseline	Australian dollars (2012)	5% discount rate on future costs and health	Reduction in BMI z-score/unit BMI avoided	The incremental cost-effectiveness ratio was AUD 4230 per unit BMI avoided and AUD 631 per 0.1	100%

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		community nurses (including one visit at 30–36 weeks gestational age) versus usual care		perspective)	years of life			outcomes		reduction in BMI z-score or AUD 2697 per unit BMI avoided and AUD 376 per 0.1 reduction in BMI z-score, if the intervention cost per child was AUD 1309 or AUD 709, respectively. Potentially cost-effective	
Hollinghurst, S., et al. 2014[200]	United Kingdom	Primary care clinic versus COCO hospital clinic and Mandometer® training versus COCO hospital clinic	Diet and PA (Primary care, home and hospital-based)	Cost-effectiveness analysis (Health care funder perspective)	Children aged between 5 and 16 with BMI ≥98th centile (the PC-COCO study); children and young people aged 9 to 17 years with a BMI SDS >95th centile (the Mandometer® study)	1 year from baseline	GBP (not stated)	NA	Reduction in BMI z-score	The ICER for a primary care clinic compared to COCO hospital clinic was GBP 175 per 0.1-point improvement in BMI SDS while the ICER for Mandometer® training compared to hospital clinic was GBP 574 per 0.1-point improvement in BMI SDS. Mandometer® training potentially cost-effective	88%
Rush, E., et al. 2014[209]	New Zealand	Project Energise, a multicomponent through-school PA and nutrition programme versus usual care (unenergised)	Diet and PA (School-based)	Cost-utility analysis (Health care funder perspective)	Younger (6 to 8 years of age) and older primary school children (9 to 11 years of age) projected nationally/Maori population	Lifetime	New Zealand dollars (2011)	3.5% discount rate on future costs and health outcomes	QALY gained	Compared to usual care, the ICER was NZD 30,438 for the younger and NZD 24,690 for the older children, and lower for Maori (younger NZD 28,241, older NZD 22,151) and for the middle socioeconomic status schools (NZD 23,211, NZD 17,891) per QALY gained. Potentially cost-effective	92%
Barrett, J. L., et al. 2015[173]	United States	The 'Active PE' policy: a requirement that 50% of PE time of state's elementary	PA (School-based)	Cost-effectiveness analysis (Societal perspective)	Children aged 6 to 11 years	10 years	US dollars (2014)	3% discount rate on future costs and health	BMI units reduced	The intervention was estimated to cost USD 1720 per BMI unit reduced over the modelled 10-year period. This translated to an	98%

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		school PE curriculum be devoted to MVPA versus current practice						outcomes		estimated USD 60.5 million in health care costs averted. Potentially cost-effective	
Long, M. W., et al. 2015[174]	United States	Implementing a sugar-sweetened beverage excise tax versus the current practice (SSB)	Diet and tax (Multiple settings possible, population-based)	Cost-utility, cost-effectiveness, cost-benefit analyses (Societal perspective)	U.S. population aged ≥2 years at baseline	2 years (10 years for the general population)	U.S. dollars (2014)	3% discount rate on future costs and health outcomes	BMI units reduced	Over 2 years, the cost per BMI unit reduced due to the tax was estimated at USD 8.54 in children and youth aged 2 to 19 years of age. Potentially cost-effective	100%
Sonneville, K. R., et al. 2015[175]	United States	Eliminating tax subsidy of TV advertising to children (TV AD) versus current practice	Diet, television viewing, and tax (Home-based)	Cost-utility, cost-effectiveness, cost-benefit analyses (Societal perspective)	Children aged 2 to 19 years	10 years	U.S. dollars (2014)	3% discount rate on future costs and health outcomes	Net cost saved per dollar spent and QALY gained	The net reduction in cost and the total QALYs gained over 10 years were USD 343 million and 4540, respectively. The net cost savings per dollar spent was estimated at USD 38. Potentially cost saving	100%
Wright, D. R., et al. 2015[176]	United States	Early care and education policy change (ECE) versus current practice	PA, diet, and television viewing (Multiple settings possible, including childcare setting)	Cost-utility, cost-effectiveness, cost-benefit analyses (Societal perspective)	Children aged 3 to 5 years	11 years	U.S. dollars (2014)	3% discount rate on future costs and health outcomes	BMI units reduced and net cost saved per dollar spent	The ICER for the SSB was estimated at USD 57.80 per BMI unit avoided over two years and a net health care cost savings of USD 51.6 was estimated for a 10-year time horizon. Potentially cost-effective	100%
Gortmaker, S. L., et al. 2015[150]	United States	Four childhood obesity interventions: SSB excise tax; eliminating tax subsidy of TV AD to children; ECE policy change; and active	PA, diet, television viewing, tax, and education (Multiple settings possible)	Cost-utility, cost-effectiveness, cost-benefit analyses (Societal perspective)	Children aged SSB 2 to 19 years; TV AD 2 to 19 years; ECE 3 to 5 years; and Active PE 6 to 11 years.	10 years	U.S. dollars (2014)	3% discount rate on future costs and health outcomes	BMI units reduced and net cost saved per dollar spent (DALYs averted/QALYs gained not fully reported)	The net cost saved per dollar spent was USD 55, USD 38, and USD 6 for SSB, TV AD, and ECE, respectively. All four preventive interventions potentially more cost-effective clinical interventions	98%

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		PE.									
Sutherland, R., et al. 2016[193]	Australia	The PA4E1 multi-component intervention versus usual care	Diet and PA (School-based, low-income communities)	Cost-effectiveness analysis (Societal perspective)	Children in their first year of high school, mean age 12 years old of mixed weight status groups	2 years	Australian dollars (2014)	Not stated	Unit (10%) reduction in BMI z-score, mean minute of MVPA gained and MET minute gained	The ICERs were AUD 56 per additional minute of MVPA/day, AUD 749 per MET hours gained per person/day and AUD 563 per 10% reduction in BMI z-score. Potentially cost-effective	93%
Graziose, M. M., et al. 2017[177]	United States	FHC, an obesity prevention nutrition education curriculum delivered over 1 year versus current practice (no-intervention)	Diet, PA, and screen time (School-based)	Cost-utility analysis (Societal perspective)	All New York City fifth-grade public school students (mean age 10 years)	Lifetime	U.S. dollars (2012)	3% discount rate on future costs and health outcomes	QALY saved	An ICER of USD 275 per QALY saved was estimated for the intervention. Cost-effective	98%
Robertson, W., et al. 2017[201]	United Kingdom	'Families for Health', a 10-week family-based childhood obesity treatment intervention versus usual care	Diet, PA, parenting skills, and relationship skills (Community-based)	Cost-utility analysis (NHS and Personal Social Services perspective)	Children aged 6 to 11 years who were overweight or obese and their parents or carers	1-year post-randomisation	GBP (2013/14)	NA	Change in children's BMI z-score and QALYs gained (EQ-5D-Y)	The ICER for the Families for Health programme was estimated at GBP 552,175 per QALY gained. Not cost-effective	100%
Klebanoff M. J., et al. 2017[155]	United States	Bariatric surgery (either gastric bypass or sleeve gastrectomy) versus no surgery	Bariatric surgery (Hospital setting)	Cost-utility analysis (Health care provider)	Adolescents (mean age 17 years) with severe obesity	3 years base case	U.S. dollars (2015)	3% annual rate for cost and QALYs	QALY gained (Instrument not stated)	ICER using a WTP threshold of USD 100,000 per QALY gained: at 3 years USD 154,684 per QALY (surgery dominated); at 5 years USD 91,032 per QALY, surgery potentially cost-effective	75%
Cradock, A. L., et al. 2017[178]	United States	Six prevention strategies: (Active PE; Active Recess; Active School Day; Healthy	PA: state-wide and national implementation (School, afterschool, and	Cost-effectiveness and cost-benefit analyses (Societal perspective)	Children aged 3 to 14 regardless of BMI status	10 years (2015 to 2025)	U.S. dollars (2014)	3% annual rate for cost	BMI unit reduction, cases of childhood obesity prevented, and health care cost savings.	All interventions showed a potential to prevent cases of obesity. The ICER for New Afterschool Programme was dominant, while the ICERs for	90%

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		Afterschool; New Afterschool Programmes; and Hip Hop to Health, Jr.) versus the status quo	childcare settings)							the remaining interventions ranged from USD 361 to USD 2825 per BMI unit change per person. All interventions potentially cost-effective	
Ekwaru, J. P., et al. 2017[216]	Canada	The Alberta Project Promoting Active Living and healthy Eating in Schools (APPLE) Schools (the intervention programme) versus general schools (No intervention)	PA and diet (Elementary schools)	Cost-utility analysis (Societal perspective)	Grade five students (about 10 years of age); weight status included healthy weight, overweight, and obesity	Lifetime	Canadian dollars (2008)	3% annual rate for cost and QALYs	QALY gained (Instrument not stated)	At a cost-effectiveness threshold of CAD 50,000, CAD 33,421 per QALY gained.	92%
Larsen, K. T., et al. 2017[217]	Denmark	Camp group (CG), a six-week high-intensity day-camp intervention versus Standard group (SG), a six-week low-intensity intervention.	PA: motivation-enhancing PA and health education (Municipal setting)	Cost-effectiveness analysis (Societal perspective)	Overweight and obese fifth-grade children with a mean age of 12 years	Two years follow-up	DKK (2012)	Not stated	Changes in BMI and BMI z-score	The ICER was DDK 149,669 per unit decrease in BMI z-score for CG compared with SG in the base case scenario. Insufficient information/potentially cost-effective	69%
Lee, B. Y., et al. 2017[179]	United States	Two levels of PA: 25 min of high-calorie-burning PA three times a week, for children 6 years and older; and 60 minutes of moderate PA each day, for children ages 6–17 years.	PA (School/community)	Cost-consequences analysis (Societal perspective)	A simulation sample representative of the U.S. population of children (6 to 17 years) with healthy weight, overweight, and obese status	Lifetime	U.S. dollars (2016)	3% for costs	Lifetime medical care costs, lost productivity, reduction in cases of obesity, quality-adjusted life-years (QALY instrument not stated)	Increasing the current level of children who get 25 minutes of high-calorie-burning PA from 31.9% to 75% was estimated to save a total of 18,913,447 QALYs. At 31.9%, an annual net present value of USD 1.1 trillion in direct medical costs was estimated. Potentially cost-effective	81%
Makkes, S., et al. 2017[206]	The Netherlands	Two intensive 1-year lifestyle treatment	PA (Clinical setting: specialised	Cost-effectiveness and cost-utility	8 to 19 years with severe	1 year of treatment and 1 year	Euros (2010)	4% and 1.5% for costs and outcomes	BMI z-scores and QALYs (EQ5D)	The difference in BMI z-score and QALYs between both groups after 24 months was	83%

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		interventions consisting of either an inpatient period of 2 months (short-stay group) or 6 months (long-stay group).	childhood obesity centre)	analyses	obesity	of follow-up		respectively		very small and possibly statistically insignificant. The ICER was one point higher in SDS-BMI per savings of EUR 1,479,463 for the short-stay compared with the long-stay group. Short-stay cost-effective	
Quattrin, T., et al. 2017[180]	United States	Family-based behavioural treatment (FBT) and an attention-controlled information control (IC) group	PA and diet: parent and child-focused (Clinical setting: patient-centred medical home)	Cost-effectiveness analysis (Societal perspective)	Children 2 to 5 years of age with overweight and obesity (BMI over the 85th percentile for their age and sex) with their parents (BMI ≥ 25)	1 year of treatment and 1 year of follow-up	U.S. dollars (2013)	NA	Child percent over BMI (%OBMI) change and parent BMI change	In the intention-to-treat group, the FBT ICER compared to IC was USD 116.1 per unit reduction in %OBMI for children and parents, the ICER was USD 353.8 per kilogram reduction in weight. FBT potentially cost-effective	81%
Beets, M. W., et al. 2018[181]	United States	Two afterschool programs (ASPs): immediate or delayed	PA and diet (Schools, community/recreation, and faith locations)	Cost-consequences analysis	Children aged 5 to 12 years including healthy weight, overweight, and obese weight status	End of the 2-year trial	U.S. dollars (2015)	NA	Changes in MVPA and changes in number of days fruits/vegetables, water, desserts, and SSBs were served.	In immediate/delayed groups, an increase of USD 0.05/USD 0.26 and USD 0.23/USD 0.08 per child per weekly enrolment fee was required to increase % of boys and girls accumulating 30 min or more of MVPA by 1%, respectively. Immediate potentially cost-effective in boys but not in girls	73%

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An, R., et al. 2018[182]	United States	Placing water dispensers at school cafeterias nationwide to promote lunchtime plain water consumption versus no action	Drinking water (School-based)	Cost-benefit analysis (Societal perspective)	All school children in primary, secondary, and high schools	Lifetime	U.S. dollars (2016)	3% discount rate on future costs and benefits	Number of cases of overweight/obesity prevented expressed in terms of per capita annual medical cost of adult overweight/obesity	The net benefit of the intervention was USD 174 per student. A net benefit of USD 199 and USD 149 per student was estimated for boys and girls, respectively. Potentially cost-effective	77%
Anderson, Y. C., et al. 2018[211]	New Zealand	Two home-based multi-disciplinary child obesity intervention programmes (high-intensity and low-intensity) versus conventional hospital-based care	Multi-disciplinary assessment and advice to promote healthy diet and PA choices (Home-based, community-based, and hospital-based care)	Cost-effectiveness analysis (Health funder perspective)	Children aged 5–16 years with a body mass index (BMI) ≥98th centile or BMI >91st centile with weight-related comorbidities. In the comparator arm, children were aged 4–15 years.	12 months from baseline	New Zealand dollars (2016)	NA	BMI z-score	The low-intensity group was NZD 939 lower than the conventional group. In the high-intensity intervention group was NZD 155. Both low- and high-intensity groups had mean BMI z-score reductions of 0.03 more than the conventional group. Potentially cost-effective	77%
Brown, V., et al. 2018[194]	Australia	Legislation to restrict TV advertising of food and beverages high in fat, sugar, and salt (HFSS) until 9:30 p.m. versus baseline or usual viewing	Diet and legislation (Population-based, home-based)	Cost-effectiveness analysis (Societal perspective)	All children 5–15 years of age	Lifetime	Australian dollars (2010)	3% discount rate on future costs and health benefits	Reductions in energy intake (mean KJ/day), reductions in BMI and HALY saved	The intervention was dominant with 88,396 HALYs saved and a total cost savings of AUD777.9M at the population level over the lifetime. Potentially cost-effective	96%
Conesa, M., et al. 2018[215]	Catalonia, Spain	Educació en Alimentació Programme (EdAl): a set of educational interventions focused on	Diet and PA (School-based)	Cost-effectiveness analysis (Societal perspective)	Children aged 7–8 years, comprising underweight to obese weight status but about	End of the trial: 28 months (2.3 years)	Euros (2007)	NA	Number of obesity cases avoided, the decrease in obesity prevalence, the decrease in BMI units, and the	Cost-effectiveness analysis not performed for girls as the intervention was not effective. For boys, the ICERs (intervention relative to control) were 968.66	73%

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		improving lifestyle choices versus control (usual care)			70% being healthy weight in both arms				decrease in BMI z-score units	EUR/case of obesity avoided, 44.68 EUR/BMI one-unit decrease, 3.56 EUR/1% obesity prevalence reduction and 65.16 EUR/BMI z-score one-unit decrease. Cost-effective in boys	
Döring, N., et al. 2018[218]	Sweden	PRIMROSE intervention: an early childhood obesity intervention delivered in the first 4 years of life versus usual care	Diet and PA; Motivational Interviewing (Clinical; child health care centres)	Cost-effectiveness analysis (Societal perspective)	Pre-school children aged 9 months of age of mixed weight status	End of the trial: child at age 4 (48 months)	Euros (2015)	Not stated	BMI unit prevented	In the base case analysis, the ICER was EUR 3109 per 1 BMI unit prevented. Inconclusive due to high uncertainty around effect measure	71%
Panca, M., et al. 2018[202]	Greater London, England	The Healthy Eating Lifestyle Programme (HELP) compared with enhanced standard care	Diet and PA: motivational multicomponent lifestyle-modification intervention (Community setting)	Cost-utility analysis (U.K. National Health Service)	Young people with obesity aged 12 to 18 years	One-year time horizon (treatment ended at 6 months and follow-up for another 6 months)	GBP (2013/14)	NA	QALY gained (EQ-5D-3L)	The ICER of the HELP versus enhanced standard care was GBP 120,630 per QALY gained and there were no differences in adjusted QALYs between both groups. HELP not cost-effective	90%
Reilly, K. L., et al. 2018[195]	Australia	Three multicomponent interventions (high, medium, and low intensity) to enhance implementation of a healthy canteen policy versus usual support	Diet-based (School-based)	Cost-effectiveness analysis (Health service delivery perspective)	Students 5 to 12 years old in primary schools of mixed weight status	End of trials (12 months). The Medium trial was scaled from 9 months to 12 months	Australian dollars (2015)	NA	Percentage point increase in the proportion of schools that adhered to the policy	The ICERs for the three interventions were AUD 2982 (high intensity), AUD 2627 (medium intensity) and AUD 4730 (low intensity) per percent increase in the proportion of schools reporting 'adherence' compared to usual support. Medium intensity potentially cost-effective	85%
Vidmar, A. P., et al. 2019[183]	United States	iPhone® app intervention with clinic visits,	App-based (Mobile health technologies) and	Cost-consequences analysis (Provider	Obese adolescents 12 to 18 years	6 months post-	U.S. dollars (not stated)	NA	Mean change in BMI z-score and excess percent over	App participants had lower total costs per patient (USD 855.15 vs. USD 1428.00) than	67%

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		targeting addictive eating behaviour versus EMPOWER clinic intervention consisting of a team of health care professionals who evaluate patients	clinical evaluation-based (Clinic and home-based)	perspective)	without significant obesity comorbidities but exhibited signs of addictive eating	baseline			the 95th percentile (%BMIp95)	the EMPOWER clinic participants. Both app participants and EMPOWER completers demonstrated comparable decreases in BMI z-scores and %BMIp95 6 months after baseline. App intervention potentially cost-effective	
Amies-Cull, B., et al. 2019[203]	England	20% reduction in the sugar content of certain high sugar products versus no reduction	Diet-based (Population-based)	Cost-consequences analysis (NHS England perspective)	The general population aged 4 to 80 years, specifically capturing children age group cohorts of 4 to 10 years and 11 to 18 years.	10 years in the base case	GBP (not stated)	Not stated	Calorie change, weight change, and BMI change for children and adults. QALYs for adults only.	A potential reduction in obesity among 4–10-year-olds by 5.5%, 11–18-year-olds by 2.2% was estimated for the intervention. Potentially cost-effective	82%
Ananthapavan, J., et al. 2019[196]	Australia	Hypothetical community-based obesity prevention interventions (CBIs) versus control	Diet, PA, change in school infrastructure, and changes to the obesogenic environment within the community (Community-based)	Cost-effectiveness analysis (Societal perspective)	Australian children aged 5 to 18 years	Lifetime	Australian dollars (2010)	3% discount rate on future costs and benefits	Change in BMI and HALY gained	For CBIs, the ICER was AUD8155 per HALY gained at a willingness to pay threshold of AUD 50,000 per HALY. Cost-effective	98%
Brown, V., et al. 2019[197]	Australia	Seven hypothetical scenarios of varying effect (reduction in BMI z-score) maintenance and subsequent decay to no effect	Multiple components including diet and PA (Population-based)	Cost-consequences analysis (Health service delivery perspective)	Australian children aged 2 years modelled into adulthood	Lifetime	Australian dollars (2010)	3% discount rate on future costs and benefits	HALYs saved, life-years saved and health care cost savings	Assuming a reduction in BMI z-score of 0.13 in children aged 2 to 5 years, the scenario that assumed lifetime maintenance of effects resulted in 36,496 HALYs saved and health care cost savings of AUD 301	92%

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										million over lifetime. Potentially cost-effective	
Canaway, A., et al. 2019[204]	United Kingdom	Intervention schools: a multifaceted, 12-month, school-based intervention. Control schools: usual care	Diet and PA (School-based)	Cost-utility analysis (Public sector perspective)	Primary school children aged 6 to 7 years of mixed weight status	30 months: intervention was delivered over 12 months and follow-up was 18 months post-intervention	GBP (2014)	3.5% for costs and outcomes	Difference in BMI z-scores and QALY gained (CHU9D instrument)	For the base case, the ICER associated with the intervention was GBP 26,815 per QALY gained. Inconclusive due to uncertainty around effectiveness and varying WTP threshold of GBP 20,000–30,000 per QALY	90%
Kenney, E. L., et al. 2019[184]	United States	Four drinking water interventions: Install water jet dispensers; Grab a Cup, Fill it Up; portable tap water dispensers; and install bottle-less water coolers.	Change in school drinking water environment (School-based)	Cost-benefit analysis (Societal perspective)	Students in kindergarten through eighth grade (K-8)	10-year time horizon	U.S. dollars (2015)	3% discount rate on future costs	Cost per case of childhood obesity prevented, cost per BMI unit reduced and health care cost savings per dollar invested	ICER not estimated. For the water jet intervention, the health care cost savings per dollar invested was USD 0.31 and the cost per BMI avoided was USD 105.29. Potentially cost-effective	90%
Sonntag, D., et al. 2019[213]	Germany	Infant formula nutrition: lower protein (LP) versus higher protein (HP) intake groups	Diet: formula feeding (Multiple settings possible)	Cost-utility analysis (Societal perspective)	Infants born from uncomplicated singleton pregnancies	Lifetime	Euros (2015)	3% discount rate on future costs and benefits	QALY gained	Slightly higher QALYs and lower lifetime costs were estimated for LP relative to HP (negative ICER), therefore LP was deemed dominant and cost-effective	94%

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Vieira, M. and Carvalho, G.S. 2019[219]	Northern region, Portugal	The PHS-pro, a learning module promoting healthy choices versus a non-randomised control group	Water intake, TV viewing time, diet, and PA (School-based)	Cost-consequences analysis (Societal perspective)	Children 10 to 14 years old of varying weight status	10 months from baseline	Euros (2012)	NA	The per capita net cost of implementing the PHS-pro intervention in children versus cost of treating a case of adult obesity	The per capita net cost of implementing the intervention was 36.14 EUR/child/year compared to direct costs estimated for treating one obese adult in Portugal (3849.15 EUR/year). Inconclusive	58%
Bandurska, E., et al. 2020[221]	Poland	12-month multidisciplinary obesity management comprising screening for overweight, specialist care, parental education, and specialist consultation versus no intervention	Diet, PA, and psychological support (Clinical and community based)	Cost-effectiveness analysis (Not stated/Provider perspective implied)	6- to 15-year-old overweight or obese children	7 years	PLN and Euros (not stated)	Not stated	Child removed from overweight or obesity	The costs of removing a child from the overweight group and obese group were PLN 27,758 (EUR 6463) and PLN 23,601 (EUR 5495), respectively. As noted earlier, the authors do not present any comparator costs or outcomes, so it is not clear if these estimates are incremental. Inconclusive	52%
Breheny, K., et al. 2020[205]	United Kingdom	The Daily Mile: running or walking around school grounds for 15-min daily versus only the usual school health and wellbeing activities	PA (School-based)	Cost-utility analysis (Public sector perspective)	Children aged 4 to 11 years in all state-funded primary and junior schools	1 year	GBP (2017)	NA	QALY gained (CHU-9D)	The ICER for the Daily Mile intervention was GBP 7445 per QALY gained for the whole group and GBP 2492 per QALY gained for girls. Potentially cost-effective in girls, inconclusive for boys	94%
Finster, M.P. and Feldman, J. 2020[55]	United States	Onsite versus online support to implement a school-based wellness program	Diet and PA (School-based)	Cost-effectiveness analysis (Not stated/Societal perspective implied)	Students in low socioeconomic status neighbourhoods (age and weight status not specified)	4 years	U.S. dollars (not stated)	Not stated	Average percentage point increase in overall wellness (School Health Index) score	The cost per average percentage point increase in the overall wellness score was USD 336 and USD 256 for the onsite and online interventions, respectively. The onsite intervention potentially cost-effective	63%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
Huse, O., et al. 2020[198]	Australia	A national mandatory restriction on all price promotions for sugar-sweetened beverages (SSBs) available for purchase for take-home consumption in Australia versus no policy	Diet (Population-based, home-setting)	Cost-effectiveness analysis (Societal perspective)	The 2010 Australian population aged 2 to 100 years	Lifetime	Australian dollars (2010)	3% discount rate on future costs and benefits	HALYs gained	With a total HALYs gained estimated at 34,260 and the intervention cost an estimated AUD 17.0M, the policy was said to be dominant (cost-saving and health-promoting). Potentially cost-effective	94%
Oosterhoff, M., et al. 2020[207]	The Netherlands	Two health promotion interventions in the school environment: Healthy Primary School of the Future (HPSF) and Physical Activity School (PAS) versus healthy practice	Diet and PA (Primary school-based)	Cost-benefit analysis (Societal perspective)	Primary school children 4 to 12 years of age	2 years	Euros (2016)	Annual discount rate of 2.5% applied to investments and benefits	Outcomes across several sectors including health care, education, household, and leisure, were expressed in monetary terms and combined	Per child, investments of EUR 859 and EUR 1017 generated benefits of EUR 8 and EUR 49 for HPSF and PAS, respectively. Inconclusive	81%
Oosterhoff, M., et al. 2020[208]	The Netherlands	Two health promotion interventions in the school environment: Healthy Primary School of the Future (HPSF) and Physical Activity School (PAS) versus healthy practice	Diet and PA (Primary school-based)	Cost-utility analysis (Societal perspective)	Primary school children 4 to 12 years of age	Lifetime	Euros (2018)	4% and 1.5% annual discount rates on future costs and benefits, respectively	QALY gained (meta-analysis)	From a societal perspective, PAS was dominated and HPSF was the most cost-effective with an ICER of EUR 19,734 per QALY gained. Potentially cost-effective	100%
Tan, E. J., et al. 2020[199]	Australia	POI sleep intervention alone and in combination	Sleep modification, diet, PA, and	Cost-effectiveness and cost-utility analyses (Health	Healthy infants received the intervention up	15 years	Australian dollars (2018)	Annual discount rate of 5% for costs	QALY (meta-analysis) and unit	The ICER for the POI Sleep intervention alone was AUD 18,125 per QALY gained and	96%

First Author and Year of Publication	Country	Intervention(s) and Comparator(s)	Intervention Component(s) and Target(s) (Setting)	Type of Economic Evaluation (Study Perspective)	Target Population and Age Range	Time Horizon/Follow-Up for Trials	Currency Unit (Price Year)	Discount Rate(s)	Measure(s) of Consequence(s)	Results and Cost-Effectiveness	CHEERS Quality Score (%)
		with food, activity, and breastfeeding advice (FAB) versus usual care	breastfeeding (Home and clinical settings)	funder perspective)	to the first 2 years of life and were then followed up to age 5 years			and effects	BMI avoided	was cost-effective at a willingness-to-pay threshold of AUD 50,000 per QALY	
Xu, H., et al. 2020[164]	China	Three school-based childhood obesity interventions: NE intervention; PA intervention; and CNP intervention, which included the NE and PA interventions.	PA and diet (School-based)	Cost-utility and cost-benefit analyses (Societal perspective)	Baseline age of 10 years implied; childhood weight status not clearly stated. Parents, teachers, and health workers also received some of the interventions.	55 years (ages 10 to 65 years)	CNY and U.S. dollars (2019)	3% discount rate on future costs and benefits	QALYs and costs averted	The ICERs were CNY 10,335.2 (USD 1478.6) and CNY 4626.3 (USD 661.8) for CNP and NE respectively, compared with PA intervention. Estimates of monetary benefits were CNY 1.2, CNY 0.7, and CNY 0.4 per CNY 1 cost for CNP, NE, and PA interventions, respectively. CNP potentially cost-effective	73%

AASC: the active after-school communities programme; ACE: the assessing cost-effectiveness in obesity study; APPLE: A Pilot Programme for Lifestyle and Exercise; ARIC: Atherosclerosis Risk in Communities; BAEW: Be Active Eat Well; BMI: body mass index; CARDIA: Coronary Artery Disease Risk Development in Young Adults; CATCH[1]: Coordinated Approach to Child Health; CHOICES: Childhood Obesity Intervention Cost Effectiveness Study; CNP: comprehensive intervention; COCO: The Bristol Care of Childhood Obesity clinic; DALY: disability-adjusted life year; DKK: Danish crowns; DWCB: disordered weight control behaviours; ECE: early care and education; EDNP: energy-dense, nutrient-poor; EPOCH: Early Prevention of Obesity in Childhood; FBT: family-based treatment; FHC: food, health, and choices; GBP: pound sterling; GP: general practitioner; HALY: Health adjusted life year; ICER: incremental cost-effectiveness ratio; ITT: intention-to-treat; LEAP: the live, eat and play trial; LYG: life year gained; MCG FitKid: the Medical College of Georgia FitKid Project; MEPS: Medical Expenditures Panel Survey; MET: metabolic equivalent; MPA: moderate physical activity; MVPA: moderate to vigorous physical activity; NA: not applicable; NE: nutrition education intervention; NHANES: National Health and Nutrition Examination Survey; NHF: National Heart Forum; P&C: parent and child; PA: physical activity; PA4E1: Physical Activity 4 Everyone; PC-COCO: Primary Care-Care of Childhood Obesity; PE: physical education; PHS-pro: Planning Health in School; PIF: potential impact fraction; PLN: Polish zloty; POI: Prevention of Overweight in Infancy; PSA: probabilistic sensitivity analysis; QALYs: quality-adjusted life years; RCT: randomised controlled trial; CNY: Chinese yuan renminbi; SPARK: The Sports, Play, and Active Recreation for Kids trial; SSB: sugar-sweetened beverages; TV AD: television advertisements; URMEL-ICE: Ulm Research on Metabolism Exercise and Lifestyle Intervention in Children; WC: waist circumference; WHtR: waist-to-height ratio; WSB: Walking School Bus programme; WTP: willingness to pay.

2.4.4 Discussions

Summary of Results and Comparative Evidence

This review identified emerging trends around economic evaluations of interventions for children with excess weight. Of note is the increase in recently published economic evaluations, with nearly half of the identified studies conducted within the past three years indicating growing public and decision-maker interest in the trade-offs between the costs and consequences of competing interventions. Although I estimated a higher percentage of preventive interventions that were either cost-effective or potentially cost-effective compared with treatment interventions (86% versus 79%), in general, there is still uncertainty about which strategy is likely to be more cost-effective, as most of the studies I reviewed focussed on preventive interventions. I observed a notable shift towards economic evaluations of treatment interventions in recent years, with only nine solely treatment interventions between 2001 and 2015 versus five between 2016 and 2020.

The most frequently adopted approach to economic evaluation in this review was CEA, where measures of consequences were typically captured in terms of units of change in body weight status, such as change in BMI z-score. Despite increasing adoption in other areas of health care, CUA remains a less common approach in this field. The use of CUA, particularly in trial-based study designs, is limited by the methodological challenges arising from measuring and valuing health states in childhood populations discussed in the utilities section above (Section 4.2.). CUA was the main method of choice for decision-analytic models adopting a longer-term time horizon because utility estimates for health states in adulthood are more established. However, longer-term modelling of costs and consequences introduces uncertainties due to assumptions about the persistence of benefits accrued from interventions implemented over short periods during childhood.

While the systematic review by Zanganeh et al.[154] did not identify cost-benefit analyses, this review identified three economic evaluations that applied a purely cost-benefit approach.[182,184,207] Cost-benefit analyses of interventions targeting childhood excess weight tend to be more commonly conducted in the U.S. In the U.K. and Australia, CBA is usually recommended for the evaluation of public sector interventions outside the health sector. The differences in approaches to economic evaluations across countries hinder comparability. Torbica et al.[222] argue that a ‘one size fits all’ approach is not feasible, and the chosen evaluative method will inevitably reflect contexts unique to individual countries. Because most childhood obesity preventive interventions are

implemented outside the health sector, the inclusion of cost-benefit analyses may give further insights in terms of wider societal budgeting and planning. For instance, Moodie et al.[190] found that although the TravelSMART Schools Curriculum programme was not cost-effective following a cost-utility-based analysis, the intervention could be cost-effective if non-obesity consequences such as environmental outcomes are considered.

There are indications that interventions may be more cost-effective when specifically targeted at certain subgroups. For instance, two studies[181,215] found that certain school-based interventions were cost-effective in boys but not in girls, while another study[205] reported an intervention to be cost-effective in girls but inconclusive in boys. The mechanisms to explain these potential differences are unclear. Future studies should strive to estimate and explain any differences in cost-effectiveness that may exist between key population subgroups.

Strengths and Limitations

A key strength of this review is the inclusion of intervention categories, such as surgical interventions, that were excluded from the previous review.[154] One evaluation of a surgical intervention was identified and showed potentially cost-effective estimates for bariatric surgery in children with severe obesity. Future reviews should widen the search for novel interventions such as pharmacological and technology-based interventions such as eHealth/mHealth interventions. As with the other reviews in this chapter, my search was limited to only one database in English, and relevant studies might have been missed. However, the number of newly published studies identified by my search was nearly as many as those identified in the systematic review that I updated and augmented.

Future studies in this area should account for differential timing of outcomes when the study time horizon exceeds one year. Robust deterministic and probabilistic sensitivity analyses should be performed where appropriate, and the variation in results across subgroups of patients should be accounted for. For studies that project cost-effectiveness beyond the period follow-up period, extensive scenario analyses should be conducted to test assumptions about the persistence of treatment effects. Finally, the authors should state the sources of funding and conflicts of interest.

2.5 Economic determinants and broader consequences of childhood excess weight

2.5.1 Background and rationale for literature review

Earlier in Section 2.2, this chapter explored the risk factors for childhood excess weight from a wide-ranging epidemiological perspective and in Section 2.3, the direct/medical care cost implications were discussed in detail. This section emphasises evidence from the economic literature on causes, pathways, and broader consequences of overweight or obesity in childhood. Economic determinants and consequences are considered separately using an array of key narrative reviews[16,69], original research[223-225], and systematic reviews[7,226-228] as frameworks for disentangling individual determinants and human capital consequences.

2.5.1 Methods

Due to time constraints, my approach to searching in this section was limited. I searched for published systematic reviews covering economic determinants of childhood excess weight via advanced Google Scholar, applying combinations of the search command terms 'socioeconomic inequalities', 'socioeconomic status (SES)', 'food pricing', 'diet', 'sugar-sweetened beverages (SSBs)', 'soft drinks', 'paediatric', 'childhood', and 'youth'. I restricted my search to studies published from 2010 to 2021. I also searched the weekly updates from Obesity Intelligence (https://khub.net/web/phe-obesity-intelligence last accessed on 20 January 2021) from November 2020 to January 2021 and the reference lists of relevant studies.

I conducted similar advanced Google Scholar searches for systematic reviews covering the broader consequences of childhood excess weight, including the search terms 'human capital', 'wages', and 'education'. I extracted key assessment items from the recently conducted systematic review by Segal et al. [7] and additional related studies identified by my searches.

2.5.3 Results

Summary of Study Results—Economic Determinants

In this section, I focus on two key economic determinants of childhood excess weight: socioeconomic inequalities and food pricing and consumption. My Google Scholar searches identified a relevant systematic review by El-Sayed et al.[226], the results of which form the core of my narrative review of socioeconomic inequalities in

childhood excess weight. For food pricing and consumption, I cite findings from original studies identified by my searches.

Socioeconomic Inequalities

Socioeconomic status (SES), the measure of an individual's combined economic and social status[229] or their proximity to resources relative to other individuals in society[226], is an established predictor of health outcomes. Many studies find that individuals in less favourable socioeconomic positions tend to present with poorer morbidity profiles and suffer higher mortality rates for chronic diseases.[230] Furthermore, evidence suggests that SES may mediate childhood-to-adulthood BMI trajectories in some population subgroups.[225]

Common measures of SES described in the literature can be broadly categorised as education-, income-, or occupation-based.[229] In the systematic review by El-Sayed and colleagues[226], SES metrics were defined at three levels: geographic- or area-level, household-level, and individual-level.[226] Most of the studies identified by this review that assessed geographic-level SES metrics using common indices such as the Townsend Deprivation Index[231,232] and the Carstairs–Morris Deprivation Index[233] found positive associations between the higher levels of area-level deprivation and obesity prevalence. For household and individual metrics, El-Sayed et al.[226] found mixed results. Apart from a few contributing studies, metrics such as the head-of-household social class and maternal education were reliable predictors, showing inverse associations with childhood obesity. Metrics such as household income and receiving free school meals showed conflicting and weak associations, respectively, with childhood obesity across the reviewed studies. More recent studies and reviews of studies have echoed the mixed results for specific SES determinants identified by the systematic review by El-Sayed and colleagues.[69,227,228,234]

Food Pricing

The 21st century has seen unprecedented access to an ever-increasing variety of food types across the world. Consequently, dietary behaviours have adapted to marked changes in food choice and availability. The evidence linking excess food consumption, measured in terms of energy intake, to excess weight gain is compelling[235,236], especially for highly processed, energy-dense foods and sugar-sweetened beverages (SSBs). Food pricing is a relevant economic determinant because policies that affect food and beverage purchases are potential drivers of energy intake.[237]

Several jurisdictions around the world have implemented population-wide policies aimed at improving food intake and reducing obesity, and there is increasing evidence of the effectiveness of SSB tax policies. A systematic review by Teng et al.[238] indicated that SSB taxes introduced in various geographical regions were effective in cutting SSB purchases. Recent research from the U.K. shows strong evidence that a soft drinks industry levy might limit exposure to liquid sugars and consequent health risks.[239]

Summary of Study Results—Broader Economic Consequences

I identified a systematic review by Segal et al.[7] published in 2020 that investigated the impact of childhood excess weight on human capital in high-income countries. I re-examined the 19 studies included in the systematic review as well as two additional studies identified by my searches[79,80] that reported labour market outcomes. A descriptive analysis of the individual studies is presented in Table 6. The studies in this review were mostly U.S.-based, and the predominant datasets used were the U.S. National Longitudinal Survey of Youth 1997 (NLSY97), the National Longitudinal Study of Adolescent Health (Add Health), and the Early Childhood Longitudinal Study-Kindergarten Class Assessment (ECLS-K).

Cognitive performance was the most researched broader economic consequence, being the focus of 17 studies.[240-256] Four studies[79,242,254,257] focussed on educational attainment, while five studies from three articles[79,80,258] focused on labour market outcomes. Thirteen studies were based on data from the U.S.[79,240-244,248,250,252-254,257,258], while two studies each were based on data from the U.K.[246,255], Taiwan[245,249], and Australia.[251,256] One additional study used Canadian data[247] and another used Swedish data.[80]

Cognitive Performance

The most common measure of cognitive performance was students' standardised scores for academic subjects in national examinations, such as the Peabody Individual Achievement Test (PIAT), Key Stage examinations, and the National Assessment Program Literacy and Numeracy examination (NAPLAN). Cognitive performance tests also took the form of high school grade point averages (GPAs).

The analyses were stratified by sex in 13 studies[240-245,248-252,254,255], seven[240,241,243,248,249,251,254] of which reported that excess weight was associated with lower cognitive function. Two studies reported a significant negative effect of excess weight on cognitive performance for girls but not for boys.[241,254] However, Black et al.[251] found that obesity was negatively related to cognitive achievement for boys but not for girls. The results from the six

studies[240,243,244,246,248,255] that performed disaggregated analysis by race were mixed with three[240,243,248] reporting lower cognitive function in association with excess weight and three[244,246,255] not reporting any significant effects. Only two studies were stratified by age: one reported no difference in cognitive function[242], while the other reported a greater magnitude of negative excess weight effects on senior-year students compared with junior grade students.[256]

Educational Attainment

In addition to three studies[242,254,257] identified by Segal and colleagues[7], my review includes a U.S.-based study by Amis et al.[79] that also examined educational attainment. Amis et al. [79] estimated the effects of being obese during adolescence on the likelihood of high school graduation and post-secondary educational attainment in the U.S., disaggregating their analysis by sex and race (whites, blacks, and Hispanics). Results were not significant for high school on-time graduation or college attendance for all children or any of the subgroups. However, children with obesity who went on to attend college were 9% less likely to graduate than their healthy-weight peers. The negative effects of being obese on college degree attainment were statistically significant overall as well as for female students and whites, who were both 12% less likely to graduate than nonobese adolescents.

Kaestner and Grossman[242] investigated the association between weight and grade attainment for children aged 9–10 and 11–12 years in the U.S., finding similar grades for overweight or obese children compared with children of healthy weight in both age subgroups. Okunade et al.[257] examined the effects of weight on adolescents stratified by sex and race in the U.S. They found a statistically significant negative relationship between excess weight and timely high school completion in females but not males. In terms of racial disparities, adverse effects were found primarily in white and Asian females, but no significant effects were reported for African Americans. Sabia and Rees[254] examined the effect of body weight on high school diplomas and college completion among adolescents in the U.S. and found a stronger negative effect on female academic achievement relative to male academic achievement.

Labour Market Outcomes

In addition to the study[258] identified by Segal and colleagues[7], this review includes two articles[79,80] comprising four studies in the U.S., U.K., and Sweden. A U.S.-based study by Pinkston[258] examined the hourly wages of adults in 2009 who were overweight, obese, and severely obese aged 12 to 16 years in 1996 (white children only). It found

that a childhood history of severe obesity had a significant large negative effect on wages for white men, whilst in women, a childhood history of both overweight and obesity had a significant and large negative effect. Furthermore, an initial penalty of 13% in wages was estimated for women entering the labour market with a BMI over 37.

A U.S.-based study by Amis and colleagues[79] followed white, black, and Hispanic children of both sexes with a mean age of 16 years for 13 years and estimated labour market earnings. The authors found that the negative effects of adolescent obesity on future earnings were predominant among females and blacks. They earned nearly 12% and 9% less, respectively, in future wages, compared to their non-obese peers.

Lundborg and colleagues[80] estimated the Swedish adult male labour market penalty for being overweight or obese as a teenager and carried out a complementary analysis on cohorts of children in the U.S. and the U.K. In their large sample of 145,193 siblings who enlisted in the military at age 18, they found that in comparison with teenagers of healthy weight, overweight and obese adolescents earned 6% and 18% less, respectively, between ages 28 and 38. Both estimates were statistically significant. To put these estimates in context, they calculated that the penalty of being obese corresponded to almost three years of schooling, or the time required to complete a university bachelor's degree. Using the United Kingdom National Child Development Study (NCDS) cohort, the authors further estimated that being obese at 16 was associated with a statistically significant 38% decrement in earnings at age 42. Estimates for overweight at the same age were substantially lower (about 2%) and not statistically significant. Using the NLSY79 data, Lundborg and colleagues estimated that men who were obese at ages 16 to 24 were likely to earn 18% less at ages 39 to 42 relative to their healthy weight counterparts.

Table 6 Descriptive analysis of the key assessment items for studies on the impact of childhood obesity on human capital

First Author and Year of Publication	Country	Type of Study/Dataset	Period Considered	Target Population	Sample Size	Stratification	Exposure	Outcome(s) Estimated	Main Results	Conclusion
Sabia, J. J. 2007[240]	United States	Individual-level longitudinal/Add Health	1994–1995 (wave 1) to 1995–1996 (wave 2)	A nationally representative sample of 14- to 17-year-olds	5129 adolescents	Sex and race (White, non-White)	Overweight and obesity (BMI z-score and pounds)	CP (High school GPA)	A difference in weight of 50 to 60 pounds (approximately two standard deviations) was associated with a 0.2-point difference in GPA for white the average white female	Significant negative relationship for white females and non-white males, but not for non-white females or white males
Ding, W., et al. 2009[241]	United States	Individual-level longitudinal/GATOR	1999 to 2003	Adolescents in grades 10, 11, and 12	893 adolescents	Sex	Obesity (BMI)	CP (High school GPA)	Obesity led to a 0.45-point decrease on GPA for the full sample. For females and males, 0.5-point decrease and 0.1-point decrease were estimated, respectively	Substantial impacts on the CP of female adolescents, but males were not significantly impacted
Kaestner, R. and M. Grossman 2009[242]	United States	Individual-level longitudinal/NLSY97	1986 to 2004	Children between the ages of 7 and 12 years	2200 observations per two-year age group	Sex and age	Overweight and obesity (BMI z-score)	CP (PAIT: maths and reading) and EA (Grade attainment)	The study found that overweight or obese children achieved similar test scores and grade attainment as children with average weight	Non-statistically significant estimates
Okunade, A. A., et al. 2009[257]	United States	Individual-level longitudinal/Add Health	1994–1995 (wave 1) to 2001–2002 (wave 3)	Students in grades 7 to 12 (aged 12 to 17 years)	8388 individuals	Sex and race (White, Black, Hispanic, Asian)	Overweight and obesity (BMI z-score)	EA (on-time high school graduation)	Asian females were most affected, with lower probabilities of on-time graduation of 38% and 14%, respectively, for obese or overweight subgroups. In white females, a strong negative effect of −9% was estimated for overweight but not for obesity. No significant effect of excess weight on academic attainment was found for males of any race or African Americans	Statistically significant negative relationship with on-time high school completion for females. Race: adverse effects primarily to white and Asian females but no significant effects for African Americans
Averett, S. L. and D. C. Stifel 2010[243]	United States	Individual-level longitudinal/NLSY97	1979 to 2002	The children ages 6 to 13 years	20,856 child years	Sex and race (White, Black)	Overweight (BMI z-score)	CP (PIAT: math and reading)	The study found that overweight white boys had math and reading scores approximately 1 SD below the mean, while overweight white girls had lower math scores. Overweight black	Statistically significant negative relationship for CP in white and black children of both sexes

First Author and Year of Publication	Country	Type of Study/Dataset	Period Considered	Target Population	Sample Size	Stratification	Exposure	Outcome(s) Estimated	Main Results	Conclusion
									boys and girls were estimated to have lower reading scores	
Fletcher, J. M. and S. F. Lehrer 2011[244]	United States	Individual-level longitudinal/Add Health	1994–1995 (wave 1) to 2001–2002 (wave 3)	Twins and siblings, mean age 17 years	1684 children comprising twins and siblings	Sex and race (White, African American, Hispanic, Asian)	Overweight and obesity (BMI z-score and pounds)	CP (High school GPA and PIAT: verbal)	The study estimated that being overweight was associated with a small decrease in academic performance that was not statistically significant at the 5% level	Non-statistically significant estimates
Chen, L. J., et al. 2012[245]	Taiwan	Individual-level longitudinal/Taichung City primary district	2002 to 2008	First-grade students in Taichung City	409 children	Sex	Overweight and obesity (BMI z-score)	CP (mean scores in language, maths, science, history)	The study found no significant relationship between initial obesity or change in weight status at grade 1 and academic performance at grade 6	Non-statistically significant estimates
Scholder, S. v. H. K., et al. 2012[246]	United Kingdom	Individual-level longitudinal/ALSPAC	3-year period (ages 9 to 11 and 11 to 14 years)	Children aged 9 years and 11 years	3001 children	Race (White only)	Fat mass (measured by DXA scan)	CP (exam result on the Key Stage 3 (KS3) test)	The study concluded that body weight status was unlikely to be causally related to academic achievement in adolescence	Non-statistically significant estimates
Bisset, S., et al. 2013[247]	Canada	Individual-level longitudinal/QLSCD	1 year of follow-up at average age 8.2 years of age	Children aged 4 to 7 years	1959 children	None	Overweight (BMI z-score)	CP (KABC: average of reading, writing, maths)	The study found that children within the lowest BMI trajectory had a reduced reading comprehension (KABC-pt2) of 3.81 points (p = 0.042) compared with their healthy-weight counterparts, but children with stable overweight were not at higher risk for poorer academic or cognitive outcomes	Non-statistically significant estimates for excess weight compared with healthy weight
Capogrossi, K. and W. You 2013[248]	United States	Individual-level longitudinal/ECLS-K	1998–1999 school year to 2006–2007 school year	A nationally representative sample of kindergartners	21,260 children	Sex, race, and school grade (White, minority)	Underweight, overweight and obesity (BMI z-score)	CP (ECLS-K: math and reading IRT scores)	The study IV QR estimates showed that weight positively affected white students with emphasis on the lower end of the academic performance distribution for 8th-grade math and reading scores	Mixed relationship: larger significant impact on lower-performing students; for minority students, either a negative or nonsignificant impact

First Author and Year of Publication	Country	Type of Study/Dataset	Period Considered	Target Population	Sample Size	Stratification	Exposure	Outcome(s) Estimated	Main Results	Conclusion
									where magnitudes ranged from an increase in scores of 1.04 points to 2.80 points	
Lu, Y.-L., et al. 2014[249]	Taiwan	Individual-level longitudinal/TEPS	2001 (7th grade) to 2003 (9th grade)	A nationally representative sample of children in the 7th grade	8690 students	Sex	Underweight and overweight (BMI)	CP (CCA scores)	The study estimated a statistically significant relationship between weight and test scores using PSM method, but not with OLS. The PSM models estimated an impact of weight status 3 to 8 times larger than that estimated by OLS	Negative relationship for academic performance in both male and female students
Amis, J. M., et al. 2014[79]	United States	Individual-level longitudinal/Add Health	1994 to 1995 and followed over 13 years	A nationally representative sample of students with mean age of 16	11,308 students	Sex and race (White, Blacks, and Hispanics)	Obesity (BMI z-score)	EA and LMO (adult earnings/income)	The study found that obese adolescents who went on to attend college were about 9% less likely to graduate compared to their nonobese peers and earned 7.5% less as adults. Obese females and whites were about 12% less likely to complete a college degree than nonobese adolescents	No significant impact on high school graduation but significant effects for college graduation and future income among blacks and females
Lundborg, P., et al. 2014[80]	Sweden (and separate analysis using U.K. and U.S. cohorts)	Individual-level longitudinal/the SNSA register of enlistment	1984 to 2003	Male siblings who enlisted for the military at age 18 years and lived in Sweden in 1999	145,193 teenage siblings	Sex (male)	Overweight and obesity (BMI)	LMO (adult earnings/income)	For the Swedish cohort, in comparison with teenagers of healthy weight, overweight and obese adolescents earned 6% and 18% less, respectively, between ages 28 and 38 years. In the U.K. cohort, the study estimated that being obese at 16 was associated with 38% lower earnings at age 42. Using NLSY79 data, the study estimated that men who were obese at ages 16 to 24 were likely to earn 18% lower at ages 39 to 42, relative to their healthy weight counterparts	Substantial penalties for excess weight in teenage years with respect to adult earnings, both in Sweden and in cohorts from the United States and the United Kingdom

First Author and Year of Publication	Country	Type of Study/Dataset	Period Considered	Target Population	Sample Size	Stratification	Exposure	Outcome(s) Estimated	Main Results	Conclusion
Afzal, A. S. and S. Gortmaker 2015[250]	United States	Individual-level longitudinal/NLSY97	Two cohorts: 1988–1994 and 1994–2000	Children aged 2 through 8	Cohort 1, *n* = 2672 and Cohort 2, *n* = 1991	Sex	Always obese, became obese/non-obese (BMI z-score)	CP (PPVT-R, PIAT Math, PIAT Reading and WISC-R)	The study concluded that childhood obesity was unlikely to be causally related to cognitive performance.	Non-statistically significant estimates
Black, N., et al. 2105[251]	Australia	Individual-level longitudinal/LSAC	2004 to 2012 (5 waves)	Children aged 4 to 5 years in the first wave (children in Cohort K)	4983 children	Sex	Obesity (BMI z-score)	CP (NAPLAN: maths and reading)	The study found that obesity was negatively related to cognitive achievement for boys but not girls. The IV estimate for literacy indicated that obese boys performed 1.3 SDs worse than healthy weight boys.	Significant negative effect for boys but non-statistically significant estimates for girls
Kenney, E., et al. 2015[252]	United States	Individual-level longitudinal/ECLS-K	1998–1999 to 2006–2007 school years	A nationally representative sample of children in the 5th grade	3362 children	Sex	Overweight and obesity (BMI z-score)	CP (ECLS-K: math and reading IRT scores)	The study reported significantly worsening teacher perceptions associated with an increase in BMI z-score from the fifth to eighth grade. However, the study did not establish an independent association between change in BMI z-score and change in objectively measured CP over the same period	Non-statistically significant estimates
Kranjac, A. W. 2015[253]	United States	Individual-level longitudinal/ECLS-K	1998–1999 to 2006–2007 school years	A nationally representative sample of kindergartners	5034 children	None	Overweight and obesity (BMI z-score and BMI)	CP (ECLS-K: math) and self-efficacy	The study found that the math trajectories of overweight children with high levels of self-efficacy exceeded those of trajectories of overweight children with high levels of self-efficacy by 3.62 points ($p < 0.005$). Estimates were not statistically significant in obese children	Self-efficacy was associated with math outcomes in overweight, but not obese children
Sabia, J. J. and D. I. Rees 2015[254]	United States	Individual-level longitudinal/Add Health	1994–1995 (wave 1) to 2007–2008 (wave 4)	A nationally representative sample of adolescents (14 years)	20,028 adolescents	Sex	Overweight and obesity (BMI z-score and pounds)	CP (High school GPA) and EA (High school diploma and college	The study's TSLS estimated that having excess weight was associated with a 0.341-point reduction and a 0.252 reduction in the probability	Negative relationship with female academic achievement and less significant in boys

First Author and Year of Publication	Country	Type of Study/Dataset	Period Considered	Target Population	Sample Size	Stratification	Exposure	Outcome(s) Estimated	Main Results	Conclusion
								completion)	of college completion in GPA for females but less significant for males	
Von Hinke, S., et al. 2016[255]	United Kingdom	Individual-level longitudinal/ALSPAC	3-year-period (11 to 14 years)	Children aged 11 years	4844 children	Sex and race (White only)	Fat mass (measured by DXA scan)	CP (exam result on the Key Stage 3 (KS3) test)	The study found that using OLS regression, leaner children recorded better CP than fatter children. In the study's genetic IV analysis; however, there was no evidence that CP was driven by children's fat mass	Non-statistically significant estimates
Pinkston, J. C. 2017[258]	United States	Individual-level longitudinal/NLSY97	1997 to 2009	Children aged 12 to 16 years in 1996	1473 white men and 1060 white women	Sex and race (White only)	Overweight, obesity and severe obesity (BMI)	LMO (hourly wage)	The study estimated a penalty of about 17% for men who were severely obese in the previous year. An initial penalty of 13% was estimated for women entering the labour market with a BMI over 37.	A childhood history of excess weight had a significantly large negative effect on wages
Shi, H. and C. Li 2018[256]	Australia	Individual-level longitudinal/LSAC	2004 to 2014 (6 waves)	Children aged 4 to 5 years in the first wave	10,858 observations	Grade level (Year 3, Year 5, Year 7, and Year 9)	Overweight and obesity (BMI z-core)	CP (NAPLAN: reading, grammar, spelling, writing, and numeracy)	The IV model estimated that obesity was associated with 0.80 SD, 1 SD, 0.84 SD, 0.91 SD, and 0.98 SD below the mean for reading, grammar, spelling, writing, and numeracy, respectively, when using only the biological mother's BMI as the instrument	Negative impact on academic performance with a larger negative impact for senior year students, particularly on numeracy

Add Health: National Longitudinal Study of Adolescent Health; ALSPAC: U.K. Avon Longitudinal Study of Parents and Children; CCA: comprehensive cognitive ability; CDC: Centres for Disease Control and Prevention; CP: cognitive performance; DXA: dual-energy X-ray absorptiometry; EA: educational attainment; ECLS-K: Early Childhood Longitudinal Study-Kindergarten Class Assessment; GATOR: Georgetown Adolescent Tobacco Research GATOR study; GPA: grade point average; IOTF: International Obesity Task Force growth charts; IRT: Item Response Theory; KABC: Kaufman's Assessment Battery for Children; LMO: labour market outcomes; MCS: Millennium Cohort Study; NAPLAN: National Assessment Program—Literacy and Numeracy; NCDS: National Child Development Study; NLSY97: U.S. National Longitudinal Survey of Youth 1997; PIAT: Peabody Individual Achievement Test; PPVT-R: Peabody Picture Vocabulary Test-Revised; PSM: propensity score matching; QLSCD: Quebec Longitudinal Study of Child Development; SNSA: Swedish National Service Administration; TEPS: Taiwan Education Panel Survey data; WISC-R: Wechsler Intelligence Scale for Children-Revise.

2.5.4 Discussion

Summary of Results and Comparative Evidence

My review of economic determinants and broader economic consequences of childhood excess weight identified mixed or weak associations for some SES metrics, such as household income and receipt of free school meals. The underlying mechanisms of association between SES measures and childhood excess weight are not fully understood.[226] Longitudinal studies could potentially disentangle causal relationships in this area.

Economists and policymakers argue that the excess obesity-related costs imposed on society justify government interventions to impose a levy on nutritionally poor foods and/or subsidise healthier choices.[15] Theoretically, an increase in the price of an energy-dense food should lead to less demand for such food.[238] Research in the U.K. indicates that implementing a soft drinks industry levy could potentially reduce exposure to soft drinks, but further research is needed to broaden understanding of the impact of this policy on substitution effects.[239] Non-price mechanisms such as the health signalling pathway where even small taxes influence voluntary behaviour change in the public, reduced portion sizes, and product reformulation have also been posited.[238,259] However, the likelihood of compensatory behaviour where SSBs are substituted for other untaxed energy-dense foods could present additional challenges.[68]

This review reaffirmed a negative association between childhood exposure to excess weight and cognitive performance. However, it is debatable whether there is an age gradient with respect to the effect of childhood excess weight on cognitive performance. In sum, the generalisability of the evidence on human capital outcomes is constrained by the predominance of studies from the U.S., and studies focused on cognitive outcomes.

Strengths and Limitations

This review provides evidence of the negative impact of childhood excess weight on human capital outcomes by including four studies on educational attainment and labour market outcomes. My searches were, however, limited for this strand of research.

2.6 Conclusions

This chapter has identified key knowledge gaps in health economic aspects of childhood excess weight, some of which are addressed in subsequent chapters of this thesis. The studies reviewed indicate that childhood excess weight contributes to significant short- and long-term incremental costs in certain high-income countries. However, there is a notable lack of original research specific to the United Kingdom, many other European countries, and nearly all low-income countries. In response to this gap, Chapters 5, 6, and 7 of this thesis focus on estimating healthcare costs associated with childhood excess weight in England. Furthermore, the structured review revealed a marked increase in the number of studies conducted over the past three years, suggesting growing public and policymaker interest in the cost-effectiveness of interventions targeting the prevention and treatment of childhood excess weight. Despite this finding, most economic evaluations continue to focus on high-income countries. In Chapter 3, I present a systematic review to support research on the cost-effectiveness of interventions addressing childhood excess weight.

Chapter 3: A systematic review of economic evaluations of interventions targeting childhood overweight and obesity

3.1 Introductions

In my structured review of studies on health economic aspects of childhood excess weight (Chapter 2 of this thesis), I identified a recent systematic review of economic evaluations of interventions targeting childhood excess weight by Zanganeh and colleagues.[154] That review was prompted by several limitations of previous reviews in this field. Some of the gaps identified by Zanganeh and colleagues included the omission of relevant search engines such as Medline and Cochrane Database of Systematic Reviews[145,149,151,153]; inadequately reported search strategies[152]; absence of quality assessment for included studies[145,152]; and exclusion of studies conducted in developing countries.[151] The review by Zanganeh and colleagues[154] identified and summarised evidence from 39 relevant studies and my updated searches as part of the structured review in Chapter 2 identified 31 additional studies following the time horizon of that systematic review.[154]

Nevertheless, my updated searches in Chapter 2 and the review by Zanganeh and colleagues were limited in scope and pointed to the need for a rigorous appraisal of the current literature on economic evaluations of childhood excess weight interventions in order to identify and summarise all potential cost-effective innovations for the management, treatment, and prevention of excess weight among children. For instance, the systematic review by Zanganeh et al.[154] excluded surgical interventions, which are crucial in the management of severe obesity. Furthermore, two other recent systematic reviews either focused solely on school-based interventions[260] or preventive interventions with dietary components only[261], highlighting the need for a systematic review of the evidence that is broader in reach.

This chapter provides a comprehensive systematic review of economic evaluations encompassing all interventions, programmes and policies designed to prevent and/or treat childhood excess weight. Ultimately, I assess the evidence for cost-effectiveness and value for money across intervention groups and draw conclusions on methods that would better inform practice and policy on childhood excess weight. This chapter and its associated published work (Onyimadu, O., Violato, M., Astbury, N. M., Huels, H., Heath, L., Shipley, A., ... & Petrou, S. (2023). A systematic review of economic evaluations of interventions targeting childhood overweight and obesity. Obesity Reviews, 24(9), e13597.)[262] summarise the methodological characteristics and results of cost-effectiveness and value for money for all included studies and include an assessment of the quality of their reporting.

For the purposes of this systematic review, childhood excess weight, a collective term for childhood overweight and obesity, is defined as age- and sex-specific body mass index (BMI) above the 85th and 95th centiles, respectively.[22,26] BMI measures the accumulation of fat, which is termed excess weight when abnormal or excessive.[1] The worldwide prevalence of childhood excess weight has increased dramatically over the past 40 years, rising from under 4% in 1975 to over 18% in 2016 among children aged five years and over.[263] These estimates underscore public health concerns since childhood excess weight is a recognised precursor to adult obesity and associated non-communicable diseases in adult populations.[6] The short-term impacts of childhood excess weight translate into poorer health and educational outcomes for affected children and increased health care expenditure and indirect costs imposed on society that, consequently, impact human capital development.[6,7,11]

Over recent years, the range of interventions and programmes aimed at preventing or treating childhood excess weight has expanded into new areas across various settings such as schools, communities, homes, and clinics. However, adopting new interventions and policies requires evaluating their cost-effectiveness, i.e., assessing costs and consequences relative to alternatives through one or more economic evaluation framework. Evidence from health economic evaluations,

defined by Drummond and colleagues[99] as “the comparative analysis of alternative courses of action in terms of both their costs and consequences” is crucial for informing investment decisions that maximise population health and social well-being in the context of constrained healthcare resources.

3.2 Methods

3.2.1 Objectives

The primary objective of this systematic review is to present the costs, outcomes, and cost-effectiveness of various strategies for managing childhood obesity. The specific goals include: gathering and synthesising the findings of individual economic evaluations to provide a thorough understanding of the economic value of current and emerging healthcare interventions; comparing different interventions to identify the most cost-effective options for healthcare resource allocation; assessing the quality of the included studies to ensure that the conclusions are reliable and valid; examining the applicability and relevance of economic evaluations across diverse settings, populations, and healthcare systems; identifying gaps in the economic evidence where further research is needed; and offering policymakers, healthcare providers, and stakeholders evidence-based information to support decisions regarding healthcare funding, resource allocation, and the implementation of interventions.

3.2.2 Search strategy

This study was registered in the PROSPERO database of systematic review protocols (registration number: CRD42021267540).[264] I conducted systematic searches from the inception of each search engine to the 5th of August 2021 and updated the searches on the 19th of April 2023 in the following 11 databases: Medline (OvidSP)[1946-present]; Embase (OvidSP)[1974-present]; PsycINFO (OvidSP) [1806-present]; CINAHL (EBSCOHost)[1982-present]; EconLIt (Proquest)[1969-present]; Cochrane Database of Systematic Reviews (Cochrane Library, Wiley)[Issue 4 of 12, April 2023]; Cochrane Central Register of Controlled Trials (Cochrane Library, Wiley)[Issue 3 of 12, March 2023]; NHS Economic Evaluation Database & Health Technology Assessment (via

https://www.crd.york.ac.uk/CRDWeb/)[up to 31/03/2015]; Science Citation Index; Social Science Citation Index; and Conference Proceedings Citation Index - Science (Web of Science Core Collection) [1900-present]. The searches were built using title/abstract keywords, subject headings, or MeSH terms, where available, for the following key concepts: obesity/overweight and exercise/dietary interventions and childhood terms and economic/cost terms. An example search strategy is presented in Appendix C **Table C 1**. No limits to publication date or publication type were applied. All results were exported into Endnote X9 before being transferred to Covidence (https://app.covidence.org/) for de-duplication and screening. I documented my findings based on the PRISMA guidelines.[265] I also searched reference lists of included publications or recent systematic reviews for unpublished reports. My separate grey literature searches involved entering combinations of terms such as “child”, “overweight”, “obesity”, “cost-effectiveness”, and “economic evaluation” in Google Scholar and reviewing the results on the first 15 pages.

3.2.3 Selection Criteria

Studies (including abstracts) identified in my searches were eligible for inclusion if: (i) they involved children (defined as extending up to 18 years[266]) at the time of administering the intervention or adult populations (e.g., expectant mothers) if outcomes of the intervention were measured in their offspring during childhood; (ii) the study intervention(s) targeted childhood excess weight or sought to improve diet or physical activity; and (iii) the study was an economic evaluation (CBA, CCA, CMA, CEA or CUA) regardless of the underpinning study design (e.g., randomised controlled trial, observational study with individual-level data, decision-analytic model, quasi-experimental design, etc.). I included studies where the intervention was hypothetical or studies where hypothetical scenarios of intervention effectiveness were tested if they met the above inclusion criteria. The authors of a previous related systematic review stated that the exclusion of modelling studies of hypothetical interventions was a limitation of their study.[261] Studies of hypothetical interventions or multiple scenarios of treatment effectiveness can serve as the basis for target setting and

forecasting. These types of studies can also broaden the discussion on economic modelling approaches within the field of childhood excess weight.

I excluded studies if: (i) the intervention was not focused on tackling excess weight or improving diet or physical activity in childhood; (ii) the study was not an economic evaluation; (iii) the title and abstract were not published in the English language; (iv) the study reported a protocol only; or (v) the study was a review article not containing primary research evidence.

I and a team of second reviewers screened titles and abstracts independently and in duplicate. Conflicts were discussed, resolved, or referred to my supervisors, who served as arbiters. I and a team of second reviewers also conducted full-text review screening independently. Similar steps were taken to resolve conflicts, as with titles and abstracts.

3.2.4 Data Extraction and Synthesis

I developed pro forma data extraction tables for collating aggregate characteristics for three intervention groups (prevention-only, prevention and treatment, and treatment-only) and critical assessment items for the individual studies. The development of the tables was also informed by the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement (2013)[267], a 24-item checklist widely recommended by researchers, editors and peer reviewers for reporting and assessing health economic evaluations. Piloting phases of the development of tables comprising critical assessment items involved independent data extractions and comparisons by me and the second reviewers. I iteratively updated the structure of all tables with my supervisors until the final versions were agreed upon. The variables extracted for each study were as follows: year of publication, country/jurisdiction, interventions and comparators, intervention category, intervention type, components and targets (a brief description of the composition of the intervention(s)), study approach, setting, study design, primary data sources, type of economic evaluation, target population and age range, sample size (if relevant), model time horizon (how long into the future the predicted outputs of cost-effectiveness are applicable), study perspective, currency, price date,

discount rate, measures of consequence(s), sensitivity analyses and key study assumptions, results, and conclusions. My supervisors resolved disputes between me and the second reviewers around data extraction.

The quality of reporting for individual studies was also assessed using the CHEERS checklist.[267] To ensure that studies were scored fairly, I derived customised denominators for individual studies depending on the applicability of each item on the CHEERS statement. All studies were assessed independently by me and a team of second reviewers, and a final score was achieved through consensus. I synthesised evidence around methodological characteristics and summarised cost-effectiveness estimates by intervention grouping: prevention-only, prevention and treatment, and treatment-only.

Due to heterogeneity in the study settings, jurisdictions, and type of economic evaluations applied, meta-analysis was not appropriate; I conducted a narrative synthesis of the economic evaluation methods, results and discussions of the included studies in accordance with the recommendations of the Synthesis Without Meta-analysis (SWiM) reporting guideline.[268]

3.2.5 Definitions and Taxonomies

I classified interventions into three different groups: (1) 'prevention-only' if they only targeted children with healthy weight or if they targeted pregnant women and newborns with the aim of preventing excess weight in the infant or child; (2) 'prevention and treatment' if they targeted children with a mixture of healthy weight and excess weight profiles or an undefined population expected to include a mix of children with healthy weight and excess weight; and (3) 'treatment-only', if the interventions solely targeted children with excess weight.

I categorised interventions as (1) behavioural (aimed at changing dietary and/or physical activity behaviours at the individual level); (2) environmental (involving modification of the environment); (3) pharmacological (medication-based); (4) surgical (bariatric surgery aimed at achieving weight

loss); or (5) policy-related (requiring regulations, legislation, fiscal actions or setting of voluntary targets across local, regional, and national jurisdictions).

The included studies reported economic evaluations applying one or more of five frameworks: (1) cost-benefit analysis (CBA), which expresses the costs and consequences of competing interventions in monetary terms; (2) cost-consequences analysis (CCA), which describes the costs and measures of consequences (effects) separately; (3) cost-minimisation analysis (CMA), which seeks to establish the least costly method of achieving given outcomes[269,270]; (4) cost-effectiveness analysis (CEA), which assesses incremental costs and incremental measures of consequences expressed in natural units (e.g., reduction in BMI z-scores or life-years gained); and (5) cost-utility analysis (CUA), a variation of CEA where consequences are expressed in metrics combining survival and preference-based health-related quality of life outcomes such as quality-adjusted life years (QALYs) or disability-adjusted life years (DALYs).[99,271,272]

The studies included in the review reported economic outcomes classified into three broad categories: cost outcomes (encompassing both direct and indirect costs), benefits or consequences (such as QALYs and DALYs), and cost-effectiveness outcomes, including the Incremental Cost-Effectiveness Ratio (ICER) and net monetary benefit (NMB). An ICER is often used to summarise the comparison between competing interventions in terms of their costs and benefits. It is a measure of the incremental cost per incremental unit of health benefit produced by an intervention relative to a comparator.[273] An NMB is a summary statistic that expresses the value of an intervention in monetary terms when a cost-effectiveness threshold has been specified.[274] A cost-effectiveness threshold is the upper limit a decision-maker is willing to pay for a unit of a health benefit.[275]

3.3 Results

3.3.1 Literature search and study selection

My literature searches were conducted on the 5th of August 2021 and initially identified 22,007 papers, of which 7,450 duplicates were identified and removed. After title and abstract screening,

390 papers were sought for full-text screening, from which 127 studies were deemed eligible for inclusion. In the updated searches conducted on 19th April 2023, a total of 7,710 papers were initially identified, and 5,677 duplicates were removed. After title and abstract screening, 46 papers were included for full-text screening, 24 of which were deemed eligible for inclusion.

After title and abstract screening, inter-rater reliability statistics for reviewer assessments ranged from 0.90 to 0.98 for proportionate agreement and 0.77 to 0.98 for random agreement probability. For full-text review, proportionate agreement ranged from 0.74 to 1.00, while random agreement probability ranged from 0.5 to 0.58. The main reason for exclusion was that the study did not report an economic evaluation (n=146). My Grey literature search did not identify any additional studies of interest. The outputs of the study selection process are displayed in **Figure 3**.

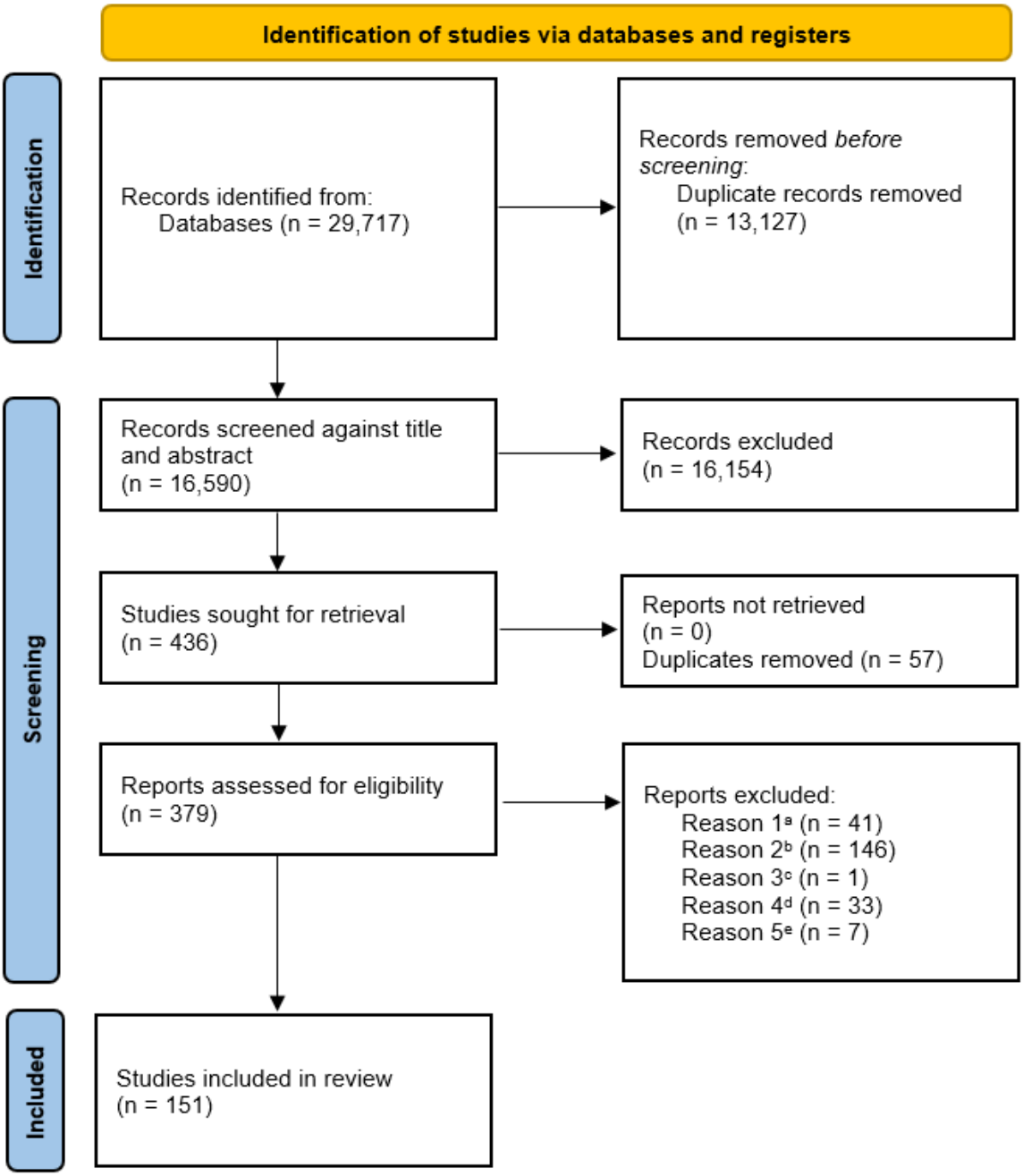

Figure 3 PRISMA flow diagram of the study selection process

a Intervention not focused on tackling excess weight (overweight or obesity) in childhood

b Not an economic evaluation

c Title and abstract not published in the English language

d Protocol study only

e Review article not containing primary research evidence

3.3.2 Study characteristics across all intervention groupings

The characteristics of the included studies are detailed with the corresponding citations in Table 7 and summarised in this section. The volume of published studies tended to increase over five-year periods from 2001, with the greatest number of studies published between 2016 and 2020. Only nine studies of the 151 included studies were conducted in low and middle-income countries (LMICs)[163,164,276-282] compared with 143 studies from high-income countries.[55,56,71,84,87,150,155,156,161,165,166,168-187,189-192,194,197-199,201,203,204,206,208-213,215-221,277,283-369] One study published in 2010 was set in a high-income country and six LMICs.[277]

Eighty-nine percent of studies in LMICs were conducted in China[163,164,277,278,280,282] and Mexico.[276,277,279,282] Other LMIC settings included Brazil (two studies)[277,281], Argentina (one study)[281], El Salvador (one study)[281], Trinidad and Tobago (one study)[281], Peru (one study)[282], India (one study)[277], Russia (one study)[277], and South Africa (one study).[277] The US was the most represented among the high-income countries, with 51 studies.[55,84,87,150,155,165,166,168-184,291-303,338,346,348,351,355-359,363,364,366,368,369] After the US, the UK[71,156,161,201,203,204,277,284,286,287,304-318,343,347,352-354,360,362] and Australia[56,185-187,189-192,194,197-199,285,288-290,319-327,339,342,345,349,350,365] accounted for the majority of the remaining studies from high-income countries, with 32 and 31 studies, respectively. Other high-income countries that formed the settings for studies included the Netherlands (five studies)[206,208,328,329,337], Germany (four studies)[212,213,333,361], Spain (four studies)[215,330-332], Canada (four studies)[216,334,335,340], New Zealand (three studies)[209-211], Finland (three studies)[220,283,341], Sweden (two studies)[218,344], Denmark (one study)[217], Poland (one study)[221], Portugal (one study)[219], and France (one study).[367]

Across the three intervention groups (prevention-only[192,199,213,218,276,283-290], prevention and treatment[55,56,87,150,161,163,164,166,168,169,171,173-179,181,182,184,187,189-191,194,197,198,203,204,208-210,212,215,216,219,277-282,291-347], and treatment-only[71,84,155,156,165,170,172,180,183,185,186,201,206,211,217,220,221,348-369]), intervention components were predominantly aimed at changing individual behaviour.[71,161,163-166,170-172,180,181,183,185,186,191,192,199,201,204,206,208,210-212,215-220,278,280,283-287,292-294,297-299,302,304,306-313,315,317,318,320,321,326-330,332,334,335,339,341,342,344,346-349,351-354,358,360-366,368,369] Forty-six studies included a mix of intervention

categories.[55,56,150,164,168,169,173,175-179,182-184,187,189,190,194,197,208,209,217,218,221,277,282,288-291,295,296,300,303,305,314,319,321,323-325,328,333,336,337,340,343,345,357,359,367] Solely environmental[213,276,338], regulatory or policy-level[174,198,203,279,281,301,316,322] intervention categories were less common. Interventions in the surgical category[155,156,350,355,356] belonged strictly to the treatment-only group. Other methodological characteristics of the three intervention groups differed considerably, such as the study setting, type of economic evaluation, study design, and perspective. Characteristics of the included studies are summarised in a more disaggregated form by intervention grouping in Table 8, Table 9 and Table 10.

Table 7 Aggregate descriptive summary of studies by grouping

	Number of included studies per characteristic (references in superscript)			
	Prevention-only (n = 13)	**Prevention and treatment (n = 100)**	**Treatment-only (n = 38)**	**All studies (n = 151)**
Year of publication				
2001-2005	0	1 [166]	2 [165,348]	3
2006-2010	0	12 [87,161,168,169,187,189,210,277,291,304,319,336]	8 [84,170,185,186,220,349-351]	20
2011-2015	2 [192,286]	23 [150,163,171,173-176,190,191,209,212,292-295,305,320,330-332,334,335,337]	8 [71,172,352-357]	33
2016-2020	7 [199,213,218,276,283-285]	44 [55,164,177-179,181,182,184,194,197,198,203,204,208,215,216,219,278,279,296-302,306-316,321-325,328,333]	14 [155,156,180,183,201,206,211,217,221,358-362]	65
2021 to April 2023	4 [287-290]	20 [56,280-282,303,317,318,326,327,329,338-347]	6 [363-368]	30
Jurisdiction				
High-income	12 [192,199,213,218,283-290]	93 [55,56,87,150,161,166,168,169,171,173-179,181,182,184,187,189-191,194,197,198,203,204,208-210,212,215,216,219,277,291-347]	38 [71,84,155,156,165,170,172,180,183,185,186,201,206,211,217,220,221,348-368]	143
LMICs	1 [276]	8 [163,164,277-282]	0	9
Intervention category				
Behavioural	7 [192,199,283-287]	51 [161,163,164,166,171,181,191,204,208,210,212,215,216,219,278,280,292-294,297-299,302,304,306-313,315,317,318,320,321,326-330,332,334,335,339,341,342,344,346,347]	28 [71,165,170,172,180,183,185,186,201,206,211,217,220,348,349,351-354,358,360-366,368]	86
Environmental	2 [213,276]	1 [338]	0	3
Policy	0	8 [174,198,203,279,281,301,316,322]	0	8
Surgical	0	0	5 [155,156,350,355,356]	5
Multiple categories	4 [218,288-290]	38 [55,56,150,168,169,173,175-179,182,184,187,189,190,194,197,209,277,282,291,295,296,300,303,305,314,319,323-325,333,336,337,340,343,345]	4 [221,357,359,367]	46
NA	0	2 [87,331]	1 [84]	3
Setting				
Community	0	6 [161,298,300,302,308,324]	0	6
Family/Home	2 [192,288]	2 [175,347]	8 [165,185,186,348,351,354,358,361]	12
Health care/clinical	2 [218,283]	0	9 [155,156,206,220,349,350,355,356,359]	11
Population-wide (state or country)	0	8 [87,168,198,203,279,301,322,343]	1 [84]	9
School/childcare centres	1 [287]	45 [55,56,163,164,166,169,171,173,177,178,182,184,204,208,209,212,215,216,219,296,299,304-307,309-315,317,318,321,323,326-330,332,340,342,345]	1 [367]	47
Multi-setting	8 [199,213,276,284-286,289,290]	38 [150,174,176,179,181,187,189-191,194,197,210,277,278,280-282,291-295,297,303,316,319,320,325,333-339,341,344,346]	19 [71,170,172,180,183,201,211,217,221,352,353,357,360,362-366,368]	65

	Number of included studies per characteristic (references in superscript)			
	Prevention-only (n = 13)	**Prevention and treatment (n = 100)**	**Treatment-only (n = 38)**	**All studies (n = 151)**
NA	0	1 [331]	0	1
Type of economic evaluation				
CBA	0	5 [150,182,300,305,328]	0	5
CCA	0	17 [179,181,197,203,219,292,293,303,307,310-312,320,329,330,335,347]	6 [84,165,186,348,349,354]	23
CMA	0	1 [56]	0	1
CEA	3 [192,218,288]	30 [55,163,168,169,173,174,176,178,212,215,281,282,294-296,298,299,309,313,317,321,323,326,332,333,339,341,342,344,346]	20 [71,170,172,180,183,211,217,220,221,352,353,357-359,361,363,364,366-368]	53
CUA	5 [199,213,276,284,286]	29 [87,161,166,171,177,189-191,194,198,204,208,209,277,291,297,301,304,308,314,316,319,322,324,325,331,336,337,340]	10 [155,156,185,201,350,355,356,360,362,365]	44
Two or more types	5 [283,285,287,289,290]	18 [164,175,184,187,210,216,278-280,302,306,315,318,327,334,338,343,345]	2 [206,351]	25
Study design				
Cross-sectional	0	1 [168]	0	1
Decision-analytic	8 [199,213,276,284,285,287,289,290]	51 [87,150,161,164,166,171,173-179,182,184,187,189-191,194,197,198,203,208,209,216,277,279,281,282,291,295,297,300-303,316,317,319,322,324,325,331,334-338,340,343]	13 [71,84,155,156,185,350,355-357,359,365,366,368]	72
Longitudinal	0	1 [292]	0	1
Feasibility/pilot study	1 [286]	4 [311,313,315,347]	3 [183,352,358]	8
Quasi-experimental/ non-RCT	0	8 [219,293,299,308,320,328,329,346]	0	8
Trial-based economic evaluation	4 [192,218,283,288]	32 [55,56,163,169,181,204,210,212,215,278,280,296,298,306,307,309,310,312,314,318,321,323,326,327,330,332,333,339,341,342,344,345]	20 [165,170,172,180,186,201,206,211,217,220,348,349,351,353,354,360,362-364,367]	56
Not stated	0	3 [294,304,305]	2 [221,361]	5
Study Perspective				
Healthcare	7 [192,199,284-286,288,290]	18 [56,161,197,203,209,281,295,304,307,309,315,323,334-336,340,343,345]	13 [71,84,155,156,201,211,349,353,354,360,362,365,366]	38
Institutional/school system	0	8 [163,215,216,296,299,326,332,338]	0	8
Multiple perspectives	0	9 [179,208,279,280,316,327,330,337,347]	2 [172,361]	11
Provider/payer/funder	1 [289]	5 [87,181,301,308,341]	6 [170,183,220,356,358,364]	12
Public sector	0	10 [204,278,306,310,312-314,317,318,342]	2 [217,367]	12
Societal	5 [213,218,276,283,287]	39 [150,164,166,169,171,173-178,182,184,187,189-191,194,198,210,212,219,282,291,297,300,302,303,319,321,322,324,325,328,329,333,339,344,346]	9 [180,185,186,206,350,351,355,359,363]	53
Not stated	0	11 [55,168,277,292-294,298,305,311,320,331]	6 [165,221,348,352,357,368]	17

CBA: cost-benefit analysis; CCA: cost-consequences analysis; CEA: cost-effectiveness analysis; CUA: cost-utility analysis; LMICs: low and middle-income countries; NA: not applicable; RCT: randomised controlled trial; Not stated (or insufficient information provided in study).

Estimation of resource use and costs

Trial-based economic evaluations were more likely to explicitly report their methods of collecting resource use and cost data compared to decision-analytic modelling based economic evaluations. Study setting, jurisdiction and perspective were crucial to the nature of resource and cost inputs factored into the economic evaluations. In school-based settings, the cost of delivering the intervention per school or student was usually derived from study records, which included data such as intervention materials, cost of the venue for physical activities, teacher and trainer or facilitator time, travel and administration costs, and miscellaneous expenses.[317,318] The control arms were

generally assigned no costs or negligible up-front costs. A prevalent costing assumption was that interventions operated in a steady state, not requiring one-off start-up costs.[173,176,185,189-191,210,319,324,325,328,350] Depending on the perspective, trials conducted in home settings could include direct costs associated with delivering the intervention collected retrospectively (typically including personnel/provider/nurse/psychologist time, vehicle hire, purchase or running costs for home visits, personnel training costs and educational materials) and health care costs for doctor or specialist visits.[192,362] Assessments of clinical interventions such as bariatric surgery included direct medical costs associated with the procedure (cost of the procedure and post-operative care)[155], long-term costs of treating obesity-related comorbidities[156], as well as out-of-pocket payments, and payments by Medicare, Medicaid or private insurance in the US.[356,368] Most of the included studies were undertaken from a societal perspective which took into account productivity costs such as absence from work and travel time of parents or caregivers, absenteeism from school, workplace absenteeism in adulthood and early retirement attributable to the development of body weight-related diseases.[164,166,169,171,180,182,189,190,206,208,213,218,276,283,291,297,302,319,328,333,355] A few studies considered a limited or modified societal perspective where costs accrued by the public and non-governmental sectors were captured, but some downstream consequences of lost productivity were omitted.[150,173,178,184,194,198,300,322,324,325,359]

The economic evaluation of e-health interventions ("the use of information and communications technology in support of health and health-related fields"[370]) and interventions with m-health (a subset of eHealth based on mobile wireless technologies[371]) components at their core emerged only within the past five years.[55,183,287,288,326,327,339,347,365] The costing of these interventions reveals contemporary complexities attended by the omission of associated resource use and costs. One study excluded costs relating to research and development of a multicomponent m-health intervention[339], while another study reported difficulties obtaining similar costs.[347] Additional costs likely to emanate from implementing mobile app-based interventions include app promotion and marketing costs to increase adoption.

Estimation of consequences

The health consequences factored into CUAs were expressed in metrics that combined survival/mortality and preference-based measures of health outcomes into a single measure, such as QALYs, DALYs or health-adjusted life years (HALYs).[272] CCAs and CEAs commonly reported health consequences as change in BMI z-score or reduction in BMI units and, to a lesser extent, other anthropometric measures such as changes in waist-to-height ratio (WHtR), waist circumference (WC), child percent over BMI (%OBMI) or percent body fat. A few studies also reported changes in obesity prevalence as measures of consequences.[87,215,320,335,343]

My review also included studies that reported relevant non-anthropometric measures of consequences, given the established relationships between diet or physical activity and body weight. These proxy measures or intermediate outcomes included changes in levels of physical activity and sedentary behaviour such as metabolic equivalent (MET), minutes of moderate to vigorous physical activity (MVPA), and changes in dietary habits such as intake of dietary energy (kilojoules). Of all the included studies, 12% reported variations of non-anthropometric measures as the primary outcome.[56,168,292-294,296,299,307,312,326,327,338,339,341,345,346,367,368] In two studies, consequences were measured primarily as a change in the proportion of schools that adhered to a canteen policy[323], the proportion of schools implementing a set of physical activity practices[342] or a change in overall wellness (School Health Index) score[55], respectively.

For trial-based studies, health consequences were typically measured at specified time intervals from baseline to follow-up. Some studies measured parental outcomes utilising the EuroQol 5Dimension (EQ-5D)[286] and the 15D.[283] One study collected separate child and parent-proxy measures using the EuroQol 5Dimension Youth version (EQ-5D-Y) and the parent's health-related quality of life using the EQ-5D.[201] A study that reported both EQ-5D-Y scores and weekday MVPA found no evidence of association between the two measures of consequences.[313] Another study assessed children's health-related quality of life with the Health Utilities Index (HUI) Mark 2 using

parents as proxies.[210] The choice of valuation protocol for calculating utility values at each trial measurement time point depended on the applied instrument. For instance, given the unavailability of a paediatric-specific Dutch utility tariff, Makkes and colleagues[206] applied a Dutch adult population value set to the EQ-5D measures and expressed concerns about the potential insensitivity of the instrument for children. Panca and colleagues[360] also assessed health-related quality of life in children using the EQ-5D and applied a valuation protocol for the UK population. In trials that used the Child Health Utility 9Dimension (CHU-9D), the measure was administered as a self-reported instrument[204,278,280,310,311,314,317,347], and the valuation protocol for a childhood population was applied, as the CHU-9D is validated in children aged 7 to 11 years.[372]

Decision analytic models tended to derive values for health consequences from multiple sources. Some studies applied utility values obtained from meta-analyses to categorical childhood weight status (healthy weight, overweight, and obesity).[199,208,290,365] Other model-based studies with time horizons extending into adulthood applied utility decrements derived for excess weight in adult populations to childhood cohorts.[216] Alternatively, a health state utility value of 1 was assigned to childhood cohorts, i.e., children were assumed to be in perfect health, regardless of their weight status.[166,276,291] Treatment effects often derived from longitudinal studies and applied to childhood BMI trajectories or transition probabilities determined the distribution of children in each weight classification over time. Upon progressing into adulthood, cohorts or individuals transitioned into a disease-free healthy weight state or excess weight-related disease states (e.g., cardiovascular diseases and cancers) with associated utility decrements. Where proxy measures such as MVPA were considered instead of weight status, a similar modelling approach was adopted: children progressed through the model with varying levels of physical activity determined by intervention effectiveness and subsequently transitioned into the appropriate disease-free or chronic disease states.[284] At the end of the model time horizon, total preference-based health-related quality of life outcomes were estimated for intervention and comparator cohorts.

Analytical methods, assumptions, and sensitivity analyses

Most trial-based studies performed regression analysis with total costs and QALY outcomes as dependent variables and the intervention group as the independent variable. Some studies reported similar demographic and baseline characteristics between intervention and control groups.[192,218] Others included covariates (e.g., baseline measures of consequences, clustering effect, age, gender and socioeconomic status) to adjust for between-group differences.[169,210,286,344] Sensitivity analyses included complete case analysis and intention-to-treat analysis.[180,283,310,347,360]

Decision analytic models typically consisted of decision trees[166,177,291], state transition or Markov models[150,156,173,182,185,187,197,198,209,213,216,284,287,297,322,325,343,350,355,356] and individual-level simulations.[87,178,184,199,276,277,289,290,301,303,336,340,359,365,366,369] Key sensitivity analysis methods in decision-analytic modelling included deterministic sensitivity analysis and scenario analysis testing various parameter and structural assumptions. Probabilistic sensitivity analysis[373] was frequently used to characterise the uncertainty of cost-effectiveness estimates in both decision-analytic modelling and trial-based studies. Cost-effectiveness acceptability curves (CEACs)[374], essential for depicting the probability of cost-effectiveness over a range of cost-effectiveness thresholds, were less frequently reported.[192,199,213,218,276,280,283,284,363] When explored, assumptions of treatment effect decay or persistence tended to have substantial implications on cost-effectiveness results.[185,187,197,216,289,325,336,350,359,366]

Discounting

Discounting accounts for future time preference, catastrophic risk and the diminishing marginal utility of the anticipated higher levels of future consumption by converting future costs, consequences, or benefits of interventions into present values.[375] The authors generally applied discount rates to future costs and benefits as recommended by the relevant jurisdictions in which the individual studies were conducted. In the UK and New Zealand, rates of 3.5% were applied[376], except for one UK-based study that applied declining long term discount rates starting at 3.5% for

costs and 1.5% for benefits[343], citing guidance issued by HM Treasury.[377] Rates of 3% were typical in the US and Australia, but the most recent studies in Australia applied a 5% discount rate to costs and benefits.[288-290,365] Across all studies, discount rates did not exceed 5%. Many studies with follow-up periods or time horizons exceeding one year did not report discount rates, and no justification was provided for their omission.[161,203,217,218,221,282,283,285,294,295,304,305,320,321,326,329,332,335,338,342,351,352,357,361,369] Where applicable, individual study discount rates are reported in Table 8, Table 9 and Table 10.

Cost-effectiveness thresholds

In the context of CUAs, judgements on cost-effectiveness were mostly based on an explicit cost-effectiveness threshold. These benchmarks for assessing ICERs varied by country and sometimes within the same country: EUR 5,000 and EUR 20,000 for Germany[213], EUR 30,000 for Spain [331] and EUR 33,000 for Finland.[283] In New Zealand and Canada, cost-effectiveness thresholds of NZD 50,000[209,336] and CAD 50,000[216,340] per QALY gained were applied, respectively. One study in a Chinese childhood population applied a GBP 20,000 per QALY threshold.[280] The highest within-country variation was in the US, where studies quoted USD 20,000[87], USD 30,000[166,291,351,355], 50,000[87,177], and USD 100,000[155,356] as cost-effectiveness thresholds for an additional QALY. In line with the National Institute for Health and Care Excellence (NICE) guidelines, UK cost-effectiveness thresholds were either set at a lower bound of GBP 20,000[161,284,286,287,314,317] or an upper bound of GBP 30,000[156,201,308,315,360], or both GBP 20,000 and 30,000 thresholds[204] per QALY gained. One UK-based study applied a threshold of EUR 3,000 per QALY gained, but no justification was provided for the decision.[304] Only one UK-based study[343] assumed a higher cost-effectiveness threshold value of GBP 60,000 per QALY, citing guidance issued by HM Treasury.[377] Studies in Australia quoted cost-effectiveness thresholds of AUD 50,000 per QALY gained[199,285,289,290,365], per DALY averted[185,187,189-191,319,350] and per HALY gained.[194,197,198,322,324,325] Studies in the Netherlands applied cost-effectiveness thresholds of EUR 19,600 per DALY averted based on the Dutch per capita income[337] and EUR 20,000 per QALY gained.[208] A study involving multiple countries applied country-specific cost-effectiveness thresholds that amounted to three times the gross domestic product per head per DALY averted.[277]

Compared with CUAs, fewer CEA studies specified a cost-effectiveness threshold, typically by performing probabilistic sensitivity analysis and graphing a cost-effectiveness acceptability curve (CEAC). Quoting annual maximum parental willingness to pay (WTP) thresholds of EUR 35[212] and EUR 123[333] for the costs of interventions per child, respectively, the authors of two German CEAs deemed both interventions cost-effective. However, the cost-effectiveness threshold applied in one of the studies was hypothetical[212], while the other was empirically derived.[333] In the US, a CEA determined that an intervention established cost-effectiveness using a cost-effectiveness threshold of 35 cents per MET-hour gained.[299] Another US-based study applied a cost-effectiveness threshold of USD 400 per BMI percentile point decrease.[363] Two UK-based CEAs applied cost-effectiveness threshold ranges of GBP 0-100 per minute of MVPA per day[318] and GBP 0-2,000 per 0.1-point improvement in BMI z-score[353], respectively. An Australian study explored separate cost-effectiveness threshold ranges of AUD 0-30,000 per unit BMI avoided and AUD 0-3000 per 0.1 reduction in BMI z-score[192], while another applied a cost-effectiveness threshold of AUD 1,000 per 0.1 BMI z-score.[288] A cost-effectiveness threshold range of AUD 0-45 per unit reduction in lunchbox energy from discretionary foods was considered in one Australian study.[339] A Swedish study explored a cost-effectiveness threshold range spanning EUR 0-10,000 per BMI unit prevented.[218] One Finnish study applied a societal cost-effectiveness threshold of EUR 100 per avoided sickness absence day[283], while another used a cost-effectiveness threshold of EUR 14-19 per one-hour increase in physical activity.[341]

Without an explicit cost-effectiveness threshold, decision-making may prove complicated if an intervention is more effective and costlier than a comparator. One of the included studies[56] met the criteria for classification as a CMA.[269,270] In CBAs, a ratio of benefits to costs exceeding one indicate value for money.[305] Some CBA-type studies determined cost-effectiveness by estimating the difference in net cost saved per unit currency spent[150,300,328] or net monetary benefit[182] between competing interventions.

Study quality assessment

Individual descriptive characteristics and CHEERS quality scores are reported for all 151 studies grouped as prevention-only (Table 8), prevention and treatment interventions (Table 9) and treatment-only interventions (Table 10). Appendix C **Table C 2** and **Table C 3** present the 24 CHEERS checklist items and a breakdown of scores for each item by study, respectively. Additional descriptive information on costs and intervention effectiveness data sources, sensitivity analysis, and study or model assumptions are available in Appendix C **Table C 4**. Higher scores are preferable as they indicate that a study has satisfactorily addressed more questions in the CHEERS checklist relative to a study with a lower-scoring study.

The lowest CHEERS scores were recorded for nine studies where only abstracts were available from my searches.[282,285,304,329,331,334,346,351,357] Scores for these nine studies ranged from 31% to 63%, mainly due to the minimalist structure and restricted word count stipulated for abstracts. However, there was considerable variation across the content of the abstracts. For instance, some abstracts described the target population insufficiently[304,331] or omitted the description of study perspective[331,351,357,369], follow-up or model time horizon[304,346,351] and discount rate.[282,285,304,329,346,351,357,369]

In my review of the remaining studies (142 full-text studies), the minimum and maximum CHEERS scores were 58% and 100%, respectively, with a mean score of 93% across all the included studies. Only five studies scored less than 70%.[161,168,294,305,338] Among these studies, there was a tendency to omit details about study perspective and discounting. The descriptions of methods, study parameters, assumptions for decision-analytical models, and uncertainty characterisation were also largely scant in these studies. Finally, the choice of comparator was scarcely justified in most of the included studies. In the following sections, study characteristics are further explored, and cost-effectiveness results are presented for the disaggregated groupings (prevention-only, prevention and treatment, and treatment-only).

3.3.3 Study characteristics: prevention-only interventions

Intervention components and target populations

Interventions in seven of the 13 prevention-only studies aimed to influence behaviours associated with diet and/or physical activity.[192,218,283,284,286,287,289] Three studies assessed interventions that combined components of diet and/or physical activity with sleep modification.[199,285,290] Two studies evaluated interventions seeking to change the nutrition environment through protein infant formula modification.[213,276] Two studies were m-health-based: one involved deploying a multi-component smartphone app intervention among thirteen-year-olds in a school setting[287], and the other compared the use of telephone or short message service (SMS) to contact mothers of infants.[288] All comparators were usual care or no intervention, except for one study that compared lower protein with higher protein content formula.[213]

All prevention-only interventions were conducted among baseline populations of pregnant women and newborn babies or children within the first five years of life, except for two studies, which targeted thirteen- and sixteen-year-olds.[284,288] One study focused on children in socioeconomically disadvantaged areas.[192] One study undertook subgroup analysis for white and South Asian subpopulations.[286]

Key cost-effectiveness results

Authors described 11 (85%) of the 13 interventions in the prevention-only studies as cost-effective or potentially cost-effective. Specifically, an early sleep intervention[199,285] and an afterschool behavioural intervention targeting healthy weight 16-year olds[284] were deemed cost-effective. Potentially cost-effective interventions included: a lower protein infant formula intervention[213,276]; four early childhood behavioural interventions[192,286,289,290]; a behavioural intervention targeting pregnant women at risk of gestational diabetes[283]; and a multi-component mobile app intervention.[287]

In Australia, SMS and telephone delivery of health messages to mothers of infants each had less than a 50% probability of being cost-effective compared with an in-person, home-visiting approach given a threshold of AUD 1,000 per 0.1 BMI z units avoided.[288] The authors of a Swedish study determined that there was inadequate evidence to support the cost-effectiveness of a population-based primary prevention intervention targeting preschool children due to uncertainty in the effect measure.[218] A Finnish study found that cost-effectiveness evidence varied depending on the measure of consequences.[283] In this case, prenatal lifestyle counselling intervention was deemed cost-effective given a societal cost-effectiveness threshold of EUR 100 per avoided sickness absence day, but not cost-effective given a societal CE threshold of EUR 33,000 per QALY gained. In one pilot trial and preliminary economic evaluation of an outdoor playground-based physical activity intervention for parents and their children where the ICER, GBP 19,588 per QALY gained, fell just below the recommended GBP 20,000 cost-effectiveness threshold, and the authors proposed a full randomised controlled trial (RCT) to confirm results.[286] Subgroup analysis in this pilot trial estimated vastly different ICERs by ethnicity: GBP 275,203 per QALY gained for a white population, and GBP 9,346 per QALY gained for a South Asian subpopulation.[286] An Australian study of a sleep intervention found that cost-effectiveness also varied by socio-economic position with probabilities of cost-effectiveness of 92%, 100% and 79% for low-, mid-, high socio-economic positions, respectively, given a cost-effectiveness threshold of AUD 50,000 per QALY gained. The cost-effectiveness results for all nine studies are detailed in Table 8.

Table 8 Descriptive analysis of the key assessment items for individual studies targeting only prevention

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Hayes, A., et al. 2014 (Australia)[192]	Healthy Beginnings: home-based early intervention consisting of eight home visits by specially trained community nurses (including one visit at 30-36 weeks gestational age) versus usual care	Behavioural; diet and PA (home-based)	Infants in socio-economically disadvantaged areas of Sydney received the intervention for the first 2 years of life (0 to 4 years old)	CEA; within-trial economic evaluation; Health care funder	2 years from baseline; 5% (costs and benefits)	Australian dollars (2012)	Reduction in BMI z-score/unit BMI avoided	Given CE threshold ranges of AUD 0-30,000 and AUD 0-3,000 per BMI unit avoided and reduction in BMI z-score, respectively, the ICERs were AUD 4,230 per unit BMI avoided and AUD 631 per 0.1 reduction in BMI z-score, if the intervention cost per child was AUD 1,309 per child over 2 years	100%
Barber, S. E., et al. 2015 (UK)[286]	Pre-schoolers in the Park intervention (PiP): an outdoor playground-based PA intervention for parents and their children versus usual practice	Behavioural; PA (community-based, school-based)	Pre-schoolers (18 months to 4 years old)	CUA; pilot trial alongside a preliminary economic evaluation; NHS and Personal Social Services	1 year; NA	Pound sterling (2012/2013)	QALY gained for parents (EQ-5D)	Given a CE threshold of GBP 20,000 per QALY gained, an ICER of GBP 19,588 per QALY gained was estimated for PiP	100%
Kolu, P., et al. 2016 (Finland)[283]	Prenatal lifestyle counselling on PA, diet, and weight gain at five antenatal versus usual care	Behavioural; PA, diet (ante-natal clinics)	Pregnant women with at least one gestational diabetes mellitus (GDM) risk factor and their infants	CEA, CUA; cluster RCT alongside an economic evaluation; societal	7 years follow up; not stated	Euros (2015)	Change in BMI (children and mothers), QALY gained (15D) and avoided sickness (mothers)	Given a societal CE threshold of EUR 100 per one avoided sickness absence day the intervention was deemed cost-effective but not cost-effective given a CE threshold of EUR 33,000 per QALY gained. Differences in BMI were significant in children but not among mothers	95%
Marsh, K., et al. 2016	lpIF (low protein content and caloric density)	Environmental; diet - protein infant formula	Infants in Mexico born to mothers	CUA; DAM (discrete event simulation);	Lifetime; 3.5% (costs and	Mexican pesos (2014)	QALY gained	Given CE thresholds of MXN 73,262 and MXN	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
(Mexico)[276]	versus a currently used formula	modification (multiple settings possible)	with excess weight	societal	benefits)			219,696 per QALY gained, the probabilities of CE for IpIF were 60.6% and 58.2%	
Döring, N., et al. 2018 (Sweden)[218]	PRIMROSE intervention: an early childhood obesity intervention delivered in the first four years of life versus usual care	Behavioural and policy; diet and PA - motivational Interviewing (clinic-based – CHCs)	Pre-school children (9 months old)	CEA; trial-based economic evaluation; societal	End of the trial: child at age 4 (48 months); not stated	Euros (2015)	BMI unit prevented	Given a CE threshold range of EUR 0-10,000 per BMI unit prevented, the probability of CE approached ~80% at ~EUR 10,000 per BMI unit prevented	93%
Gc, V. S., et al. 2019 (UK)[284]	A comparatively simple after-school intervention and a more complex multicomponent intervention versus usual care	Behavioural; PA (school and community-based)	A hypothetical cohort of healthy children (16-year-olds)	CUA; DAM (Markov model); NHS	65 years; 3.5% (costs and benefits)	Pound sterling (2013/2014)	QALY gained (EQ-5D)	Given a CE threshold of GBP 20,000 per QALY gained, an ICER of GBP 11,486 per QALY gained was estimated for the after-school intervention. The multi-component intervention was extendedly dominated with an ICER of GBP 68,056 per QALY gained	100%
Sonntag, D., et al. 2019 (Germany)[213]	Infant formula nutrition: lower protein (LP) versus higher protein (HP) intake groups	Environmental; diet - protein infant formula modification (multiple settings possible)	Infants born from uncomplicated singleton pregnancies	CUA; DAM (Markov model) based on the European Childhood Obesity Project (CHOP) trial; societal	Lifetime; 3% (costs and benefits)	Euros (2015)	QALY gained (EQ-5D)	Given societal CE thresholds of EUR 5,000 and EUR 20,000 per QALY gained, the probabilities of cost-effectiveness for LP relative to HP were 76% and 85%, respectively	100%
Tan, E. J., et al. 2020 (Australia)[199]	Prevention of Overweight in Infancy (POI) sleep intervention alone and in combination with food, activity, and	Behavioural; sleep modification, diet, PA, and breastfeeding advice (home and clinical settings)	Healthy infants received the intervention up to the first 2 years of life and then	CUA; DAM (the EPOCH microsimulation model) based on a trial; health funder	15 years; 5% (costs and benefits)	Australian dollars (2018)	QALY gained (meta-analysis) and unit BMI avoided	Given a CE threshold of AUD 50,000 per QALY gained, the ICERs per QALY gained for the Sleep intervention alone and	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	breastfeeding advice (FAB) versus usual care		followed up to age 5 years					FAB combination were AUD 18,125 (probability of CE: 74%) and AUD 94,667 (probability of CE: 23%), respectively	
Taylor, R., et al. 2020 (Australia)[285]	Sleep intervention during the first two years of life versus usual care	Behavioural; sleep modification, antenatal group-based education session (home and clinical settings)	Mother-infant dyads (the first two years of life)	CUA, CEA; DAM (insufficient information); health funder	5 years and 15 years; not stated	Australian dollars (2018)	BMI unit avoided, QALY gained	Given a CE threshold of AUD 50,000 per QALY gained, ICERs of AUD 18,204 per QALY gained and AUD 536 per BMI unit avoided were estimated for the sleep intervention	57%
Kalita, N., et al. 2022 (UK)[287]	The LifeLab Plus intervention: comprising (1) an education module and practical sessions for students; (2) teacher training; and (3) access to an interactive smartphone app versus control (usual schooling)	Behavioural; multi-component - diet, PA, and app-based m-health (school-based)	Hypothetical cohort of healthy weight adolescents (mean age of 13 years)	CEA, CUA; DAM (Markov model); societal	20 years; 3.5% (costs and benefits)	Pound sterling (2015)	QALY gained (EQ-5D-3L)	Given a CE threshold of GBP 20,000 per QALY gained, the probability of LifeLab Plus being cost-effective was 69% with an ICER of GBP 14,367 per QALY gained	100%
Killedar, A., et al. 2022 (Australia)[288]	Communicating Healthy Beginnings Advice by Telephone (CHAT) trial, consisting of three arms: (1) short message service (SMS) intervention; (2) telephone intervention; and (3) usual care (home-visiting approach)	Behavioural, policy; m-health - SMS and telephone contact to mothers of infants to prevent obesity (home-based)	Mothers and their infants (up to 2 years old) in New South Wales, Australia	CEA; trial-based economic evaluation; health payer's	2 years; 5% (costs and benefits)	Australian dollars (2018)	Reduction in BMI z-score/unit BMI avoided	Given a CE threshold of AUD 1,000 per 0.1 BMI-z units avoided, the probabilities of CE for the SMS and telephone interventions were 48% and 41%, respectively	100%
Tran, H. N. Q., et al. 2022 (Australia)[289]	Romp & Chomp: a community-wide obesity prevention intervention versus no intervention	Behavioural, environmental, policy; diet - daily water, fruits and vegetables,	Australian children (0 to 5 years old)	CEA, CUA; DAM (the Early Prevention of Obesity in Childhood (EPOCH)	10 years; 5% (costs and benefits)	Australian dollars (2018)	Unit BMI avoided, QALY gained	Given a CE threshold of AUD 50,000 per QALY gained, a 64% probability of CE was estimated. The	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
		fewer sweet drinks, PA - daily active play, reduced screen time (multiple settings possible)		microsimulation model based on the Romp & Chomp quasi-experimental trial); funder				ICERs were AUD 1,126 per BMI unit avoided, and AUD 26,399 per QALY gained	
Killedar, A., et al. 2023 (Australia)[290]	Sleep intervention during the first two years of life versus usual care	Behavioural, policy; sleep modification, antenatal group-based education session (home and clinical settings)	Mother-infant dyads across three socioeconomic position (SEP) groups: low-, mid- and high-SEP (the first two years of life)	CEA, CUA; DAM (the EQuity-informative Early Prevention of Obesity in Childhood (EQ-EPOCH) model: a discrete-time microsimulation model) based on a trial; health funder	17 years; 5% (costs and benefits)	Australian dollars (2018)	BMI unit avoided, QALY gained (meta-analysis)	Given a CE threshold of AUD 50,000 per QALY gained, the probability of CE in each SEP group was 91.7%, 99.6%, and 78.5% for low-, mid- and high SEP, respectively. ICERs per QALY gained were, AUD 23,010, AUD 18,206, and AUD 31,981 for low-, mid- and high SEP, respectively	100%

BMI: body mass index; CE: cost-effectiveness; CEA: cost-effectiveness analysis; CHCs: child health care centres; CUA: cost-utility analysis; DAM: decision analytic model; EQ-5D: EuroQol 5Dimension; ICER: incremental cost-effectiveness ratio; NA: not applicable; PA: physical activity; QALY: quality-adjusted life year.

3.3.4 Study characteristics: prevention and treatment interventions

Intervention components and target populations

Fifty-four percent of the interventions targeting prevention and treatment focused on changing individual behaviour by influencing dietary habits and physical activity, one of which involved the use of app-based mobile technology (m-health).[339] A few solely behavioural interventions also sought to reduce television viewing.[166,191,320] Nine studies modelled interventions at policy levels featuring the implementation of sugar-sweetened beverage (SSB) excise taxation[174,279,281,301,343], policies on reduction in sugar content[203] or repackaging of high sugar products and energy-dense beverages[322], restriction on price promotion of SSBs[198], and restriction of television advertising of SSBs and foods high in fat, sugar and salt (HFSS).[316,343] Four interventions included components delivered using online or web-based technology (e-health)[378] at schools[55,56,326] and childcare centres.[327] Thirty-eight studies evaluated interventions with the main components cutting across multiple intervention categories.[55,56,150,168,169,173,175-179,182,184,187,189,190,194,197,209,277,282,291,295,296,300,303,305,314,319,323-325,333,336,337,340,343,345] All but three of these multi-category interventions involved behavioural components: of the three that did not, one intervention targeted food standards across English schools[305], while two others sought to change the school drinking water environment in the US.[182,184] One study considered hypothetical scenarios of reduction in the prevalence of obesity, and no intervention was specified.[87] The information describing the intervention categorisation in another study was insufficiently described.[331] The comparators for the prevention and treatment group of interventions were predominantly usual care or a “do nothing” option.

Targeted age ranges varied substantially across studies. However, the age ranges in a considerable number of studies tended to include primary school children aged 5 and 6 years and children in preadolescence/early adolescence (approximately 8 to 13 years). Eight studies were conducted solely on girls[166,171,302,306,310,312,313,318], while the remaining studies included boys and girls. Some studies

focused entirely on children in socioeconomically deprived settings or conducted subgroup analyses for children from disadvantaged backgrounds.[55,194,209,297,321,336]

Key cost-effectiveness results

Of the 100 studies that targeted prevention and treatment of childhood excess weight, 75% estimated that interventions were either cost-effective[55,161,163,164,166,177,187,191,194,198,208,209,212,215,216,277,278,280,291,299,304,308,314,320,322,324,325,330,333,336,337,343] or potentially cost-effective.[56,150,168,169,171,173-176,178,181,182,184,203,204,210,219,279,292-294,296-298,300-303,305,313,316,321,323,326-329,332,334,335,339-341] Eleven deemed interventions unlikely to be cost-effective compared to current practice or control, all of which were carried out in school-settings, namely: a programme to increase walking to school[319]; two to three after-school sessions per week of physical activity programmes[189]; a programme to increase active transport[190]; a girls' dance programme[306]; an intervention aimed at increasing physical activity and improving diet in primary school children[307]; a drama-based healthy lifestyles week programme[309]; training of teachers to deliver a physical activity programme[311]; a teacher-led physical activity intervention for girls[312]; replacing normal desks with sit-stand desks[315]; a school-based, peer-led 12-week physical activity programme[317]; a peer led physical activity programme for girls[318]; and a school-based physical activity programme for girls.[310] The remaining five studies were hypothetical analyses that compared varying scenarios of theoretical reductions in excess weight or estimated targets for the reduction of excess weight or increase in physical activity that would be cost-effective.[87,179,197,295,331] Cost-effectiveness results for all prevention and treatment interventions are further described in Table 9.

Most studies were conducted in samples representative of the broader childhood population, but cost-effectiveness tended to vary by gender when considered. In one study, specifying a package size cap of 375 mL on packaged single-serve SSBs appeared more cost-effective in boys.[322] In another, an educational intervention focused on improving lifestyle choices was cost-effective for boys but not for girls.[215] However, another study found that running or walking around school grounds for 15

minutes daily was cost-effective for the overall sample and specifically for girls, but it was not cost-effective for boys.[314] Similarly, one study found that a policy to reduce the sugar content in certain high sugar products by 20% had potentially larger health benefits for girls than boys[203], and another study found that a primary school intervention targeting diet and physical activity was more effective in girls and children with excess weight.[278] One study reported that cost-effectiveness varied between boys and girls, depending on the intervention (immediate or delayed afterschool programmes).[181] Of the eight studies conducted solely in female subpopulations, four studies (50%) reported that the interventions were either cost-effective[166,171,313] or potentially cost-effective[302], respectively. The remaining four studies stated that they did not find evidence of cost-effectiveness.[306,310,312,318]

Cost-effectiveness also varied by ethnicity, age, and socioeconomic status (SES). One study estimated lower ICERs for a multicomponent through-school physical activity and nutrition programme in the Maori subpopulation and children in middle SES schools compared to the entire population and lower ICERs for older children across all subgroups compared with younger children.[209] Similarly, another study that focused on four interventions targeting television viewing, diet and physical activity, reported lower ICERs for Maori and Pacific populations compared to the general population of children in New Zealand.[336] A study of a programme that targeted physical activity, physical education, and aimed to modify school food service conducted in a predominantly Hispanic sample, was deemed cost-effective[291], and another study found a family-centred, mental health intervention focused on Black and Latino children who attended high-poverty, urban schools in the US to be potentially cost-effective.[297] An economic evaluation of legislation restricting television advertising of food and beverages HFSS demonstrated greater health benefits and cost-savings for children in the more deprived areas.[194] Finally, one study targeting students in low SES neighbourhoods found an online intervention more cost-effective than the onsite version.[55]

Table 9 Descriptive analysis of the key assessment items for individual studies targeting prevention and treatment

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Wang, L. Y., et al. 2003 (US)[166]	Intervention targeting obesity (Planet Health) versus “no intervention”	Behavioural; diet, PA, and TV viewing (school-based)	Girls with mixed-weight status (10 to 14 years old)	CUA; DAM (decision tree overweight progression model); societal	25 years (age 40 to 65 years); 3% (costs and benefits)	USUS dollars (1996)	QALY saved	Given a CE threshold of USD 30,000 per QALY saved, an ICER of USD 4,305 per QALY saved was estimated	93%
Brown, H. S., et al. 2007 (US)[291]	The CATCH[a] intervention versus control	Behavioural, environmental; PA, PE, and modification to school food service (family-, home-, and school-based components)	Children of mixed-weight status across grades three, four, and five (8 to 11 years old)	CUA; DAM (decision tree excess weight progression model); societal	26 years (age 40 to 65 years); 3% (costs and benefits)	US dollars (2004)	QALY saved and averted medical and labour productivity costs	Given a CE threshold of USD 30,000 per QALY saved, an of ICER of USD 900 per QALY saved was estimated	94%
Nixon, J., et al. 2008 (UK)[304]	Three interventions with or without primary prevention, screening of BMI and treatment for children above threshold versus "do nothing"	Behavioural, policy; screening and primary prevention (school-based)	School children (not stated)	CUA; insufficient information; NHS	Not stated; not stated	Euros (not stated)	QALY gained	Given a CE threshold of EUR 3,000 per QALY gained, primary prevention without screening (ICER EUR 290 per additional QALY) had a 100% probability of being cost-effective	37%
Peterson, M., et al. 2008 (US)[168]	State-wide social marketing: exposure to varying levels of ADs versus "no ADs"	Behavioural, policy; PA, TV, and billboard AD (population-wide)	Children of mixed-weight status attending public schools (12 to 17 years old)	CEA; cross-sectional study (survey asked how exposure to media campaign impacted PA); not stated	NA; NA	US dollars (not stated)	Intention to be active; and becoming more active (measure not specified)	Cost per person to become more active was lowest for billboard alone at USD 5.11 but cost USD 8.87 per person for the entire campaign	58%
Wang, L. Y., et al. 2008 (US)[169]	An after-school intervention (MCG FitKid) versus usual after-school care control	Behavioural, environmental; diet, PA, and academic enrichment	Third graders with mixed-weight status (mean age of 8.7 years old)	CEA; within-trial economic evaluation; societal	1 year after randomisation; NA	US dollars (2003)	Reduction in percent body fat (%BF)	Students who attended at least 40% of the intervention reduced %BF by 0.76% at an additional cost of USD 317/student,	97%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
		activities (school-based)						compared with students in the control group	
Magnus, A., et al. 2009 (Australia)[187]	A ban on TV ADs for energy-dense, nutrient-poor (EDNP) foods and beverages versus current practice	Behavioural, policy; diet and legislation (population-wide, home-setting)	Children (5 to 14 years old)	CEA, CUA; DAM (cohort multi-state transition model: the ACE-Obesity study); societal	Lifetime; 3% (costs and benefits)	Australian dollars (2001)	Changes in BMI and DALY saved	Given a CE threshold of AUD 50,000 per DALY saved, the intervention had a 100% probability of CE (gross ICER of AUD 3.70 per DALY saved and cost per BMI unit saved of AUD 0.33)	100%
Moodie, M., et al. 2009 (Australia)[319]	The Walking School Bus (WSB) programme versus "current practice" defined as "do nothing"	Behavioural, policy; PA specifically to increase walking to school (population-wide, school-based)	Primary school children (5 to 7 years old)	CUA; DAM (cohort multi-state transition model: the ACE-Obesity study); societal	Lifetime; 3% (costs and benefits)	Australian dollars (2001)	BMI unit saved and DALY saved	Given a CE threshold of AUD 50,000 per DALY saved, WSB had a 0% of being CE	100%
Cecchini, M., et al. 2010 (Brazil, China, India, Mexico, Russia, South Africa, England)[277]	Comparison of strategies targeting children grouped into: (1) school-based health promotion; (2) fiscal measures; (3) food AD regulation; and (4) food labelling	Behavioural, policy; diet, PA, AD, taxation, and subsidies (school-based, population-wide)	School-based health promotion (8 to 9 years old); fiscal measures (≥0 years old); food AD regulation (2 to18 years old); and food labelling (≥0 years old)	CUA; DAM (microsimulation model adapted from the chronic disease prevention model (CDP)); not stated	20 years and 50 years; 3% (costs and benefits)	US dollars (2005)	DALY averted and life years gained	Given country-specific CE thresholds, the study found that fiscal measures had the most consistently favourable ICERs across LMICs in both 20- and 50-year time horizons. Food labelling and regulation of food AD performed well in many countries but showed smaller health effects compared with fiscal measures. Poor ICERs were reported for school-based health promotion interventions within 50 years but tended to improve in longer time	90%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								horizons	
McAuley, K. A., et al. 2010 (New Zealand)[210]	The APPLE[a] project: the provision of community activity coordinators at each intervention school versus usual care	Behavioural; diet, PA, and lifestyle-based (school- and community-based)	Children representative of the wider population (5 to 12 years old)	CEA, CUA; within-trial economic evaluation; societal	4 years from baseline (2 years of follow-up); 5% (costs)	New Zealand dollars (2006)	Reduction in weight z-score and QALY gained (HUI values)	While mean HUI values did not differ between the two groups, reduction in BMI z-score was equivalent to 2.0 kg of weight-gain prevented at age 15. The implementation cost for the intervention was NZD 664 - NZD 1,708 per kg of weight-gain prevented from baseline to follow-up (4 years)	98%
Mernagh, P., et al. 2010 (New Zealand)[336,379]	Four interventions: (1) Switch-Play versus no intervention (2) BAEW (3) School Nutrition Policy Initiative (SNPI) and (4) APPLE[a]	Behavioural, policy; reduction of TV viewing, diet, and PA (community-based, school setting)	Children in the general population, including for BAEW, Maori and Pacific subpopulations (for APPLE[a], BAEW, SNPI and Switch-Play, 9, 8, 11 and 10 years old respectively)	CUA; DAM (simulation model with 14 obesity-related chronic disease states); health care	Lifetime; 3.5% (costs and benefits)	New Zealand dollars (2010)	QALY gained	Given a maximum CE threshold of NZD 50,000 per QALY gained, the ICERs for Switch-Play; BAEW; SNPI; and APPLE[a] were 4,824 and 38,630; 123,536, 154,178 and 168,391; 134,252; and 205,101 NZD per QALY gained, respectively, compared to no intervention	92%
Moodie, M. L., et al. 2010 (Australia)[189]	The Active After-school Communities programme: 2 to 3 sessions per week of PA programmes during the after-school period versus no intervention	Behavioural, policy; PA (population-wide, school-based)	Children in grade 4 to 6 of mixed weight status (5 to 11 years old)	CUA; DAM (cohort multi-state transition model: modelled as part of the ACE-Obesity study); societal	Lifetime; 3% (costs and benefits)	Australian dollars (2001)	BMI unit saved and DALY saved	Given a CE threshold of AUD 50,000 per DALY saved, the probability of cost-effectiveness was only 8.9% (net cost per DALY saved of AUD 82,000 estimated)	100%
Pringle, A., et al. 2010 (UK)[161]	Seven community-based interventions	Behavioural; PA (community-	A sample of people in the UK	CUA; DAM (insufficient	Not stated; not stated	Pound sterling	MPA improvement in completers, QALY	Given a CE threshold of GBP 20,000 per QALY	65%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	categories to increase MPA: inter- and intra-category comparisons	based)	(~one-third of sample 10 to 17 years old)	information); NHS		(2003)	gained	gained, the cost per QALY gained ranged from GBP 47 to GBP 509 within each intervention category	
Trasande, L. 2010 (US)[87]	Hypothetical scenarios in which childhood obesity is reduced	NA; NA (population-wide)	The 2005 cohort of children in the US (6- and 12-years old cohorts)	CUA; DAM (cohort simulation model to estimate economic consequences of childhood obesity reduction scenarios); provider/payer perspective	Lifetime; 3% (costs and benefits)	US dollars (2005)	QALY saved	Given CE thresholds of USD 20,000 and USD 50,000 per QALY saved, a one percent-point reduction in obesity among 6- and 12-years old would save 67,910 QALYs and 102,749 QALYs, and USD 166 million and USD 260 million in total medical expenditures, respectively	83%
Martínez, P. M., et al. 2011 (Spain)[330]	Weekly recreational, non-competitive PA programme conducted after school hours versus usual afterschool care	Behavioural; PA (school-based)	Children of mixed weight status (9 to 10 years old)	CCA; within-trial economic evaluation; societal and institutional	7 months from baseline; NA	Euros (2005)	Decrease in the percent of body fat	Usual afterschool care estimated at EUR 844,56/year/child, was 3 times more expensive than the intervention. The decrease in triceps skinfold thickness and percent of body fat for the intervention group relative to usual care ranged from -1.25mm to -1.87mm and -0.59% to -0.67%, respectively	87%
Moodie, M., et al. 2011 (Australia)[190]	TravelSMART Schools Curriculum programme versus current practice	Behavioural, policy; PA (population-wide, primary school-based)	Children of mixed weight status (10 to 11 years old)	CUA; DAM (cohort multi-state transition model: modelled as part of the ACE-Obesity study); societal	Lifetime; 3% (costs and benefits)	Australian dollars (2001)	BMI unit saved and DALY saved	Given a CE threshold of AUD 50,000 per DALY saved (with cost-offsets), the intervention was estimated at a net cost per DALY saved of AUD 117,000	100%
Ramos-Goñi JM,	Hypothetical	NA; NA (NA)	A mixed group of	CUA; DAM (Markov	70 years; 3%	Euros (not	QALY gained	Given a CE threshold of	31%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Valcárcel-Nazco C, Castilla-Rodríguez I. 2011 (Spain)[331]	scenarios of public health intervention to prevent and correct childhood obesity (insufficient information)		children with healthy weight and obesity (not stated)	model); not stated	(costs and benefits)	stated)		EUR 30,000 per QALY gained, the study proposed that any intervention exceeding 1% prevention/correction should be implemented if costs was less than EUR 2 per child and per year	
Te Velde, S., et al. 2011 (Netherlands)[337,380]	Two fruit and vegetable school-based interventions: 2-year Pro Children (PC) intervention and the Schoolgruiten (SG) intervention versus "no intervention"	Behavioural, environmental; provision of free fruits and vegetables (family- and school-based)	10-year-olds in the Netherlands	CUA; DAM (multi-state life table); health services and societal	Lifetime; 3% (costs and benefits)	Euros (2006)	DALY averted	Given a CE threshold of EUR 19,600 per DALY averted (based on Dutch per capita income), the ICER for PC and for SG in versus no intervention was calculated to be 5,728/DALY and 10,674/DALY, respectively	100%
Wang, L. Y., et al. 2011 (US)[171]	Planet Health, a school-based intervention targeting obesity and disordered weight control behaviours (DWCB) versus "no intervention"	Behavioural; diet, PA, and DWCB prevention (purging or diet pill use) and TV viewing (school-based)	Girls with mixed weight status (10 to 14 years old)	CUA; DAM and RCT; societal	10 years; 3% (costs and benefits)	US dollars (2010)	QALY gained (15D instrument)	CE threshold not stated: the ICER for the intervention was estimated at net savings of USD 2,966 per QALY gained	100%
Monsivais, P., & Rehm, C. D. 2012 (US)[292]	Complete or partial replacement of fruit juice with fresh, inexpensive, popular fruits	Behavioural; diet – nutrient and energy intake (home-, school-, and childcare-based)	Children in the US (3 to 18 years old)	CCA; longitudinal study (secondary analyses using the 2001-2004 NHANES and a national food price database); not stated	A one-day reduction in dietary energy per day; NA	US dollars (not stated)	Reduction in dietary energy (Kilojoules/day) and increase in fibre (grams/day)	Replacing all juice with fresh, whole fruit is estimated to reduce energy intake by 233 kJ/day and increase fibre intake by 4.3 g/day but would cost an extra USD 0.54/day	76%
Gesell, S. B., et al. 2013 (US)[293]	PA-enhanced ASP based in a community	Behavioural; PA (school- and	Elementary school students	CCA; observational prospective cohort	12 weeks from baseline; NA	US dollars (2010)	Increase in MVPA	Increased PA in favour of the intervention was	82%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	recreation centre versus a standard school-based ASP	community-based)	who attend ASP (not stated)	study of a natural experiment involving costing; not stated				reported (a difference of 14.7 percent points in MVPA between groups). The standard school-based ASPs would also cost more (an additional USD 1.59 per child for 12 weeks) to achieve similar results	
Kesztyüs, D., et al. 2013 (Germany)[212]	Ulm Research on Metabolism Exercise and Lifestyle Intervention in Children (URMEL-ICE) integrated into the usual school curriculum versus usual care (no intervention)	Behavioural; diet, PA, media, teaching, activity breaks and homework assignments (school-based)	Primary school children in their second grade from a mixed-weight group (mean ages 7.64 and 7.53 years old in the intervention and control groups, respectively)	CEA; within-trial economic evaluation; societal	1 year; NA	Euros (2008)	WC and WHtR gain prevented and BMI difference between groups	Given a maximum parental WTP threshold of EUR 35 for the intervention per year, the ICER was EUR 11.11 per cm WC and EUR 18.55 per unit WHtR gain prevented for the intervention group with respect to the control group	95%
Meng, L., et al. 2013 (China)[163]	Three interventions: (1) NE, (2) PA and (3) comprehensive (included the NE and PA interventions) versus control (usual care)	Behavioural; diet and PA (school-based)	Children of mixed-weight status (6 to 13 years old)	CEA; within-trial economic evaluation; institutional	1 academic year from baseline; NA	Chinese Yuan/US dollars (2010)	BMI reduction, BMI z-score avoided, overweight and obesity case avoided	No significant differences were found between control and NE or PA individually. The ICERs for the comprehensive group were US$120 per 1 kg/m^2 BMI reduction, USD 249 per BMI z-score avoided, USD 1,309 per one overweight and obesity case avoided compared with control	92%
Moodie, M. L., et al. 2013 (Australia)[191]	BAEW: an intervention to increase PA and healthy eating versus	Behavioural; reduction of TV viewing, diet, and PA (community-	Children of mixed-weight status (4 to 12 years old)	CUA; DAM (cohort multi-state transition model: the ACE-Obesity study);	Lifetime; 3% (costs and benefits)	Australian dollars (2006)	BMI units saved and DALY averted	Given a CE threshold of AUD 50,000 per DALY saved (with cost-offsets), the intervention yielded a	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	usual practice	based, primary school setting)		societal				net cost per DALY saved of AUD 29,798 in comparison with the comparator	
Nelson, M. 2013 (England)[305]	The School Food Trust: an intervention targeting healthier school food provision versus no intervention	Environmental, policy; diet - school food standards (school-based)	Children in English primary and secondary schools (not stated)	CBA; back-of-the-envelope calculations (Insufficient information); not stated	6 years; not stated	Pound sterling (2008)	Monetary benefits (observed changes in food services)	The ratio of benefits to costs of introducing a breakfast club was 4.38 (GBP 897 000/GBP 205 000)	64%
Tran, B., et al. 2013 (Canada)[334]	APPLE[b] schools to prevent childhood obesity versus usual care	Behavioural; diet, PA, and lifestyle-based (school- and community-based)	Children of mixed weight status (11-year-olds)	CEA, CUA; DAM (state transition model); health care system	Lifetime; 3% (costs and benefits)	Canadian dollars (not stated)	Cases of excess weight prevented and QALY gained	CE threshold not stated: the ICER of the APPLE[b] Schools programme was CAD 15,833 per QALY gained and CAD 24,359 or 11,047 per case of obesity or overweight prevented in adulthood, resulting in a benefit-cost ratio of 13:1	59%
Babey, S. H., et al. 2014 (US)[294]	Four categories of interventions compared: after-school programmes; before-school programmes; PE classes and extended-day PE; and short PA breaks during the school day	Behavioural; PA, PE (community-based and school-based)	Elementary, middle, and high school students (not stated)	CEA; Insufficient information - estimated the costs, reach and effect on PA for various interventions based on previously reported data; not stated	Not stated; not stated	US dollars (2013)	Reach, MET-hours gained	Reach and cost per student were most favourable for extending the school day with mandatory PE participation and short PA breaks during the school day, with cost/MET-hours gained of USD 0.65-0.98 and USD 0.002-0.01 respectively	61%
Rush, E., et al. 2014 (New Zealand)[209]	Project Energise, a multicomponent through-school PA and nutrition programme versus usual care (unEnergised)	Behavioural, policy; diet and PA (school-based)	Younger (6 to 8 years of age) and older primary school children (9 to 11 years old)	CUA; DAM (Markov model) based on results of a RCT; Health care funder	Lifetime; 3.5% (costs and benefits)	New Zealand dollars (2011)	QALY gained	Given a CE threshold of NZD 50,000 per QALY gained, the ICER (among younger and older children, respectively) was NZD 30,438 and NZD 24,690, and lower for	92%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								Maori (NZD 28,241, NZD 22,151) and for the middle SES schools (NZD 23,211, NZD 17,891) per QALY gained	
Swinburn, B., et al. 2014 (Australia)[320]	BAEW: an intervention to increase PA and healthy eating versus usual practice	Behavioural; reduction of TV viewing, diet, and PA (community-based, primary school setting)	Children of mixed-weight status (4 to 12 years old)	CCA; economic evaluation based on a quasi-experimental, non-randomised study (follow-up data after completion of BAEW was cross-sectional as measurements were on new cohorts of children); not stated	3-year follow-up; not stated	Australian dollars (not stated)	Decrease in prevalence of overweight/obesity	No significant difference in effects between both groups was reported, but by the end of follow-up, intervention schools invested ~AUD 30,000 per year, which was less than half the amount during BAEW and much lower than comparison schools (over AUD 66,000 per school year)	80%
Tran, B. X., et al. 2014 (Canada)[335]	APPLE[b] schools to prevent childhood obesity versus usual care	Behavioural; diet, PA and lifestyle-based (school and community-based)	Children of mixed weight status (11-year-olds)	CCA; DAM (BMI trajectories were projected from age 11 to 70 years using the National Population Health Survey (NPHS) collected between 1996 - 2008; healthcare system	59 years (11-70 years); not stated	Canadian dollars (not stated)	Difference in life course prevalence of obesity	On average, the life course prevalence of obesity was 0.8% less among APPLE[b] schools' children, with potential annual cost savings at CAD 33 to 82 million and CAD 150 to 330 million in the province of Alberta and Canada, respectively	70%
Barrett, J. L., et al. 2015 (US)[173]	The "Active PE" policy: a requirement that 50% of PE time of state's elementary school PE curriculum be devoted to MVPA versus current practice	Behavioural, policy; PA (school-based)	Children (6 to 11 years old)	CEA; DAM (Markov model was adapted from two models, the ACE, and CHOICES models) based on two trials (SPARK and CATCH[b]); modified societal	10 years; 3% (costs and benefits)	US dollars (2014)	BMI units reduced	The intervention was estimated to cost USD 1,720 per BMI unit reduced. This translated to an estimated USD 60.5 million in healthcare costs averted	98%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Gortmaker, S. L., et al. 2015 (US)[150]	Four childhood obesity interventions: (1) SSB excise tax; (2) eliminating tax subsidy of TV AD to children (TV AD); (3) ECE policy change (ECE); and (4) Active PE	Behavioural, environmental, policy; PA, diet, TV viewing, taxation, TV AD, and education (multiple settings possible)	SSB (2 to 19 years old), TV AD (2 to 19 years old), ECE (3 to 5 years old), and Active PE (6 to 11 years old)	CBA; DAM (Markov model was adapted from two models, the ACE, and CHOICES models); modified societal	10 years; 3% (costs and benefits)	US dollars (2014)	BMI units reduced and net cost saved per USD spent	The net cost saved per dollar spent was USD 55, USD 38, and USD 6 for SSB, TV AD and ECE respectively	98%
Long, M. W., et al. 2015 (US)[174]	Implementing a SSB excise tax versus the current practice	Policy; diet and tax (multiple settings possible)	The US population (≥ 2 years old at baseline)	CEA; DAM (Multi-state model adapted from the ACE model); societal	2 years (10 years for general population); 3% (costs and benefits)	US dollars (2014)	BMI units reduced	Over 2 years, the cost per BMI unit reduced due to the tax was estimated at USD 8.54 in children and youth aged 2 to 19 years of age	100%
McCollister, K. E., et al. 2015 (US)[295]	Hypothetical assessment of Healthy Caregivers-Healthy Children (HC2) implemented in childcare centres versus control centres	Behavioural, environmental; diet, PA, PA-focused curricula for teachers, parents and children, and menu modifications (childcare centre-based, family-based)	Children in Florida (2 to 5 years old)	CEA; DAM based on the HC2 trial; health care	3 years follow up from the start of intervention and projected lifetime horizons; not stated	US dollars (2013)	Percent obesity avoided	If HC2 reduces obesity by 1%, 5% and 10%, the study projects lifetime savings of USD 228,000, USD 1,140,000, and USD 2,280,000, respectively	70%
Mora, T., et al. 2015 (Spain)[332]	Health education programme: 3-hour classes per week on healthy eating habits and PA versus control	Behavioural; diet, PA (school-based)	School children in Spain (6 years old)	CEA; within-trial economic evaluation (the AVall study); institutional/school system	Two years of intervention and 4-year follow-up; not stated	Euros (2008)	Change in BMI	A ratio of net intervention costs and net intervention effects of EUR 41 per 1.13 kg/m^2 BMI reduction was estimated	82%
Sonneville, K. R., et al. 2015 (US)[175]	Eliminating tax subsidy of TV AD to children (TV AD)	Behavioural, environmental, policy; diet, TV	Children (2 to 19 years old)	CBA, CUA; DAM (Multi-state model adapted from the	10 years; 3% (costs and benefits)	US dollars (2014)	QALY gained and net cost saved per $ spent	CE threshold not stated: the net reduction in cost (implementation and	100%

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	versus current practice	viewing, and tax (home-based)		ACE model); modified societal				health care costs) and the total QALY gained over 10 years were USD 343 million and 4,540, respectively. The net cost savings per dollar spent was estimated at USD 38	
Wright, D. R., et al. 2015 (US)[176]	ECE policy change versus current practice	Behavioural, environmental, policy; PA, diet, and TV viewing (multiple settings possible, including childcare setting)	Children (3 to 5 years old)	CEA; DAM (Multi-state model adapted from the ACE model); societal	10 years; 3% (costs and benefits)	US dollars (2014)	BMI units reduced and net cost saved per USD spent	The ICER for the SSB was estimated at USD 57.80 per BMI unit avoided over a two-year period, and a net healthcare cost savings of USD 51.6 was estimated for a 10-year time horizon	100%
Jago, R., et al. 2016 (UK)[306]	Bristol Girls Dance Programme versus control	Behavioural; PA - dance (school-based)	Girls (11 to 12 years old)	CEA, CUA; cluster RCT alongside an economic evaluation; public sector perspective (costs to local authorities and to the NHS)	1 year after baseline; NA	Pound sterling (2013/2014)	Change in MVPA and QALY gained (EQ-5D-Y)	CE threshold not stated: the study found no difference in MVPA and no QALY gained at 1 year between the intervention (costing GBP 73 per participant) and control	90%
Ladapo, J. A., et al. 2016 (US)[296]	Students for Nutrition and Exercise (SNaX) intervention (a 5-week middle-school-based obesity-prevention programme) versus control	Behavioural, environmental; diet - water consumption, signs and posters, school cafeteria (school-based)	Sixth to eighth grade students in middle-schools in Los Angeles (not stated)	CEA; RCT alongside an economic evaluation; institutional/school system	5 weeks (trial period); NA	US dollars (2014)	Number served: portions of fruits and vegetables, free/reduced-price lunches, full-priced lunches, all lunches served; snacks	The CE of the programme was valued at USD 1.20 per additional fruit portion served, USD 8.43 per additional full-priced lunch, USD 2.11 per additional reduced-price/free lunch and USD 1.69 per unit reduction in snacks sold	92%
Lawlor, D. A., et al. 2016 (UK)[307]	Active for Life Year 5 (AFLY5): an intervention designed to increase PA and improve diet amongst	Behavioural; diet and PA (school-based)	Children at year 5 during the intervention (9 to 10 years old)	CCA; cluster RCT alongside an economic evaluation; NHS and Personal Social Services	1 year follow-up; NA	Pound sterling (2012/2013)	Changes in levels of PA, sedentary behaviour, and fruit and vegetable consumption	Although the intervention only cost GBP 18/child, there was no improvement in levels of PA, sedentary behaviour and fruit and	89%

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	primary-school students versus control							vegetable consumption	
Sutherland, R., et al. 2016 (Australia)[321]	The Physical Activity 4 Everyone (PA4E1) multi-component intervention versus usual care	Behavioural; PA (school-based, low-income communities)	Children of mixed weight status groups in their first year of high school (mean age 12 years old)	CEA; RCT alongside an economic evaluation (efficacy trial); societal	2 years; not stated	Australian dollars (2014)	Mean minute of MVPA gained and MET minute gained, unit (10%) reduction in BMI z-score, BMI unit avoided	ICERs were AUD 56 per additional minute of MVPA/day, AUD 749 per MET hours gained per person/day, AUD 563 per 10% reduction in BMI z-score and AUD 1,408 per BMI unit avoided	93%
Cradock, A. L., et al. 2017 (US)[178]	Six recommended prevention strategies as follows: (Active PE; Active Recess; Active School Day; Healthy Afterschool; New Afterschool Programmes; and Hip Hop to Health, Jr.) versus the status quo	Behavioural, environmental, policy; PA in state-wide and national implementation (school, afterschool, and childcare settings)	Children regardless of BMI status (3 to 14 years old)	CEA; DAM (Individual level, discrete-time, microsimulation model); modified societal	10 years (2015 to 2025); 3% (cost)	US dollars (2014)	BMI unit reduction, cases of childhood obesity prevented, and health care cost savings	The ICER for New Afterschool Programme was dominant, while the ICERs for the remaining interventions ranged from USD 361 to USD 2,825 per BMI unit change per person	91%
Crino, M., et al. 2017 (Australia)[322]	Package size cap versus product reformulation to reduce kilojoule content of packaged SSBs	Policy; diet - SSBs (nation-wide)	Children (2 to 19 years old)	CUA; DAM (multi-state life table Markov model); limited societal	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	Change in BMI and HALY gained	Given a CE threshold of AUD 50,000 per HALY gained, both interventions were dominant. Package size cap and energy reduction would save 73,883 HALYs and 144,621 HALYs, yielding cost-offsets of 750.9m and 1.4bn AUD, respectively	96%
Ekwaru, J. P., et al. 2017 (Canada)[216]	APPLE[b] Schools (the intervention programme) versus general schools (no	Behavioural; diet, PA and lifestyle-based (school-based)	Grade five students of mixed weight status (~ 10 years old)	CEA, CUA; DAM (state transition model with yearly cycles and capturing 13 chronic	Lifetime; 3% (costs and benefits)	Canadian dollars (2008)	QALY gained, person year of excess weight prevented, and person year of	Given a CE threshold of CAD 50,000 per QALY gained, the probability of CE was 64% in the base	96%

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	intervention)			diseases); school system's cost perspective			obesity prevented	case scenario (the ICERs were CAD 33,421 per QALY gained, CAD 1,555 per person year of excess weight prevented, and CAD 1,709 per person year of obesity prevented)	
Graziose, M. M., et al. 2017 (US)[177]	Food, Health, & Choices (FHC), an obesity prevention NE curriculum delivered over 1 year versus current practice (no intervention)	Behavioural, policy; diet, PA, and screen time (school-based)	All New York City fifth-grade public school students (mean age 10 years old)	CUA; DAM (decision tree type, longitudinal, obesity progression model) based on a RCT; societal	Lifetime; 3% (costs and benefits)	US dollars (2012)	QALY saved	Given a CE threshold of USD 50,000 per QALY saved, the ICER was USD 275 per QALY saved	98%
Hajizadeh, N., et al. 2017 (US)[297]	ParentCorps (family-centred enhancement to pre-kindergarten programming) versus standard pre-kindergarten programming	Behavioural; group series (mental health) for families and professional development for teachers (school- and family-based)	Black and Latino children from pre-kindergarten entry through the end of kindergarten attending high-poverty, urban schools in the US (~ age 5 years old)	CUA; DAM (Markov Model projecting the long-term impact of cluster RCT) based on a RCT; societal	Lifetime; 5% (costs and benefits)	US dollars (2015)	Achievement test scores, change in rates of obesity and QALY gained	CE threshold not stated: ParentCorps was predicted to save USD 4387 per child with a QALY increase of 0.27	98%
Kesztyüs, D., et al. 2017 (Germany)[333]	"Join the Healthy Boat": a state-wide health promotion programme in primary schools versus control	Behavioural, policy; PA, beverages, TV viewing (school-based, state-wide)	Children (mean aged ~ 7 years old)	CEA; RCT alongside an economic evaluation; societal	1 year post intervention; NA	Euros (2010/2011)	Changes in WC and WHtR	Given a parental WTP for the intervention of EUR 123 per year, the intervention was cost-saving. The costs per incidental case of averted abdominal obesity varied between EUR 1,515 and EUR 1,993, with a cost per child and year of EUR 25	97%

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Lee, B. Y., et al. 2017 (US)[179]	Two hypothetical levels of PA: 25 minutes of high-calorie-burning PA three times a week and 60 minutes of MPA each day	Behavioural, policy; PA (school- and community-based)	The US population of children (6 to17 years old)	CCA; DAM (two-stage model: the first stage was an agent-based model; the second stage was a Markov model defined by 15 health states); health sector, societal	Lifetime; 3% (costs)	US dollars (2016)	Reduction in cases of obesity, QALY saved	Increasing the current level of children who get 25 minutes of high-calorie-burning PA from 31.9% to 75% was estimated to save a total of 18,913,447 QALYs and avert USD 16.6bn in direct medical costs and USD 23.6 bn in lost productivity	96%
Moore, J. B., et al. 2017 (US)[298]	Minigrant programme (2010-2011) to increase PA among youth versus waitlist control group (2011-2012)	Behavioural; targeted grant funding for the implementation of multilevel PA interventions (community setting)	Children in grades 4 to 8 (not stated)	CEA; a repeated, cross-sectional, group-RCT alongside an economic evaluation; not stated	1 year after baseline; NA	US dollars (2011)	Increase in MVPA (minutes per day)	The CE ratio (USD/MVPA minutes per day) ranged from USD 0.02 to USD 0.58 across both years of intervention	82%
Wang, H., et al. 2017 (US)[299]	Ready for Recess: a programme for increasing PA in elementary schools versus no intervention	Behavioural; PA - accelerometers (school-based)	Elementary school students in the US (not stated)	CEA; Non-randomised trial alongside an economic evaluation; institutional/school system	One year post intervention; NA	US dollars (2008)	Total MET-hours gained	Given a CE threshold of 35 cents per MET-hour gained, Ready for Recess cost 32 cents per MET-hour gained per student per school day	92%
An, R., et al. 2018 (US)[182]	Placing water dispensers at school cafeterias nationwide to promote lunchtime plain water consumption versus no action	Environmental, policy; drinking water (school-based)	All school children in primary, secondary, and high schools (not stated)	CBA; DAM (Markov model); societal	Lifetime; 3% (costs and benefits)	US dollars (2016)	Number of cases of excess weight prevented expressed in terms of per capita annual medical cost of adult excess weight	The net benefit of the intervention was USD 174 per student. A net benefit of USD 199 and USD 149 per student was estimated for boys and girls, respectively	100%
Anokye, N., et al. 2018 (UK)[308]	Stage 1 (introductory and less intensive sports sessions) versus stage 2	Behavioural; PA (community-based)	Inactive people over 14 years old	CUA; economic evaluation alongside a quasi-experiment (with an interrupted	Immediately after 6 weeks of intervention; NA	Pound sterling (2015/2016)	QALY gained	Given a CE threshold of GBP 30,000 per QALY gained, stage 2 had a 29% probability of being cost-	100%

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	(portfolio of community sport sessions)			time series design); programme provider				effective relative to stage 1	
Beets, M. W., et al. 2018 (US)[181]	Two ASPs: immediate or delayed	Behavioural; diet and PA (faith locations, schools, recreation, and community-based)	Children of mixed weight status (5 to 12 years old)	CCA; trial-based economic evaluation; programme provider	End of the 2-year trial; NA	US dollars (2015)	Changes in MVPA and changes in number of days fruits/ vegetables, water, desserts, and SSBs served	The ICERs for a 1% increase in the number of children accumulating 30 minutes or more of MVPA/day ranged from USD 0.05-0.23 (immediate) and USD 0.26-0.08 (delayed) for boys and girls, respectively	88%
Brown, V., et al. 2018 (Australia)[194]	Legislation to restrict TV AD of food and beverages HFSS until 9:30 pm versus baseline or usual viewing	Behavioural, policy; diet and legislation (population-wide, home-setting)	Australian children (5 to 15 years old)	CUA; DAM (state-transition cohort model using disease-specific life tables estimates of mortality and morbidity for nine obesity-related diseases); limited societal	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	Reductions in energy intake (mean KJ/day), reductions in BMI and HALY saved	Given a CE threshold of AUD 50,000 per HALY saved, the intervention was dominant	100%
Conesa, M., et al. 2018 (Spain)[215]	The intervention Educació en Alimentació Programme (EdAl): a set of educational intervention focused on improving lifestyle choices versus control (usual care)	Behavioural; diet and PA (school-based)	Children mixed weight status but about 70% being healthy weight in both arms (7 to 8 years old)	CEA; trial-based economic evaluation; institutional	End of the trial: 28 months (2.3 years); NA	Euros (2007)	Number of obesity cases avoided, decrease in obesity prevalence, decrease in BMI units, and decrease in BMI z-score units	For boys, the ICERs of EUR 968.66/case of obesity avoided, EUR 44.68/BMI one-unit decrease, EUR 3.56/1% obesity prevalence reduction and EUR 65.16/BMI z-score one-unit decrease were reported	95%
Reilly, K. L., et al. 2018 (Australia)[323]	Three multicomponent interventions (high, medium, and low intensity) to enhance	Behavioural, environmental and policy; diet-based (school-based)	Students in primary schools of mixed weight status (5 to 12 years old)	CEA; trial-based economic evaluation (3 separate trials); Health service delivery	End of trials (12 months); NA	Australian dollars (2015)	Percent point increase in the proportion of schools that adhered to the	The ICERs for the three interventions were AUD 2,982 (high intensity), AUD 2,627 (medium intensity) and AUD 4,730 (low	97%

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	implementation of a healthy canteen policy versus "usual support"						policy	intensity) per percent increase in the proportion of schools reporting "adherence" compared to "usual support"	
Wyatt, K., et al. 2018 (UK)[309]	Healthy Lifestyles Programme (HeLP): drama-based healthy lifestyles week, goal setting and reinforcement activities versus usual care	Behavioural; diet and PA (school-based)	Children in Southwest England (9 to 10 years old)	CEA; Cluster RCT alongside economic evaluation; NHS	24 months post baseline; 3.5% (costs and benefits)	Pound sterling (2015)	Change in BMI, WC, percent body fat or PA levels	Intervention cost of GBP 214 per child, but study found no significant difference between the intervention and control groups in change in BMI, WC, percent body fat or PA levels	95%
Amies-Cull, B., et al. 2019 (England)[203]	20% reduction in the sugar content of certain high sugar products versus no reduction	Policy; diet (population-wide)	The general population (cohorts of 4 to 10 years old and 11 to 18 years old)	CCA; DAM (state transition model adapted from the PRIMEtime-CE model, a cohort chronic disease multistate lifetable model); NHS	10 years in the base case; not stated	Pound sterling (not stated)	Calorie change and reduction in obesity	The study estimated a potential reduction in obesity among 4–10-year-olds by 5.5%, 11–18-year-olds by 2.2% for the intervention. A total net healthcare cost saving of GBP 285.8 million was estimated over 10 years	91%
Ananthapavan, J., et al. 2019 (Australia)[324]	Hypothetical community-based obesity prevention interventions (CBI) versus control	Behavioural, environmental and policy; diet, PA, change in school infrastructure and changes to the obesogenic environment within the community (community-based)	Australian children (5 to 18 years old)	CUA; DAM (multiple cohort state transition model comprising 9 diseases, each with four possible health states); limited societal	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	Change in BMI and HALY gained	Given a CE threshold of AUD 50,000 per HALY, the ICER for CBIs was AUD 8,155 per HALY gained	100%
Basto-Abreu, A., et	SSB excise tax	Policy; diet: SSB	The 2014 Mexican	CCA, CBA; DAM	10 years; 3%	Peso and US	SSB consumption,	The excise tax of 1 peso	100%

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al. 2019 (Mexico)[279]	scenarios compared (1 peso versus 2 pesos per litre)	consumption (population-wide)	population including children (not stated)	(cohort simulation model that adapted the CHOICES model); societal and public payer	(costs and benefits)	dollars (2014)	obesity cases prevented, DALY averted and QALY gained	per litre of SSB is estimated to prevent 94,300 cases of childhood obesity, versus 283,300 cases for MXN 2 per litre. The costs saved per dollar invested was USD 3.98 and USD 6.88 for MXN 1 and MXN 2 per litre tax, respectively	
Brown, V., et al. 2019 (Australia)[197]	Seven hypothetical scenarios of varying effect (reduction in BMI z-score): maintenance and subsequent decay to no effect	Behavioural, environmental and policy; multiple components including diet and PA (multi-setting)	Australian children (2 years old with modelling assumptions extending into adulthood)	CCA; DAM (multiple cohort life table model adapted from the CRE-Obesity Policy model); health service delivery	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	HALYs saved, life years saved and health care cost-savings	Given a CE threshold of AUD 50,000 per HALY saved, and assuming a reduction in BMI z-score of 0.13 in children aged 2 to 5 years, the scenario of lifetime effect maintenance resulted in 36,496 HALYs saved and health care cost-savings of AUD 301 million	100%
Canaway, A., et al. 2019 (UK)[204]	Intervention schools: a multifaceted, 12-month, school-based intervention versus control schools (usual care)	Behavioural; diet and PA (school-based)	Primary school children of mixed weight status (6 to 7 years old)	CUA; trial-based economic evaluation; public sector	30 months: intervention was delivered over a 12-month period and follow-up was 18 months post-intervention; 3.5% (costs and benefits)	Pound sterling (2014)	Difference in BMI z-scores and QALY gained (CHU-9D)	Given a CE threshold of GBP 20,000 – GBP 30,000 per QALY, the ICER associated with the intervention was GBP 26,815 per QALY gained	100%
Charles, J. M., et al. 2019 (UK)[310]	'Girls Active' programme versus usual practice	Behavioural; PA – accelerometer, guidance and review of PA and PE practices	Girls in UK secondary schools (11 to 14 years old)	CCA; economic evaluation alongside a cluster RCT; public sector, multi-agency perspective	14 months post-baseline; 3.5% (costs)	Pound sterling (2015/2016)	Mean minutes of MVPA per day, QALY gained (CHU-9D), and service use	'Girls Active' cost between GBP 2-7 per student, per school year. The study did not demonstrate any statistically significant	98%

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		(school-based)		(community care, GP and local authority, school)				differences between groups for any of the measures of consequences	
Coffield, E., et al. 2019 (US)[300]	Shape Up Somerville: Eat Smart Play Hard (SUS) intervention designed to increase PA options and availability of healthful foods compared with control areas	Behavioural, environmental; diet and PA (community-based)	Elementary school students in the US (mean age 8 years old)	CBA/return on investment; DAM (two-part regression model) based on a non-randomised controlled trial; limited societal	2-year intervention, 10-year time horizon for model; 3% (costs and benefits)	US dollars (2014)	Healthcare costs, productivity losses averted	The study estimates that SUS saved USD 1.51 for every USD 1.00 invested in the programme, giving a net benefit of USD 197,120 over 10 years	95%
Gammon, C., et al. 2019 (UK)[311]	Physically active lesson (PAL) training programme delivered to teachers in after-school sessions versus control schools	Behavioural; PA (school-based)	UK secondary school year 7 and 9 students (mean age 12.9 years old)	CCA; economic evaluation alongside a feasibility study and pilot cluster-RCT; not stated	8 weeks post training; NA	Pound sterling (not stated)	Change in sedentary time and PA, self-reported well-being, and mental health, QALY gained (CHU-9D)	Training delivery cost GBP 910. Evidence of preliminary effectiveness was not demonstrated in feasibility and pilot studies	75%
Harrington, D., et al. 2019 (UK)[312]	'Girls Active' teacher-led school-based intervention versus usual practice	Behavioural; PA – teacher-led PE, teacher training and peer leadership (school-based)	Girls (11 to 14 years old)	CCA; economic evaluation alongside a cluster-RCT; public sector perspective (costs to local authorities and the NHS)	14 months after the start of the intervention; 3.5% (costs)	Pound sterling (2015/2016)	Change in MVPA	'Girls Active' demonstrated no significant effect. The slight increase in MVPA at 7 months did not persist to 14months. Intervention costs ranged from GBP 23 to GBP 95/student	90%
Kenney, E. L., et al. 2019 (US)[184]	Installing water jet dispensers versus three other water consumption strategies: (1) Grab a Cup, Fill it Up; (2) portable tap water dispensers; and (3) install bottle-less	Environmental, policy; change in school drinking water environment (school-based)	Students in kindergarten through eighth grade (not stated)	CBA, CEA; DAM (the CHOICES model: a stochastic, discrete-time, individual-level microsimulation model); modified societal	10 years; 3% (costs)	US dollars (2015)	Case of childhood obesity prevented, BMI unit reduced and health care cost savings per dollar invested	For the water jets school-based intervention, the health care cost savings per dollar invested was USD 0.31 and the cost per BMI avoided was USD 105.29	95%

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	water coolers								
Li, B., et al. 2019 (China)[278]	Chinese Primary School Children Physical Activity and Dietary Behaviour Changes Intervention (CHIRPY DRAGON) versus control	Behavioural; diet and PA (school- and family-based)	Primary school children in China (mean age ~6 years old)	CEA, CUA; economic evaluation alongside a RCT; public sector	1 year; NA	Pound sterling (2016/2017)	Change in BMI, QALY gained (CHU-9D)	Given a CE threshold of GBP 20,000 to 30,000 per QALY gained, the probability of the intervention being cost-effective was at least 95% with an ICER of GBP 1,700 per QALY gained	95%
Long, M. W., et al. 2019 (US)[301]	SSB excise tax and Supplemental Nutrition Assistance Programme (SNAP) SSB restriction versus usual practice	Policy; SSB consumption (population-wide)	Entire population of Maine including children	CUA; DAM (the CHOICES model: A stochastic, discrete-time, individual-level microsimulation model); state-level stakeholder perspective	10 years; 3% (costs and benefits)	US dollars (2015)	BMI reduction, cases of obesity prevented (reported for children and entire population) and QALY gained	CE threshold not stated: ten-year (2017-2027) CE estimates for SSB excise tax and SNAP SSB Restriction, respectively: net costs (USD million) -74.0 and -10.9; and QALYs gained 3,560 and 749	93%
Sebire, S. J., et al. 2019 (UK)[313]	PLAN-A intervention: a peer led PA programme versus control	Behavioural; PA (school-based)	Year 8 girls at English secondary schools (12 to 13 years old)	CEA; economic evaluation alongside cluster randomised control feasibility study; public sector perspective (to be funded by local government or academy schools)	1 year after participant selection; NA	Pound sterling (2016)	Increase in MVPA and QALY gained (EQ-5D-Y)	The study estimated a 6.1 minute between-arms difference in weekday MVPA at follow-up in favour of the intervention arm, with an intervention cost of cost GBP 37 per girl. No significant changes in QALYs were observed in both groups	95%
Vieira, M. & Carvalho, G.S. 2019 (Portugal)[219]	The 'Planning Health in School' programme (PHS-pro), a learning module promoting healthy choices versus a non-randomised control group	Behavioural; water intake, TV viewing time, diet, and PA (school-based)	Children of varying weight status (10 to 14 years old)	CCA; economic evaluation alongside a non-randomised controlled trial; societal	10 months from baseline; NA	Euros (2012)	The per capita net cost of implementing the PHS-pro intervention in children versus cost of treating a case of adult obesity	The per capita net cost of implementing the intervention was EUR 36.14/child/year compared to direct costs estimated for treating one adult with obesity in Portugal (EUR 3849.15/year)	83%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Ananthapavan, J., et al. 2020 (Australia)[325]	12 childhood interventions: (1) alcohol price increase; (2) community-based interventions to promote (3) healthy eating and PA; (4) menu kilojoule labelling on fast food; (5) package size cap on SSBs; (6) reformulation in response to the Health Star Rating (HSR) system; (7) reformulation to reduce sugar in SSBs; (8) restricting TV AD of unhealthy foods; (9) restrictions on price promotions of SSBs; (10) school-based intervention to reduce sedentary behaviour; (11) school-based intervention to increase PA; and (12) 20% sales tax on SSBs tax; supermarket shelf tags on healthier products versus "no intervention"	Behavioural, environmental, policy; PA, active play equipment, legislation on alcohol, SSB package size cap, TV AD of unhealthy food, SSB promotion, fast food labelling, voluntary healthy food tagging (school-based, community-based, population-wide)	Children with varying weight classifications, depending on the intervention (2 to 18 years old)	CUA; DAM (The ACE-Obesity Policy model - a proportional, multi-state life table Markov cohort model); limited societal	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	HALYs gained	Given a CE threshold of AUD 50,000 per HALY gained, the study found that all childhood interventions were either dominant or had a ICER ranging from AUD 1,728 to AUD 8,155	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Breheny, K., et al. 2020 (UK)[314]	The Daily Mile: running or walking around school grounds for 15-min daily versus only the usual school health and wellbeing activities	Behavioural, policy; PA (school-based)	Children in all state-funded primary and junior schools (4 to 11 years old)	CUA; within trial cost-utility analysis; public sector	1 year; NA	Pound sterling (2017)	QALY gained (CHU-9D)	Given a CE threshold of GBP 20,000 per QALY gained, the ICER for the intervention had a 76% probability of CE in the whole sample (GBP 7,445 per QALY gained) and an ICER of GBP 2,492 per QALY gained in girls, but was not cost-effective in boys	100%
Clemes, S. A., et al. 2020 (UK)[315]	Replacing normal desks with sit-stand desks in classrooms for 4.5 months versus usual practice	Behavioural; PA (school-based)	Children in Bradford primary schools (9 to 10 years old)	CCA, CUA; economic evaluation alongside a pilot cluster RCT and DAM: extrapolation with Markov-type model (the MOVES model); health system and Personal Social Services	4 month and 30-year time horizons; 3.5% (costs and benefits)	Pound sterling (2016)	Mean METs/day, change in weekday sitting time and QALY gained (EQ-5D-Y)	Given a CE threshold of GBP 30,000 per QALY gained, the study estimated an incremental CE ratio of GBP 78,986 per QALY gained for the intervention over a 30-year time horizon	95%
Ferguson, M. C., et al. 2020 (US)[302]	The original Fierce & Fit programme versus scenarios that varied the length of the programme, frequency of meetings and amount of PA per meeting	Behavioural; PA (community-based)	Girl Scouts from kindergarten through eighth grade in Maryland (5 to 14 years old)	CBA, CCA; DAM (individual-level simulation model linked to a fifteen-health state Markov model); societal	Lifetime; 3% (costs and benefits)	US dollars (2016)	Average change in BMI percentile, reduction in cases of overweight and obesity and QALY gained	Changing the Fierce & Fit programme to a 12-week programme, with two meetings per week and 30 minutes of PA per session saved a further USD 84,828 in lifetime medical costs, USD 81,365 in lifetime productivity losses and 7.85 QALYs, giving a cost-benefit of USD 95,943	89%
Finster, M.P. & Feldman, J. 2020 (US)[55]	Onsite versus online support to implement a school-based	Behavioural, environmental; diet and PA, web-	Students in low SES neighbourhoods	CEA; economic evaluation alongside a RCT (Healthy	4 years; not stated	US dollars (not stated)	Average percent point increase in overall wellness	The cost per average percent point increase in overall wellness score was	76%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	wellness programme	based (e-health) (school-based)	(age and weight status not specified)	Schools Randomised Trial); not stated			(School Health Index) score	USD 336 and USD 256 for the onsite and online interventions, respectively	
Huse, O., et al. 2020 (Australia)[198]	National mandatory restriction on all price promotions for SSBs available for purchase for take-home consumption in Australia versus no policy	Policy; diet (population-wide)	The 2010 Australian population (2 to 100 years old)	CUA; DAM (multi-state life table Markov model); limited societal	Lifetime; 3% (costs and benefits)	Australian dollars (2010)	HALY gained	With a total HALYs gained estimated at 34,260 and the intervention cost an estimated AUD 17.0M, the policy was said to be dominant (cost-saving and health promoting)	100%
Mytton, O. T., et al. 2020 (UK)[316]	Restriction of TV AD of food and beverages HFSS between 5.30am and 9pm (scenario A: withdrawn; scenario B: displaced to 9pm to 5.30am) versus no intervention	Policy; diet (population-wide, home-based)	Children in the UK (5 to 17 years old)	CUA; DAM (the PRIMEtime model: multi-state life table model); health sector, societal	Lifetime; 1.5% for first 30 years, 1.3% for the next 45 years, and 1.1% thereafter (benefits)	Pound sterling (2015)	Change in % of children with obesity; DALY averted	CE threshold not stated: if HFSS was either withdrawn or displaced, the number of DALYs avoided would be 120,000 and 35,000, respectively, while the health-related net monetary benefits (millions) would be GBP 7,400 and GBP 2,200, respectively	91%
Oosterhoff, M., et al. 2020 (Netherlands)[208]	Two health promotion interventions in school environment: HPSF and Physical Activity School versus normal practice	Behavioural; diet and PA (school-based)	Primary school children (4 to 12 years old)	CUA; DAM based on a quasi-experimental study; healthcare and societal	Lifetime; 4% and 1.5% (costs and benefits, respectively)	Euros (2018)	QALY gained (meta-analysis)	Given a CE threshold of EUR 20,000 per QALY gained, PAS was dominated and HPSF was the most cost-effective with an ICER of EUR 19,734 per QALY gained	100%
Oosterhoff, M., et al. 2020 (Netherlands)[328]	Two health promotion interventions in school environment: HPSF and Physical Activity School versus	Behavioural; diet and PA (school-based)	Primary school children (4 to 12 years old)	CBA/social return on investment; economic evaluation alongside a quasi-experimental study; societal	2 years; 2.5% (costs and benefits)	Euros (2016)	Outcomes expressed in monetary terms (combined across several sectors including healthcare and education)	Per child, investments of EUR 859 and EUR 1,017 generated benefits of EUR 8 and EUR 49 for HPSF and PAS, respectively	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	normal practice								
Xu, H., et al. 2020 (China)[164]	Three interventions: (1) NE, (2) PA, and (3) comprehensive (included the NE and PA interventions)	Behavioural; diet and PA (school-based)	Parents, teachers, and health workers also received some of the interventions (age and weight status not clearly stated but a baseline age of 10 years was implied)	CUA, CBA; DAM (an obesity progression model) based on a trial; societal	55 years (ages 10 to 65 years); 3% (costs and benefits)	Renminbi and US dollars (2019)	QALY gained, cases of obesity prevented, and costs averted	Given a CE threshold of USD 5,000 per QALY gained, the ICERs were CNY 10,335.2 (USD 1,478.6) and CNY 4626.3 (USD 661.8) per QALY gain for CNP and NE respectively, compared with PA intervention. Estimates of monetary benefits were CNY 1.2, CNY 0.7, and CNY 0.4 per CNY 1 cost for CNP, NE, and PA interventions, respectively	89%
Corder, K. L., et al. 2021 (UK)[317]	GoActive: a school-based, peer-led 12-week programme versus control	Behavioural; PA (school-based)	Children in non-fee-paying schools (13 to 14 years old)	CEA; DAM (exploratory economic modelling using the physical activity CE (PACE) model), based on a cluster RCT; health sector, public sector (cost to local authorities)	10 months post-intervention and 10 years; 3.5% (benefits)	Pound sterling (2019)	Change in minutes of MVPA and QALY gained (CHU-9D)	At 10 months, there was a mean decrease of 8.3 minutes of MVPA in the control group, compared with 10.4 minutes in the intervention. The intervention cost GBP 13 per student. However, lower QALY gains were estimated for the intervention compared to control. Conclusions were similar in explanatory modelling (CE threshold GBP 20,000)	96%
Jago, R., et al. 2021 (UK)[318]	PLAN-A intervention: a peer led PA programme versus control	Behavioural; PA (school-based)	Girls in secondary schools (13 to 14 years old)	CEA, CUA; cluster randomised controlled trial alongside an economic evaluation;	12 months of intervention; NA	Pound sterling (2019)	Change in MVPA (minutes per day) and QALY gained (CHU-9D and EQ-5D-Y visual analogue	Given a CE threshold range of GBP 0-100 per minutes of MVPA per day, the probability of CE remained below 20%. There was no	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
				public sector			scale (VAS))	strong evidence of between-arm difference for MVPA and QALY. The intervention cost GBP 31/ person	
Kenney, E. L., et al. 2021 (US)[303]	Five hypothetical policies: (1) eliminating TV AD tax subsidy; (2) policy to reduce TV time in licensed childcare settings; (3) Fit5Kids childcare curriculum to reduce TV time at home; (4) motivational interviewing to reduce TV time during Women, Infants, and Children (WIC) clinic visits; and (5) home visits to reduce TV viewing	Behavioural, policy; TV viewing (multiple settings - home, childcare and clinic-based)	Children of different age groups (2 to 19 years old)	CCA; DAM (the CHOICES microsimulation model); societal	10 years (model projection 2020 to 2030); 3% (costs)	US dollars (2019)	Cases of childhood obesity prevented	Making food AD no longer tax-deductible would reach the most children (106 million) and prevent the most cases of obesity (78,700 cases), with net health care cost savings	100%
Lonsdale, C., et al. 2021 (Australia)[326]	Nine-to-ten-month intervention: Internet-Based Professional Learning to Help Teachers Promote Activity in Youth (iPLAY) to increase school-based PA compared versus control	Behavioural; PA: 20-meter shuttle laps, web-based (e-health) (school-based)	Children in grades 3 and 4 in New South Wales, Australia (mean age 8.85 years old)	CEA; cluster randomised controlled trial alongside an economic evaluation; school system	24 months after intervention allocation; not stated	Australian dollars (2018)	Multistage 20-meter shuttle run to assess cardiorespiratory fitness: incremental laps	At 12 months and 24 months respectively, the ICER was AUD 27 and AUD 15 for each additional lap achieved	83%
Reeves, P., et al. 2021 (Australia)[327]	Web-based menu planning intervention	Behavioural; diet, web-based menu	Children in childcare services	CCA, CEA; economic evaluation conducted	12 months after randomisation;	Australian dollars	Compliance of menus with dietary	The intervention cost AUD 482 more than usual care.	97%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	for childcare service food delivery versus usual care	planning (e-health) (childcare centre-based)	in New South Wales (3 to 6 years old)	alongside a trial; health sector and societal	NA	(2017/2018)	guidelines, mean servings of each food group	Although menu and food group compliance did not improve, there were significant improvements in servings of fruit and discretionary food. CEA suggested a favourable incremental cost per unit increase in compliance score with the web-based intervention	
van Schayck, C., et al. 2021 (Netherlands)[329]	School lifestyle interventions (HPSF): combination of increased PA and healthy nutrition, increased PA alone and the control group	Behavioural; diet and PA (school-based)	Children in elementary schools (4 to 12 years old)	CCA; economic evaluation conducted alongside a quasi-experimental study (prospective controlled non-randomised study); societal	4 years post baseline; not stated	Euros (not stated)	Change in BMI z-score	Increased PA and healthy nutrition resulted in a decreased BMI z-score (-0.04); increased PA alone resulted in a decreased BMI z-score (-0.01); BMI z-score increased in control group (0.05). The net societal cost for increased PA and healthy nutrition was EUR 1/child/day	63%
Auerbach, J. D., Fitzhugh, E. C., & Zavisca, E. 2021 (US)[338]	Increased thoroughfare connectivity and walkability around schools versus the status quo (usual school busing)	Environmental; PA - walking to school - (school- and community-based)	Elementary and secondary school pupils	CBA, CCA; DAM (data engineering of spatial data to find optimal thoroughfares); school system	10 years; not stated	US dollars (2017)	Additional walking time gained (MVPA)	CE threshold not stated: on average, additional thoroughfare connections would provide elementary and middle school students with an additional 37 minutes of MVPA and 54 minutes of MVPA, respectively. Compared with busing, sidewalks saved USD 427 and USD 109,129 for elementary and middle schools,	66%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								respectively, over 10 years	
Brown, A., et al. 2021 (Australia)[339]	Multi-component m-health to improve quality of school lunchboxes versus control (waitlist/data collection only)	Behavioural; App-based mobile health technology (m-health) support messages to parents, information pack, education, diet (family-, school-based)	Parents and their children (5 to 12 years old)	CEA; trial-based economic evaluation; societal	10 weeks; NA	Australian dollars (2019)	Reduction in dietary energy (Kilojoules)	Given a CE threshold of AUD 40 per person per unit reduction in lunchbox energy, the probability of CE was 99%. The ICERs per reduction in total kilojoules and discretionary kilojoules from the lunchbox were AUD 0.54 and AUD 0.24	100%
Ekwaru, J. P., et al. 2021 (Canada)[340]	Comparison of three interventions: (1) Comprehensive School Health (CSH) approach; (2) multicomponent intervention prioritised by the key stakeholders; and (3) PE curriculum modifications	Behavioural, environmental; diet and PA (school-based)	Children in Canadian schools (4 to 18 years old)	CUA; DAM (Microsimulation model); healthcare system	Lifetime; 1.5% (costs)	Canadian dollars (2016)	QALY gained	ICER calculations were insufficiently reported, but a CE threshold of CAD 50,000 per QALY gained was stated. The incremental intervention effects and total costs were given as follows: CSH (0.014 QALY gained and CAD 682); Multicomponent (0.009 QALY gained and CAD 444); and PE curriculum modifications (0.008 QALY gained and CAD 416)	100%
Kuvaja-Köllner, V., et al. 2021 (Finland)[341]	PA counselling sessions and after-school exercise clubs versus control (verbal and written advice)	Behavioural; PA (group-based PA counselling with parents and after-school clubs) (family-, school-based)	Primary school children (6 to 9 years old) and their parents	CEA; trial-based economic evaluation; payer (extended service payer's perspective)	2 years; 3% (costs and benefits)	Euros (2014)	Increase in PA (hours)	Given a CE threshold range of EUR 14-19 per 1-hour increase in PA, the intervention had a 95 % probability of CE: costs per increased PA hour were EUR 6.21 without and EUR 8.62 with parents' time use, respectively	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Sutherland, R., et al. 2021 (Australia)[342]	The Physical Activity 4 Everyone (PA4E1) multi-component intervention versus usual care	Behavioural; PA (school-based, low-income communities)	Children in disadvantaged secondary schools of mixed weight status groups in their first year of high school	CEA; RCT alongside an economic evaluation (implementation trial); public sector (public finance)	24 months; not stated	Australian dollars (not stated)	Percent change in the proportion of schools implementing at least four of the seven school PA practices	CE threshold not stated: the ICER was estimated to be AUD 25,944 per percent increase in the proportion of schools implementing at least four of the seven PA practices	88%
Zanganeh, M., et al. 2021 (China)[280]	Chinese Primary School Children Physical Activity and Dietary Behaviour Changes Intervention (CHIRPY DRAGON) versus control	Behavioural; diet (school lunch) and PA (school- and family-based)	Primary school children in China (6 to 7 years old) and their parents and grandparents	CEA, CUA; trial-based economic evaluation; public sector and societal	1 year; NA	Chinese Yuan (Pound sterling/U.S. dollars) (2016/2017)	Change in BMI z-score, QALY gained (CHU-9D)	Given a CE threshold of GBP 20,000 per QALY gained, the probability of the intervention being cost-effective was at least 96% with an ICER of 8,888 Yuan (GBP 1,760/USD 2,502) per QALY gained (public sector perspective). Per BMI z-score change, the ICER was Yuan 273 (GBP 54/USD 77)	100%
Cobiac, L. J., Law, C., & Scarborough, P. 2022 (UK)[343]	Three interventions compared: (1) a SSB tax (whole population); (2) a ban on TV advertising of unhealthy foods (children aged 5-17); and (3) a weight loss program (adults)	Behavioural and policy; diet - SSB tax, ban on TV advertising (population-wide)	The general population (infant cohort and children 5 to 17 years old)	CCA, CUA; DAM (state transition model adapted from the PRIMEtime-CE model, a cohort chronic disease multistate lifetable model that applied the Population Attributable Fraction (PAF) for targeted diseases); health sector	Lifetime; 3.5% costs and 1.5% benefits (0-30 years) 3% costs and 1.29% benefits (31-75 years) and 2.5% costs and 1.07% benefits (76-125 years)	Pound sterling (2015)	Obesity prevalence and QALY gained	Given a CE threshold of GBP 60,000 per QALY gained, the interventions had positive net monetary benefits, both in combination (GBP 31,400) and individually (SSB tax: GBP 12,100 and TV AD bans: GBP 18,300)	91%
Derwig, M., et al. 2022 (Sweden)[344]	Child-centred health dialogue in Child Health Services (CHC)	Behavioural; 10-minute healthy lifestyle, diet, and	Mixed group of children with healthy weight	CEA; trial-based economic evaluation; societal	12-month follow-up; NA	Euros (2017)	Change in BMI z-score	CE threshold not stated: ICER was EUR 183 per 0.1 z-BMI unit prevented. In	95%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	versus usual care including health visits	PA (to all), targeted overweight children - weight stabilisation intervention (home and clinical setting)	and overweight (4 years old) and their caregivers					subgroup analysis, change in BMI z-score varied by gender and socioeconomic index	
Lane, C., et al. 2022 (Australia)[345]	A multi-component Physically Active Children in Education (PACE) versus wait list control	Behavioural, environmental, policy; PA - support for leadership, school-policy development, in-school champions, in-person contact, online sessions, email, and telephone contact (school-based)	Primary school age children in New South Wales	CCA, CEA; trial- based economic evaluation; health service	12 months; NA	Australian dollars (2018)	Additional minute of PA implemented by classroom teachers	CE threshold not stated: the ICER was AUD 29 for an additional minute of weekly PA implemented per school	100%
Lane, C., et al. 2022 (Australia)[56]	Adapted Physically Active Children in Education (Adapted PACE) to reduce in-person contact versus the original PACE intervention	Behavioural, environmental, policy; PA - support for leadership, school-policy development, in-school champions, in-person contact, additional email, telephone, and online contact (e-health) with Adapted PACE	Children across Australia (5 to 14 years old)	CMA; trial-based economic evaluation (non-inferiority cluster randomised controlled trial); health service	12-month follow-up; NA	Australian dollars (2019)	Likelihood of non-inferiority (additional minute of weekly PA), cost savings per school	The study estimated a 96% probability of Adapted PACE being non-inferior to PACE. Relative to PACE, Adapted PACE was associated with cost-savings of USD 373 per school	95%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
		(school-based)							
Mahashabde, R., et al. 2022 (US)[346]	WISE (Together, We Inspire Smart Eating) versus usual nutrition education (UNE)	Behavioural; diet - nutrition promotion (family- and school-based)	Children (3 to 5 years old) and their parents	CEA; economic evaluation based on a quasi-experimental, non-randomised study; societal	Not stated; not stated	US dollars (not stated)	Intake of WISE-specific vegetables/fruits captured using an adapted Food Frequency Questionnaire (FFQ), decrease in BMI percentile	CE threshold not stated: the incremental costs for 1 unit reduction in BMI percentile and 1-unit FFQ increase were USD 0.23 and USD 0.41, respectively	55%
Alcaraz, A., et al. 2023 (Argentina, Brazil, El Salvador, and Trinidad and Tobago)[281,381]	Current SSB consumption prevalence versus counterfactual scenario of no SSB consumption	Policy; diet - availability and consumption of SSB or clean drinking water, taxes, and AD regulation (multiple settings possible)	Investigated all age groups: costs and outcomes in children (0 to 18 years old) were reported	CEA (CUA in adults only); DAM (simulation model used to determine the Population Attributable Fraction (PAF) for targeted diseases and health economic impact of SSB consumption); healthcare system	1 year; NA	US dollars (2020)	Cases of obesity and overweight	In 2020, 1.5 million cases of overweight and obesity in children (under 18 years of age) were attributable to SSB consumption, and USD 18 million was expended in 1 year on direct medical costs to treat overweight and obesity attributable to SSB consumption in children	86%
Jackson-Morris, A., & Meyer, C. L. 2023 (Mexico, China, Peru)[282]	Country-specific priority interventions (insufficient information) versus the status quo scenario	Multiple categories; fiscal policies, social marketing, breastfeeding promotion, school-based policies, and nutritional counselling (multiple settings possible)	National cohorts of children in Mexico, China, and Peru (0 to 19 years old)	CEA/return on investment; DAM (insufficient information); societal	2025-2090 in Mexico 2025-2092 in China and Peru; not stated	US dollars (not stated)	Years of life lost, reduction in lifetime costs	Years of life lost not reported. Implementing country-specific interventions was estimated to reduce lifetime costs by USD 124 billion (Mexico), USD 14 billion (Peru), and USD 2 trillion (China)	52%
Mahdi, S., et al.2023 (UK)[347]	Exposure to app (Change4Life Food scanner) versus no	Behavioural; diet - nutrition promotion (family-	Parents of children (4-11 years old)	CCA; pilot and feasibility trial alongside an	3 months; NA	Pound sterling (2019/2020)	QALY gained (CHU-9D)	Mean reduction reductions between groups were reported for in QALYs (-	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	intervention	based)		economic evaluation; societal, healthcare system				0.004); healthcare costs (GBP -30.77) and workplace productivity losses (GBP -64.24)	

ACE: the assessing cost-effectiveness in obesity study; AD: advertisement/advertising; APPLE: A Pilot Programme for Lifestyle and Exercise; APPLE: Alberta Project Promoting active Living and healthy Eating; ASP: after-school programme; BAEW: Be Active Eat Well; BMI: body mass index; CATCH: Coordinated Approach to Child Health; CATCH: The Child and Adolescent Trial for Cardiovascular Health; CBA: cost-benefit analysis; CCA: cost-consequences analysis; CE: cost-effectiveness; CEA: cost-effectiveness analysis; CHOICES: Childhood Obesity Intervention Cost Effectiveness Study; CHU-9D: Child Health Utility 9Dimension; CUA: cost-utility analysis; DALY: disability-adjusted life year; DAM: decision analytic model; ECE: early care and education ; GP: General practitioner; HALY: Health-adjusted life years; HFSS: high in fat, sugar and salt; HPSF: Healthy Primary School of the Future; HUI: Health Utilities Index; ICER: incremental cost-effectiveness ratio; LMIC: lower middle-income country; MET: metabolic equivalent; MPA: moderate physical activity; MVPA: moderate to vigorous physical activity; NA: not applicable; NE: nutrition education; NHANES: National Health and Nutrition Examination Survey; NHS: National Health Service; PA: physical activity; PA4E1: Physical Activity 4 Everyone; PE: physical education; PLAN-A: school-based peer-led PA intervention; QALY: quality adjusted life year; RCT: randomised controlled trial; SES: socioeconomic status; SPARK: The Sports, Play, and Active Recreation for Kids trial; SSB: sugar-sweetened beverage; TV: television; WC: waist circumference; WHtR: waist-to-height ratio; WTP: willingness to pay.

3.3.5 Study characteristics: treatment-only interventions

Intervention components and target population

Of the 38 treatment-only interventions, 28 (74%) were behavioural interventions with components focused on diet and physical activity.[71,165,170,172,180,185,186,201,206,211,220,348,349,351-354,358,360-369] One intervention included the use of a mobile health technology (m-health) component to target addictive eating behaviour.[183] Five were bariatric surgery interventions.[155,156,350,355,356] Five interventions involved components across multiple categories[183,217,221,357,359], and one was a hypothetical intervention with no stated components.[84] Another study was based on a hypothetical e-health intervention.[365] Interventions were mostly compared to usual care or "do nothing".

Most non-surgical interventions targeted pre-teen and early teen years (approximately 6 to 13 years). Except for one bariatric surgery intervention delivered to children as young as 13 years[355], the minimum age for children who received surgical interventions was 15.

Key cost-effectiveness results

Only five (13%) of the treatment-only interventions evaluated were described as unlikely to be cost-effective by the authors, all of which were based primarily on behavioural components, namely: home-based general practitioner (GP) consultations[186]; primary care surveillance followed by structured secondary prevention[349]; a 10-week family-based behavioural intervention[201]; a community-delivered multicomponent intervention[360]; and a family-based weight management programme in the UK that involved motivational interviewing.[362] A US-based study found that a motivational interviewing intervention with telephone and in-person visits from paediatricians, nurse practitioners and registered dietitians had a 50% probability of being cost-effective given a cost-effectiveness threshold of approximately USD 400 per BMI percentile point decrease. This probability rose to about 90% at USD 1,500 per BMI percentile point decrease.[363]

Duration of follow-up and model time horizon drove cost-effectiveness results. For instance, an intervention that involved GP consultations at home was not cost-effective after the trial follow-up

of 15 months[186] but proved to be cost-effective when modelled over a lifetime.[185] Similarly, two studies found that bariatric surgery was not cost-effective using a three-year horizon, but became cost-effective beyond a ten-year time horizon.[155,356] Other studies based on a lifetime horizon found bariatric surgery cost-effective.[156,350,355] Two studies investigated cost-effectiveness for types of surgical procedures compared to no surgery: one study assessed laparoscopic adjustable gastric banding (LAGB) and laparoscopic Roux-en-Y gastric bypass (RYGB)[355], while another assessed RYGB and laparoscopic Sleeve Gastrectomy (SG).[156] Both studies estimated higher ICERs for RYGB. Cost-effectiveness results for treatment-only interventions are detailed in Table 10.

Table 10 Descriptive analysis of the key assessment items for individual studies targeting only treatment

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
Goldfield, G., et al. 2001 (US)[165]	Mixed group treatment (group and individualized) versus group treatment only	Behavioural; diet, PA, and self-monitoring (family-based)	Children with obesity and their families (8 to 12 years old)	CCA; within-trial economic evaluation; not stated	1 year; NA	US dollars (not stated)	Change in BMI z-score or change in percent overweight	Both groups showed similarity in weight control results, but group treatment was less expensive (USD 1,390 versus USD 491)	79%
Raynor, H. A., et al. 2002 (US)[348]	20-week intervention: group and individual versus group sessions	Behavioural; diet (family-based)	Children with obesity and their families (8 to 12 years old)	CCA; within-trial economic evaluation; not stated	12 months after baseline; NA	US dollars (not stated)	Change in BMI, change in energy intake and serving intake	The study found significant decreases in percent of overweight for children and parents in both groups but no significant difference in effects or cost per 1,000 kcal was observed between the two groups	71%
Moodie, M., et al. 2008 (Australia)[185]	The LEAP trial: involved GP consultations at home versus "no intervention"	Behavioural; diet, PA, and GP consultations (family-based and GP-mediated)	Children with overweight and moderate obesity (5 to 9 years old)	CUA; DAM (Markov model adapted from the ACE model) modelled on a RCT; societal	Lifetime (9-month follow-up of LEAP trial); 3% (costs and benefits)	Australian dollars (2001)	DALY saved	Given a CE threshold of AUD 50,000 per DALY saved, the probability of CE was 79.8% (net cost per DALY saved of AUD 4,670)	96%
Wake, M., et al. 2008 (Australia)[186]	The LEAP trial: involved GP consultations at home versus "no intervention"	Behavioural; diet, PA, and GP consultations (family-based and GP-mediated)	Children with overweight and moderate obesity (5 to 9 years old)	CCA; within-trial economic evaluation; societal	15 months after randomisation; NA	Australian dollars (2003)	Children's change in BMI, PA, and dietary habits	The intervention incurred higher costs but improvements in BMI and PA did not differ between groups at 15 months follow-up. Dietary habits improved in the intervention arm	92%
Janicke, D. M., et al. 2009 (US)[170]	Parent-only intervention versus family-based intervention	Behavioural; diet and PA (rural community setting, family-based)	Children with overweight or obesity and their parents (8 to 14 years old)	CEA; within-trial economic evaluation; service provider	10-month follow-up after randomisation; NA	US dollars (not stated)	BMI unit reduction	Change in weight status between groups not significantly different but parent-only intervention	79%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								was USD 521 compared to USD 872 for family intervention	
Kalavainen, M., et al. 2009 (Finland)[220]	Family-based group treatment (15 separate sessions for parents and children) versus routine counselling (two appointments for children)	Behavioural; diet and PA (primary health care)	Children with obesity (7 to 9 years old)	CEA; within-trial economic evaluation; service provider	12 months post baseline; NA	Euros (2004)	reduction in BMI z-score	The study estimated an additional cost of EUR 266 for a 0.1 reduction in BMI z-score for the family-based group compared with routine counselling	97%
Wake, M., et al. 2009 (Australia)[349]	LEAP2: primary care screening followed by consultations (brief counselling), alongside family materials versus control	Behavioural; diet, PA, and primary care screening followed by brief counselling (clinic-based)	Children with overweight or mild obesity (5 to 10 years old)	CCA; within-trial economic evaluation; health sector	12 months after randomisation; NA	Australian dollars (2007)	Change in BMI, PA in counts/minute, nutrition score	The intervention failed to significantly improve BMI, PA, or nutrition, despite being more expensive (AUD 1,317 per child versus AUD 81 per child for control)	97%
Ananthapavan, J., et al. 2010 (Australia)[350]	Laparoscopic adjustable gastric banding versus no surgery	Surgical; bariatric surgery (clinic-based)	Adolescents with severe obesity (15 to 19 years old)	CUA; DAM (cohort multi-state transition model: the ACE-Obesity study) based on a case series of 28 adolescents; societal	Lifetime; 3% (costs and benefits)	Australian dollars (2001)	Change in BMI, DALY saved	Given a CE threshold of AUD 50,000 per DALY saved, a net cost per DALY saved of AUD 4,400 was estimated for the intervention	100%
Nowicka, P., et al. 2010 (US)[351]	BB: an intensive programme versus a control group that received traditional clinical weight management counselling	Behavioural; diet and PA (home- and family-based)	Children with overweight (8 to 16 years old)	CBA, CEA, CUA; within-trial economic evaluation; societal	Not stated; not stated	US dollars (not stated)	QALY saved, adult obesity averted	Given a CE threshold of USD 30,000 per QALY saved, the ICERs for the BB intervention compared with control were USD 2,511 per QALY saved and USD 1,506 per adult obesity averted. The net benefit	43%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								was USD -2,785, but control had a significantly larger negative net benefit	
Wang, L. Y., et al. 2010 (US)[84]	Hypothetical intervention: 1%-point decrease in the number of adolescents with excess weight	NA; NA (population-wide)	Adolescents with overweight and obesity (16 to 17 years old)	CCA; DAM (BMI progression model estimating consequences of body weight reduction scenarios); healthcare perspective	Lifetime; 3% (costs and benefits)	US dollars (2007)	QALY gained	In the least favourable scenario, a 1%-point reduction in adolescents with overweight/obesity would reduce medical costs by USD 463 million and increase QALYs by 34,394	93%
Hollingworth, W., et al. 2012 (UK)[71]	Lifestyle interventions (identified in literature review of 10 RCTs) to treat childhood excess weight versus no intervention	Behavioural; diet and PA (hospital- and community-based)	Children with overweight or obesity in state schools (4 to 5 and 10 to 11 years old)	CEA; DAM (the National Heart Forum 'Obesity Model') and literature review of RCTs; NHS	Lifetime; 3.5% (costs and benefits)	Pound sterling (not stated)	Life year gained	For children aged 10 to 11 years, the discounted cost per life year gained was estimated at GBP 13,589. Similar results are reported for children aged 4 to 5 years	91%
Robertson, W., et al. 2012 (UK)[352]	'Families for Health': a 12-week manualised programme involving a 2.5-hour session each week: a 'before-and-after' evaluation	Behavioural; healthy eating, PA, information on parenting skills, social and emotional development (community-, family-based)	Children with overweight or obesity (7 to 13 years old)	CEA; pilot study (report of the 2-year follow up results, with economic evaluation); not stated	2 years after the start of the intervention; not stated	Pound sterling (2006)	Change in BMI z-score	The analysis demonstrated a cost of GBP 2,543 per unit reduction in BMI z-score	75%
Epstein, L. H., et al. 2014 (US)[172]	Two assumptions of parent/child treated separately (PC): PC-1 (parent and child treated on separate days) and PC-2	Behavioural; diet and PA (clinic- and family-based)	Children at or above the 85th BMI percentile and had a parent with excess weight (8 to 12 years old)	CEA; within-trial economic evaluation; payer and societal	1 year from baseline; NA	US dollars (2013)	Unit of weight loss (defined in children as percent over BMI (%OBMI))	In children, the cost-effectiveness for FBT was USD 209.17/% over BMI, compared to USD 1,036.50/% over BMI for PC-1 and USD 973.98/%	87%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	(parent and child treated on same days) versus family-based (FBT) obesity treatment							over BMI for PC-2. Similarly, FBT was cheaper per unit of weight loss for parent compared to separate treatment	
Hollinghurst, S., et al. 2014 (UK)[353]	Mandometer® training versus Primary Care-Care of Childhood Obesity (PC-COCO) clinic	Behavioural; diet, PA and Mandometer® training (primary care, home, and clinic-based)	The PC-COCO study - children with BMI ≥ 98th centile (5 and 16 years old); the Mandometer® study - children with BMI >95th centile (9 to 17 years old)	CEA; within-trial economic evaluation (based on two trials - the PC-COCO study and the Mandometer® study); health care funder	1 year from baseline; NA	Pound sterling (not stated)	Reduction in BMI z-score	Given a CE threshold range of GBP 0-2,000 per 0.1-point improvement in BMI z-score, the PC-COCO clinic was the preferred choice until GBP 600. Beyond GBP 600, Mandometer® was most likely to be cost effective	92%
Law, C., et al. 2014 (UK)[354]	Mind, Exercise, Nutrition, Do it! (MEND) programme versus control	Behavioural; diet, PA, and mental wellbeing (family-based)	Adolescents with overweight/obesity (7 to 13 years old)	CCA; within-trial economic evaluation; NHS and Personal Social Services	10-week follow-up; NA	Pound sterling (2010/2011)	Change in BMI	Participant BMI decreased by, on average, 0.76 kg/m^2 over the 10-week follow-up, at a cost of GBP 773 per completer	92%
Li, L. 2014 (US)[355]	LAGB and RYGB versus no obesity treatment	Surgical; bariatric surgery (clinic-based)	Children with severe obesity in the U.S (13 to 19 years old)	CUA; DAM (Markov model); societal	Lifetime; 3% (costs and benefits)	US dollars (2012)	QALY gained	Given a CE threshold of UDS 30,000 per QALY, the costs per QALY gained were USD 3,379 and USD 5,192 for LAGB and RYGB, respectively, compared with no treatment	87%
Bairdain, S., & Samnaliev, M. 2015 (US)[356]	RYGB no surgery	Surgical; bariatric surgery (clinic-based)	Adolescents with obesity (mean age 17.3 years old)	CUA; DAM (Markov model) based on results of a RCT; payer	3 and 7 years from the age of 18 years; 3% (costs and benefits)	US dollars (2013)	Unit change in BMI and QALY gained (EQ-5D)	Given a CE threshold of USD 100,000 per QALY gained, bariatric surgery was not cost-effective in the first 3 years. By year	96%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
								7 post-operation, bariatric surgery was deemed to be cost-effective at USD 36,570 per QALY gained	
Kass, A. E. 2015 (US)[357]	A family-based social facilitation weight loss maintenance intervention delivered at high intensity ("SFM-High") versus standard of care	Behavioural, policy; diet, PA, and screening - parent-child dyads (multi-setting: primary care-, community-, school-based)	Children with overweight, obesity and severe obesity (mean age ~9.5 years old)	CEA; DAM (insufficient information - long term economic modelling of an RCT); not stated	Lifetime; not stated	US dollars (not stated)	Life year gained	Compared to standard of care, the ICER for treating children with SFM-High was USD 17,877 per life year gained	48%
Klebanoff M. J., et al. 2017 (US)[155]	Bariatric surgery (RYGB and SG modelled as a single cohort) versus no surgery	Surgical; bariatric surgery (clinic-based)	Adolescents with severe obesity (mean age 17 years old)	CUA; DAM (state-transition model); health care provider	3 (base case), 4 and 5 years; 3% (costs and benefits)	US dollars (2015)	QALY gained	Given a CE threshold of USD 100,000 per QALY saved, at 3 years USD 154,684 per QALY (surgery dominated); at 5 years USD 91,032 per QALY	87%
Larsen, K. T., et al. 2017 (Denmark)[217]	Camp group (CG), a six-week high-intensity day-camp intervention versus Standard group (SG), a six-week low-intensity intervention	Behavioural; PA - motivation-enhancing PA and health education (family-based, municipal setting)	Fifth-grade children with overweight and obesity (mean age of 12 years old)	CEA; RCT alongside an economic evaluation; local government (municipality)	Two years follow-up; NA	Danish crowns (2012)	Changes in BMI and BMI z-score	The ICER was DDK 149,669 per unit decrease in BMI z-score for CG compared with SG (CG was costlier but also more effective)	87%
Makkes, S., et al. 2017 (Netherlands)[206]	Two intensive 1-year lifestyle treatment interventions consisting of either an inpatient period of 2 months (short-stay group) or 6	Behavioural; diet, PA, and active participation of the parents/caregivers (clinical setting: specialised childhood obesity centre)	Children with severe obesity (8 to 19 years old)	CEA, CUA; RCT alongside an economic evaluation; societal	1 year of treatment and 1 year of follow-up; 4% and 1.5% (costs and benefits, respectively)	Euros (2010)	BMI z-scores and QALY gained (EQ-5D)	The difference in BMI z-score and QALYs between both groups after 24 months was statistically insignificant. Short stay was significantly less	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	months (long-stay group)							expensive	
Quattrin, T., et al. 2017 (US)[180]	Family-based behavioural treatment (FBT) and an attention-controlled information control (IC) group	Behavioural; diet and PA - parent and child-focused (family-based and clinical setting)	Children with overweight and obesity (BMI over the 85th percentile for their age and sex) with their parents (BMI ≥25) (2 to 5 years old)	CEA; RCT alongside an economic evaluation; societal	1 year of treatment and 1 year of follow-up; NA	US dollars (2013)	Percent over BMI (%OBMI) change (overweight or underweight relative to the 50th percentile BMI reference standard) and changes in BMI	The FBT ICER compared to IC was USD 116.1 per unit reduction in %OBMI for children and parents, the ICER was USD 353.8 per kilogram reduction in weight	100%
Robertson, W., et al. 2017 (UK)[201]	'Families for Health', a 10-week family-based childhood obesity treatment intervention versus usual care	Behavioural; diet, PA, parenting skills and relationship skills (family and community-based)	Children with overweight or obesity and their parents or carers (6 to 11 years old)	CUA; RCT alongside an economic evaluation; NHS and Personal Social Services	1 year post randomisation; NA	Pound sterling (2013/2014)	Change in BMI z-score and QALY gained (EQ-5D-Y)	Given a CE threshold of GBP 30,000 per QALY, the ICER for the 'Families for Health' programme was estimated at GBP 552,175 per QALY gained	100%
Saelens, B. E., et al. 2017 (US)[358]	Professional-delivered versus Peer-delivered (previously treated parents) Paediatric Weight Management Treatment	Behavioural; diet, and PA (family-based)	Children with overweight or obesity and their parents (7 to 11 years old)	CEA; economic evaluation based on the costing of two pilot trials (the Engaging Parents in Child Health (EPICH) and Parent Partnership trials); Payer	1 year after treatment ended; NA	US dollars (2015)	BMI change	Similar decreases in in child z-BMI were observed in both groups but costs were significantly lower for peer compared to professional delivery	89%
Sharifi, M., et al. 2017 (US)[359]	Study of Technology to Accelerate Research (STAR) intervention versus usual care	Behavioural, policy; diet, PA - electronic health record (EHR)-based decision support for primary care providers, and self-guided behaviour-change support for parents	Children with obesity (6 to 12 years old)	CEA; DAM (the CHOICES microsimulation model was used to project the effect of implementing the STAR trial nationally) based on a trial; modified	10 years (model projection 2015-2025); 3% (costs)	US dollars (2014)	BMI reduction, cases of obesity averted, and life-year saved	The intervention cost USD 237 per BMI unit reduced. If maintenance of effect was assumed, at 10 years, USD 774 per life-year saved was estimated	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
		(clinic-based)		societal					
Anderson, Y. C., et al. 2018 (New Zealand)[211]	Two home-based multi-disciplinary child obesity intervention programmes (high-intensity and low-intensity) versus conventional hospital-based care	Behavioural; multi-disciplinary assessment and advice to promote healthy diet and PA choices (home-, community-, and hospital-based care)	Children with BMI ≥ 98th centile or BMI > 91st centile with weight-related comorbidities (treatment arms 5 to 16 years old; comparator arm 4 to 15 years old)	CEA; trial-based economic evaluation; health funder	12 months from baseline; NA	New Zealand dollars (2016)	BMI z-score	The low-intensity group was NZD 939 lower than the conventional group. In the high-intensity intervention group, it was NZD 155. Both low- and high-intensity groups had mean BMI z-score reductions of 0.03 more than the conventional group	97%
Panca, M., et al. 2018 (England)[360]	HELP: a weight management programme for adolescents versus enhanced standard care	Behavioural; motivational, multicomponent lifestyle (diet and PA) modification intervention (family- and community-based)	Young people with obesity (12 to 18 years old)	CUA; trial-based economic evaluation; NHS	Treatment ended at 6 months and follow-up for another 6 months; NA	Pound sterling (2013/2014)	QALY gained (EQ-5D-3L)	Given a CE threshold of GBP 30,000 per QALY, the ICER was GBP 120,630 per QALY gained and there were no differences in adjusted QALYs between both groups	100%
Panca, M., et al. 2018 (UK)[156]	Bariatric surgery: RYGB and SG versus no surgery	Surgical; bariatric surgery (clinic-based)	Adolescents with BMI > 40kg/m^2 (mean age for RYGB and SG 17.8 and 18.7 years respectively)	CUA; DAM (Markov cohort model used to estimate the long-term health economic consequences based on data collected from 18 adolescents who underwent bariatric surgery); NHS	Lifetime; 3.5% (costs and benefits)	Pound sterling (2013/2014)	QALY gained	Given a CE threshold of GBP 30,000 per QALY, the ICER for males and females, respectively, were GBP 2,018 and GBP 2,005 (RYGB); and GBP 1,978 and GBP 1,941 (SG)	100%
Vidmar, A. P., et al. 2019 (US)[183]	iPhone® app intervention with clinic visits that targeted addictive	Behavioural, environmental; App-based mobile health technology (m-	Adolescents with obesity without significant obesity comorbidities but	CEA; economic evaluation alongside a pilot study; provider	6 months post-baseline; NA	US dollars (not stated)	Mean change in BMI z-score and excess percent over the 95th percentile (%BMIp95)	The app intervention had a lower cost than the EMPOWER clinic intervention (USD	100%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	eating behaviour versus the Children's Hospital Los Angeles multi-disciplinary weight management clinic (EMPOWER) intervention consisting of a team of healthcare professionals who evaluated patients	Health) and clinical evaluation-based (clinic- and home-based)	exhibiting signs of addictive eating (12 to 18 years old)					855.15 vs. USD 1,428.00). EMPOWER completers demonstrated comparable decreases in BMI z-scores and %BMIp95 6 months after baseline	
Bandurska, E., et al. 2020 (Poland)[221]	A 12-month multidisciplinary obesity management comprising screening for overweight, specialist care, parental education, and specialist consultation versus no intervention	Behavioural, environmental; diet, PA, and psychological support (clinic- and community based)	Children with overweight or obesity (6 to 15 years old)	CEA; economic evaluation based on a longitudinal intervention study where a cohort was followed (insufficient information); not stated	7 years; not stated	Polish zloty and Euros (not stated)	Child removed from overweight or obesity	The costs of removing a child from the overweight group and obese group were PLN 27,758 (EUR 6,463) and PLN 23,601 (EUR 5,495), respectively	74%
Lier, L., et al. 2020 (Germany)[361]	The Children's Health InterventionaL Trial (CHILT) intervention: weekly medical consultations, nutritional or psychological therapy sessions and exercise sessions	Behavioural; diet and PA (family-based)	Children with obesity (8 to 16 years old)	CEA/return on investment; DAM (insufficient information); health care and societal	11-month intervention, 10-year cost saving projection; 3% (costs)	Euros (not stated)	Change in BMI z-score	Participant BMI z-score decreased by, on average, 0.19-units. Future cost savings were estimated to be between EUR 1,859 - EUR 1,926 per participant, equating to a return on investment of 3.3–7.0%	91%
Viner, R. M., et al. 2020 (UK)[362]	HELP: a weight management programme for adolescents versus	Behavioural; motivational, multicomponent lifestyle (diet and PA)	Children with obesity (12 to 18 years old)	CUA; economic evaluation alongside a RCT; NHS	1 year follow-up; NA	Pound sterling (2013/2014)	QALY gained (EQ-5D-3L)	There were no differences in QALY outcomes or resource use between the HELP	95%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	enhanced standard care	modification intervention (family- and community-based)						intervention and control during follow-up, but HELP incurred an excess intervention cost of GBP 850	
Woolford, S. J., et al. 2022 (US)[363]	Motivational interviewing for parents of children with excess weight versus usual care	Behavioural; motivational interviewing (by telephone or in-person visits) - primary care practitioner and registered dietitian (clinical setting, family-based)	Parent-child dyads: children with baseline BMI between the 85th-97th percentiles (2 to 8 years old)	CEA; trial-based economic evaluation; societal	2-year follow-up; not stated (acknowledged but not applied)	US dollars (2019)	BMI percentile point change	Given a CE threshold of roughly USD 400 per BMI percentile point decrease, the probability of CE was roughly 50%. The ICER was USD 363 per BMI percentile point decrease per participant over 2 years	98%
Zoellner, J. M., et al. 2022 (US)[364]	iChoose (high intensity, parent-child dyads) versus Family Connections (low intensity, parents only)	Behavioural; nutrition education, physical activity, behaviour modification techniques (community- and family-based)	Parent-child dyads: children with overweight: BMI 85th - <95th percentile and obesity: BMI ≥95th percentile (mean age ~10 years old)	CEA; trial-based economic evaluation; Provider/payer (community programme implementation perspective)	6 months; NA	US dollars (not stated)	Change in BMI z-score	BMI z-score changes were statistically insignificant within both groups. Implementation costs per child with improved BMI z-score were USD 2841 and USD 955 for iChoose and Family Connections, respectively	92%
Carrello, J., et al. 2023 (Australia)[365]	Hypothetical e-health intervention versus 'do nothing' approach	Behavioural; diet and PA (multiple settings possible)	Children with overweight and obesity (14/15 years old)	CUA; DAM (the Early Prevention of Obesity in Childhood (EPOCH) microsimulation model); healthcare system	Lifetime; 5% (costs and benefits)	Australian dollars (2019)	QALY gained (meta-analysis)	Given a CE threshold of AUD 50,000 per QALY gained, a 96% probability of CE was estimated	100%
Omorou, A. Y., et al. 2023 (France)[367]	Screening for overweight and obesity in schools	Policy and behavioural; screening by school	Children with overweight and obesity (14 to 18	CEA; trial-based economic evaluation; public	2 academic years; not stated	Euros (2021)	Averted case of overweight/obesity, BMI unit decrease,	The screening and care strategy resulted in ICERs of EUR 1634.48	93%

Author, year of publication (country)	Intervention(s) and comparator(s)	Intervention category; components and targets (setting)	Target population (age/age range)	Type of economic evaluation; study design; study perspective	Study follow-up or decision analytic model time horizon; discounting	Currency unit (Price year)	Measure(s) of consequences	Key/base case results	CHEERS quality score
	and subsequent care versus usual care	nurse, group care management - 7 x 1.5 hr sessions (if overweight or obesity identified) - diet and PA (school-based)	years old: mean age 15.6 years)	(public payer)	(acknowledged but not applied)		and increase in MPA	per averted case of overweight and obesity, EUR 255.43 per kg/m2 decrease per screened adolescent, and EUR 165.28 per 1000 MET. minute/week increase per screened adolescent	
Pryor, S., et al. 2023 (US)[366,369]	Bright Bodies intervention (high-intensity weight management program) versus traditional clinical weight management	Behavioural; diet and PA (home- and family-based)	Children and adolescents with obesity: BMI > = 95th percentile (8 to 16 years old)	CEA; DAM (microsimulation model based on data from randomised controlled trial); healthcare system	10 years (24 months trial follow-up); 3% (costs)	US dollars (2020)	BMI unit reduction	In the base case analysis (assuming depreciating effects post-intervention), Bright Bodies reduced a participant's BMI by 1.67 kg/m^2 per year over ten years compared with control. Bright Bodies was associated with an additional cost of USD 360/person, and cost-savings USD 1,126 per person over 10 years	100%
Siegel, R., et al. 2023 (US)[368]	Two interventions: (1) Loss-framed incentives; and (2) gain-framed incentives versus control	Behavioural; financial incentives/ disincentives (home- and community-based)	Children with obesity (12 to 18 years old)	CEA; DAM (decision tree); not stated	6 months; NA	US dollars (not stated)	Incremental adherence index point (adherence to the weight management programme)	The ICERs for the gain group and the loss group were USD 5.73 and USD 3.38 per incremental adherence point, respectively	93%

ACE: the assessing cost-effectiveness in obesity study; BB: Bright Bodies; BMI: body mass index; CCA: cost-consequences analysis; CE: cost-effectiveness; CEA: cost-effectiveness analysis; CHOICES: Childhood Obesity Intervention Cost Effectiveness Study; CUA: cost-utility analysis; DALY: disability-adjusted life year; DAM: decision analytic model; EQ-5D-Y: EuroQol 5Dimension Youth version; GP: General practitioner; HELP: Healthy Eating and Lifestyle Programme; ICER: incremental cost-effectiveness ratio; LAGB: Laparoscopic adjustable gastric banding; LEAP: the live, eat and play trial; NA: not applicable; NHS: National Health Service; PA: physical activity; QALY: quality-adjusted life year; RCT: randomised controlled trial; RYGB: laparoscopic Roux-en-Y gastric bypass; SG: laparoscopic sleeve gastrectomy.

3.4 Discussion

3.4.1 Summary of Findings

This systematic review underscores evolving developments in the economic evaluation of interventions for children with excess weight and syntheses evidence of cost-effectiveness and value for money. The increase in the number of studies over recent years highlights the growing interest in the topic in the context of the increasing prevalence of childhood excess weight and constrained public resources for its management. Although this review included few studies from LMICs, I expect that in the coming years, there will be a notable increase in studies reporting economic evaluations of interventions targeting excess weight in children living in LMICs. This expectation is hinged on the global trend of increased obesity prevalence driven by changing diet and lifestyle, among other factors.[382]

The grouping of studies into prevention-only, prevention and treatment, and treatment-only interventions further elucidates intervention and population characteristics and the methodological diversity across studies. Prevention-only interventions were the least represented (9%) in the included studies and were typically delivered to pregnant women[283], mother-infant dyads[285,290], and children in the first few years of life.[192,199,213,218,276] The settings of choice were primarily clinical[218,283] or home-based, along with family members.[192,288] Unique intervention components in this group included reduced protein content in infant formula[276] and sleep modification[285,290], both deemed cost-effective. In general, individual prevention-only interventions were likely to be cost-effective compared to usual care.

Prevention and treatment interventions were the most common of the three groups of interventions evaluated. Schools were the predominant setting for this group of interventions.[55,56,163,164,166,169,171,173,177,178,182,184,204,208,209,212,215,216,219,296,299,304-307,309-315,317,318,321,323,326-330,332,340,342,345]

The intervention components in this group overwhelmingly targeted individual behaviour but often cut across environmental and policy categories.[161,163,164,166,171,181,191,204,208,210,212,215,216,219,278,280,292-294,297-

[299,302,304,306-313,315,317,318,320,321,326-330,332,334,335,339,341,342,344,346,347] Most interventions in this grouping tended to be cost-effective compared to usual care or a "do nothing" option.

In addition to other intervention categories, treatment-only interventions featured bariatric surgery[155,156,350,355,356], generally deemed cost-effective over a lifetime horizon compared to usual care or no treatment. Like prevention-only interventions, the settings were more likely to be healthcare-based[155,156,206,220,349,350,355,356,359] or in the home alongside family members.[165,185,186,348,351,354,358,361] Generally, treatment-only interventions were likely to be cost-effective in the long run.

The literature reveals pertinent discourses surrounding the clinical significance of treatment effect sizes and the policy implications of statistically insignificant differences in BMI effects between compared interventions.[383] Some studies have defined a clinically meaningful benefit as at least a 5% reduction in body weight from baseline.[384] However, this definition remains open to debate.[385] Importantly, a lack of statistically or clinically significant differences in effects does not foreclose a favourable decision on cost-effectiveness.[386-388] A case in point is studies that apply cost-minimisation analysis (CMA),[389] a method of health economic evaluation which becomes relevant when conducted alongside non-inferiority randomised controlled trials and where an intervention may offer economic benefits despite the absence of clinically or statistically significant difference in treatment effect. In health economic evaluations, the gold standard for characterising uncertainty is rooted in probabilistic sensitivity analysis, where the uncertainties surrounding input parameters of treatment effects and costs are accounted for jointly.[373] Related to probabilistic sensitivity analysis are several approaches for reporting the variability in economic outcomes. These include the construction of a confidence interval for the cost-effectiveness ratio or performing a value of information analysis to quantify the expected value of reducing or eliminating decision uncertainty.[387]

The cost-effectiveness thresholds for CUAs were generally based on methods guidance for individual countries[390,391] but occasionally differed within countries. No national or international cost-effectiveness thresholds were specified for CEAs reporting ICERs in natural units, e.g., the

incremental cost per unit change in BMI z-score. However, in a few instances, the authors applied a threshold range to help readers and decision-makers decide whether an intervention offered good value for money. For CEAs, I recommend reporting graphical summaries of probabilities of cost-effectiveness across a plausible range of thresholds using CEACs and cost-effectiveness acceptability frontiers (CEAFs).[392] In a few of the included studies, authors determined that the intervention was unlikely to be cost-effective if similarity in effects were estimated, but the intervention was costlier. Generally, interventions in the included studies were deemed cost-effective, although many studies did not sufficiently justify the comparator choice.

3.4.2 Methodological challenges

Studies of the three intervention groupings shared some methodological characteristics and concerns. The plethora of measures of consequences in CEAs and CUAs (the most frequently applied economic evaluation methods for assessing paediatric excess weight interventions) complicate inter-study comparability. Including various outcomes for CCA can broaden the application of an economic evaluation for multiple decision-makers with diverse preferences and priorities. However, this is not always feasible, and rigour is required in selecting outcomes with the broadest applicability. Stakeholder-led prioritisation and development of core outcome sets for interventions targeting childhood excess weight are in the early stages and currently focus on outcomes for specific age ranges,[393] settings,[394] or interventions.[395] The use of CEA, the type of economic evaluation specified for disease/condition-specific outcomes or proxy measures of intervention effectiveness, limits the scope of cost-effectiveness based decision-making.[396] Thus, proxy measures such as change in MET or MVPA and change in dietary habits should preferably only be reported as ancillary outcomes. Further, for CEAs, widely adopted natural units such as BMI z-scores are preferable to unstandardised measures such as child percent over BMI (%OBMI) because they account for the variation in children's body composition by age and gender.[397]

Anthropometric outcomes, particularly those structured around measures of BMI, have been heavily criticised for lack of equivalent representation of body fat across sex and ethnic groups.[398-400] To attenuate this bias, summary measures that integrate the deleterious effects of excess weight on health-related quality of life with its impact on longevity have been proposed.[396,401] Preference-based measures such as the QALY and DALY meet this criterion. In addition, they are the measures of choice for NICE[376] in England and Wales, the Pharmaceutical Benefits Advisory Committee (PBAC)[402] in Australia, and health technology assessment agencies in several other high-income countries.[403] The challenges with eliciting utilities for measures like the QALY in children are not unique to the study of excess weight and have been given sufficient coverage in the literature.[119-121] Specifically, the following methodological concerns were relevant to the studies included in my review: (1) the heterogeneous nature of the childhood subgroups, (2) the challenge of capturing effects across developmental stages in childhood, and (3) constraints surrounding the cognitive abilities of children to complete complex preference-based measures. Current efforts at resolving these issues, for example, through the use of parental proxy assessment of health states and adaptations of existing utility instruments like the EQ-5D-Y or the development of entirely new paediatric-specific utility instruments like the CHU-9D and weight-specific instruments such as the Weight-specific Adolescent Instrument for Economic evaluation (WAItE), still bear the risk of bias and age restrictions.[120,122,123,141]

Only a minority of studies in my review assessed parental health-related quality of life, and none of the included studies evaluated well-being outcomes using a preference-based measure.[404] In recognition of the potential health-related externalities that may accrue to parents and caregivers of children experiencing excess weight, Frew[143] advocated for including family member benefits if relevant to the economic evaluation perspective. Furthermore, the multi-sectoral nature of interventions targeting excess weight implies that non-health benefits may be excluded when the QALY paradigm is strictly applied. Additional value may be found in quantifying and including well-being outcomes[143] or conducting economic evaluations from a societal perspective using a CBA framework.[405]

Decision analytic models offer the opportunity to capture potential downstream benefits experienced in adulthood after the administration of an intervention might have been discontinued. Since the evidence supporting treatment effectiveness is usually immature, assumptions surrounding the persistence or waning of effects are likely to be needed beyond what available data may show. Most included decision-analytic model-based studies used optimistic scenarios of prolonged treatment benefits to estimate base case results over an extended period.[197,216,325,350,359] On the other hand, a common limitation of trial-based studies tended to be the shortness of study timeframes.[308,347] I recommend reporting results from extensive scenarios with varying assumptions of effect decay and for different time horizons informed by clinical and expert opinion and observational evidence where this becomes available. In line with previous guidelines, trial time horizons should be considered carefully to ensure that they correspond with expected changes in measures of outcome, and modelling should be attempted to bridge the knowledge gap due to inadequate study follow-up.[387]

I noted substantial heterogeneity in the measurement and valuation of resource use and cost outcomes across studies, driven chiefly by national context, study perspective, and setting. Many studies conducted for a US population converted charges to costs and included a range of medical expenditures.[87,356] The preponderance of societal perspectives is encouraging as it indicates a lower risk of bias towards underestimating costs. On the other hand, excluding intervention set-up costs could potentially overestimate the cost-effectiveness of interventions requiring a substantial upfront investment in technology or a considerable learning curve for personnel, for instance, achieving proficiency in a new surgical procedure. While robust sensitivity analysis that includes one-off intervention costs may mitigate this bias, justification of the assumption in the base case analysis should be provided.

Preventing or treating childhood excess weight using e-health and m-health interventions is nascent yet promising. As suggested by some of the studies I reviewed, there might be an opportunity to

cost-effectively translate existing lifestyle interventions to online and mobile app-based versions.[55,56] However, the ethical issues linked with these interventions, such as data ownership and protection, also pose additional challenges.[57] Furthermore, the complexities associated with costing e-health and m-health interventions present a knowledge gap in the assessment of cost-effectiveness.[58] I advocate for transparency in reporting any difficulties associated with estimating the cost components of these interventions.

My review established that threshold-based assessment of cost-effectiveness was predisposed to considerable variation by gender, age, ethnicity, and SES across the three groups of interventions targeting childhood excess weight. This finding calls for attention to disparities in the prevalence and burden of childhood excess weight reported in many population subgroups.[46,406,407] Nevertheless, the number of studies that explored trade-offs between cost-effectiveness and health inequalities in subgroups of interest remains underwhelming. In line with Weatherly and colleagues[408], I recommend that researchers planning to conduct economic evaluations of interventions targeting childhood excess weight should review the literature to identify equity-relevant subgroups within the broader study populations.

Finally, my finding that most interventions evaluated were reported to be cost-effective calls into question the appropriateness of comparators. The overwhelming majority of interventions were compared to variations of usual care or “do nothing” approaches. Even in studies that evaluated multiple interventions, fully incremental analyses were rarely estimated. I acknowledge that most children with excess weight may not have access to any weight control support and doing nothing may be a tenable comparator. However, I believe that the choice of comparators might be aided and justified by literature searches to identify relevant interventions based on the target population, setting and study perspective.

3.4.3 Comparison with the existing literature

The study by Zanganeh and colleagues[154] was an extensive review of the methods, study quality, and the results of economic evaluations of 39 studies published between 2001 and 2017. Still, it excluded surgical procedures and innovative interventions such as sleep modification and interventions delivered through information and communication technologies. Some key findings from Zanganeh and colleagues were echoed in my review. For instance, interventions with individual-level behavioural components remained the dominant intervention category, studies are still predominantly conducted in high-income countries, and evidence synthesis is likely to remain challenging for the foreseeable future due to unresolved methodological heterogeneity.

Similarly, the searches for another systematic review by Oosterhoff and colleagues[260] were conducted in 2017 and comprised only economic evaluations of school-based interventions targeting children aged 4-12. The more recent systematic review by Mahdi and colleagues[261], which critically appraised the methods applied in economic evaluations of obesity interventions in children, was limited to dietary interventions intended to prevent obesity and excluded studies of hypothetical interventions and studies conducted in infants. Fundamentally, my systematic review was not restricted by the aforementioned limitations of previous studies. This review included three times as many studies as the review by Zanganeh et al. and captured several novel interventions, underscoring the rapidly evolving pace of research in the economic evaluation of childhood excess weight interventions.

3.4.4 Strengths and limitations

This systematic review summarises cost-effectiveness evidence and offers recommendations for practice and policy across 151 economic evaluations of interventions targeting childhood excess weight. My delineation of interventions into three groups (prevention-only, prevention and treatment, and treatment-only) untangles both shared methodological characteristics and inter-study diversity. Extending the work of previous reviews, my inclusion of a broader range of

intervention categories and components situates economic research in this area in its historical and contemporary contexts. My comprehensive eligibility criteria and searches across relevant databases allowed for a robust assessment of interventions targeting childhood outcomes. I also included studies of hypothetical interventions suitable for forecasting and target setting.

Despite its strengths, this review is not without limitations. I did not use the new version of the CHEERS statement issued in 2022.[409] The new statement lends itself more readily to all types of health economic evaluations. However, since most of the included studies were published before 2022, I deemed scoring them against a newly published standard unfair. Secondly, due to time constraints, I did not contact the authors of the nine abstracts included in my review, which could have improved my reporting assessment of their studies using the CHEERs statement.

Between-study variations in methodological approaches precluded the use of meta-analysis for combining cost-effectiveness evidence across studies. The setting, jurisdiction, cost-effectiveness threshold and type of economic evaluation varied vastly across studies. Therefore, I adopted a narrative review approach comparable to previous reviews in the field.[154,261,378]

Finally, while the systematic review aimed to identify interventions targeting excess weight, particularly those focused on physical activity and diet, it may not have captured all relevant interventions. Broad inclusion criteria and practical constraints in the search strategy likely limited comprehensive coverage, leading to the exclusion of some excess weight interventions.

3.4.5 Recommendations for policy and future research

No single type of economic evaluation is appropriate for assessing interventions targeting every childhood population across all settings and perspectives. Conducting economic evaluations from multiple perspectives may illuminate the interplay between health and other sectors in preventing and/or addressing childhood excess weight problems. I propose the following good practices and methodological considerations when undertaking economic evaluations in this area: (1) When selecting measures of consequences for conducting CCAs and CEAs, priority should be given to

standardised natural units that measure changes in body fat composition, as this would facilitate interpretation and promote generalisability. (2) To aid decision-making, CEACs and CEAFs should be graphed for a plausible cost-effectiveness threshold range, even if a national cost-effectiveness threshold is unavailable. (3) For CUAs, utility values should be elicited with particular consideration for the age appropriateness and sensitivity of the instrument, the valuation protocol, and the potential health-related quality of life impacts of the intervention on family members or carers. (4) CBAs are encouraged to remedy any missed externalities accrued in non-health sectors. (5) The choice of comparators should be justified, and a fully incremental analysis should be performed for all included interventions. (6) Robust sensitivity analysis should be performed to test assumptions of treatment effect maintenance or decay, and costing assumptions surrounding intervention start-up costs and productivity costs should be performed. (7) Finally, pre-study searches of the literature and deliberating with experts to identify subgroups relevant to the decision problem and study jurisdiction are highly recommended.

3.5 Conclusions

This chapter reports a systematic review of economic evaluations of interventions targeting childhood excess weight and found that most interventions in the prevention-only, prevention and treatment, and treatment-only groups were reported to be cost-effective. However, intervention cost-effectiveness was sensitive to age, sex, socioeconomic status, and model assumptions surrounding treatment effect. My study identified important methodological issues which, if addressed, will enhance the quality and comparability of economic evaluations of interventions targeting childhood excess weight. The finding in this chapter that decision-analytic models were the most frequently used vehicle for conducting health economic evaluations of interventions targeting childhood excess weight inspired my study estimating childhood transition probabilities between weight status categories (Chapter 4 of this thesis). The transition parameters I estimate in Chapter 4 can feed into decision-analytic cost-effectiveness models related to the evaluation of childhood excess weight interventions.

Chapter 4: Childhood transitions between weight status categories: Analyses based on the UK Millennium Cohort Study

4.1 Introduction

In the context of the increasing prevalence of childhood excess weight and limited healthcare resources, the logical aspirations of governments and decision-makers include prioritising the implementation of cost-effective interventions, programmes and policies for the management of childhood excess weight.[144] Economic evaluations conducted alongside randomised controlled trials (RCTs) of interventions targeting childhood excess weight tend to assess incremental costs and incremental consequences over short follow-up periods, which typically do not capture changes in body weight status over the longer term.[410] Decision-analytic models can address this limitation by estimating costs and consequences over longer, policy-relevant time horizons.[144,411] Among other advantages, decision-analytic models can also identify and quantify parameter uncertainty and decision uncertainty associated with the cost-effectiveness of interventions such as those implemented in early childhood, whose benefits may not materialise fully in the short or medium term.[144,411]

In my systematic review of economic evaluations of interventions targeting childhood excess weight (Chapter 3), I reported that decision-analytic models, particularly state transition models (STMs), were the most frequently used vehicle for conducting health economic evaluations of interventions targeting childhood excess weight.[410] STMs characterise the movements between mutually exclusive and jointly exhaustive health states (e.g. childhood bodyweight categories: underweight, healthy weight, overweight and obesity) over discrete time steps for a given condition (e.g. childhood overweight and/or obesity).[412] Preference for STMs has been ascribed to their simplicity in

representing the complex epidemiological patterns and stochastic processes surrounding the progression of chronic diseases.[411,412]

Movements between health states over discrete time intervals are driven by risks specified in terms of transition estimates (transition probabilities or intensities), which may vary by the effect of the health condition or the intervention effect of interest. Repeated measurements of childhood body weight collected in longitudinal studies allow for the estimation of transition probabilities between states of childhood body weight using a state transition modelling approach such as multistate modelling (MSM).[413-418] In a continuous-time multistate modelling framework (also known as a continuous-time Markov process), individuals observed over time move between a finite number of states in continuous time.[412,419-421] Multistate models can also account for the impact of sociodemographic characteristics and risk factors associated with the accumulation of childhood excess weight on body weight trajectories. In theory, the derived transition estimates may be incorporated into decision-analytic modelling-based economic evaluations to estimate outcomes in terms of costs and health metrics, such as quality-adjusted life years (QALYs) associated with prevention and treatment strategies targeting childhood excess weight.

Transition probabilities are critical parameters in decision analytic modelling-based economic evaluations of prevention and treatment strategies targeting childhood excess weight, as they determine body weight trajectories. Therefore, methods and assumptions surrounding their estimation can significantly influence cost-effectiveness-based decision-making.[412] Having conducted searches for related published studies as well as searched the reference lists of relevant studies, I identified several methodological weaknesses in the application of continuous-time MSM, which could hinder the use of the derived transition parameters in health economic evaluations. For instance, transition probabilities have been assumed to be homogeneous throughout the course of childhood without justification or robust testing and validation.[413-415,417,422] Further, studies have been based on restricted sample sizes and age groups[413-415,417] and unrepresentative samples.[413,414,417] My

study, distilled in this chapter and the associated published work (Onyimadu, O., Astbury, N. M., Achana, F., Petrou, S., & Violato, M. (2024). Childhood Transitions Between Weight Status Categories: Evidence from the UK Millennium Cohort Study. PharmacoEconomics, 42(6), 649-661.)[423], is the first to estimate nationally representative childhood weight status transition parameters from a UK perspective.

In this chapter, I used the Millennium Cohort Study (MCS), a cohort study of a UK-representative sample of children aged three to 17 years, to develop Markov multistate transition models using time-to-event analysis. My models incorporated a stratified cluster sampling design to obtain transition estimates for body weight status. I tested the assumption of time-homogeneous transition probabilities and conducted internal validation of my estimates. I also examined the relationships between transition estimates and factors that could plausibly be associated with transitions between body weight categories.

4.2 Methods

4.2.1 Study Design and Population

The MCS is a nationally representative longitudinal survey of around 19,000 children born in the UK between 2000 and 2002.[61] Children were eligible to be included in the sample if at the age of nine months, if they were alive, living in the UK, eligible to receive Child Benefit and born in the eligible period (2000-2002).[424,425] Children not born in the UK but established as residents in the UK at the age of nine months were also eligible to enter the study.

Probability methods of selection, combined with stratification and clustering, were determined to be the most efficient way to achieve the core aims of the sample design: to ensure a proper representation of the entire UK population while also having adequate numbers of key subgroups for analysis. Thus, the population was stratified by country via electoral wards into ‘disadvantaged’ and ‘advantaged’ strata. Cut-offs were applied to a ward-based Child Poverty Index (CPI) for England, Wales, Scotland, and Northern Ireland to identify which wards were considered ‘disadvantaged’ or

'advantaged'. In England, an additional stratum, 'ethnic minority', defined as wards where at least 30% of their total population were of 'Black' or 'Asian' ethnicities, was specified. Technical details of how these wards were sampled and disproportionately stratified by neighbourhood disadvantage, ethnicity, and country are reported by Plewis.[425] Clustering was used to incorporate the broader socioeconomic context into the study and to reduce field costs such as interviewer travel time and costs. The MCS consisted of nine strata and 398 electoral wards (clusters) across the UK. The disproportionately stratified cluster sample required the generation of weighted estimates of means and variances (survey weights) by the MCS database constructors since children had different probabilities of being selected, depending on their area-level socioeconomic status.

To date, eight MCS waves have been conducted at ages nine months (Wave 1 in 2001), three years (Wave 2 in 2004), five (Wave 3 in 2006), seven (Wave 4 in 2008), 11 (Wave 5 in 2012), 14 (Wave 6 in 2015), 17 years (Wave 7 in 2018) and 23 years (Wave 8 in 2023). The data from Wave 8, representing young adulthood, was not accessible at the time of this study and, therefore, was not included in the analyses. The primary data collection from parents in the first survey was done through computer-assisted interviews and self-completion.[424] Trained interviewers used standardised methodologies to measure child height and weight (to the nearest 0.1 cm and nearest 0.1 kg, respectively) and data on sociodemographic and family characteristics at waves 1 to 7.[426] My assessment of transitions between body weight categories spanned children aged 3 (Wave 2, when height was first measured) to 17 years. The datasets used for this study are publicly available; details for accessing them are provided in Appendix D (Data availability).

The study population for my base case analysis included singletons with at least two BMI measurements across MCS waves and complete data on relevant variables (described below). BMI was calculated as kg/m^2 and then converted into standard deviation (SD) scores (BMI z-scores) using the British Growth Reference (UK90) for age-adjusted and sex-specific categories.[427] Conversions to BMI z-scores were implemented using Stata 17 statistical software.[428,429] Children in my study

population were then grouped into bodyweight categories for each BMI measurement based on the UK cut-offs for population monitoring: less than or equal to the 2nd centile (underweight), greater than the 2nd and less than the 85th centile (healthy weight), greater than or equal to the 85th and less than the 95th centile (overweight), and greater than or equal to the 95th centile (obesity).[22] In sensitivity analyses, I applied the World Health Organization (WHO) references and classifications for children aged 60 months or younger (underweight (or thinness): BMI z-score < -2; healthy weight: BMI z-score ≥ -2 & ≤ 2; overweight: BMI z-score > 2 & ≤ 3; and obesity: BMI z-score > 3) and children aged 61 months or older (underweight (or thinness): BMI z-score < -2; healthy weight: BMI z-score ≥ -2 & ≤ 1; overweight: BMI z-score > 1 & ≤ 2; and obesity: BMI z-score > 2).[30] This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies.[430]

4.2.2 Covariates

The choice of the individual-level child, mother, and sociodemographic factors to include in my analysis was informed by the relevant literature.[413-415,417,426,431] Child and mother factors were: child's sex (male, female); ethnicity (white, non-white); gestational age at birth[432] (preterm (<37 weeks 0 days), early term (≥37 weeks 0 days & <38 weeks six days), full term (≥39 weeks 0 days & <40 weeks six days), late term (≥41 weeks 0 days & <41 weeks six days), post-term (≥42 weeks 0 days)); mother's age at birth of child (12-19, 20-29, ≥30 years); mother's BMI category during pregnancy (underweight, healthy weight, overweight/obesity); mother's frequency of alcohol consumption during pregnancy (monthly or more frequently, less than once a month, never); and mode of delivery (natural, assisted, planned caesarean section, emergency caesarean section). Sociodemographic covariates included: mother's highest academic qualification (first/higher degree, diplomas in higher education, A/AS/S levels, O level/GCSE grades A-C, GCSCE grades D-G, Other academic qualifications, none of these qualifications); and family income categorised as Organisation for Economic Co-operation and Development (OECD) weighted quintiles.[433]

4.2.3 Statistical analysis

Model derivation and validation

My evaluation was based on a multistate transition modelling approach within the maximum-likelihood estimation framework specified by the MSM function[420] in the statistical software R.[434] My multistate model aimed to estimate transitions between body weight categories. It was defined by a continuous-time, finite-state stochastic process, with the Markovian assumption that subsequent movement to another state depends only on the current state and not on past states.[419,435] The principal outputs from my Markov multistate transition model were transition hazard rates (also known as transition intensities), representing the instantaneous risk of moving from one state to another, such as from healthy weight to overweight. Transition probabilities could then be derived for cycle lengths of interest (such as weeks/months/years) by taking the matrix exponential of the transition intensity matrix.[420] Hazard ratios were also estimated. In the context of this chapter, a hazard ratio compares the rate at which a weight status transition happens between two population subgroups, providing an estimate of the relative risk of a transition between weight status categories in one subgroup compared to another.

My models specified four predefined weight status categories: underweight, healthy weight, overweight, and obesity. I allowed for only clinically plausible transition intensities between adjacent waves of data. For example, even if a child had a healthy weight status in Wave 2 and an obese weight status in Wave 3, an instantaneous progression between the healthy weight and obesity states was only possible between the intermediate state. Therefore, though unobserved, the child must have progressed to an overweight status first. This assumption is consistent with the assumptions underpinning the methods of existing studies on childhood BMI transitions.[414,415] Consequently, my four-state model consisted of six possible transitions: underweight to healthy weight; healthy weight to underweight; healthy weight to overweight; overweight to healthy weight; overweight to obesity; and obesity to overweight.

Figure 4 and **Figure 5** are diagrammatic and mathematical representations of the model structure, respectively, depicting multistate modelling in continuous time. The arrows in Figure 4 show what instantaneous hazards are allowed based on expert and clinical opinion. In this model, the instantaneous hazard of transitioning is only possible between adjacent health states (weight status categories).

Figure 4 Model structure

$$\begin{pmatrix} -q12 & q12 & 0 & 0 \\ q21 & -(q21+q23) & q23 & 0 \\ 0 & q32 & -(q32+q34) & q34 \\ 0 & 0 & q43 & -q43 \end{pmatrix}$$

Figure 5 Matrix of transition intensities

In **Figure 4**, if 1, 2, 3, and 4 represent the health states underweight, healthy weight, overweight, and obesity, then $q12$, $q21$, $q23$, $q32$, $q34$, and $q43$ (**Figure 5**) represent the transition intensities or hazards from underweight to healthy weight, healthy weight to underweight, healthy weight to overweight, overweight to healthy weight, overweight to obesity, and obesity to overweight, respectively. A zero in any row indicates that an instantaneous hazard is not allowed. The transition intensities in each row must sum to zero. Jackson provides further details on Markov multistate transition models.[420]

I estimated transition intensities and annual transition probabilities for a base case analysis and two scenario analyses. The base case model reflected my hypothesis that transition probabilities are not time-homogeneous across all waves, i.e. they depend significantly on a child's age in the year of observation. For the base case analysis, I extracted a dataset of children with measures of BMI for

each wave. I then extracted five corresponding pairwise datasets from adjacent sequential waves as follows: Waves 2 and 3 (ages 3 and 5), 3 and 4 (ages 5 and 7), 4 and 5 (ages 7 and 11), 5 and 6 (ages 11 and 14), and 6 and 7 (ages 14 and 17). Repeated measures of BMI were required to construct each pairwise dataset such that the same children in the earlier wave of a pair were followed into the later wave of the pair. A time-homogeneous process was assumed only within these five adjacent pairs of MCS waves with piecewise linkage between successive pairwise datasets (between adjacent waves but not across the whole of childhood). In other words, the transition hazards estimated were constant within adjacent pairwise datasets but varied across age.[436-438]

Scenarios 1 and 2 assumed that transition probabilities were time-homogeneous across all waves, i.e. throughout childhood. I extracted a single dataset for scenario 1 consisting of individuals with at least one repeated measure of BMI between Wave 2 (age 3) and any other wave. In scenario 2, I assumed that the transition probabilities between Waves 2 and 3 were identical to those between successive pairs of adjacent waves. Therefore, I only extracted a dataset of children with repeated BMI measurements between waves 2 and 3 (ages 3 and 5) for scenario 2.

Finally, I derived a validation dataset, which I used to test the performance of the three models by comparing observed and predicted (model) estimates of prevalence. I identified 5,486 children with complete BMI measurements from waves 2 to 7, forming the basis of my validation dataset. Subsequently, I normalised and scaled the survey weights attached to each child a hundred times, replicating an additional 218,366 children. I merged the replicated datasets with the original validation dataset, which resulted in 221,436 children. Of these, 0.78%, 72.70%, 15.90%, and 10.63% fell in the underweight, healthy weight, overweight, and obesity categories at baseline (Wave 2/age 3), respectively. These baseline percentages were then inputted as baseline cohorts into Markov traces of my derived base-case and scenario analyses to simulate the projected yearly prevalence for each bodyweight category. Estimates of weighted and unweighted prevalence by wave using both

the UK cut-offs for population monitoring of weight status and the WHO cut-offs are reported in Appendix D (Observed prevalence).

Integrating complex survey design within models

The sample design of the MCS data aimed to ensure an adequate representation of the UK childhood population as well as guarantee sufficient sampling for critical subgroups.[425] Consequently, the survey was geographically clustered and disproportionately stratified with oversampling of children in disadvantaged socioeconomic circumstances and, in England, children from minority ethnic backgrounds. Despite these measures, the MCS surveys reported complex response patterns characterised by higher non-response rates for ethnic minorities and families in deprived areas and inter-wave attrition.[61,439] The MCS database constructors provide survey weights that account for the clustered sample design, the unequal probability of being sampled, survey non-response, and adjust for inter-wave attrition.[61] To avoid bias in the estimation of point estimates (transition hazards and transition probabilities), I incorporated these survey weights into a validated adaption of the MSM R package.[440]

Confidence intervals surrounding the transition hazards and probabilities derived without adequate handling of variance will be artificially narrow.[440] Variance estimation for parameter point estimates posed an additional layer of complexity to my estimation strategy because the survey design variables provided by the MCS database constructors are suited to the linearisation/Taylor series estimation method[441], which does not lend itself to the MSM function. The computationally intensive replication method I adopted is an alternative to linearisation (the more common method used to estimate the variance of complex survey estimators to account for the sampling design and avoid or reduce bias).[442] Several replication methods are specified for variance estimation. Examples include the bootstrap method, balanced repeated replication (BRR), Fay's method, and Jackknife methods (jk1, jk2, and jk-n).[443,444] The jk-n is appropriate for sampling designs with two or more primary sampling units (PSUs) per stratum, such as the MCS, which has nine strata and 398 PSUs. Other

replication methods are inadequate for this study; for example, BRR is only suitable for designs with exactly two PSUs per stratum.[444] Consequently, I derived 398 jackknife (jk-n) replicate weights (matching the number of clusters in the MCS as stipulated in the methods for variance calculation by Valliant and Dever[444]) in Stata[428] for each modelling dataset and then used the replicated weights to calculate estimates of variance.[444-446]

The widely used R package for Markov multistate transition modelling[420] required modification to allow the incorporation of survey weights and the derived replicate weights. I applied a validated adaptation that was used to analyse the Population Assessment of Tobacco and Health (PATH) study.[440] Both PATH and MCS provide survey weights that can be used to derive point estimates. However, a critical difference between the PATH study and my MCS analysis is that PATH provides replicate weights, whereas MCS does not. I derived the replicate weights for the MCS as described above, and accelerated the time-consuming variance estimation process using parallel computing approaches.[447]

Robustness check for complete case analysis

Similar to other longitudinal studies of childhood excess weight using the MCS, where maximum likelihood estimation formed the basis of the statistical method[448,449] or where other methods, such as regression analyses, were applied[431,450], my analyses were based on complete-case analysis, where I included only children with complete data on the child, mother, and sociodemographic variables, outlined earlier. I tested the robustness of the derived transition hazards from my base case analysis by estimating and comparing transition hazards before and after excluding children with incomplete data on explanatory variables. My sensitivity analysis entailed the estimation of unadjusted transition hazards before excluding children with incomplete data on the child, mother, and sociodemographic variables.

4.3 Results

The initial sample consisted of 18,294 children aged nine months (Wave 1) when multiple births were excluded. Of these, 1,080 children with no records on the mother and implausible or missing bodyweight records were excluded. Of the remaining 17,214 children, 1,482 children were further excluded due to missing data on one or more covariates. The percentage missingness is as follows: ethnicity (0.15%), mother's age at birth of child (0.01%), mother's BMI category during pregnancy (8.05%), mother's frequency of alcohol consumption during pregnancy (0.05%), mode of delivery (0.16%), mother's highest academic qualification (0.21%) and family income (0.3%). After excluding children with missing or implausible body weight records and/or missing relevant explanatory variables, the MCS cohort comprised 15,732 children aged nine months (Wave 1).

My samples and datasets were derived from the remaining 15,732 children if they had valid records of gestational age at birth and body weight recorded in subsequent Waves. Estimation of BMI z-scores using the Stata-based formulas for the British 1990 growth reference (UK90)[22] and the WHO growth reference[30] generated different missing values per dataset. Children with invalid z-scores based on both the UK90 and WHO reference standards were excluded to ensure consistency in sample size across datasets derived from both references.

For the base case analysis, I extracted a dataset of children with measures of BMI for each wave (starting from Wave 2 when the children were three years old), which amounted to 11,731, 12,396, 11,325, 10,681, 9,126, and 7,768 children in Waves 2, 3, 4, 5, 6, and 7, respectively. I then extracted five pairwise datasets comprising sequential adjacent waves (i.e., Waves 2 and 3 (ages 3 and 5), 3 and 4 (ages 5 and 7), 4 and 5 (ages 7 and 11), waves 5 and 6 (ages 11 and 14), and 6 and 7 (ages 14 and 17)) with repeated BMI measurements as follows: 10,399 children for the Waves 2 to 3 dataset, 10,729 for the Waves 3 to 4 dataset, 9,685 children for the Waves 4 to 5 dataset, 8,593 children for the Waves 5 to 6 dataset, and 7,085 children for the Waves 6 to 7 dataset. Baseline sociodemographic characteristics for waves 2 to 3 are reported Table 11. In this study, a pairwise

dataset was constructed by matching the same child between adjacent or contiguous waves, where measures of BMI were available for both waves.

Table 11 Descriptive statistics for the base dataset (Wave 2; n = 10,399)

Variable	Variable levels	n	%
Mean (SD) age in years at wave 2			3.13 (0.20)
Sex			
	Boys	5,227	50.26
	Girls	5,172	49.74
Distribution of BMI category[a]			
	Underweight	126	1.21
	Healthy weight	7,331	70.5
	Overweight	1,718	16.52
	Obesity	1,224	11.77
Ethnicity			
	White	9,115	87.65
	Non-white	1,284	12.35
Gestational age at birth			
	Preterm (<37 weeks)	696	6.69
	Early term (≥37 & <39 weeks)	1,928	18.54
	Full term (≥39 & <41 weeks)	5,198	49.99
	Late term (≥41 & <42 weeks)	2,202	21.18
	Postterm (≥42 weeks)	375	3.61
Mothers' age at birth of child			
	12 to 19 years	680	6.54
	20 to 29 years	4,599	44.23
	30 years and over	5,120	49.24
Mother BMI category during pregnancy			
	Underweight	535	5.14
	Healthy weight	6,821	65.59
	Overweight or obesity	3,043	29.26
Mothers' frequency of alcohol consumption during pregnancy			
	Monthly or more frequent	1767	16.99
	Less than once a month	1,514	14.56
	Never	7,118	68.45
Mode of delivery			
	Natural	7,036	67.66
	Assisted	1,109	10.66
	Planned caesarean section	957	9.2
	Emergency caesarean section	1,297	12.47
Mothers' highest academic qualification at baseline			
	First/higher degree	2,000	19

Variable	Variable levels	n	%
	Diplomas in higher education	1,035	10
	A / AS / S levels	1,083	10.41
	O level / GCSE grades A-C	3,611	35
	GCSE grades D-G	1,015	9.76
	Other academic qualifications	222	2.13
	None of these qualifications	1,433	13.78
Family income: OECD weighted quintiles at baseline (age 9 months)			
	Lowest quintile: most deprived	1,874	18.02
	Second quintile	2,158	20.75
	Third quintile	2,119	20.38
	Fourth quintile	2,188	21.04
	Highest quintile: least deprived	2,060	19.81

For scenario 1, children with a BMI record in Wave 2 and at least one BMI record in any subsequent wave were included in a single dataset, resulting in 42,047 observations or 7,502 children. Of these, 7,502, 7,452, 7,293, 6,812, and 5,486 observations represented the number of children with two, three, four, five, and six BMI records in successive waves, respectively. By default, the R MSM package for fitting multistate models to panel data will produce a transition intensity matrix for this dataset under the assumption of time homogeneity. Similarly, the R MSM package produces a single transition matrix for the scenario 2 dataset, which should fit any dataset constructed from contiguous waves or all the MCS waves if the assumption of time homogeneity holds. My model validation exercise investigated this assumption.

Figure 6 depicts the predicted and the observed prevalence in the validation dataset at six time points, signifying BMI measurements at Waves 2, 3, 4, 5, 6, and 7. Figure 6 suggests that a non-time-homogenous pattern in transitions between body weight categories during childhood fits the observed data best based on the prevalence estimated at the individual waves. Appendix D (Predicted-to-observed prevalence ratios) shows prevalence estimates and confidence intervals. In sensitivity analysis, my replication of Figure 6 using the WHO references and cut-offs (Appendix D: Sensitivity analyses: **Figure *3***) highlights a similar pattern. Prevalence estimates and their confidence

intervals using the WHO reference and cut-offs are also reported in Appendix D (Sensitivity analysis: **Table D 1**).

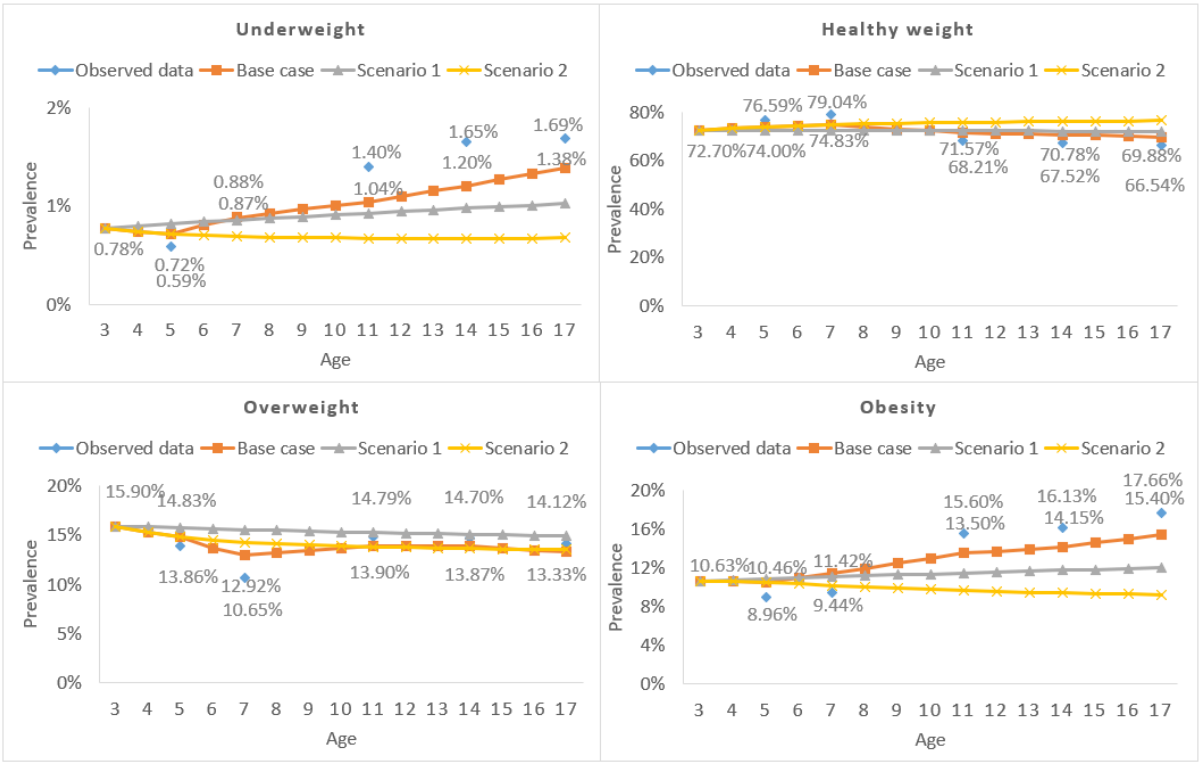

Figure 6 Observed and modelled projections for survey-weighted children followed from age 3 to 17 years

Table 12 reports the base case estimates of annual transition probabilities and confidence intervals across childhood and adolescence. Figure 7Figure 8, and Figure 9 depict transition probabilities between healthy weight, overweight and obesity by age group. These three Figures serve as summaries of key probabilities from Table 12. However, they do not include certain transition probabilities, such as transitions from underweight to healthy weight or the probabilities of remaining in the healthy weight state, both of which are integral to the analysis and influence the predicted prevalence in Figure 6.

Table 12 Base case analysis: unadjusted estimates of annual transition probabilities for transitions between weight status categories

From \ To	Underweight		Healthy weight		Overweight		Obesity	
	Annual probability	95% CI	Annual probability	95% CI	Annual probability	95% CI	Annual probability	95% CI
Waves 2 (mean age 3) to 3 (mean age 5), n = 10,399								
Underweight	0.7228	0.4704, 0.8699	0.2719	0.1283, 0.5155	0.0051	0.0018, 0.0133	0.0002	0, 0.0008
Healthy weight	0.0024	0.0010, 0.0052	0.9624	0.9496, 0.9719	0.0332	0.0261, 0.0414	0.0020	0.0010, 0.0038
Overweight	0.0003	0.0001, 0.0008	0.1928	0.1534, 0.2381	0.7132	0.6343, 0.7790	0.0937	0.0675, 0.1268
Obesity	0.0000	0, 0.0001	0.0178	0.0101, 0.0309	0.1419	0.1079, 0.1817	0.8403	0.7873, 0.8820
Waves 3 (mean age 5) to 4 (mean age 7), n = 10,729								
Underweight	0.7224	0.3939, 0.8931	0.2733	0.1057, 0.5929	0.0041	0.0012, 0.0124	0.0002	0, 0.0008
Healthy weight	0.0039	0.0018, 0.0073	0.9677	0.9566, 0.9761	0.0267	0.0212, 0.0331	0.0017	0.0009, 0.0030
Overweight	0.0004	0.0001, 0.0010	0.1736	0.1392, 0.2133	0.7281	0.6545, 0.7893	0.0979	0.0714, 0.1312
Obesity	0.0000	0, 0.0001	0.0097	0.0051, 0.0177	0.0874	0.0616, 0.1214	0.9029	0.8608, 0.9333
Waves 4 (mean age 7) to 5 (mean age 11), n = 9,685								
Underweight	0.9326	0.8339, 0.9735	0.0669	0.0263, 0.1645	0.0005	0.0002, 0.0016	0.0000	0, 0
Healthy weight	0.0014	0.0006, 0.0030	0.9836	0.9785, 0.9873	0.0146	0.0119, 0.0178	0.0004	0.0002, 0.0007
Overweight	0.0000	0, 0.0001	0.0253	0.0155, 0.0408	0.9223	0.8911, 0.9444	0.0524	0.0401, 0.0680
Obesity	0.0000	0, 0	0.0002	0.0001, 0.0006	0.0168	0.0097, 0.0287	0.9830	0.9707, 0.9902
Waves 5 (mean age 11) to 6 (mean age 14), n = 8,593								
Underweight	0.9042	0.7654, 0.9628	0.0949	0.0369, 0.2316	0.0009	0.0003, 0.0029	0.0000	0, 0.0001
Healthy weight	0.0022	0.0009, 0.0051	0.9798	0.9710, 0.9856	0.0175	0.0133, 0.0229	0.0005	0.0002, 0.0010
Overweight	0.0002	0, 0.0003	0.0758	0.0550, 0.1034	0.8716	0.8185, 0.9101	0.0524	0.0349, 0.0778
Obesity	0.0000	0, 0	0.0016	0.0008, 0.0033	0.0382	0.0258, 0.0556	0.9602	0.9411, 0.9734
Waves 6 (mean age 14) to 7 (mean age 17) n = 7,085								
Underweight	0.9186	0.8185, 0.9648	0.0806	0.0350, 0.1789	0.0008	0.0002, 0.0025	0.0000	0, 0.0001
Healthy weight	0.0023	0.0006, 0.0079	0.9787	0.9654, 0.9859	0.0183	0.0132, 0.0249	0.0007	0.0003, 0.0018

Overweight	0.0001	0, 0.0005	0.0787	0.0551, 0.1101	0.8507	0.7702, 0.9043	0.0705	0.0406, 0.1192
Obesity	0.0000	0, 0	0.0017	0.0007, 0.0041	0.0391	0.0245, 0.0610	0.9592	0.9349, 0.9748

Point estimates incorporate survey weights, and confidence intervals were derived using replicate weights.

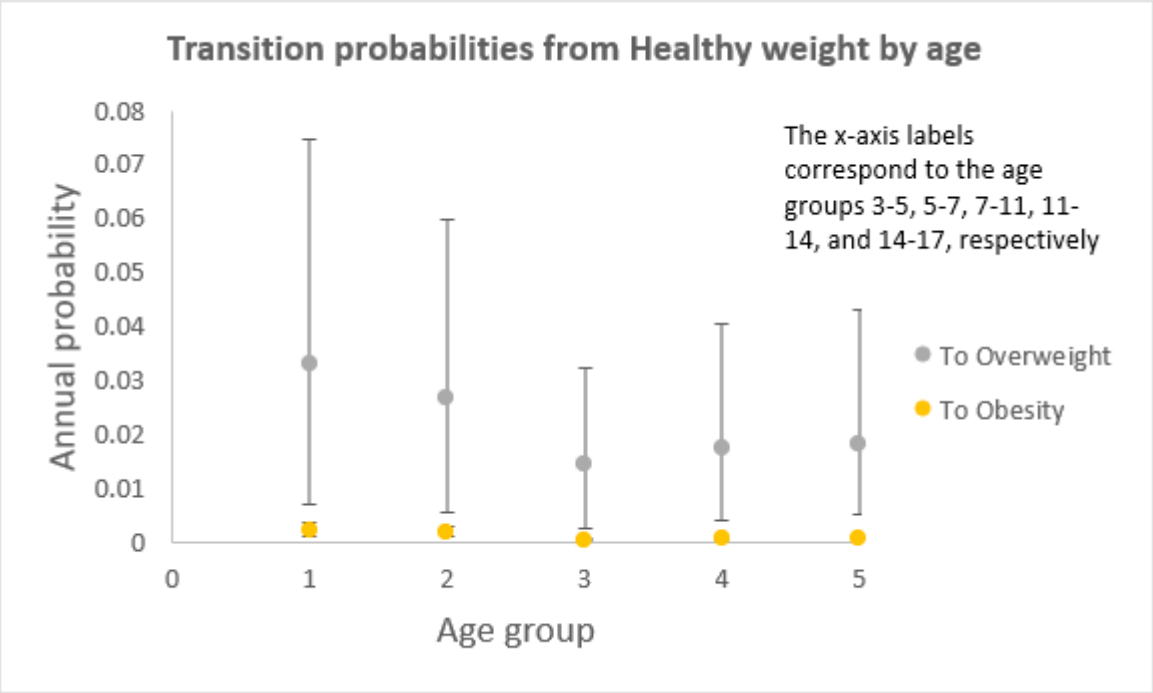

Figure 7 Transition probabilities by age groups from healthy weight to overweight and obesity

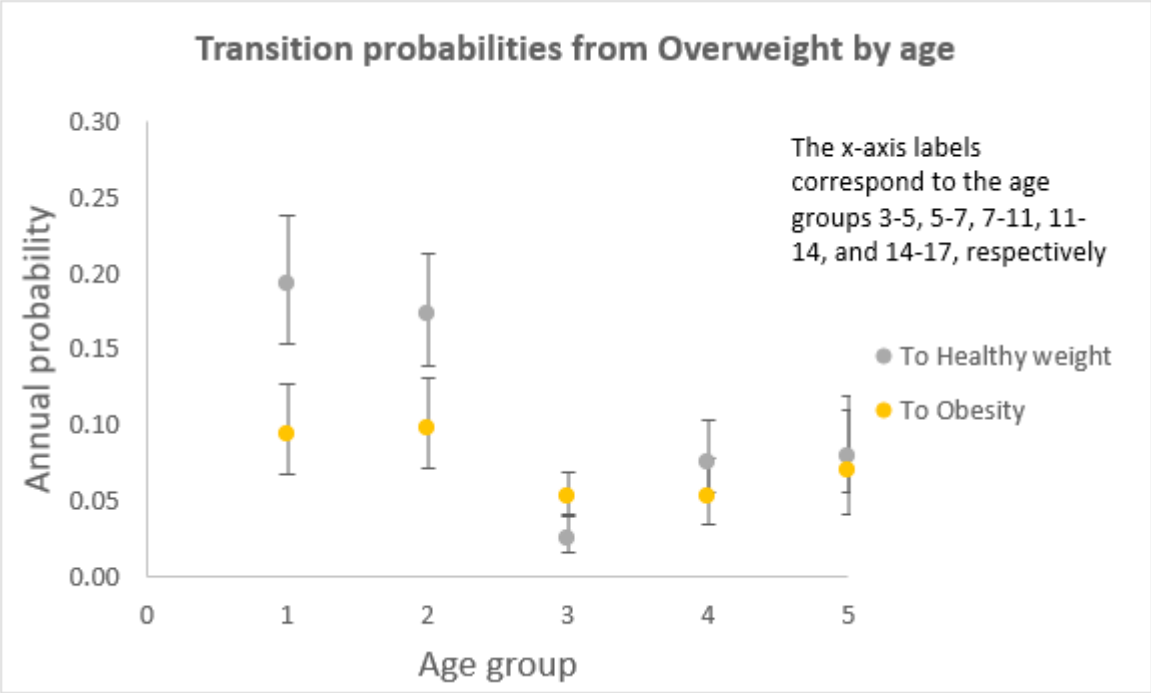

Figure 8 Transition probabilities by age groups from Overweight to healthy weight and obesity

Figure 9 Transition probabilities by age groups from obesity to healthy weight overweight

The annual transition probabilities in Table 12 demonstrate a substantial age gradient in transitions from healthy weight to non-healthy weight states, with children over 7 years less likely to transition. Annual transitions from healthy weight to overweight for children aged 3 to 5 and 5 to 7 years were 0.0332 (95% confidence interval [CI]: 0.0261-0.0414) and 0.0267 (95% CI: 0.0212-0.0331), respectively. These estimates contrasted significantly with those estimated for children aged 7 to 11, 11 to 14 and 14 to 17, which were 0.0146 (95% CI: 0.0119-0.0178), 0.0175 (95% CI: 0.0133-0.0229), and 0.0183 (95% CI: 0.0132-0.0249), respectively. However, the resolution of unhealthy weight is more strongly age-dependent, with children aged three to seven more likely to transition from underweight, overweight, and obesity to healthy weight than older children. For instance, children aged 3 to 5 and 5 to 7 years experienced transitions from overweight to healthy weight at annual probabilities of 0.1928 (95% CI: 0.1534-0.2381) and 0.1736 (95% CI: 0.1392-0.2133), which were at least two times the annual probabilities for similar transitions in older children. My sensitivity analysis estimates of transition probabilities using the WHO references and cut-offs (Table 13) support these findings. The underlying difference between the base case and the sensitivity analyses

is that children aged 3 to 5 years had greater annual transitions compared to children aged 5 to 7 years using WHO references and cut-offs.

Table 13 WHO references and cut-offs: unadjusted estimates of annual transition probabilities for transitions between weight status categories

From \ To	Underweight		Healthy weight		Overweight		Obesity	
	Annual probability	95% CI	Annual probability	95% CI	Annual probability	95% CI	Annual probability	95% CI
Waves 2 (mean age 3) to 3 (mean age 5), n = 10,399								
Underweight	0.6523	0.1805, 0.8995	0.3347	0.0974, 0.7776	0.0126	0.0030, 0.0399	0.0004	0.0001, 0.0020
Healthy weight	0.0016	0.0004, 0.0042	0.9301	0.9178, 0.9405	0.0650	0.0570, 0.0731	0.0033	0.0021, 0.0049
Overweight	0.0001	0, 0.0003	0.0574	0.0337, 0.0961	0.8530	0.7935, 0.8969	0.0895	0.0694, 0.1101
Obesity	0.0000	0, 0	0.0022	0.0005, 0.0092	0.0683	0.0285, 0.1562	0.9295	0.8346, 0.9710
Waves 3 (mean age 5) to 4 (mean age 7), n = 10,729								
Underweight	0.7171	0.2362, 0.9268	0.2784	0.0724, 0.7456	0.0044	0.0008, 0.0177	0.0001	0, 0.0005
Healthy weight	0.0037	0.0015, 0.0064	0.9674	0.9563, 0.9763	0.0281	0.0218, 0.0359	0.0008	0.0004, 0.0014
Overweight	0.0002	0, 0.0006	0.1300	0.1075, 0.1559	0.8233	0.7791, 0.8595	0.0465	0.0330, 0.0644
Obesity	0.0000	0, 0	0.0068	0.0036, 0.0125	0.0898	0.0607, 0.1307	0.9034	0.8568, 0.9357
Waves 4 (mean age 7) to 5 (mean age 11), n = 9,685								
Underweight	0.9323	0.8044, 0.9777	0.0672	0.0222, 0.1938	0.0005	0.0001, 0.0018	0.0000	0, 0
Healthy weight	0.0016	0.0007, 0.0036	0.9838	0.9783, 0.9875	0.0144	0.0117, 0.0178	0.0002	0.0001, 0.0003
Overweight	0.0000	0, 0.0001	0.0203	0.0134, 0.0309	0.9566	0.9383, 0.9694	0.0231	0.0172, 0.0307
Obesity	0.0000	0, 0	0.0002	0.0001, 0.0005	0.0194	0.0115, 0.0325	0.9804	0.9670, 0.9884
Waves 5 (mean age 11) to 6 (mean age 14), n = 8,593								
Underweight	0.9151	0.7964, 0.9661	0.0844	0.0338, 0.2018	0.0005	0.0001, 0.0018	0.0000	0, 0
Healthy weight	0.0026	0.0011, 0.0057	0.9856	0.9777, 0.9905	0.0117	0.0084, 0.0163	0.0001	0, 0.0003
Overweight	0.0001	0, 0.0002	0.0595	0.0457, 0.0768	0.9220	0.8914, 0.9437	0.0184	0.0106, 0.0316
Obesity	0.0000	0, 0	0.0017	0.0009, 0.0033	0.0542	0.0365, 0.0796	0.9441	0.9171, 0.9626
Waves 6 (mean age 14) to 7 (mean age 17) n = 7,085								
Underweight	0.9086	0.8002, 0.9598	0.0907	0.0400, 0.1977	0.0007	0.0002, 0.0021	0.0000	0, 0
Healthy weight	0.0026	0.0008, 0.0079	0.9832	0.9715, 0.9894	0.0140	0.0097, 0.0201	0.0002	0.0001, 0.0005
Overweight	0.0002	0, 0.0003	0.0520	0.0350, 0.0764	0.9196	0.8762, 0.9483	0.0282	0.0167, 0.0471
Obesity	0.0000	0, 0	0.0011	0.0004, 0.0030	0.0406	0.0233, 0.0695	0.9583	0.9275, 0.9763

Point estimates incorporate survey weights, and confidence intervals were derived using replicate weights.

In Figure 10 (replicated using WHO references and cut-offs in Appendix D: Sensitivity analyses: **Figure 4**), I illustrate the consequence of the choice of transition probabilities using four hypothetical cohorts of children. Each quadrant represents a cohort of 10,000 children with homogenous starting weight status categories (underweight, healthy weight, overweight and obesity) at three years of age and followed up to 18 years. However, the model can also assess a cohort of children with mixed baseline weight status profiles, as seen in Figure 6. Over time, children in these homogeneous cohorts transition into competing weight status categories. These movements are determined by transition probabilities estimated in this study for the base case and scenario analyses.

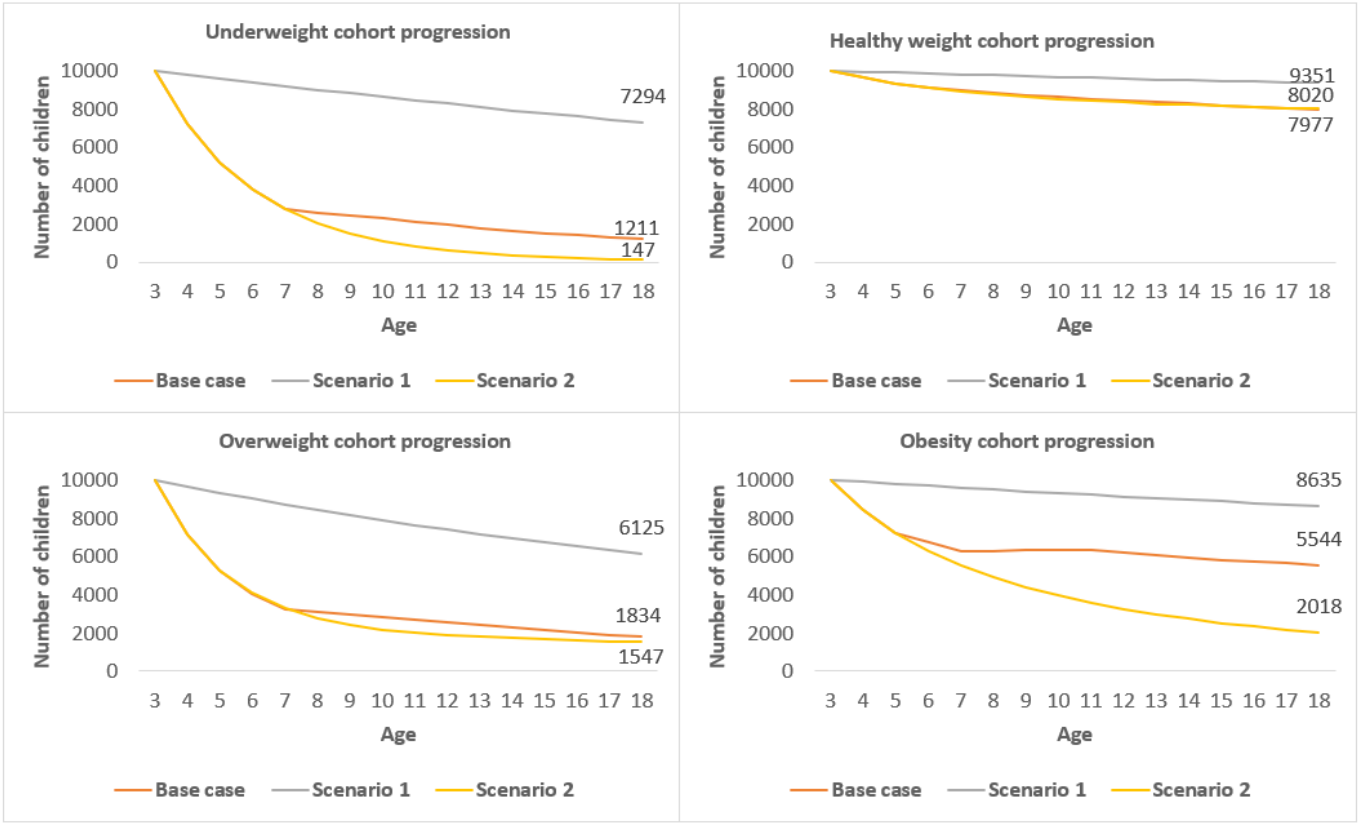

Figure 10 Modelled prevalence for four hypothetical cohorts of 10,000 children aged three at baseline in underweight, healthy weight, overweight, and obesity categories

Considering the healthy weight cohort, for instance, by age 18, 79.77% of children in the UK with healthy weight at three years of age would still be in a state of healthy weight, given usual practice. The remaining 20.23% of the cohort would have transitioned into other health states over a 15-year period, as determined by the transition probabilities in Table 12.

The substantial sample sizes for sex subgroups allowed moderately narrow confidence intervals to be estimated for all base case analysis datasets. Table 14 reports transition hazard ratios and 95% confidence intervals for boys aged three to 17 (with girls as the reference category).

Table 14 Base case analysis: hazard ratios of transitions between weight status categories for sex for ages 3-17 years

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Waves 2-3 (ages 3-5 years): boys versus girls			
Underweight to Healthy weight	0.8527	0.8370	0.8686
Healthy weight to Underweight	1.7301	1.0978	2.7267
Healthy weight to Overweight	1.2321	1.1844	1.2817
Overweight to Healthy weight	0.8715	0.8448	0.8990
Overweight to Obesity	1.1510	1.0717	1.2363
Obesity to Overweight	0.9776	0.9708	0.9845
Waves 3-4 (ages 5-7 years): boys versus girls			
Underweight to Healthy weight	1.0396	0.8370	1.2914
Healthy weight to Underweight	1.0099	0.8084	1.2617
Healthy weight to Overweight	1.0782	1.0393	1.1185
Overweight to Healthy weight	1.1589	1.1487	1.1691
Overweight to Obesity	1.1723	1.0963	1.2535
Obesity to Overweight	1.1416	0.9959	1.3087
Waves 4-5 (ages 7-11 years): boys versus girls			
Underweight to Healthy weight	1.9113	1.3044	2.8006
Healthy weight to Underweight	1.0898	0.7912	1.5011
Healthy weight to Overweight	1.1812	1.1651	1.1974
Overweight to Healthy weight	1.2480	1.0584	1.4716
Overweight to Obesity	0.9835	0.9418	1.0271
Obesity to Overweight	1.1861	1.1150	1.2617
Waves 5-6 (ages 11-14 years): boys versus girls			
Underweight to Healthy weight	0.3744	0.1797	0.7803
Healthy weight to Underweight	1.2660	0.7591	2.1114
Healthy weight to Overweight	0.7131	0.5899	0.8619
Overweight to Healthy weight	1.3487	1.2386	1.4687
Overweight to Obesity	0.9109	0.8675	0.9565
Obesity to Overweight	1.1002	0.9808	1.2341
Waves 6-7 (ages 14-17 years): boys versus girls			
Underweight to Healthy weight	0.6151	0.5517	0.6857
Healthy weight to Underweight	1.7408	1.1573	2.6186
Healthy weight to Overweight	1.0099	0.9960	1.0241
Overweight to Healthy weight	1.0224	0.8992	1.1626
Overweight to Obesity	1.7784	1.1780	2.6847
Obesity to Overweight	1.4793	1.3940	1.5699

Boys and girls showed significant differences in transition rates between weight status categories at all age groupings. Transition hazard ratios for other explanatory variables for children between 3-5 years are reported in Table 15. Analysis of maternal and birth characteristics (Table 15) was limited to children aged 3-5 due to time constraints associated with running the computationally intensive model and because some of the covariates seemed more likely to manifest their most potent effects at younger ages. For instance, it was plausible to assume that the weight status transition effects of the mode of delivery, the gestational age or the mother's BMI category during pregnancy would manifest with greater urgency in early childhood when related clinical complications tended to be observed.

Table 15 Base case analysis: hazard ratios of transitions between weight status categories for explanatory variables for Waves 2-3 (ages 3-5 years)

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Ethnicity: None-white versus White			
Underweight to Healthy weight	**0.3678**	**0.1533**	**0.8829**
Healthy weight to Underweight	**2.1510**	**1.4377**	**3.2182**
Healthy weight to Overweight	1.1127	0.6327	1.9571
Overweight to Healthy weight	1.0034	0.5947	1.6931
Overweight to Obesity	1.3304	0.6641	2.6649
Obesity to Overweight	0.7917	0.3921	1.5986
Gestational age at birth: Early term versus Preterm			
Underweight to Healthy weight	**1.3012**	**1.2621**	**1.3415**
Healthy weight to Underweight	**0.4104**	**0.3867**	**0.4357**
Healthy weight to Overweight	0.7493	0.5006	1.1216
Overweight to Healthy weight	1.1271	0.6516	1.9498
Overweight to Obesity	1.4264	0.8831	2.3041
Obesity to Overweight	1.4968	0.7649	2.9290
Gestational age at birth: Full term versus Preterm			
Underweight to Healthy weight	1.7352	0.6782	4.4396
Healthy weight to Underweight	0.6197	0.2277	1.6868
Healthy weight to Overweight	0.8207	0.4341	1.5515
Overweight to Healthy weight	1.0325	0.4632	2.3014
Overweight to Obesity	1.1938	0.4743	3.0051
Obesity to Overweight	1.6642	0.6030	4.5929
Gestational age at birth: Late term versus Preterm			
Underweight to Healthy weight	**1.4176**	**1.3062**	**1.5385**
Healthy weight to Underweight	**0.2412**	**0.1522**	**0.3822**
Healthy weight to Overweight	0.8376	0.5822	1.2051
Overweight to Healthy weight	0.9424	0.5316	1.6707
Overweight to Obesity	1.2386	0.6923	2.2158

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Obesity to Overweight	1.6260	0.7580	3.4876
Gestational age at birth: Post term versus Preterm			
Underweight to Healthy weight	1.8279	0.0989	33.7671
Healthy weight to Underweight	1.5103	0.1823	12.5135
Healthy weight to Overweight	0.7435	0.4995	1.1066
Overweight to Healthy weight	**0.8952**	**0.8632**	**0.9285**
Overweight to Obesity	1.1118	0.7662	1.6133
Obesity to Overweight	0.9708	0.6411	1.4700
Mother's age at birth of child: 20 to 29 versus 12 to 19			
Underweight to Healthy weight	0.2347	0.0277	1.9908
Healthy weight to Underweight	0.2119	0.0102	4.3876
Healthy weight to Overweight	1.0065	0.5642	1.7955
Overweight to Healthy weight	1.2527	0.6707	2.3397
Overweight to Obesity	1.5805	0.4833	5.1679
Obesity to Overweight	1.1069	0.4335	2.8265
Mother's age at birth of child: 30 and over versus 12 to 19			
Underweight to Healthy weight	0.2564	0.0374	1.7565
Healthy weight to Underweight	0.4179	0.0197	8.8644
Healthy weight to Overweight	0.9557	0.5305	1.7216
Overweight to Healthy weight	1.2348	0.6439	2.3681
Overweight to Obesity	1.2164	0.3421	4.3254
Obesity to Overweight	0.8831	0.3338	2.3364
Mother's BMI category during pregnancy: Underweight versus Healthy weight			
Underweight to Healthy weight	0.5495	0.0233	12.9557
Healthy weight to Underweight	**3.4408**	**1.0325**	**11.4670**
Healthy weight to Overweight	0.4988	0.1512	1.6454
Overweight to Healthy weight	0.8862	0.3070	2.5582
Overweight to Obesity	1.3547	0.2484	7.3871
Obesity to Overweight	1.1655	0.2467	5.5064
Mother's BMI category during pregnancy: Overweight/obesity versus Healthy weight			
Underweight to Healthy weight	1.8999	0.6911	5.2231
Healthy weight to Underweight	1.5651	0.3678	6.6595
Healthy weight to Overweight	**1.5604**	**1.3981**	**1.7416**
Overweight to Healthy weight	**0.7090**	**0.6265**	**0.8024**
Overweight to Obesity	**1.1315**	**1.1068**	**1.1569**
Obesity to Overweight	**0.6292**	**0.5978**	**0.6621**
Mother's frequency of alcohol consumption during pregnancy: Monthly or more frequently versus Never			
Underweight to Healthy weight	1.0696	0.0006	1974.7089
Healthy weight to Underweight	0.3341	0.0006	194.2117
Healthy weight to Overweight	0.7443	0.5031	1.1009
Overweight to Healthy weight	0.9696	0.7577	1.2407
Overweight to Obesity	0.9519	0.6496	1.3950
Obesity to Overweight	1.0401	0.6714	1.6114
Mother's frequency of alcohol consumption during pregnancy: Less than monthly versus Never			
Underweight to Healthy weight	0.9510	0.1290	7.0130

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Healthy weight to Underweight	1.5395	0.3604	6.5765
Healthy weight to Overweight	0.8337	0.5696	1.2202
Overweight to Healthy weight	0.9123	0.6610	1.2590
Overweight to Obesity	1.3815	0.8251	2.3132
Obesity to Overweight	1.4954	0.9672	2.3120
Mode of delivery: Assisted versus Natural			
Underweight to Healthy weight	1.6352	0.5455	4.9021
Healthy weight to Underweight	2.0876	0.1205	36.1722
Healthy weight to Overweight	1.0239	0.6814	1.5386
Overweight to Healthy weight	0.8241	0.5282	1.2858
Overweight to Obesity	0.7033	0.2722	1.8172
Obesity to Overweight	0.8927	0.4722	1.6876
Mode of delivery: Planned C-section versus Natural			
Underweight to Healthy weight	1.3663	0.0146	127.9112
Healthy weight to Underweight	3.3230	0.0486	227.2999
Healthy weight to Overweight	0.8705	0.4688	1.6164
Overweight to Healthy weight	0.9126	0.5294	1.5733
Overweight to Obesity	0.9142	0.4621	1.8088
Obesity to Overweight	0.7139	0.3238	1.5742
Mode of delivery: Emergency C-section versus Natural			
Underweight to Healthy weight	0.7150	0.2818	1.8139
Healthy weight to Underweight	1.5273	0.3489	6.6851
Healthy weight to Overweight	0.9529	0.6361	1.4276
Overweight to Healthy weight	0.7280	0.4894	1.0828
Overweight to Obesity	1.2291	0.6097	2.4777
Obesity to Overweight	1.1922	0.6486	2.1911
Mother's highest academic qualification: Diplomas versus Degree			
Underweight to Healthy weight	1.3337	0.1086	16.3778
Healthy weight to Underweight	0.5733	0.0738	4.4525
Healthy weight to Overweight	1.1242	0.8690	1.4544
Overweight to Healthy weight	0.9410	0.7659	1.1561
Overweight to Obesity	1.3402	0.9862	1.8214
Obesity to Overweight	0.9572	0.6748	1.3578
Mother's highest academic qualification: A levels versus degree			
Underweight to Healthy weight	2.1883	0.2986	16.0394
Healthy weight to Underweight	0.7443	0.0896	6.1829
Healthy weight to Overweight	**1.4411**	**1.2651**	**1.6415**
Overweight to Healthy weight	1.0566	0.8801	1.2686
Overweight to Obesity	0.8852	0.6295	1.2448
Obesity to Overweight	1.0547	0.8494	1.3095
Mother's highest academic qualification: O levels versus degree			
Underweight to Healthy weight	**1.3986**	**1.1922**	**1.6407**
Healthy weight to Underweight	1.4939	0.4538	4.9178
Healthy weight to Overweight	**1.5239**	**1.1415**	**2.0344**
Overweight to Healthy weight	1.0015	0.9422	1.0645
Overweight to Obesity	1.2628	0.9176	1.7380

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Obesity to Overweight	0.8610	0.6829	1.0855
Mother's highest academic qualification: GCSE D G versus Degree			
Underweight to Healthy weight	1.5850	0.1913	13.1352
Healthy weight to Underweight	1.2865	0.7821	2.1161
Healthy weight to Overweight	**1.5135**	**1.3820**	**1.6575**
Overweight to Healthy weight	0.8863	0.6654	1.1805
Overweight to Obesity	**1.1914**	**1.0045**	**1.4131**
Obesity to Overweight	**0.7937**	**0.6414**	**0.9821**
Mother's highest academic qualification: Other versus Degree			
Underweight to Healthy weight	2.8722	0.1588	51.9360
Healthy weight to Underweight	5.8279	0.4293	79.1193
Healthy weight to Overweight	1.5500	0.5184	4.6346
Overweight to Healthy weight	0.7921	0.1887	3.3247
Overweight to Obesity	1.6253	0.3949	6.6889
Obesity to Overweight	0.5913	0.0654	5.3473
Mother's highest academic qualification: None versus Degree			
Underweight to Healthy weight	**1.2929**	**1.1639**	**1.4363**
Healthy weight to Underweight	**1.9423**	**1.0077**	**3.7439**
Healthy weight to Overweight	**1.8226**	**1.7165**	**1.9351**
Overweight to Healthy weight	1.0523	0.8884	1.2464
Overweight to Obesity	**2.2404**	**1.5479**	**3.2429**
Obesity to Overweight	**1.3421**	**1.0609**	**1.6977**
Family income: Lowest quintile versus Highest quintile			
Underweight to Healthy weight	**1.3331**	**1.2548**	**1.4163**
Healthy weight to Underweight	**1.7105**	**1.1677**	**2.5057**
Healthy weight to Overweight	**1.5544**	**1.4516**	**1.6646**
Overweight to Healthy weight	**0.8815**	**0.7908**	**0.9825**
Overweight to Obesity	**1.3520**	**1.3452**	**1.3589**
Obesity to Overweight	0.8792	0.7081	1.0915
Family income: Second quintile versus Highest quintile			
Underweight to Healthy weight	1.5798	0.6050	4.1254
Healthy weight to Underweight	**2.0106**	**1.2304**	**3.2857**
Healthy weight to Overweight	**1.1117**	**1.0611**	**1.1648**
Overweight to Healthy weight	**0.8096**	**0.7649**	**0.8568**
Overweight to Obesity	1.0154	0.9183	1.1229
Obesity to Overweight	**0.9531**	**0.9383**	**0.9681**
Family income: Third quintile versus Highest quintile			
Underweight to Healthy weight	0.9645	0.8619	1.0792
Healthy weight to Underweight	**1.3398**	**1.0247**	**1.7518**
Healthy weight to Overweight	**1.3970**	**1.3622**	**1.4328**
Overweight to Healthy weight	**0.8311**	**0.8200**	**0.8423**
Overweight to Obesity	**0.9554**	**0.9428**	**0.9681**
Obesity to Overweight	**0.9537**	**0.9351**	**0.9726**
Family income: Fourth quintile versus Highest quintile			
Underweight to Healthy weight	**2.0835**	**1.8819**	**2.3066**
Healthy weight to Underweight	**2.5822**	**2.3607**	**2.8246**
Healthy weight to Overweight	**1.1440**	**1.1324**	**1.1558**

Transition	Estimate	Lower 95% CI	Upper CI 95% CI
Overweight to Healthy weight	**0.7755**	**0.7670**	**0.7842**
Overweight to Obesity	**0.9795**	**0.8768**	**1.0941**
Obesity to Overweight	**0.8167**	**0.7539**	**0.8848**

Statistically significant hazard ratios are indicated with bold number formats.

Ethnicity, gestational age, mother's age at childbirth, mother's BMI category during pregnancy, mother's highest academic qualification, and family income had statistically significant associations with hazards of transitioning between weight categories. Non-white children were less likely to transition from underweight to healthy weight than their White counterparts. Preterm children were associated with higher likelihoods of transitioning from healthy weight to underweight compared to children born early term or late term. Children born to mothers aged 20 to 29 years and 30 years and over were less likely to progress from underweight to healthy weight (reference category: mother ≤19 years). Children born to mothers in the underweight category were more likely to progress from healthy weight to underweight (reference category: healthy weight mothers). Children born to mothers who were overweight or obese were more likely to transition from healthy weight to overweight and from overweight to obesity (reference category: healthy weight mothers). Using degree-level education as the referent, I did not find statistically significant differences in the transition hazards of children born to mothers in the "other" academic qualifications category. However, I found statistically significant differences in transition hazards for children born in the remaining maternal education categories, with the most significant differences in the "none" category. Children born to mothers with no academic qualifications were more likely to transition from healthy weight to overweight and obesity. Compared to families in the highest quintile of household income (the least deprived), children in all other quintiles experienced unfavourable transitions from healthy weight to excess weight profiles. Mother's consumption of alcohol during pregnancy and mode of delivery appeared not to play any significant role in a child's chance of transitioning from one weight status to another for children.

4.4 Discussion

4.4.1 Summary of main findings

To my knowledge, my study is the first to incorporate a complex survey design in estimating transition hazard rates and confidence intervals between weight status categories in the UK childhood population. I developed, validated, and applied a multistate transition model that estimates transition rates between childhood bodyweight categories using data from the UK Millennium Cohort Study. Compared to the scenario models, which

assumed that transition probabilities were time-homogeneous across all waves, the base case model, which allowed for time-heterogeneous transition probabilities, showed closer agreement with the validation dataset for all states/bodyweight categories. My base case analysis points to a substantial decrease in the prevalence of children in the healthy weight category with increasing age and concomitant increases in the prevalence of children in both the underweight and obese categories.

I also found a substantial age gradient, with children between 3 and 7 years old showing a greater predisposition to switch from overweight or obesity to healthy weight than older children. Sex, ethnicity, family income, and maternal factors also drove weight status transitions. The homogeneous cohorts depicted in Figure 10 mirror many clinical trials targeting childhood obesity where baseline health or weight status profiles are similar within the trial arms[172,192,197,218,220,286,348,451], underscoring the importance of applying appropriate transition probabilities to economic models.

4.4.2 Comparison with the literature

My findings regarding prevalence are consistent with results from the National Child Measurement Programme (NCMP)[452], a nationally representative cross-sectional survey that assesses overweight and obesity levels in children living in England aged 4 to 5 years (reception class) and 10 to 11 years (year 6). The NCMP reported a higher prevalence of obesity and underweight in 10-11-year-olds compared to 4-5-year-olds from 2021 to 2022.[452] Similar findings are highlighted in Figure 6.

Point estimates and confidence intervals from earlier multistate transition studies based on surveys are likely biased because they do not account for survey weights and the unequal probability of selecting individuals.[415] Moreira et al. investigated bodyweight transitions in a Portuguese birth cohort of 4,887 children, with BMI measurements taken at ages 4, 7, and 10.[415] However, their analysis was not based on a nationally representative study population and did not validate results in the relevant population. Other continuous-time MSM studies relied on small sample sizes (507[414], 928[417], 1,653[413], and 2,334 children[422]) that were not representative of the population from which they were drawn. These gaps constrain the robustness of comparisons with estimates from my analyses.

My methodological approach to estimating transition rates differed fundamentally from previous studies, where transition rates and probabilities were estimated based on the assumption that variations and trends in estimates across waves were insignificant. The authors of a US-based study of 1,653 children with 11 consecutive BMI assessments between the ages of five and 12 years reported that weight status tended to persist over time, implying a negligible probability of transitioning between weight status categories.[413] Such an assumption may be reasonable when considering a restricted age group and inevitable if sample sizes are limited or lack national representativeness. I tested this underlying assumption and found it implausible over the 14 years of my study data. I, therefore, recommend that the premise of time-homogeneous transition rates should be limited only to adjacent waves of surveys to achieve the best fit to observed or population-wide data.

Compared with previous studies, my study investigated a broader range of sociodemographic characteristics and risk factors associated with childhood weight status transitions, with previous studies mainly focusing on transitions in weight status by sex, ethnicity and socioeconomic status and finding that they did matter.[413,414,417,422] While further research is needed to determine the causal mechanisms that mediate these variations in transition, ignoring subgroup analyses when conducting cost-effectiveness analyses of interventions targeting childhood excess weight may bias policy recommendations.

4.4.3 Strengths and limitations

Multistate transition modelling is a compelling instrument for investigating epidemiological patterns in childhood excess weight and quantifying them in terms of transition probabilities and hazard ratios. My results indicate that prevention and treatment interventions could have different outcomes in terms of cost-effectiveness, depending on the child's age and subgroup at implementation, assuming other components of economic evaluations, such as costs, do not vary.

My study benefits from the large sample size of the MCS and its longer time horizon (3-17 years) compared with previous studies, where the maximum follow-up was eight years.[414] My study provides for extrapolations of transition probabilities for any cycle length up to 18 years. It incorporates the survey weights and complex design of the MCS, hence producing estimates that can be applied to modelling in the UK childhood population. A further strength is the robust testing of the prior methodological assumption regarding the time homogeneity of

transition rates associated with childhood weight status categories. I justified my base case model and showed that its results best fit the observed data.

My study was not without limitations. Firstly, as with most longitudinal surveys, bodyweight status was interval censored between adjacent surveys, i.e., the exact time of transition is often unknown. In some instances, when estimating hazard rates for explanatory variables, the model estimates did not converge when there were no observed transitions within the data (Appendix D: Checking for model convergence). This limitation necessitated merging affected levels for specific covariates such as ethnicity, thus failing to provide the sufficient granularity required to investigate all sub-groups of interest. I recommend applying a half-cycle correction[453] when using my estimates of transition to design cost-effectiveness models.

Secondly, the intervals between waves were uneven. Since the assumption of time-homogeneous transition hazard rates does not hold throughout childhood, it then follows that estimates of annual transition probabilities are less accurate for adjacent waves with wider time intervals. Based on the overall model fitness for the data, I recommend that, at a minimum, future cohort studies collect biennial measurements of BMI during childhood.

Apart from sex, the analysis of additional covariates was limited to children aged 3 to 5 years, primarily due to time constraints stemming from the computational demands of the model. Moreover, certain covariates were considered more likely to exert their most significant effects during early childhood. For instance, it was reasonable to assume that covariates such as mode of delivery, gestational age, and maternal BMI during pregnancy would have a more pronounced impact on weight status transitions during this period, when related clinical complications are often observed. However, this assumption may be less applicable to time-varying covariates, such as socioeconomic status.

While the use of a cohort design offers significant strengths for estimating transition probabilities, it also has limitations compared to cross-sectional surveys like the Health Survey for England.[454] Cohort data may be influenced by time-sensitive effects, such as the implementation of new policies, which impact the entire cohort but may not be generalisable to the current UK childhood population. I note that there have been temporal changes in the prevalence of weight status categories, particularly during and since the COVID-19 pandemic. In the absence of new data, it is unclear what impact these changes have on the magnitude of effect for transition

probabilities. However, my analyses provide the best estimates of state transitions given data constraints, and future updates can be made supported by the methodological approach in this study.

I acknowledge that my model estimates are better suited for cost-effectiveness modelling within a state transition, Markov framework. State transition models are currently the most widely applied approaches for conducting economic evaluations of childhood excess weight interventions.[410] Markov models are not as data-intensive as microsimulation models, such as discrete event simulation models. The consequence is that detail-oriented microsimulation models maximise the individual-level information provided by rich databases such as the MCS, thereby robustly expressing the heterogeneity of the sample.[144] There is an opportunity to extend the MCS analysis by replicating my study using microsimulation models.

The choice of reference population or standard for assessing growth and cut-off points for defining weight status category is worth careful consideration and justification because the estimates of prevalence and transition probabilities between body weight profiles are bound to differ when different standards and cut-offs are applied. For instance, using the WHO references and cut-offs, children in Wave 2 (3-year-olds) are less likely to be classified under the overweight and obesity categories. Given its global perspective, the WHO's cautious approach in classifying children under five is partly motivated to prevent the imposition of restrictive diets on young children.[29] I adopted the British 1990 growth reference (UK90) and UK cut-offs for population monitoring, used for most published studies on obesity and overweight among children in the UK in my base case analysis[22], and replicated several analyses using the WHO references and cut-offs.[30] The trends and patterns I identified were broadly consistent using both standards and cut-offs, as the findings based on the UK cut-offs are reinforced by sensitivity analyses using the WHO cut-offs.

4.5 Conclusions

In this chapter, I present transition estimates of body weight status for a representative UK childhood population. My study demonstrated marked age-related gradients in the transitions between childhood body weight profiles, with children between the ages of 3 and 7 years more likely to move from excess weight to healthy weight than older children. The propensity for movements between weight status categories also varied by sex across all ages and was dependent on child, maternal, and sociodemographic factors. Transition estimates derived in this

chapter, along with the excess costs associated with childhood overweight and obesity (estimated in Chapters 5, 6 and 7 of this thesis), can serve as input parameters in the cost-effectiveness modelling of interventions targeting childhood excess weight.

Chapter 5: Primary Care Resource Use and Costs Associated with Childhood Weight Category

5.1 Introduction

My scoping review (Chapter 2 of this thesis) revealed significant gaps in the evidence surrounding the economic burden of childhood excess weight, particularly in the UK. A recent systematic review and meta-analysis of the global economic burden of childhood overweight and obesity further reinforced these findings.[81] Notably, only seven of the 48 studies included were conducted in Europe, specifically Germany, Ireland, and the Netherlands, underscoring the need for more research in this area.[81] In the UK, we lack national estimates of the potential excess cost of childhood overweight and obesity from electronic healthcare records (EHRs). Understanding the potential effects of childhood excess weight on health service usage and associated healthcare costs is crucial to informing healthcare policymakers and service planners, enabling them to estimate the cost implications of hypothetical and actual reductions in rates of excess weight, particularly in the context of new preventive interventions.

This chapter investigates the relationship between childhood weight status (underweight, healthy weight, overweight and obesity) and annual healthcare resource utilisation and costs from a primary care (a patient's first point of contact with healthcare[455]) perspective in the UK. Resource use counts and costs are also disaggregated by sex, age, ethnicity, and socioeconomic status. To estimate potential incremental costs (difference in costs) associated with childhood excess weight, I accessed EHRs for children from the Clinical Practice Research Datalink (CPRD) database with linkage to Hospital Episode Statistics (HES), using a retrospective cross-sectional analysis study design. CPRD is an anonymised database of primary care medical records collected in general practice surgeries in the United Kingdom.[60,456] Linked HES data for the study population form the basis for the analyses in Chapter 6.

Analyses of large cohort databases such as CPRD with population-wide record linkages offer an opportunity to establish the short- to medium-term economic consequences of childhood excess weight. Additionally, estimates

from CPRD analyses can contribute to decision-analytic modelling approaches to determine the long-term impact of childhood excess weight on health and social care services[457] and their economic sequelae.

A study published in 2017 found that among the three major EHR databases in the United Kingdom (CPRD, The Health Improvement Network and QResearch), CPRD accounted for 63.6% of publications over a ten-year period.[458] Research based on EHRs can be harnessed in various decision-making settings, including informing the parameters of economic models. In addition, CPRD-based analyses are the most widely used primary care focused sources of evidence in health technology appraisal submissions for National Institute for Health and Care Excellence (NICE) technology assessments, representing over 60% of EHR sourced submissions.[459]

In this chapter, I estimated the mean annual resource use and costs 12 months before and after body mass index (BMI) measurements during childhood visits to general practice (GP) surgeries.

5.2 Methods

5.2.1 Data sources for Chapters 5-7: CPRD and HES databases

EHRs, defined as longitudinal, individual-level electronic records containing or linking records from Electronic Medical Records (EMRs) for the purpose of sharing across healthcare settings[460], play increasingly crucial roles in population monitoring and health policy development.[461] The average use of EMRs in primary care practices across the Organisation for Economic Co-operation and Development (OECD) countries increased from 70% in 2012 to 93% in 2021.[461]

In the UK, CPRD, a not-for-profit research service covering 60 million patients, 18 million of whom are currently registered patients, is among the most widely used sources of EHR.[458,459,462] The Medicines and Healthcare Products Regulatory Agency delivers CPRD data services to researchers with funding from the National Institute for Health and Care Research (NIHR) as part of the Department of Health and Social Care.[462] The CPRD patient population is largely representative of the general population in England in terms of patient-level socioeconomic status (SES). However, a slightly higher presence in deprived areas of the UK has been acknowledged.[463]

CPRD uses two software systems to collect fully-coded patient electronic health records from GP practices: Vision® or EMIS Web®.[462] CPRD Aurum holds routinely collected data from practices using EMIS Web® electronic

patient record system software, while CPRD GOLD contains data contributed by practices using Vision® software.[464] The two systems are managed as separate databases due to differences in structure and clinical coding.[462] For instance, 78% and 94% of English patients in CPRD GOLD and CPRD Aurum had SES and rural-urban classification (RUC) data at the patient level, respectively.[463] After due consultation with my supervisors and the CPRD team, performing a feasibility count (detailed in my CPRD data application protocol in Appendix E) and referring to relevant studies[463,465], I deemed CPRD Aurum more appropriate for my thesis. This chapter focuses on the utilisation of primary healthcare resources for all causes and their costs.

The HES database is a repository for administrative data from English National Health Service (NHS) hospitals and NHS-commissioned activity in the independent sector.[466] Up to 98% of hospital activity in England is said to be funded by the NHS.[467] HES databases, comprising hospital admissions records (admitted patient care), outpatient records, accident and emergency activities, maternity, and adult critical care, are available through NHS Digital.[467,468]

The HES databases are valuable resources for a variety of study designs. HES data analyses serve various purposes, including monitoring trends and patterns in NHS hospital activity, uncovering long-term health trends, and informing national policy-making.[468] Each HES record contains comprehensive information about a patient receiving care in an NHS hospital. This includes the patient's personal details (age, gender, ethnicity), clinical information (diagnoses, operations), administrative details (methods and dates of admission and discharge dates), and geographical information (treatment location, patient's residential area).[468] The present analysis focuses on CPRD linkage with three relevant HES databases: the admitted patient care dataset (defined as hospital episodes of treatment requiring the use of a hospital bed), outpatient records (includes outpatient appointments which may be cancelled), and the accident and emergency dataset (which includes records of attendance at accident and emergency departments).[466,468]

5.2.2 Study population

My study population is restricted to England because children in CPRD Aurum are only eligible for linkage to HES data if they have a valid NHS identifier and reside in a region within England. Children were eligible for the study if they:

I. were aged two years or above;

II. had at least one contemporaneous height and weight measurement (the exposure) during a visit to a GP surgery between the 1st of January 2015 and the 30th of March 2019; and

III. could be linked to HES data.

The decision to select children from the above-mentioned timeframe was first determined by practical considerations for linkage with HES data, which is detailed in Chapter 6 but discussed briefly in this paragraph. The latest version of the Healthcare Resource Groups (HRG) currency design (a standardised classification system utilised by the National Health Service (NHS) in the UK to categorise similar treatments for the purpose of healthcare service costing and payment), known as HRG4+, was introduced in 2012/13 and fully implemented in 2014/15.[469] Substantial differences in resource categorisation in the previous version do not allow meaningful comparisons with the current classification system. Therefore, to maintain a consistent approach to costing and reduce methodological bias, it was decided to focus on a childhood cohort with height and weight measurements starting in 2015 and resource use extending 12 months before the measurements. Finally, the 30th of March 2020 time point was the date of CPRD data availability at the time of conducting this study. This date also coincides with the end of the HES financial year, which is the period from 1st of April in one calendar year to 31st of March in the following calendar year when HES data are collated, processed and finalised for dissemination.[466] Thus, children who had visited a GP practice and had their height and weight measured by 30th of March 2019 would have at least 12 complete months of data on resource use following a BMI record. The third criterion (HES data linkage) allowed me to have a common study population for all the analyses reported in Chapters 5-7.

I adopted a simplifying framework to derive a study population where each child enters the study only once to avoid double counting resource use. Double counting of resources could occur under two scenarios. In the first and most common scenario, a child could have multiple BMI measurements in one year. To mitigate this situation, it was decided to use the last BMI measurement in a calendar year as the annual index BMI measurement. In sensitivity analysis, a separate dataset was derived using the first BMI measurement each calendar year as the index BMI measurement for analyses that determine if there was a significant difference in the characteristics of the datasets based on the alternative approaches.

The second scenario is realised if a child has a BMI record in successive years (for instance, 1st of January 2015 and 1st of January 2016). Suppose both records are included in the analysis as unique observations. In that case, the resource use for the year that follows the 2015 BMI measurement (i.e. the period covering 1st of January 2015 to 31st of December 2015) would overlap with the resource use the year before the 2016 BMI measurement, resulting in double counting. Therefore, it was decided that only the last BMI record of children with multiple BMI measurements between adjacent years should be adopted as the index BMI measurement in the baseline analyses.

A considerably less common possibility in the raw dataset occurred if BMI measurements for a child were recorded across multiple, non-contiguous years, resulting in no overlap of resource use (for instance, measurements in 2015 and 2018). In theory, such measurements from the same child could be treated as unique without the risk of double counting resource use and costs. However, only 10% of the dataset consisted of children with multiple BMI measurements taken two years or more apart. In the interest of expediency, it was decided to uphold the decision rule, adopting only the last BMI record of children with multiple BMI measurements as the index BMI measurement, regardless of the proximity between multiple measurements. These procedures ensured that a study population with unique children was derived.

5.2.3 Study design for Chapters 5-7

The study design was a retrospective cross-sectional analysis. The healthcare resource use (consultations, prescriptions and tests) and healthcare costs at the primary care level were estimated over two distinct periods of time, namely:

I. one year before the date of contemporaneous height and weight measurements (date of exposure, alternatively defined as the date of index BMI measurement)
II. one year after the date of contemporaneous height and weight measurements (date of exposure, alternatively defined as the date of index BMI measurement)

The general model specification for this study in its simplified form is as follows:

Equation 1

$$Y = \beta_0 + \beta_1 X + \sum_{i=1}^{k} \beta_{2i} Z_i + \epsilon$$

where Y represents the outcome (resource use counts or costs); β_0 is the intercept; β_1 is the coefficient of the exposure variable X, weight status (categories: underweight, overweight, and obesity, with healthy weight as the referent category); β_{2i} are the coefficients of the k=5 categorical covariates Z_i (sex, age, ethnicity, Index of Multiple Deprivation and region); ϵ is the error term. Subsection 5.2.7 in this chapter describes the analytical approach to estimation in detail.

5.2.4 Exposure: weight status category

To determine levels of exposure (weight status category), I calculated BMIs as kg/m^2 and then converted them into standard deviation (SD) scores (BMI z-scores) using the British Growth Reference (UK90) for age-adjusted and sex-specific categories.[427] The dates of birth needed to calculate BMI z-scores were not provided due to CPRD's data anonymity requirements; only the month of birth was available. Therefore, I assumed that the date of birth for all children included in the study was on the 15th day of their month of birth. Conversions to BMI z-scores were implemented using Stata 17 statistical software.[429] I then categorised children in the study according to bodyweight categories for each BMI record based on the UK cut-offs for population monitoring: less than or equal to the 2nd centile (underweight), greater than the 2nd and less than the 85th centile (healthy weight), greater than or equal to the 85th and less than the 95th centile (overweight), and greater than or equal to the 95th centile (obesity).[22]

5.2.5 Use of primary care and associated costs

Primary care consultations

Consultations (patient-facing events conducted in general practice or primary care setting by a healthcare professional) were considered duplicates if they had the same patient identification ('patid'), unique identifier given to the consultation ('consid'), date associated with the event ('consdate'), encrypted, unique identifier given to the practice staff member who took the consultation in CPRD Aurum ('staffid'), job category of the staff

member who created the event ('jobcatid') and EMIS medical dictionary term (description of the observation, event or activity). I excluded duplicate consultations based on the above criteria.

Having excluded duplicates, I applied two decision rules for further exclusions. My first decision rule was designed to exclude records or EMIS medical dictionary terms associated with overhead or administrative activities that were not directly patient-facing. Exclusions were implemented by generating a list of activity terms (EMIS medical dictionary terms) in the consultation dataset to determine the inclusion rule with my supervisors, based on suggestions from clinicians and other colleagues with CPRD knowledge, and keeping only patient-facing activities.

The second consultation inclusion/exclusion criterion examined the job category/ descriptions of the staff member who created the event ('jobcatid'). First, primary care consultations with a missing staff member or job description were excluded. I then took a conservative approach, excluding entries relating to consultations with support staff and other non-healthcare professionals, such as 'Receptionists' and 'Clerical Workers', because my focus was on clinical consultations.

The next stage involved valuing and costing the consultations based on the included job descriptions of the staff conducting the consultations. The type of consultation was categorised as surgical (i.e. conducted in the surgery), home (i.e. conducted in the patient's home), or phone (conducted over the telephone), as a function of the relevant EMIS medical dictionary term. These three consultation types had different costs attributed to them as derived from the 2021 Unit Costs of Health and Social Care, Personal Social Services Research Unit (PSSRU)[470] cost compendium due to their differences in time length, where they took place and other associated costs (e.g. travel costs in the case of home consultations).

When necessary, information on staff bands or grades (e.g. GP, nurse, locum GP) was sourced from the PSSRU[470,471] cost compendium, NHS websites[472-474], or previous studies. The average cost of the three consultation types was applied if the activity term was missing or there was uncertainty about the consultation type classification. Unit costs were derived from the Unit Costs of Health and Social Care, PSSRU cost compendium[470] and adjusted to 2021/22 prices using the NHS Cost Inflation Index (NHSCII).[471] I categorised primary care consultations as occurring during the year before or after a BMI measurement based on the date associated with the consultation (variable 'consdate' or 'obsdate' if 'consdate' was missing) (see Appendix E).

Primary care prescriptions

In terms of prescriptions, I dropped duplicate observations, which were identified if rows of prescriptions had identical variables comprising the patient identifier (variable 'patid'), the date associated with the prescription ('issuedate'), the CPRD code to describe the treatment ('prodcodeid'), the EMIS product dictionary term (description of the observation, event or activity), the total quantity entered by the GP for the prescribed treatment ('quantity') and the estimated cost of the treatment to the NHS ('estnhscost').

I used the prescription costs ('estnhscost') provided by CPRD, excluding observations where 'quantity' was -1 and setting the quantity to zero if the prescription cost was zero. Finally, I categorised primary care prescriptions as occurring during the year before or after a BMI measurement based on the date associated with the prescription ('issuedate') (see Appendix E).

Primary care tests and investigations

Data on tests and investigation requests were approached similarly to consultations and prescriptions. Duplicates were excluded based on the patient identifier (variable 'patid'), the date associated with the test or investigation request ('obsdate'), and the EMIS product dictionary term (description of the observation, test, or activity).

I extracted direct access unit costs from the NHS Reference Cost 2020/21 to facilitate costing.[475] Under a direct access scheme or service, patients are directly referred from primary and community care for tests and investigations prior to specialist or secondary care consultation. Using the code list derived from the CPRD Code Browsers, I matched tests and EMIS product dictionary terms to the CPRD code to describe the respective tests or observations ('medcodeid'). Where the same 'medcodeid' had multiple unit costs for different observations, I took the average cost. The average cost for each category of tests was also applied in cases where a 'medcodeid' could not be defined for a test. Costs were adjusted to 2021/22 prices using the NHS Cost Inflation Index (NHSCII).[471] I categorised primary care tests and investigations as occurring during the year before or after a BMI measurement based on the date associated with the test or investigation request ('obsdate') (see Appendix E).

5.2.6 Covariates

Relevant literature informed the choice and selection of covariates to include in the regression analysis, which I have outlined below.[92,93] Covariates routinely included in regression-based cost-of-illness studies on childhood

excess weight include sex, age, ethnicity, socioeconomic status, region, the number of chronic conditions, early childhood/in utero environment, and mother's BMI.[88,92-94] Consequently, in my protocol (see Appendix E), I had planned to adjust my analysis using potential confounding covariates such as sociodemographic factors (age, sex, and ethnicity), family socioeconomic circumstances (patient level Index of multiple deprivation), and other relevant covariates such as neonatal factors (birth weight, gestational age at birth, birth order and family history of chronic conditions such as diabetes and hypertension). However, the collection and reporting of data on neonatal factors in the CPRD were sparse and proved impractical to include. Therefore, the factors included as covariates in this study were as follows: sex (male or female); age (continuous variable); ethnicity ("White", "Black", "Bangladeshi", "Indian", "Pakistani", "Chinese/Other Asian", "Mixed", and "Other/Uknown"); region ("North East", "North West", "Yorkshire and The Humber", "East Midlands", "West Midlands", "East of England", "London", "South East", "South West" and "Missing"); the English Index of Multiple Deprivation (IMD)[66] score ("Highest quintile" (the least deprived quintile), "Fourth quintile", "Third quintile", "Second quintile", and "Lowest quintile" (the most deprived quintile)). CPRD provided region and ethnicity data, while IMD data were obtained using the HES-linked datasets. HES-linked datasets were also used to validate and update CPRD data on ethnicity where relevant.

5.2.7 Analytical Approach for Chapters 5-7

I generated descriptive statistics detailing the study population's BMI distribution, weight status categories, and sociodemographic characteristics. In addition, I generated estimates of the mean and total resource use and costs for the cohort and graphed the distribution of the resource use and costs in the cohort. As recommended in the literature, my approaches to model selection for estimating healthcare resource use and costs were predicated on statistical and theoretical considerations, as well as parsimony.[476-478] These approaches are laid forth in the rest of this subsection.

Model specification for healthcare resource use

Given the high proportion of zero counts in resource utilisation that typically characterises resource categories of health care services, my approach to estimating resource use (number of consultations, prescriptions and tests) involved the application of two candidate estimation strategies: the zero-inflated negative binomial regression (ZINB) model and the zero-inflated Poisson regression (ZIP) model.[97,479,480] Both estimation strategies are often

deemed superior to their standard forms (the Poisson and negative binomial regression models) for analysing count data (outcomes characterised by discrete and non-negative integers) with excess zero counts.[481] The ZINB and ZIP models are zero-augmented mixture models consisting of a zero-inflated component that models the probability of an excess zero (usually using a logistic regression) and a count component that models the count outcome, which could be a zero count or a positive whole number, using either a negative binomial or a Poisson regression.[479] Zero-inflated mixture models assume that while the positive counts arise from the decision to utilise healthcare, the zeros emanate from two sources: genuine zero counts and zeros due to a separate process.[479,480] In the context of this research, the zero-inflated framework can be applied to the outcomes (number of consultations, prescriptions or tests). For instance, a plausible assumption regarding GP visits might be that the childhood population consists of two groups: children who would never consult a GP and children who would. A child with zero records of consulting a GP during the year before or after the index BMI measurement might be someone who would never visit (a genuine zero). On the other hand, the zero record might be from a child who would consult a GP but happened not to during the years of interest straddling the index BMI measurement. In the zero-augmented, maximum likelihood (ML) regression coefficients are typically estimated using the iterative weighted least squares algorithm.[479]

The following ZINB equations specify the count models applied in this study's estimation of resource use counts. Equation 2 represents the first component (zero-inflation model) and uses logistic regression to model the log-odds of an excess zero (probit model can also be specified).

Equation 2

$$logit\left(Pr\left(Y=0\middle|X,Z\right)¿=\alpha_0+\alpha_1 X+\sum_{i=1}^{k}\alpha_{2i}Z_i\right.$$

where Y represents the outcome (resource use counts); α_0 is the intercept for the logistic regression; $\alpha_1$is the coefficient of the exposure variable X, weight status (categories: underweight, overweight, and obesity, with healthy weight as the referent category); α_{2i} are the coefficients of the k=5 categorical covariates Z_i (sex, age, ethnicity, Index of Multiple Deprivation and region).

Equation 3 describes the second component (the count model), which models the expected count outcome (resource use), including only the non-zeros.

Equation 3

$$\log ¿¿ = \beta_0 + \beta_1 X + \sum_{i=1}^{k} \beta_{2i} Z_i + \epsilon$$

where Y represents the outcome (resource use counts); β_0 is the intercept; β_1 is the coefficient of the exposure variable X, weight status (categories: underweight, overweight, and obesity, with healthy weight as the referent category); β_{2i} are the coefficients of the k=5 categorical covariates Z_i (sex, age, ethnicity, Index of Multiple Deprivation and region); ϵ is the error term (assumed to follow a negative binomial distribution to account for overdispersion).

Another type of model indicated for analysing non-negative, integer-valued count data with excess zeros is the hurdle model.[97,479,480] Like the zero-inflated mixture models (ZINB and ZIP), hurdle models are extensions of the standard Poisson and negative binomial models. However, their underlying assumptions for handling zeros and positive counts differ from the zero-inflated mixture models.[97,479] Hurdle models combine a zero hurdle component, which models the probability of zero versus non-zero resource use counts, with zero-truncated Poisson or negative binomial distributions to model the distribution of positive counts, given that the count is zero. Hurdle models assume that the zero counts are explicitly generated separately from the positive counts.[479] They employ the conceptual justification frequently used for the two-part models described in detail below in the subsection on the model specification for healthcare costs.[97,480]

In the literature, approaches for selecting an appropriate count data model vary in complexity and can sometimes be contentious.[97,478,482] These approaches include checking model fit, overdispersion (examining the mean and variance of the count data), and theoretical context. To determine the preferred model among all three models (ZINB, ZIP and hurdle models), my underlying approach involved comparing the goodness of fit using Akaike Information Criterion (AIC) and Bayesian information Criterion (BIC) statistics.[480,483] If all models achieved convergence, I chose the model with the lowest AIC and BIC values as my preferred model. I controlled for the earlier discussed vector of covariates in the zero-inflated and count components of the zero-augmented and the

hurdle models. Both parts of the ZINB and ZIP models produce separate coefficients, which are not intuitively interpretable. Therefore, I also used the margins commands in Stata to predict the total resource use count and the marginal or incremental effects for the combined versions of the zero-augmented models.[484] I also used the Stata margins commands to predict the hurdle model's overall effects if appropriate. Coefficients estimated from both parts or components of the chosen model were also reported (Appendix E).

Model specification for healthcare costs

As continuous variables, the cost variables (consultations, prescriptions and tests) required a different analytical approach than modelling counts of resource utilisation. Several regression approaches, including OLS regression and the generalised linear model (GLM) with gamma distribution, have been applied to modelling observational healthcare cost data.[97,484,485] Healthcare cost data is expected to be inherently non-linear and right-skewed due to the tendency for a large proportion of the population to accrue low or zero costs.[486] Therefore, the normality assumptions (homoscedasticity) underlying the OLS regression are often violated.[487] Log transformations of cost data attempt to address this problem, but re-transformation introduces potential biases.[487] Further, a one-part model approach (Equation 1) does not take zero-cost observations into account.[485]

The two-part models are widely recognised as the statistical models of choice for handling the substantial skewness and mass of zeros and a continuous distribution of positive values often seen in healthcare cost data.[97,484] The two-part model applied to cost data is the analogue of the earlier described hurdle model for count data analysis.[97] The first part (the binary component) describes the probability of observing a non-zero cost (typically using logistic or probit regression), while the second part estimates the mean costs of a resource use category, given that a cost was incurred (usually using a GLM).[479,484]

The following equations specify the two-part GLM models applied in this study. The first part (Equation 4) typically uses logistic regression to model the probability that the outcome Y (costs) is greater than zero.

Equation 4

$$logit\left(Pr\left(Y>0\middle|X,Z\right)¿=\alpha_0+\alpha_1 X+\sum_{i=1}^{k}\alpha_{2i}Z_i$$

where Y represents the outcome (costs); α_0 is the intercept for the logistic regression; $\alpha_1$is the coefficient of the exposure variable X, weight status (categories: underweight, overweight, and obesity, with healthy weight as the referent category); α_{2i} are the coefficients of the k=5 categorical covariates Z_i (sex, age, ethnicity, Index of Multiple Deprivation and region).

The second part (Equation 5) uses a GLM with a suitable link function $g(.)$ to model the positive values of the cost outcome Y.

Equation 5

$$g¿¿=\beta_0+\beta_1 X+\sum_{i=1}^{k}\beta_{2i}Z_i+\epsilon$$

where Y represents the outcome (costs); β_0 is the intercept of the GLM; β_1 is the coefficient of the exposure variable X, weight status (categories: underweight, overweight, and obesity, with healthy weight as the referent category); β_{2i} are the coefficients of the k=5 categorical covariates Z_i (sex, age, ethnicity, Index of Multiple Deprivation and region); and ϵ is the error term in the GLM (assumed to follow a specific distribution depending on the link function).

In the first instance, I applied the two-part GLM models widely used to estimate the excess costs of childhood overweight and obesity in related economic studies.[88,92,93,97] Consistent with the literature and conventional wisdom, I specified a logit model in the first part and a GLM with log link and gamma distribution in the second part to account for the non-linear relationship between BMI and healthcare costs.[88,93,94,97,484,485] I controlled for the set of covariates and demographic factors listed earlier in the first and second parts of the two-part GLM model.[484] Both parts of the two-part GLM model produce separate coefficients, which may not be intuitively interpretable. Analogous to the approach for handling resource use counts, I used the margins commands to predict the total cost and the marginal effects for the combined versions of the two-part models.[484]

Evidence from the literature is mixed regarding what tests or sets of tests can be used to select an optimal link function[477,488-490], and regression-based cost-of-illness studies in childhood excess weight have taken different approaches.[88,92,93] As part of my modelling diagnostic approach, I used the Park test/GLM family test to assess the

variance structure or candidate family distributions and the Box-Cox transformation/regression to evaluate the link function of the GLM distribution.[491] The Park test examines the relationship between the residuals' variance and the model's predicted values, while the Box-Cox regression identifies a transformation of the dependent variable that makes the relationship between the predictors and the transformed dependent variable as linear as possible.[491] Whenever the diagnostic test results were uncertain, I used the outputs of AIC and BIC as pragmatic guides for selecting the combined two-part GLM model.[477,489,490]

In recognition of the influence that extreme outliers can have on GLM models[477,492], I adopted the approach taken by Menard and Biener et al., which excluded extreme data points in my sensitivity analysis.[93,492] However, I did not remove outliers or influential data points in my primary analyses if, after checking, they were not due to coding or reporting errors.[477,492] I conducted clustered regression analyses at the patient level to effectively account for within-patient correlation in resource utilisation.[484] I ran all models using Stata 17 statistical software.[481]

5.3 Results

5.3.1 Study Population

For the primary analysis, a sample of 268,469 unique children was identified after retaining only the last BMI measurement for each child in the dataset. Of the 268,469 unique children, 238 with missing IMD data were excluded. The numbers of children with missing/unknown data on their region (3,307) and ethnicity (40,466) were substantial and, therefore, not excluded from the dataset of unique children. Therefore, I generated a category missing/unknown category for both covariates. My final study population was 268,231 unique children aged two years and above.

The sociodemographic and socioeconomic characteristics of the study population are reported in Table 16. The percentage of boys was higher, at 55.26%, than the percentage of girls. The sample size in the study population decreased significantly during mid-childhood and early adolescence, declining from 12,393 children at 11 years of age to 2,234 children at 12 years of age, with only 53 children recorded for age 15 years. Children in the healthy weight category accounted for 67.27% of all children compared to other weight status categories (underweight: 4.10%; overweight: 11.54%; and obesity: 17.09%). Children of Bangladeshi origin were the least represented (1.7%) ethnic group. White children accounted for 63.12% of the study population. Children from London were

the most represented group (at 24.10%) by region, while their counterparts in the North East and Yorkshire and The Humber were the least represented at 3.47% and 3.57%, respectively. Children residing in areas with the highest levels of socioeconomic deprivation were the most represented at 27.82% and 23.10% for the lowest and second lowest quintiles, respectively, compared to 15.36% in the highest quintile.

In a sensitivity analysis, I replicated the abovementioned methods. However, I designated the first BMI measurement as the index measurement, which did not change the overall sample of unique children.

Table 16 Descriptive statistics for study population of 268,231 unique children

Variable	Variable levels	n	%
Sex			
	Boys	148,230	55.26
	Girls	120,001	44.74
Mean (SD) age in years			6.82 (2.66)
Age distribution			
	Two years old	20,336	7.58
	Three years old	28,071	10.47
	Four years old	28,275	10.54
	Five years old	33,539	12.50
	Six years old	31,120	11.60
	Seven years old	32,145	11.98
	Eight years old	30,712	11.45
	Nine years old	26,576	9.91
	Ten years old	21,310	7.94
	11 years old	12,393	4.62
	12 years old	2,234	0.83
	13 years old	1,003	0.37
	14 years old	464	0.17
	15 years old	53	0.02
Distribution of BMI category			
	Underweight	11002	4.10
	Healthy weight	180438	67.27
	Overweight	30950	11.54
	Obesity	45841	17.09
Ethnicity			
	White	169,299	63.12
	Black	16,708	6.23
	Bangladeshi	4,554	1.70
	Indian	7,665	2.86
	Pakistani	10,875	4.05

Variable	Variable levels	n	%
	Chinese/Other Asian	7,778	2.90
	Mixed	10,886	4.06
	Other/Uknown	40,466	15.09
Region			
	North East	9,302	3.47
	North West	45,577	16.99
	Yorkshire and The Humber	9,585	3.57
	East Midlands	5,252	1.96
	West Midlands	43,491	16.21
	East of England	12,433	4.64
	London	64,644	24.10
	South East	43,206	16.11
	South West	31,434	11.72
	Missing	3,307	1.23
Index of Multiple Deprivation			
	Fifth quintile (lowest level of deprivation)	41,201	15.36
	Fourth quintile	42,887	15.99
	Third quintile	47,562	17.73
	Second quintile	61,969	23.10
	First quintile (highest level of deprivation)	74,612	27.82

To improve and aid comparisons between my dataset and one that may be derived from a nationally representative survey, such as the National Child Measurement Programme (NCMP), England, I also report BMI distributions for children aged 4-5 (Reception) and 10-11 years (Year 6) in my dataset as well the corresponding prevalence from the NCMP 2022/23 survey (see Table 17).[493] In the NCMP survey for 2022/23, the BMI distribution for Reception children (4-5 years) was: underweight 1.20%; healthy weight 77.50%; overweight 12.20%; and obesity 9.20%.[493] For Year 6 children (10-11 years), the 2022/23 BMI category prevalence according to the NCMP was: underweight 1.60%; healthy weight 61.90%; overweight 13.90%; and obesity 22.70%.[493] The underweight category is the least represented in the NCMP compared with my sample.

Table 17 BMI distributions for the CPRD-HES study population compared with the NCMP 2022/23 survey prevalence for children at ages 4-5 and 10-11

Variable	Variable levels	n	My sample population (%)	NCMP 2022/23 survey (%)
Distribution of BMI category at ages 4-5 (reception) - boys and girls				
	Underweight	2,997	4.85	1.20

Healthy weight	44,258	71.6	77.50
Overweight	6,833	11.05	12.20
Obesity	7,726	12.5	9.20
Distribution of BMI category at ages 4-5 (reception) - boys			
Underweight	1,820	5.36	1.50
Healthy weight	23,966	70.54	77.00
Overweight	3,778	11.12	12.20
Obesity	4,411	12.98	9.30
Distribution of BMI category at ages 4-5 (reception) - girls			
Underweight	1,177	4.23	0.80
Healthy weight	20,292	72.89	78.10
Overweight	3,055	10.97	12.10
Obesity	3,315	11.91	9.00
Distribution of BMI category at ages 10-11 (year 6) - boys and girls			
Underweight	1,213	3.6	1.60
Healthy weight	19,488	57.82	61.90
Overweight	4,352	12.91	13.90
Obesity	8,650	25.67	22.70
Distribution of BMI category at ages 10-11 (year 6) - boys			
Underweight	592	3.08	1.40
Healthy weight	10,826	56.3	59.70
Overweight	2,486	12.93	13.80
Obesity	5,324	27.69	25.10
Distribution of BMI category at ages 10-11 (year 6) - girls			
Underweight	621	4.29	1.70
Healthy weight	8,662	59.84	64.20
Overweight	1,866	12.89	14.00
Obesity	3,326	22.98	20.10

Furthermore, I reproduce time series graphs showing trends in childhood weight status prevalence in Reception and Year 6 from 2006/07 to 2022/23 (Figure 11 and Figure 12). Both figures show peaks in 2020/21 and the lowest prevalences in 2022/23.

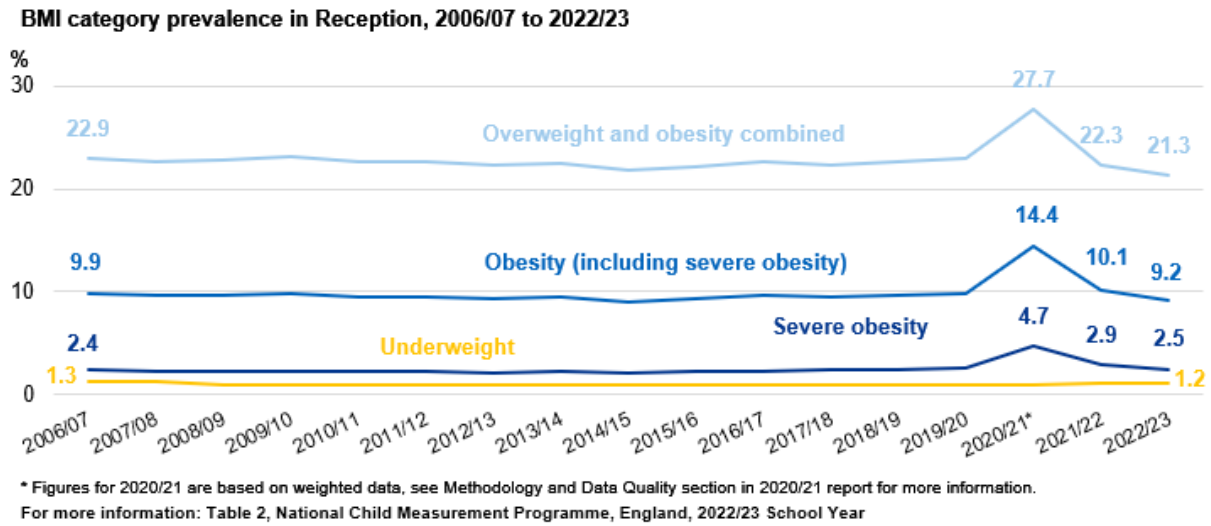

Figure 11 Time series prevalence of weight status categories in Reception from 2006/07 to 2022/23 (source: [493])

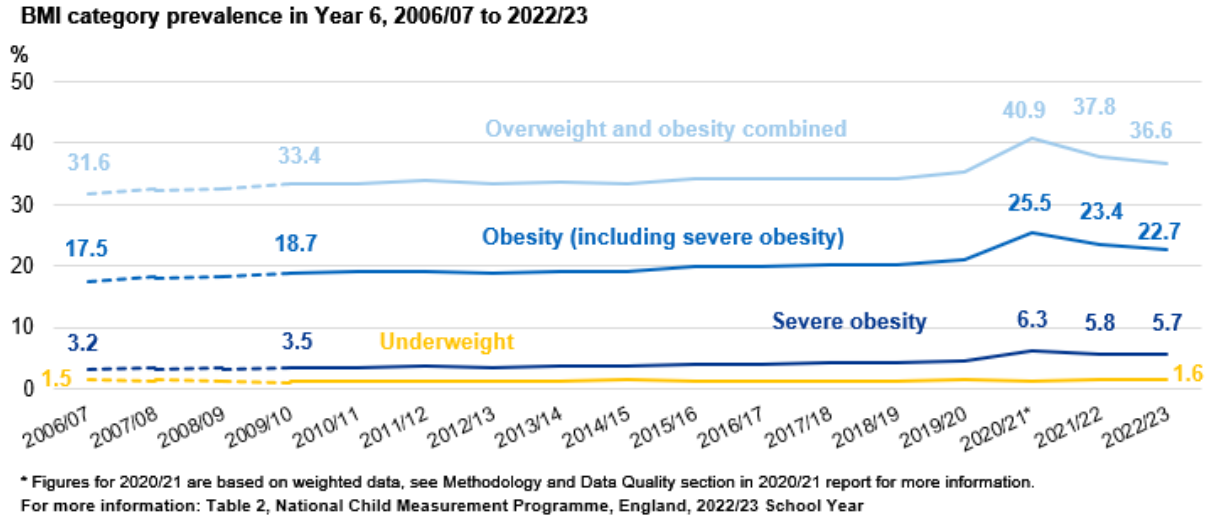

Figure 12 Time series prevalence of weight status categories in Year 6 from 2006/07 to 2022/23 (source: [493])

5.3.2 Model specification

There are no built-in Stata programmes for resource use variables (consultations, prescriptions, and tests) to generate whole model outputs for a hurdle model. Using codes like those developed by Deb and colleagues[480] was computationally prohibitive in my dataset. I have, therefore, restricted my analysis to ZINB and ZIP models. AIC and BIC comparisons between the ZINB and ZIP models (with lower values indicating better fit: see Appendix E) show that the ZINB model fits the data better than the ZIP model. However, p-values for the likelihood ratio Chi-squared test show that both models were statistically significant, and their predicted means (margins) and

standard errors were similar. I report ZINB model estimates, except when the ZINB iterations did not converge for some covariates in some resource use types when estimating the whole model. I reported ZIP model estimates in such cases and noted them in table footnotes.

For costs, when comparing the identity (or linear), log and power links, the restricted log-likelihood and Chi-squared statistic tended to favour the log link function (see Appendix E for Stata formula for Box-Cox transformation and outputs). Using the modified Park test, the coefficient of the predicted cost favoured the Gamma family, although the Gaussian and Poisson distributions performed well in a few instances. However, AIC and BIC estimates strongly favoured using the Gamma family with a log link function in all datasets. Therefore, I report model outputs derived from a two-part model with a logit first part and GLM second part with the log link and gamma distribution for the primary analysis of costs. These estimates are reported in later sections of this chapter. Statistical significance is set at a threshold of $p < 0.05$ throughout the results and discussion sections.

5.3.3 Consultations – descriptive results and model estimates for resource use counts and costs

Appendix E provides a detailed breakdown of the data cleaning and processing for the consultation record data. Tables Table 18 and Table 20 report descriptive statistics about primary care consultations. In the year before the index BMI measurement, 197,690 children had 1,027,863 cumulative consultations in GP surgeries, while in the year after the index BMI measurement, 235,052 children visited GP surgeries, accounting for 1,127,181 cumulative consultations.

Table 18 Mean number of primary care consultations per child in the study population of 268,231 children

	Mean	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	3.832	4.729	0	104	3.814	3.850
One year after BMI measurement	4.202	4.261	0	98	4.186	4.218

The predicted mean consultations per child (adjusted for childhood weight status and all covariates) in the years before and after the index BMI measurement were 3.833 (95% CI: 3.815-3.851) and 4.202 (95% CI: 4.187-4.218), respectively. These predicted numbers represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two parts of the model are

reported in Appendix E. Table 19 shows the estimated mean number of consultations by weight status category and covariates, as well as the incremental effects with respect to the referent levels of individual covariates. On average, children in the obesity categories utilised an additional 0.313 and 0.371 more consultations than children in the healthy weight status category in the year before and after an index BMI measurement, respectively (Table 19, column "Incremental effects"). Girls received an additional 0.280 and 0.317 primary care consultations than boys in the year before and after an index BMI measurement, respectively. These differences were statistically significant. The distribution of mean number of consultations by age took a U-shape, with children aged 2 and 15 years reporting the highest number of consultations and children aged 7 years reporting the lowest number. In the year before an index BMI measurement, children of Bangladeshi origin had 1.436 more consultations at the primary care level than white children (the reference group for ethnicity), and this difference was statistically significant. The number of consultations increased slightly with worsening socioeconomic status Children in the East Midlands had more consultations than their peers in London (the reference group for region). This difference was statistically significant in the year before an index BMI measurement but not statistically significant in the year after.

Table 19 Mean and incremental number of primary care consultations one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after‡			
Variable	Mean number of consultations	Standard error	Incremental effects	Standard error	Mean number of consultations	Standard error	Incremental effects	Standard error
BMI								
Underweight	3.581***	0.041	-0.199***	0.043	4.411**	0.039	0.287**	0.040
Healthy weight (referent)	3.780***	0.011	-	-	4.124***	0.010	-	-
Overweight	3.877***	0.026	0.097***	0.029	4.160**	0.024	0.036**	0.026
Obesity	4.093***	0.024	0.313***	0.026	4.496**	0.021	0.371**	0.023
Sex								
Boys (referent)	3.709***	0.011	-	-	4.061**	0.010	-	-
Girls	3.989***	0.014	0.280***	0.018	4.378**	0.013	0.317**	0.016
Age								
2 years (referent)	5.185***	0.040	-	-	5.693**	0.036	-	-
3 years	5.035***	0.032	-0.150***	0.051	5.480**	0.028	-0.212**	0.045
4 years	4.837***	0.031	-0.348***	0.051	4.395**	0.026	-1.298**	0.044
5 years	3.851***	0.026	-1.334***	0.047	3.916**	0.023	-1.777**	0.042
6 years	3.498***	0.025	-1.687***	0.047	3.841**	0.022	-1.851**	0.042
7 years	3.090***	0.022	-2.095***	0.046	3.663**	0.021	-2.030**	0.042

Variable	Year before				Year after‡			
	Mean number of consultations	Standard error	Incremental effects	Standard error	Mean number of consultations	Standard error	Incremental effects	Standard error
8 years	3.171***	0.023	-2.014***	0.046	3.747**	0.022	-1.946**	0.042
9 years	3.184***	0.025	-2.001***	0.047	3.823**	0.024	-1.87**	0.043
10 years	3.273***	0.029	-1.912***	0.049	3.790**	0.027	-1.902**	0.045
11 years	3.345***	0.038	-1.840***	0.055	4.150**	0.038	-1.543*	0.052
12 years	3.458***	0.088	-1.727***	0.097	4.301*	0.092	-1.392*	0.098
13 years	3.877***	0.176	-1.308***	0.181	4.422	0.142	-1.271	0.146
14 years	4.102***	0.218	-1.083***	0.221	4.052	0.191	-1.641	0.194
15 years	5.234***	0.568	0.049	0.569	3.103	0.416	-2.590	0.418
Ethnicity								
Other/ Unknown	2.631***	0.020	-1.284***	0.024	3.822**	0.019	-0.261**	0.022
Bangladeshi	5.351***	0.084	1.436***	0.085	5.795*	0.074	1.712*	0.075
Black	3.943***	0.039	0.028	0.041	4.346**	0.034	0.263**	0.036
Chinese/Other Asian	4.508***	0.060	0.594***	0.062	4.851*	0.050	0.768*	0.052
Indian	4.811***	0.061	0.897***	0.062	5.065*	0.053	0.982*	0.055
Pakistani	4.964***	0.052	1.049***	0.054	5.378**	0.047	1.295**	0.048
White (referent)	3.914***	0.012	-	-	4.083**	0.011	-	-
Mixed	4.044***	0.046	0.130***	0.048	4.382**	0.041	0.299**	0.042
IMD								
Fifth quintile: least deprived (referent)	3.767***	0.023	-	-	4.053**	0.021	-	-
Fourth quintile	3.761***	0.022	-0.006	0.031	4.069**	0.020	0.017**	0.028
Third quintile	3.862***	0.021	0.095***	0.031	4.161**	0.019	0.108**	0.028
Second quintile	3.873***	0.019	0.106***	0.031	4.220**	0.017	0.167**	0.027
First quintile: most deprived	3.865***	0.018	0.098***	0.030	4.368**	0.016	0.316**	0.027
Region								
North East	3.715***	0.046	-0.071	0.051	3.720**	0.039	-0.784**	0.044
North West	4.061***	0.022	0.275***	0.031	4.074**	0.020	-0.430**	0.028
Yorkshire and The Humber	3.762***	0.048	-0.025	0.052	3.909**	0.042	-0.594**	0.047
East Midlands	4.203***	0.064	0.416***	0.067	4.652*	0.058	0.149*	0.061
West Midlands	3.565***	0.021	-0.222***	0.030	4.134**	0.019	-0.37**	0.027
East of England	3.553***	0.042	-0.233***	0.047	3.918**	0.038	-0.585**	0.043
London (referent)	3.786***	0.021	-	-	4.503**	0.018	-	-
South East	3.826***	0.023	0.040	0.031	4.116**	0.021	-0.388**	0.028
South West	4.092***	0.028	0.306***	0.036	4.332**	0.027	-0.171**	0.033
Missing	4.205***	0.079	0.419***	0.082	3.772*	0.064	-0.732*	0.067

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10; ‡ Estimates based on ZIP model as ZINB model did not converge.

The mean costs per child were £125.47 (95% confidence interval [CI]: 124.81- 126.13) and £129.82 (95% CI: 129.22-130.43) in the year before and after the index BMI measurement. The total costs of consultations were £33,655,164.74 in the year before and £34,822,824.92 in the year after the index BMI measurement.

Table 20 Mean primary care consultation costs per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	125.47	173.55	0	4,069.28	124.81	126.13
One year after BMI measurement	129.82	158.84	0	4,180.53	129.22	130.43

Figure 13 depicts the distribution of consultation costs, showing the frequency of data points in bins and kernel density plots with smoothed estimates of the distribution. It can be observed that costs are heavily right-skewed.

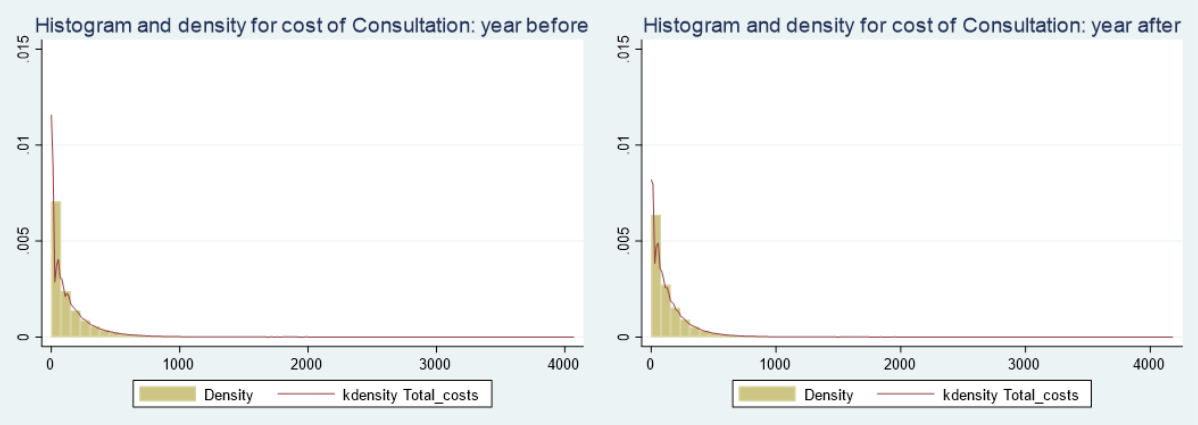

Figure 13 Combined histogram and kernel density plot of consultation costs in the years before and after a BMI measurement

The predicted total costs of primary care consultations per child (adjusted for childhood weight status and all covariates) in the year before and after a BMI measurement were £125.55 (95% CI: 124.90-126.20) and £129.90 (95% CI: 129.31-130.49), respectively. Table 21 presents the modelled mean costs of consultations by weight status category and covariates, as well as the incremental effects with respect to the referent levels of individual covariates. In the year before a BMI measurement, the mean total costs of consultations were highest in children with obesity. In comparison to healthy weight children, childhood obesity cost an additional £9.92 and an additional £12.37 (statistically significant) in the year before and after an index BMI measurement, respectively (Table 21, column “Incremental costs”). In the year following the index BMI measurement, the underweight

status incurred the highest primary care consultation costs (£18.63 relative to healthy weight). These differences were statistically significant. On average, girls accrued more annual primary care consultation costs in the years that straddled an index BMI measurement by £11.96 and £14.61 in the year before and after, respectively, a statistically significant cost difference. The mean costs of consultations were U-shaped, with children aged 2 and 15 years reporting the highest and those aged 7 reporting the lowest costs of consultations, respectively. Older children had statistically significant higher costs compared to the 2-year-olds (the reference group). The cost of primary care consultations was higher in children of Bangladeshi origin than for any other ethnic group. The mean costs of consultations increased with worsening socioeconomic status. However, no statistically significant difference was observed compared with costs in the highest quintile (least deprived) in the year before an index BMI measurement. The cost of primary care consultations was higher among children in London than in other regions in the year before and after a BMI measurement, and these cost differences were statistically significant.

Table 21 Mean and incremental costs of primary care consultations one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean cost of consultations	Standard error	Incremental costs	Standard error	Mean cost of consultations	Standard error	Incremental costs	Standard error
BMI								
Underweight	118.85***	1.520	-5.09***	1.573	145.98***	1.520	18.63***	1.548
Healthy weight (referent)	123.93***	0.398	-	-	127.35***	0.398	-	-
Overweight	125.75***	0.966	1.81*	1.043	124.64***	0.966	-2.72***	0.941
Obesity	133.85***	0.856	9.92***	0.946	139.72***	0.856	12.37***	0.870
Sex								
Boys (referent)	120.22***	0.419	-	-	123.37***	0.419	-	-
Girls	132.18***	0.524	11.96***	0.669	137.98***	0.524	14.61***	0.615
Age								
2 years (referent)	174.75***	1.471	-	-	174.88***	1.471	-	-
3 years	158.14***	1.150	-16.60***	1.862	160.78***	1.150	-14.09***	1.668
4 years	149.00***	1.108	-25.76***	1.839	139.07***	1.108	-35.81***	1.632
5 years	127.47***	0.950	-47.28***	1.749	124.46***	0.950	-50.42***	1.561
6 years	118.12***	0.924	-56.63***	1.734	121.88***	0.924	-52.00***	1.560
7 years	104.28***	0.839	-70.47***	1.691	115.80***	0.839	-59.08***	1.545
8 years	106.41***	0.864	-68.33***	1.706	116.56***	0.864	-58.32***	1.550
9 years	105.92***	0.936	-68.83***	1.744	116.83***	0.936	-58.05***	1.591
10 years	106.97***	1.066	-67.77***	1.818	114.15***	1.066	-60.73***	1.660
11 years	107.78***	1.408	-66.97***	2.039	123.32***	1.408	-51.55***	1.923
12 years	113.42***	3.291	-61.32***	3.607	132.83***	3.291	-42.05***	3.781
13 years	127.05***	6.348	-47.69***	6.518	139.28***	6.348	-35.60***	5.624
14 years	135.09***	8.904	-39.65***	9.024	128.41***	8.904	-46.47***	8.071

Variable	Year before				Year after			
	Mean cost of consultations	Standard error	Incremental costs	Standard error	Mean cost of consultations	Standard error	Incremental costs	Standard error
15 years	178.71***	22.048	3.96	22.099	99.27***	22.048	-75.61***	19.156
Ethnicity								
Other/Unknown	84.56***	0.733	-43.02***	0.867	114.64***	0.733	-10.75***	0.837
Bangladeshi	174.82***	3.077	47.24***	3.126	181.69***	3.077	56.30***	2.862
Black	127.05***	1.404	-0.53	1.510	133.44***	1.404	8.05***	1.357
Chinese/Other Asian	150.89***	2.254	23.31***	2.315	154.90***	2.254	29.52***	2.000
Indian	163.42***	2.278	35.84***	2.329	165.33***	2.278	39.94***	2.099
Pakistani	172.96***	2.041	45.38***	2.091	179.74***	2.041	54.35***	1.924
White (referent)	127.58***	0.435	-	-	125.39***	0.435	-	-
Mixed	133.55***	1.683	5.97***	1.744	136.35***	1.683	10.96***	1.610
IMD								
Fifth quintile: least deprived (referent)	125.33***	0.853	-	-	128.17***	0.853	-	-
Fourth quintile	125.31***	0.811	-0.02	1.150	127.96***	0.811	-0.21	1.074
Third quintile	125.72***	0.783	0.39	1.146	127.54***	0.783	-0.63	1.055
Second quintile	125.41***	0.701	0.09	1.121	128.77***	0.701	0.60	1.028
First quintile: most deprived	125.81***	0.655	0.49	1.099	134.52***	0.655	6.34***	1.030
Region								
North East	119.77***	1.615	-16.82***	1.844	109.63***	1.615	-44.93***	1.591
North West	127.00***	0.772	-9.60***	1.170	117.25***	0.772	-37.32***	1.050
Yorkshire and The Humber	120.16***	1.730	-16.43***	1.946	112.21***	1.730	-42.35***	1.729
East Midlands	130.07***	2.321	-6.52***	2.480	137.86***	2.321	-16.71***	2.349
West Midlands	114.56***	0.775	-22.03***	1.154	121.86***	0.775	-32.71***	1.058
East of England	123.57***	1.573	-13.02***	1.803	128.15***	1.573	-26.41***	1.677
London (referent)	136.59***	0.834	-	-	154.56***	0.834	-	-
South East	120.41***	0.785	-16.18***	1.172	124.46***	0.785	-30.10***	1.099
South West	126.29***	0.956	-10.30***	1.294	128.58***	0.956	-25.98***	1.205
Missing	133.79***	2.948	-2.8	3.080	115.63***	2.948	-38.94***	2.580

Significance codes: *** for *p*-values ≤ 0.01, ** for *p*-values ≤ 0.05, * for *p*-values ≤ 0.10.

The average incremental effects reported in Table 21 do not fully convey the complex relationships between the exposure variable (BMI category), covariates and the outcome or dependent variable (primary care consultation costs). To improve the interpretation of results by investigating potential effect modification by covariates, I calculated the incremental effects of the BMI category on costs separately for each covariate (see Appendix E for point estimates and their 95% CIs). These calculations are expressed graphically in Figure 14-Figure 18. For each covariate level, an error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Across all covariates, excess costs associated with obesity weight status were sustained in the year preceding or following the index BMI measurement. However, in the year after the index BMI measurement, these additional costs were lower than those of children in the underweight category. Both findings were statistically significant. Unlike in the year after the index BMI measurement, in the year before, the underweight category recorded the lowest costs for all covariates. With respect to healthy weight, primary care consultation costs in the overweight category were statistically insignificant in the year before a BMI measurement but lowest in the year after and statistically significant.

In the obesity category, girls appeared to incur a higher cost than boys. However, this within-category difference was not statistically significant. Costs tended to follow a U-shape, with the lowest costs accrued between the ages of seven and ten compared to 2-year-olds in the obesity category. These within-category differences were statistically significant. Compared to their peers, higher costs were estimated for children of Bangladeshi origin, while black and white children incurred the least costs. Economic costs across IMD levels weren't markedly different, and children living in East of England and London incurred more consultation costs than their counterparts in other regions. Apart from age, the variations in costs within the obesity category were generally not statistically significant for the majority of covariates.

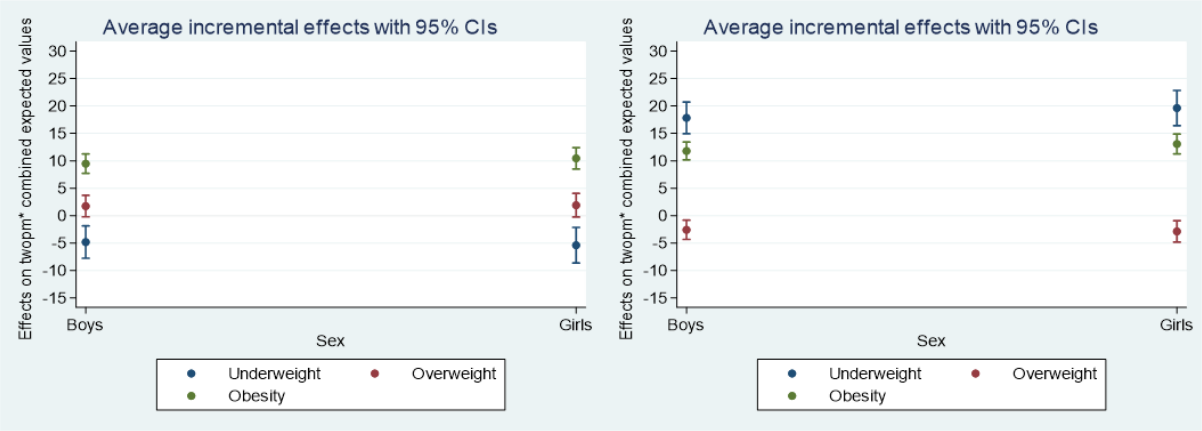

Figure 14 The relationship between consultation costs (£) and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

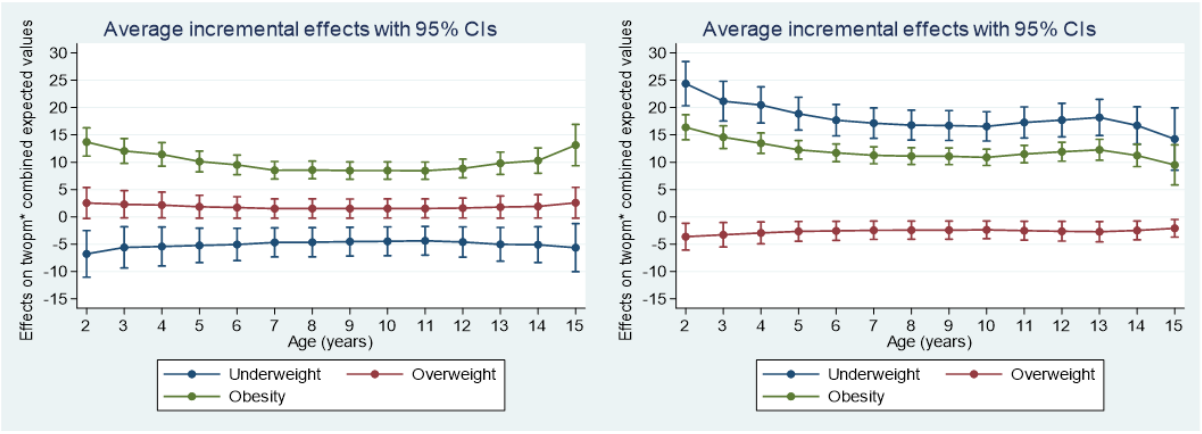

Figure 15 The relationship between consultation costs (£) and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

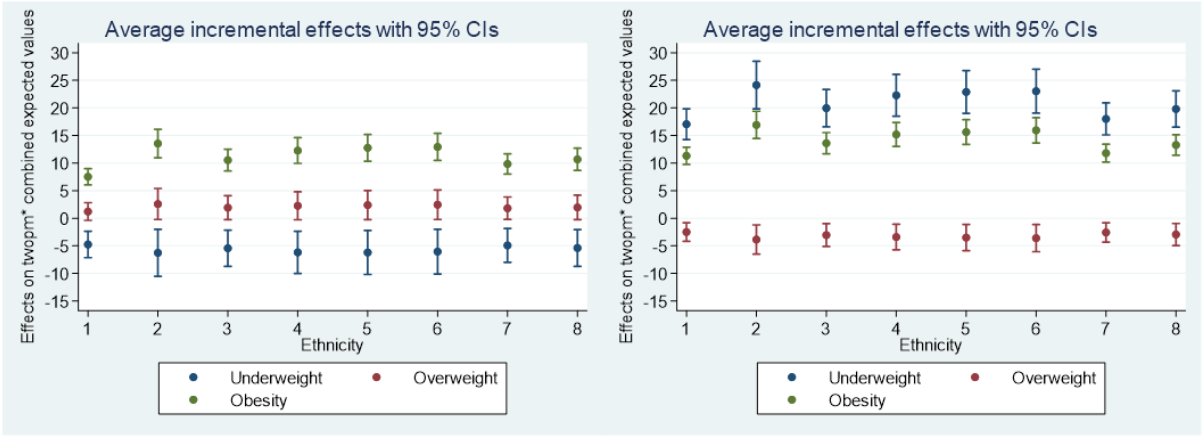

Figure 16 The relationship between consultation costs (£) and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

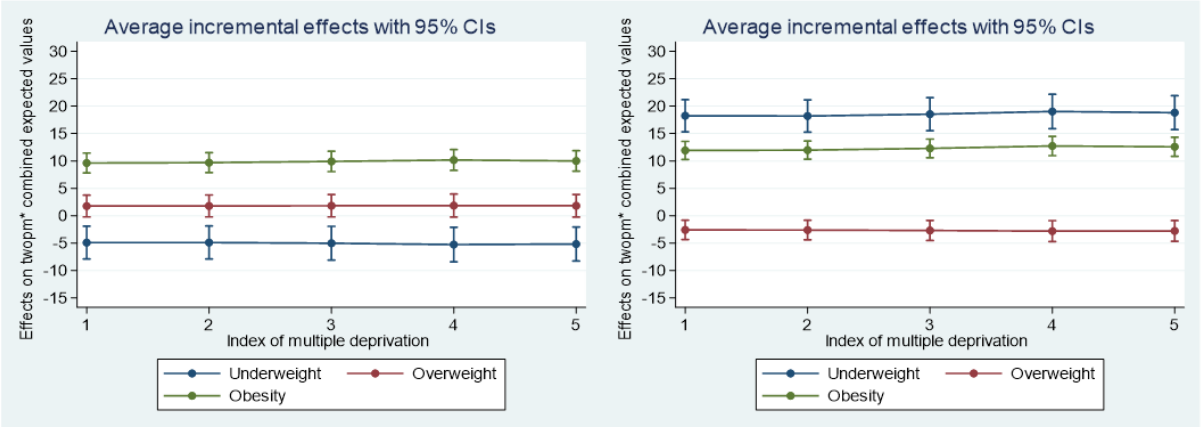

Figure 17 The relationship between consultation costs (£) and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

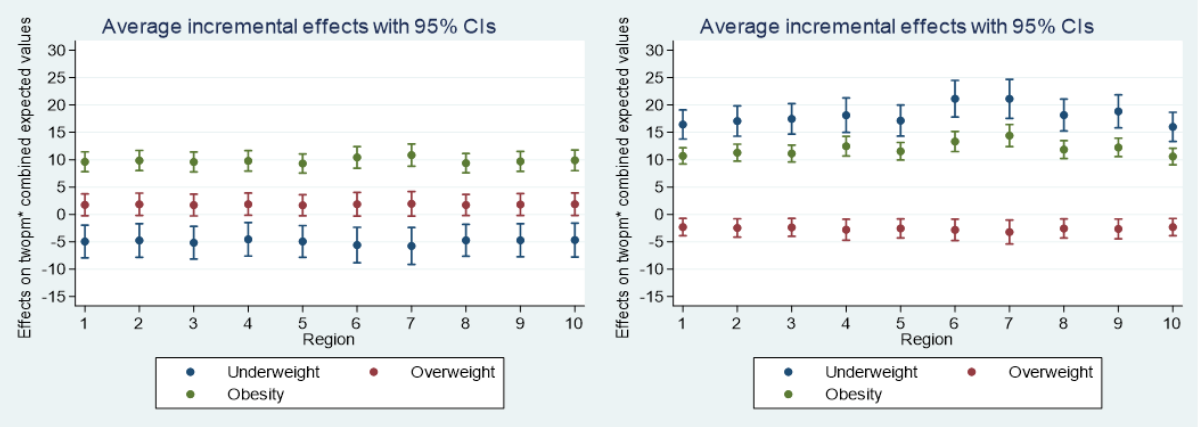

Figure 18 The relationship between consultation costs (£) and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

5.3.4 Prescriptions – descriptive results and model estimates for resource use counts and costs

The data cleaning and processing results for prescription records in the study dataset are reported in Appendix E. In the year before the BMI measurement, 192,441 children received 1,851,273 prescriptions, while in the year after the BMI measurement, 197,860 children accounted for 1,789,330 cumulative prescriptions. A descriptive breakdown of the mean prescriptions per child across the study population is reported below in Table 22 and Table 24.

Table 22 Mean number of primary care prescriptions per child in the study population of 268,231 children

	Mean	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	6.902	12.595	0	401	6.854	6.949
One year after BMI measurement	6.671	12.351	0	426	6.624	6.718

The predicted total prescriptions per child (adjusted for childhood weight status and all covariates) in the years before and after a BMI measurement were 6.905 (95% CI: 6.857-6.952) and 6.670 (95% CI: 6.624-6.716), respectively. **Table 23** details the modelled mean number of prescriptions by weight status category and

covariates, as well as the incremental effects with respect to its referent levels of individual covariates. On average, children in the obesity and overweight categories had more prescriptions than children in the healthy weight status category. However, the differences were not statistically significant. Girls received 0.5 fewer primary care prescriptions than boys in the years encompassing the index BMI measurement, and these differences were statistically significant. The mean number of prescriptions for children 3-9 years decreased relative to 2-year-olds (the reference group) and the differences were statistically significant. The incremental differences in the number of prescriptions were greater for all ethnic groups compared to white children, highest among children in the lowest IMD quintile (most deprived) relative to those in the highest quintile, and higher for children in all other regions compared to those in London.

Table 23 Mean and incremental number of primary care prescriptions one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after‡			
Variable	Mean number of prescriptions	Standard error	Incremental effects	Standard error	Mean number of prescriptions	Standard error	Incremental effects	Standard error
BMI								
Underweight	6.141***	0.112	-0.624***	0.115	6.221***	0.116	-0.297**	0.119
Healthy weight (referent)	6.765***	0.029	-	-	6.518***	0.028	-	-
Overweight	7.370***	0.077	0.605***	0.082	7.025***	0.074	0.507***	0.079
Obesity	7.306***	0.060	0.541***	0.068	7.110***	0.060	0.592***	0.067
Sex								
Boys (referent)	7.127***	0.033	-	-	6.897***	0.032	-	-
Girls	6.626***	0.035	-0.501***	0.048	6.384***	0.035	-0.513***	0.047
Age								
2 years (referent)	7.653***	0.091	-	-	6.429***	0.085	-	-
3 years	6.529***	0.071	-1.124***	0.116	5.926***	0.069	-0.503***	0.109
4 years	6.617***	0.068	-1.036***	0.114	6.169***	0.068	-0.26**	0.108
5 years	6.228***	0.063	-1.425***	0.111	5.832***	0.062	-0.597***	0.105
6 years	6.524***	0.069	-1.129***	0.115	6.349***	0.067	-0.081	0.108
7 years	6.404***	0.067	-1.249***	0.114	6.468***	0.067	0.039	0.108
8 years	6.618***	0.069	-1.035***	0.115	6.800***	0.069	0.37***	0.109
9 years	7.334***	0.080	-0.319***	0.122	7.520***	0.080	1.091***	0.116
10 years	8.020***	0.098	0.367***	0.135	7.977***	0.094	1.548***	0.127
11 years	8.714***	0.133	1.061***	0.162	8.818***	0.130	2.389***	0.156
12 years	8.428***	0.332	0.775**	0.345	8.092***	0.312	1.663***	0.323
13 years	8.355***	0.519	0.702	0.527	6.981***	0.410	0.552	0.419

Variable	Year before				Year after‡			
	Mean number of prescriptions	Standard error	Incremental effects	Standard error	Mean number of prescriptions	Standard error	Incremental effects	Standard error
14 years	8.212***	0.642	0.559	0.648	5.755***	0.461	-0.674	0.469
15 years	8.100***	1.791	0.447	1.793	3.133***	0.749	-3.296***	0.753
Ethnicity								
Other/Unknown	3.652***	0.042	-3.279***	0.054	3.907***	0.041	-2.758***	0.053
Bangladeshi	10.97***	0.223	4.04***	0.227	10.27***	0.215	3.605***	0.219
Black	9.131***	0.125	2.2***	0.132	8.616***	0.120	1.952***	0.127
Chinese/Other Asian	8.509***	0.157	1.579***	0.162	7.925***	0.150	1.261***	0.155
Indian	9.184***	0.162	2.253***	0.165	8.514***	0.159	1.849***	0.162
Pakistani	10.121***	0.161	3.19***	0.165	9.531***	0.152	2.866***	0.156
White (referent)	6.931***	0.032	-	-	6.665***	0.031	-	-
Mixed	7.764***	0.123	0.833***	0.128	7.485***	0.122	0.82***	0.127
IMD								
Fifth quintile: least deprived (referent)	6.689***	0.060	-	-	6.437***	0.059	-	-
Fourth quintile	6.650***	0.057	-0.038	0.081	6.424***	0.056	-0.013	0.079
Third quintile	6.867***	0.058	0.178**	0.082	6.599***	0.056	0.163**	0.080
Second quintile	6.992***	0.053	0.303***	0.081	6.769***	0.052	0.332***	0.080
First quintile: most deprived	7.122***	0.050	0.434***	0.081	6.889***	0.048	0.452***	0.079
Region								
North East	7.084***	0.135	1.002***	0.146	6.623***	0.128	0.699***	0.138
North West	7.859***	0.065	1.778***	0.086	7.508***	0.064	1.584***	0.083
Yorkshire and The Humber	7.621***	0.148	1.539***	0.158	7.155***	0.136	1.232***	0.145
East Midlands	7.360***	0.180	1.279***	0.188	7.324***	0.176	1.4***	0.184
West Midlands	7.405***	0.065	1.324***	0.084	7.177***	0.063	1.253***	0.081
East of England	6.169***	0.107	0.087	0.120	5.934***	0.105	0.011	0.117
London (referent)	6.081***	0.051	-	-	5.923***	0.049	-	-
South East	7.136***	0.061	1.055***	0.082	6.957***	0.060	1.034***	0.079
South West	6.085***	0.060	0.003	0.081	5.960***	0.060	0.037	0.079
Missing	7.602***	0.224	1.521***	0.231	6.179***	0.182	0.256	0.189

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10; ‡ Estimates based on ZIP model as ZINB model did not converge.

The mean annual costs of prescriptions per child in the years straddling the index BMI measurement were £125.77 (95% CI: 118.48-133.06) and £134.83 (95% CI: 127.13-142.53), respectively Table 24. The total prescription costs attributable to children in the study were £33,735,468.02 and £36,166,742.30 in the year before and after the index BMI measurement. The average costs of prescriptions per child (based on Table 22 and Table 24) were £18.23 and £20.12 in the year before and after the index BMI measurement.

Table 24 Mean primary care prescription costs per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	125.77	1,927.23	0	867,058.60	118.48	133.06
One year after BMI measurement	134.83	2,034.53	0	876,728.60	127.13	142.53

Figure 19 depicts heavily skewed box plot distributions of prescription costs with outliers in the year before and after the index BMI measurement. Only 3 children and 5 children incurred costs above £100,000 and £50,000 in the year before the index BMI measurement, respectively. Similarly, in the year after the index BMI measurement, only 4 children and 8 children had mean prescription costs over £100,000 and £50,000, respectively. The most common British National Formulary (BNF) medication chapter amongst children with prescription costs above £50,000 was "Nutrition and Blood" at 50% and 75% in the year before and after an index BMI measurement, respectively. Commonly prescribed items in this category such as Loprofin® and FruitiVits® are typically prescribed for dietary management of restrictive therapeutic diets, metabolic disorders and other conditions requiring a low protein diet. The high costs of these medications in this category were due to the frequency of prescription and the quantity of items per prescription. The most prescribed medications among the entire study population were those targeting the respiratory system (28.96% and 30.00% in the year preceding and following the index BMI measurement), followed by medications for treating infections (17.54% and 15.20% in the corresponding years).

Among children with a prescription cost exceeding £50,000, a higher proportion fell under the underweight category in the year before and after the index BMI measurement (20.00% and 12.50%) compared to the overall proportion of children in the underweight category reported in Table 16 (4.10%). Among children with a prescription cost exceeding £50,000, a higher proportion fell under the overweight category in the year before ("20.00%) and the obesity category after the index BMI measurement (37.50%) compared to the overall proportion of children in those categories reported in Table 16 (11.54% and 17.09%, respectively).

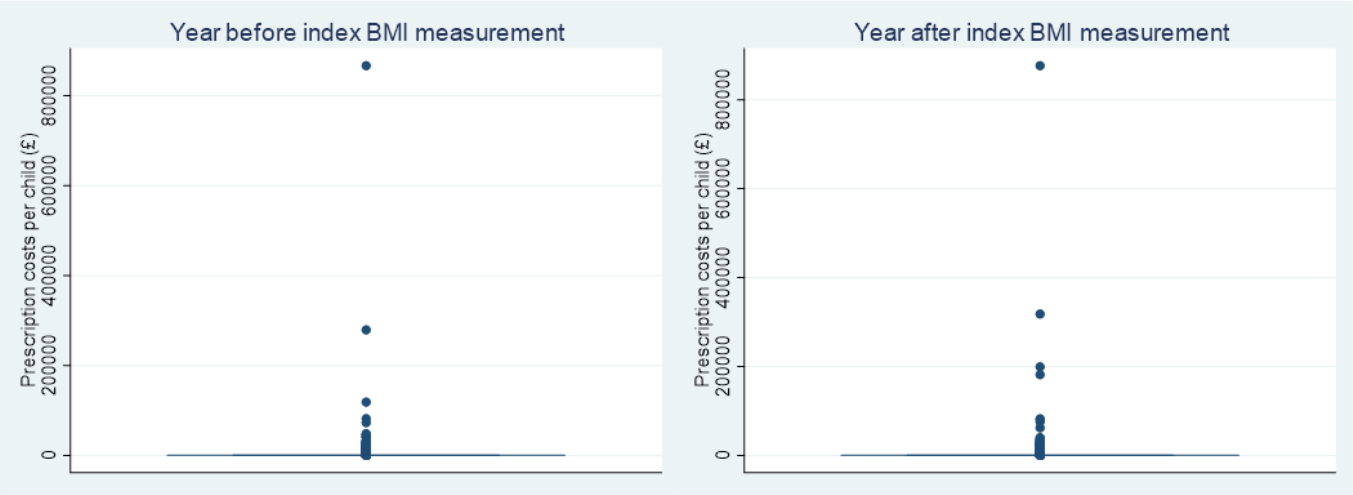

Figure 19 Box plots showing distributions of prescription costs one year before and after index BMI measurement

The predicted total costs of prescriptions per child (adjusted for childhood weight status and all covariates) in the years before and after a BMI measurement were £125.40 (95% CI: 119.45-131.35) and £135.04 (95% CI: 127.77-142.31), respectively. The predicted mean costs of prescriptions by weight status category and covariates, as well as the incremental effects with respect to its referent levels of individual covariates, are reported in Table 25. One year after the index BMI measurement, children with underweight and obesity recorded higher costs than their peers in the healthy weight category on primary care prescriptions by an additional £38.42 and £26.32, respectively (Table 25, column "Incremental costs"). These differences were statistically significant. On average, girls incurred statistically significantly lower prescription costs than boys (by £13.21 and £12.86 in the years straddling the index BMI measurement). The mean costs of prescriptions tended to increase steadily with age, with statistically significant differences in comparison to 2-year-olds. Children of Pakistani origin incurred the highest costs, exceeding their white contemporaries by an additional £106.38 and £58.49 (statistically significant) one year before and after the index BMI measurement, respectively. The mean costs of prescriptions were lowest in the fifth IMD quintile (least deprived), but relative differences compared with other quintiles were not statistically significant. The lowest regional costs on prescriptions one year before or after the index BMI measurement was observed in the South West, and in comparison with London (the reference group), the differences were statistically significant.

Table 25 Mean and incremental costs of primary care prescriptions one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean cost of prescriptions	Standard error	Incremental costs	Standard error	Mean cost of prescriptions	Standard error	Incremental costs	Standard error
BMI								
Underweight	148.77***	13.562	25.48*	13.814	167.18***	12.367	38.42***	12.454
Healthy weight (referent)	123.29***	2.807	-	-	128.76***	2.639	-	-
Overweight	135.28***	11.127	11.99	10.045	129***	4.407	0.24	4.580
Obesity	121.41***	4.090	-1.88	4.717	155.07***	12.568	26.32**	11.588
Sex								
Boys (referent)	131.25***	4.097	-	-	140.71***	4.408	-	-
Girls	118.04***	2.673	-13.21***	3.660	127.85***	4.146	-12.86***	4.377
Age								
2 years (referent)	164.44***	8.489	-	-	136.47***	6.000	-	-
3 years	109.16***	4.105	-55.28***	9.259	115.28***	6.708	-21.19**	8.435
4 years	102.28***	3.861	-62.17***	9.096	112.49***	5.196	-23.98***	7.472
5 years	100.06***	6.788	-64.39***	10.411	112.2***	9.670	-24.27**	9.951
6 years	103.8***	4.161	-60.65***	9.300	124.02***	6.605	-12.45	8.524
7 years	111.48***	4.295	-52.96***	9.291	122.57***	4.318	-13.9**	6.958
8 years	115.52***	4.340	-48.92***	9.372	139.25***	9.567	2.78	10.376
9 years	151.83***	13.736	-12.61	14.538	155.54***	5.423	19.07**	7.575
10 years	161.5***	6.071	-2.94	10.254	180.1***	7.580	43.64***	9.089
11 years	194.84***	10.347	30.4**	13.122	200.49***	9.853	64.02***	11.155
12 years	207.44***	23.816	42.99*	25.092	212.38***	23.079	75.91***	23.708
13 years	190.47***	25.506	26.03	26.770	166.34***	28.078	29.87	28.557
14 years	158.08***	24.481	-6.37	25.663	137.61***	41.798	1.15	42.058
15 years	134.54**	54.533	-29.9	55.206	75.62**	37.678	-60.85	38.018
Ethnicity								
Other/Unknown	47.98***	2.425	-83.47***	3.221	56.01***	2.258	-86.38***	3.712
Bangladeshi	162.74***	15.862	31.29*	16.095	203.34***	43.610	60.95	43.683
Black	154.75***	17.510	23.3	17.776	145.08***	6.032	2.69	6.892
Chinese/Other Asian	130.75***	8.229	-0.7	8.547	230.2***	86.137	87.81	85.510
Indian	131.85***	8.785	0.4	9.056	135.09***	8.391	-7.29	8.789
Pakistani	237.83***	42.088	106.38***	41.513	200.88***	11.924	58.49***	12.137
White (referent)	131.45***	2.231	-	-	142.39***	3.050	-	-
Mixed	130.37***	7.850	-1.08	8.044	138.39***	7.875	-4.00	8.292
IMD								
Highest quintile (referent)	119.33***	4.067	-	-	147.08***	11.571	-	-
Fourth quintile	122.23***	4.506	2.91	5.392	129.94***	5.613	-17.13	10.568
Third quintile	132.43***	4.543	13.1**	5.401	135.05***	4.271	-12.03	10.519
Second quintile	121.35***	3.549	2.02	4.870	131.74***	5.406	-15.34	12.046
Lowest quintile	129.05***	5.444	9.72*	5.409	134.15***	4.066	-12.93	10.438
Region								

Variable	Year before				Year after			
	Mean cost of prescriptions	Standard error	Incremental costs	Standard error	Mean cost of prescriptions	Standard error	Incremental costs	Standard error
North East	137.16***	8.092	23.29***	9.032	146.63***	11.939	15.61	12.604
North West	133.42***	3.917	19.55***	5.735	145.99***	7.502	14.98*	8.828
Yorkshire and The Humber	128.27***	7.961	14.4	8.890	153.42***	22.032	22.4	22.374
East Midlands	126.3***	10.521	12.43	11.305	121.68***	8.750	-9.34	10.980
West Midlands	149.97***	9.743	36.1***	10.526	152.13***	6.076	21.12***	7.750
East of England	121.82***	7.542	7.95	8.569	123.36***	8.205	-7.66	10.501
London (referent)	113.87***	4.136	-	-	131.02***	7.145	-	-
South East	132.46***	5.136	18.59***	6.430	137.7***	4.208	6.68	7.561
South West	88.7***	2.828	-25.16***	4.797	99.91***	4.079	-31.11***	6.535
Missing	108.81***	8.300	-5.06	9.249	106.12***	12.892	-24.9*	13.731

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

Point estimates and their 95% CIs of the incremental effects of the BMI category on prescription costs by covariate are reported in Appendix E and graphically depicted below (**Figure 20**-**Figure 24**). An error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Among all covariates, incremental prescription costs relative to healthy weight were highest for underweight, followed by obesity one year before and after the index BMI measurement. These differences were statistically significant. While children in the overweight category had the lowest incremental costs, these differences were statistically significant in the year after the index BMI measurement but not in the year before. For children in the overweight category, incremental prescription costs were statistically significant in the year after the index BMI measurement but not in the year before. Incremental prescription costs in the obesity category seemed lower in girls compared to boys, but the differences were not statistically significant. Similarly, within-category cost differences for the remaining covariates were not statistically significant.

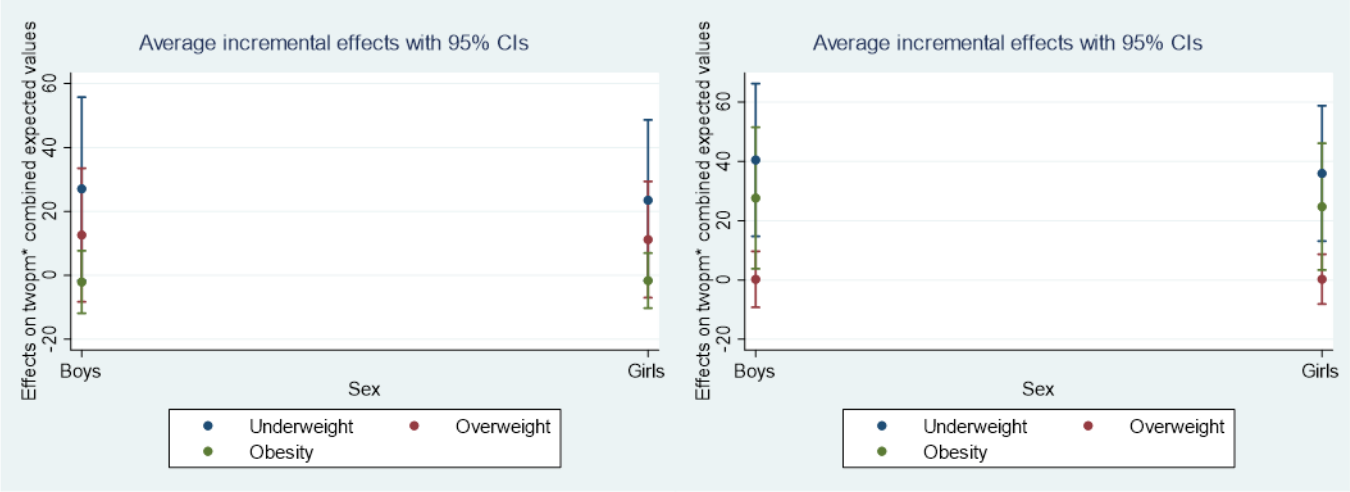

Figure 20 The relationship between prescription costs (£) and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

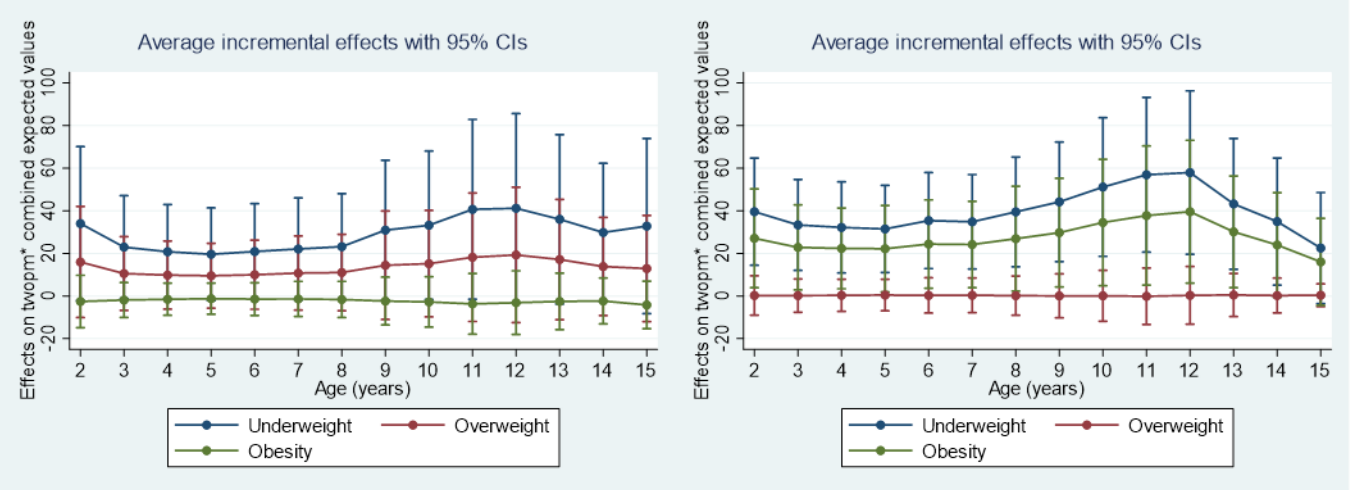

Figure 21 The relationship between prescription costs (£) and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

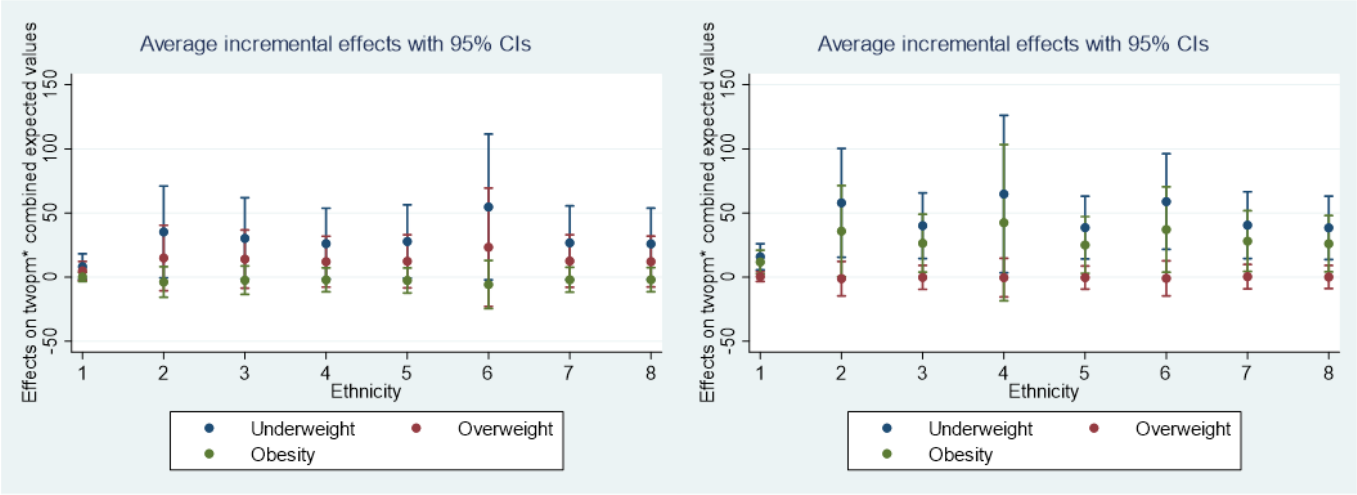

Figure 22 The relationship between prescription costs (£) and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

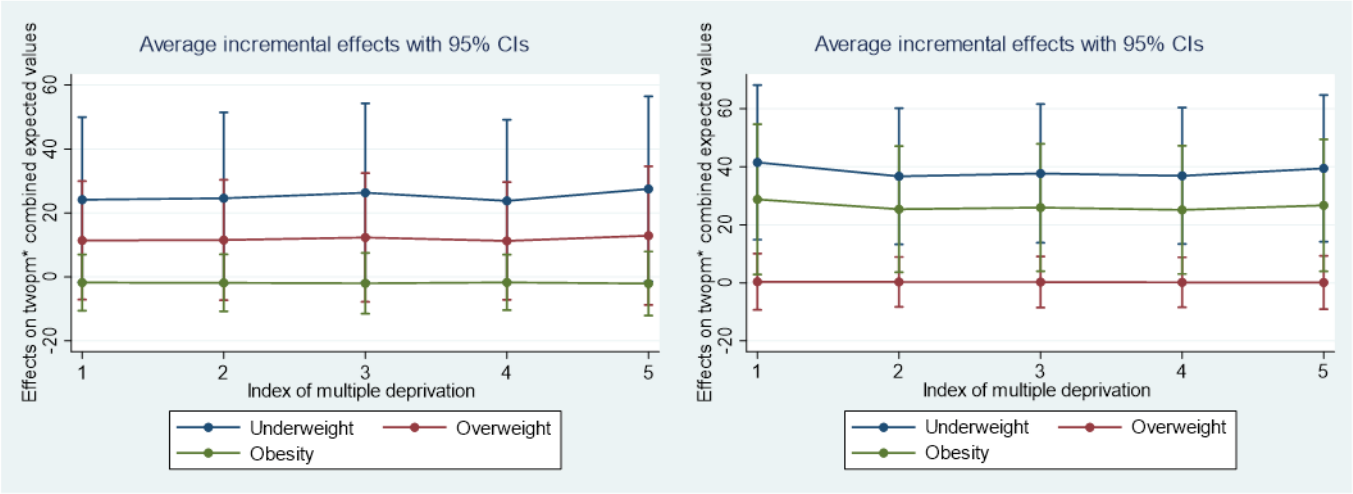

Figure 23 The relationship between prescription costs (£) and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

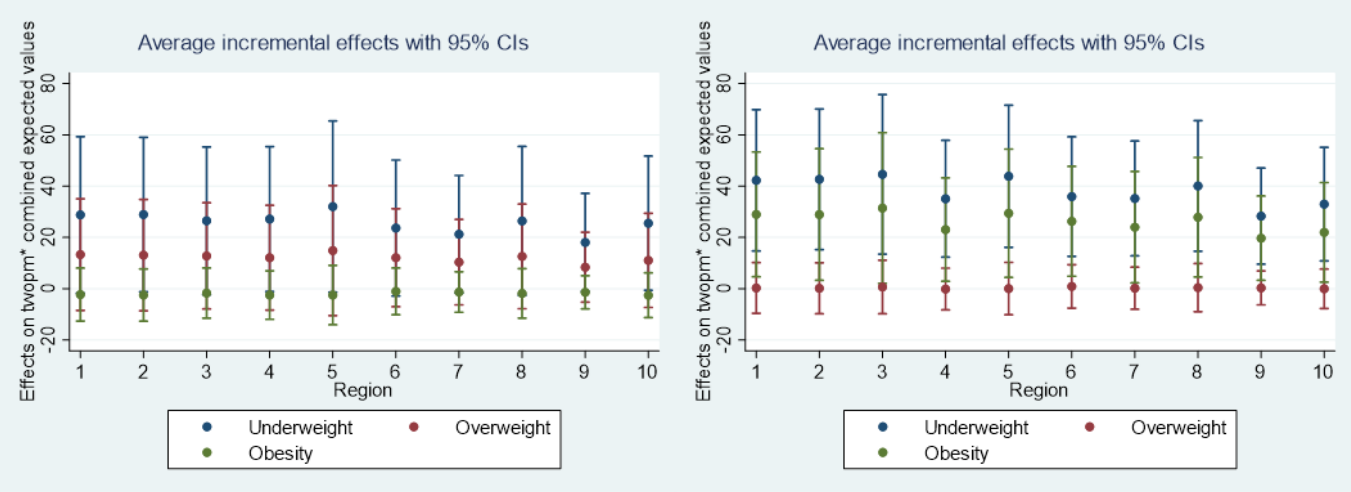

Figure 24 The relationship between prescription costs (£) and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

5.3.5 Primary care tests – descriptive results and model estimates for resource use counts and costs

Primary care tests were classified into eight categories (biochemistry, cytology and histology, diagnostics, haematology, immunology, microbiology, radiology and investigation requests). Table 26 details the total number of observations corresponding to tests and the mean number of tests per child after restricting the dataset to my cohort of unique children and removing duplicates. The total number of tests administered across all test categories in the years before and after the index BMI measurement were 1,066,417 and 1,341,961, respectively. Haematology and biochemistry tests were the most frequently administered test categories, followed by microbiology and diagnostics. The distribution of test categories varied by BMI category: in the year before the index BMI measurement, for children who received at least one biochemistry test, the distribution in the underweight, healthy weight, overweight and obesity categories was 4.01%, 66.48%, 11.52% and 18.00%, respectively. In the underweight, healthy weight, overweight and obesity categories, the BMI distribution for children who received one or more haematology tests was 5.03%, 68.73%, 10.21% and 16.04%, respectively, and 2.99%, 63.64%, 12.60% and 20.77%, respectively, for diagnostic tests. Comparable distributions were observed in the year after the index BMI measurement.

Table 26 Mean number of primary care tests per child in the study population of 268,231 children

	Total number of tests	Mean	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement							
Biochemistry	375,767	1.401	4.562	0	281	1.384	1.418
Cytology and Histology	25,529	0.095	0.478	0	24	0.093	0.097
Diagnostics	68,999	0.257	1.059	0	41	0.253	0.261
Haematology	419,971	1.566	6.288	0	532	1.542	1.590
Immunology	20,188	0.075	0.611	0	31	0.073	0.078
Investigation Requests	11,230	0.042	0.552	0	27	0.040	0.044
Microbiology	127,987	0.477	2.045	0	113	0.469	0.485
Radiology	16,746	0.062	0.333	0	17	0.061	0.064
Total	1,066,417	3.976	11.340	0	613	3.933	4.019
One year after BMI measurement							
Biochemistry	452,689	1.688	4.846	0	300	1.669	1.706
Cytology and Histology	21,987	0.082	0.424	0	28	0.080	0.084
Diagnostics	196,564	0.733	1.849	0	55	0.726	0.740
Haematology	493,746	1.841	6.486	0	276	1.816	1.865
Immunology	20,941	0.078	0.568	0	26	0.076	0.080
Investigation Requests	14,295	0.053	0.661	0	43	0.051	0.056
Microbiology	123,350	0.460	1.841	0	129	0.453	0.467
Radiology	18,389	0.069	0.336	0	20	0.067	0.070
Total	1,341,961	5.003	11.723	0	566	4.959	5.047

The predicted total tests per child (adjusted for childhood weight status and all covariates) in the year before and after the index BMI measurement were 3.973 (95% CI: 3.930-4.016) and 5.003 (95% CI: 4.959-5.047), respectively. Table 27 shows the modelled mean number of tests by weight status category and covariates, as well as the incremental effects with respect to its referent levels of individual covariates. On average, children classified as underweight were more likely to undergo testing, followed by those in the healthy weight category, with the obesity category ranking third. The overweight category exhibited the lowest number of administered tests. For example, in the year following the index BMI measurement, children in the underweight category received 1.62 additional tests compared to those of healthy weight, while children in the overweight and obesity categories underwent 0.62 and 0.30 fewer tests, respectively. These differences were statistically significant. Girls were likelier to receive 0.79 and 0.89 additional primary care tests than boys in the year before and after the index BMI

measurement, respectively. From the age of three, the mean number of tests tended to increase steadily and was statistically significant compared to 2-year-olds. Children of Pakistani origin underwent 2.59 and 3.23 additional tests, on average, at the primary care level one year before and after the index BMI measurement, respectively, compared to white children, and this difference was statistically significant. The number of tests administered was similar across IMD quintiles, with no statistically significant difference in comparison with the reference IMD level. Children in other regions had a statistically significant tendency to receive fewer tests than their peers in London (the referent group) during the year before and after the index BMI measurement.

Table 27 Mean and incremental number of primary care tests one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before‡				Year after‡			
Variable	**Mean number of tests**	**Standard error**	**Incremental effects**	**Standard error**	**Mean number of tests**	**Standard error**	**Incremental effects**	**Standard error**
BMI								
Underweight	4.194***	0.107	0.135	0.110	6.681***	0.131	1.624***	0.133
Healthy weight (referent)	4.059***	0.027	-	-	5.057***	0.028	-	-
Overweight	3.688***	0.060	-0.371***	0.066	4.442***	0.058	-0.615***	0.065
Obesity	3.778***	0.052	-0.281***	0.059	4.761***	0.051	-0.296***	0.058
Sex								
Boys (referent)	3.619***	0.028	-	-	4.606***	0.029	-	-
Girls	4.413***	0.034	0.793***	0.044	5.495***	0.035	0.889***	0.045
Age								
2 years (referent)	3.021***	0.064	-	-	3.48***	0.065	-	-
3 years	3.36***	0.061	0.339***	0.088	3.683***	0.057	0.203**	0.087
4 years	3.789***	0.064	0.768***	0.090	4.384***	0.064	0.903***	0.091
5 years	3.814***	0.062	0.793***	0.089	4.471***	0.058	0.99***	0.087
6 years	3.974***	0.061	0.952***	0.088	4.909***	0.064	1.429***	0.091
7 years	3.779***	0.058	0.758***	0.086	5.055***	0.063	1.575***	0.091
8 years	4.074***	0.065	1.053***	0.091	5.515***	0.069	2.034***	0.095
9 years	4.39***	0.073	1.369***	0.097	5.903***	0.077	2.422***	0.101
10 years	4.711***	0.086	1.69***	0.107	6.225***	0.094	2.745***	0.115
11 years	5.181***	0.125	2.16***	0.141	7.371***	0.142	3.891***	0.157
12 years	6.142***	0.321	3.121***	0.328	8.758***	0.364	5.278***	0.370

Variable	Year before‡				Year after‡			
	Mean number of tests	Standard error	Incremental effects	Standard error	Mean number of tests	Standard error	Incremental effects	Standard error
13 years	7.875***	0.790	4.853***	0.792	8.691***	0.572	5.211***	0.576
14 years	8.198***	0.891	5.176***	0.893	7.94***	0.777	4.46***	0.780
15 years	9.782***	2.156	6.761***	2.157	7.412***	1.929	3.932**	1.930
Ethnicity								
Other/Unknown	2.774***	0.046	-1.17***	0.055	4.323***	0.052	-0.455***	0.061
Bangladeshi	6.123***	0.197	2.179***	0.201	7.547***	0.206	2.77***	0.210
Black	3.694***	0.085	-0.249***	0.092	4.799***	0.087	0.021	0.094
Chinese/Other Asian	5.111***	0.146	1.167***	0.151	6.063***	0.141	1.285***	0.146
Indian	5.911***	0.152	1.967***	0.156	6.883***	0.155	2.105***	0.158
Pakistani	6.53***	0.138	2.587***	0.141	8.009***	0.143	3.231***	0.146
White (referent)	3.944***	0.029	-	-	4.778***	0.030	-	-
Mixed	3.846***	0.100	-0.098	0.105	4.919***	0.106	0.141	0.111
IMD								
Fifth quintile: least deprived (referent)	3.934***	0.057	-	-	5.017***	0.062	-	-
Fourth quintile	3.936***	0.057	0.002	0.079	4.921***	0.057	-0.096	0.084
Third quintile	3.907***	0.050	-0.027	0.075	4.936***	0.051	-0.08	0.080
Second quintile	4.015***	0.045	0.081	0.073	4.963***	0.046	-0.054	0.078
First quintile: most deprived	4.022***	0.044	0.088	0.073	5.12***	0.045	0.104	0.078
Region								
North East	2.911***	0.103	-1.918***	0.119	3.133***	0.083	-3.042***	0.103
North West	3.645***	0.049	-1.184***	0.077	4.352***	0.049	-1.823***	0.078
Yorkshire and The Humber	3.884***	0.122	-0.944***	0.136	4.762***	0.117	-1.414***	0.133
East Midlands	4.072***	0.146	-0.756***	0.157	5.216***	0.179	-0.96***	0.188
West Midlands	3.817***	0.051	-1.012***	0.077	4.742***	0.051	-1.434***	0.078
East of England	3.86***	0.104	-0.968***	0.119	4.93***	0.109	-1.246***	0.125
London (referent)	4.828***	0.057	-	-	6.176***	0.058	-	-
South East	3.962***	0.055	-0.867***	0.081	5.116***	0.060	-1.059***	0.085
South West	3.42***	0.056	-1.408***	0.081	4.49***	0.061	-1.686***	0.085
Missing	3.33***	0.157	-1.498***	0.169	3.585***	0.162	-2.59***	0.173

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10; ‡ Estimates based on ZIP model as ZINB model did not converge.

The mean costs per child and the total costs of primary care tests in the years straddling the index BMI measurement were £55.19 (95% CI: 54.58-55.80) and £116.32 (95% CI: 115.38-117.26) and £14,804,600.23 and £31,200,615.73, one year before and after, respectively (Table 28). Diagnostic tests were the primary drivers of costs in this cost category.

Table 28 Mean primary care test costs per child in the study population of 268,231 children

	Total costs of tests (£)	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement							
Biochemistry	715,798.00	2.67	8.73	0	534.00	2.64	2.70
Cytology and Histology	247,672.90	0.92	4.66	0	240.55	0.91	0.94
Diagnostics	9,156,617.00	34.14	146.17	0	5,410.79	33.58	34.69
Haematology	1,566,390.00	5.84	23.45	0	1,984.23	5.75	5.93
Immunology	200,021.30	0.75	6.06	0	307.15	0.72	0.77
Investigation Requests	61,269.03	0.23	3.76	0	219.34	0.21	0.24
Microbiology	1,338,552.00	4.99	21.39	0	1,181.81	4.91	5.07
Radiology	1,518,279.00	5.66	36.86	0	3,045.92	5.52	5.80
Total	14,804,600.23	55.19	161.57	0	5,418.39	54.58	55.80
One year after BMI measurement							
Biochemistry	861,510.50	3.21	9.26	0	570.14	3.18	3.25
Cytology and Histology	215,287.20	0.80	4.36	0	354.35	0.79	0.82
Diagnostics	25,039,428.47	93.35	242.30	0	6,947.78	92.43	94.27
Haematology	1,841,553.00	6.87	24.19	0	1,029.41	6.77	6.96
Immunology	207,482.00	0.77	5.63	0	257.61	0.75	0.79
Investigation Requests	74,847.49	0.28	4.37	0	438.69	0.26	0.30
Microbiology	1,290,048.00	4.81	19.25	0	1,349.15	4.74	4.88
Radiology	1,670,460.00	6.23	36.75	0	3,199.02	6.09	6.37
Total	31,200,615.73	116.32	248.94	0	6,947.78	115.38	117.26

depicts the distribution of test costs, showing the frequency of data points in bins and kernel density plots with smoothed distribution estimates. It can be observed that costs are heavily right-skewed.

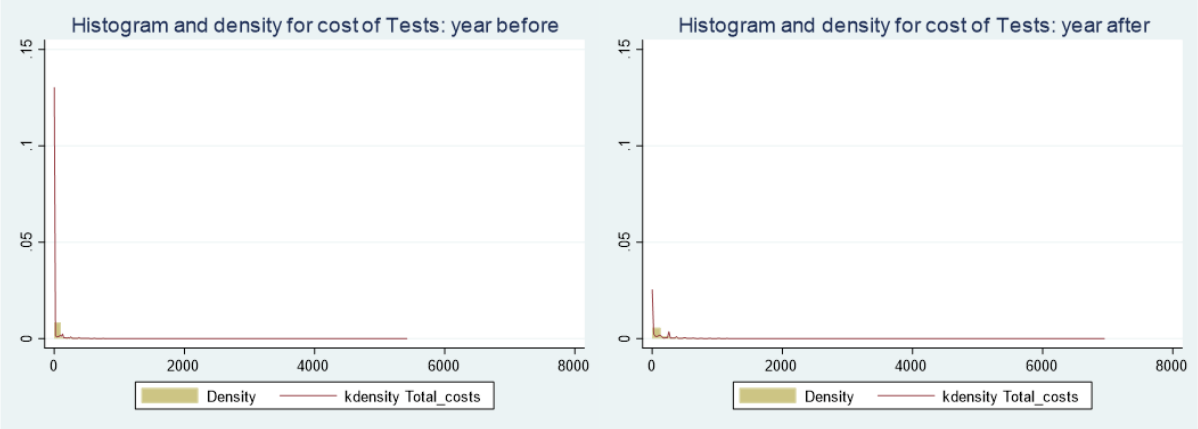

Figure 25 Combined histogram and kernel density plot of test costs in the years before and after a BMI measurement

The predicted total costs of tests per child (adjusted for childhood weight status and all covariates) in the year before and after a BMI measurement were £55.20 (95% CI: 54.59-55.80) and £116.20 (95% CI: 115.29-117.11), respectively. Table 29 presents the predicted mean costs of tests by weight status category and covariates, as well as the incremental effects with respect to its referent levels in individual covariates. In contrast to the number of tests, the mean total costs of tests were statistically significantly higher in children with overweight and obesity (an additional £4.66 and £9.54 for overweight and £3.59 and £4.22 for obesity in the year before and after the index BMI measurement, respectively) compared to children with healthy weight status. Compared to boys, girls had higher costs by £2.63 in the year before the index BMI measurement but lower costs by £2.83 in the year following the index BMI measurement, and both differences were statistically significant. The mean costs of tests tended to increase steadily with age. Children of Bangladeshi origin had higher test costs than their white peers by an additional £14.80 and £43.381 one year before and after the index BMI measurement, respectively, followed by children from Pakistan and India, respectively. The mean costs of tests were lower in the lowest IMD quintile (the most deprived) than in the highest IMD quintile (least deprived) compared by an additional £2.97 and £20.14 within one year before and after the index BMI measurement, respectively. In contrast to counts of tests, test costs were higher for children from many regions compared to their counterparts from London.

Compared to children in London, children from the North West and Yorkshire and the Humber had the highest test costs (an additional £6.12 and £23.42 for the North West and £8.45 and £20.18 for Yorkshire and the Humber, respectively, one year before and after the index BMI measurement.

Table 29 Mean and incremental costs of primary care tests one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean cost of tests	Standard error	Incremental costs	Standard error	Mean cost of tests	Standard error	Incremental costs	Standard error
BMI								
Underweight	46.17***	1.301	-8.14***	1.350	97.48***	1.966	-17.47***	2.036
Healthy weight (referent)	54.30***	0.379	-	-	114.95***	0.572	-	-
Overweight	58.97***	0.973	4.66***	1.045	124.49***	1.426	9.54***	1.534
Obesity	57.89***	0.770	3.59***	0.870	119.17***	1.115	4.22***	1.265
Sex								
Boys (referent)	54.03***	0.417	-	-	117.43***	0.621	-	-
Girls	56.66***	0.462	2.63***	0.623	114.60***	0.691	-2.83***	0.923
Age								
2 years (referent)	32.40***	0.807	-	-	37.52***	0.801	-	-
3 years	31.94***	0.665	-0.46	1.045	40.61***	0.669	3.09***	1.043
4 years	36.87***	0.652	4.47***	1.037	64.60***	0.857	27.08***	1.174
5 years	43.05***	0.694	10.65***	1.065	84.06***	0.982	46.55***	1.267
6 years	50.46***	0.774	18.05***	1.117	109.34***	1.200	71.82***	1.442
7 years	53.83***	0.849	21.42***	1.171	126.34***	1.368	88.82***	1.583
8 years	65.48***	1.014	33.07***	1.296	157.06***	1.677	119.54***	1.857
9 years	77.52***	1.271	45.11***	1.505	178.25***	1.932	140.73***	2.091
10 years	86.26***	1.521	53.86***	1.724	191.77***	2.301	154.26***	2.436
11 years	95.60***	2.127	63.20***	2.277	221.90***	3.282	184.38***	3.379
12 years	99.76***	5.291	67.36***	5.358	220.65***	8.182	183.13***	8.224
13 years	92.06***	6.680	59.65***	6.731	187.14***	11.122	149.62***	11.154
14 years	110.36***	11.355	77.96***	11.387	160.65***	11.173	123.13***	11.203
15 years	145.23***	31.006	112.83***	31.017	200.00***	26.564	162.49***	26.576
Ethnicity								
Other/Unknown	33.63***	0.597	-24.79***	0.747	79.64***	0.942	-40.54***	1.138
Bangladeshi	73.22***	2.364	14.80***	2.422	163.56***	3.898	43.38***	3.964
Black	51.83***	1.167	-6.58***	1.270	119.36***	1.865	-0.83	1.999
Chinese/Other Asian	65.27***	2.003	6.85***	2.063	125.69***	2.826	5.50*	2.917
Indian	65.66***	1.851	7.243***	1.909	127.76***	2.637	7.57***	2.715
Pakistani	71.58***	1.631	13.16***	1.695	141.96***	2.310	21.78***	2.400
White (referent)	58.42***	0.423	-	-	120.18***	0.617	-	-
Mixed	55.03***	1.506	-3.39**	1.570	129.14***	2.374	8.96***	2.458
IMD								
Fifth quintile: least deprived (referent)	56.66***	0.811	-	-	127.60***	1.261	-	-
Fourth quintile	55.33***	0.779	-1.33	1.103	121.12***	1.209	-6.47***	1.705

Variable	Year before				Year after			
	Mean cost of tests	Standard error	Incremental costs	Standard error	Mean cost of tests	Standard error	Incremental costs	Standard error
Third quintile	56.14***	0.737	-0.52	1.087	119.02***	1.128	-8.57***	1.679
Second quintile	55.22***	0.680	-1.44	1.080	113.44***	0.976	-14.16***	1.616
First quintile: most deprived	53.69***	0.612	-2.97***	1.051	107.46***	0.871	-20.14***	1.579
Region								
North East	51.95***	1.660	-1.25	1.806	103.96***	2.685	-2.81	2.860
North West	59.32***	0.828	6.12***	1.084	130.19***	1.305	23.42***	1.626
Yorkshire and The Humber	61.65***	1.905	8.45***	2.046	126.96***	2.956	20.18***	3.128
East Midlands	53.95***	2.148	0.76	2.253	121.89***	3.194	15.12***	3.331
West Midlands	54.83***	0.759	1.64	1.014	117.32***	1.112	10.55***	1.462
East of England	57.83***	1.741	4.63**	1.876	125.40***	2.588	18.63***	2.767
London (referent)	53.20***	0.664	-	-	106.77***	0.932	-	-
South East	54.66***	0.755	1.47	1.029	113.40***	1.100	6.63***	1.473
South West	52.19***	0.884	-1.01	1.124	113.96***	1.403	7.19***	1.715
Missing	58.24***	2.813	5.04*	2.907	101.08***	3.327	-5.70	3.481

Significance codes: *** for *p*-values ≤ 0.01, ** for *p*-values ≤ 0.05, * for *p*-values ≤ 0.10.

I also estimated the incremental effects of the BMI category on test costs separately for each covariate (see Appendix E for point estimates and their 95% CIs). These estimates are expressed graphically in **Figure 26**-**Figure 30**. An error bar crossing the red horizontal line (zero) for each covariate level shows a lack of statistical significance at $p < 0.05$.

The additional costs for tests exhibited many similar patterns and trends to prescription costs across most covariates. The overweight category accounted for the highest incremental cost, followed by the obesity category in the year before and after the index BMI measurement for all covariates. The estimation of higher costs in the overweight and obesity categories (compared to healthy weight) were all statistically significant. Children in the underweight category had the lowest test costs, and these differences were statistically significant in the year before and after the index BMI measurement.

Incremental test costs in the overweight and obesity categories were lower for girls in the year after the index BMI measurement. However, the within-category differences for most covariates, including sex, were not statistically significant. The exception was age. Among children in the underweight category, those aged 2 to 3 years incurred higher costs compared to children aged 5 years or older in the year following the index BMI measurement. Conversely, in the overweight category, children aged 2 to 3 years incurred lower costs than those over the age of 6 during the same period. These differences were statistically significant.

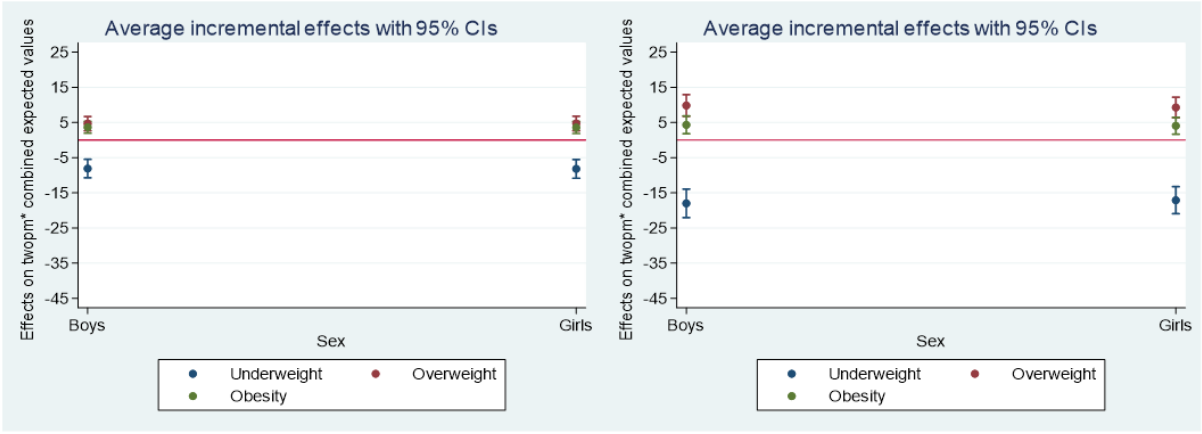

Figure 26 The relationship between test costs (£) and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

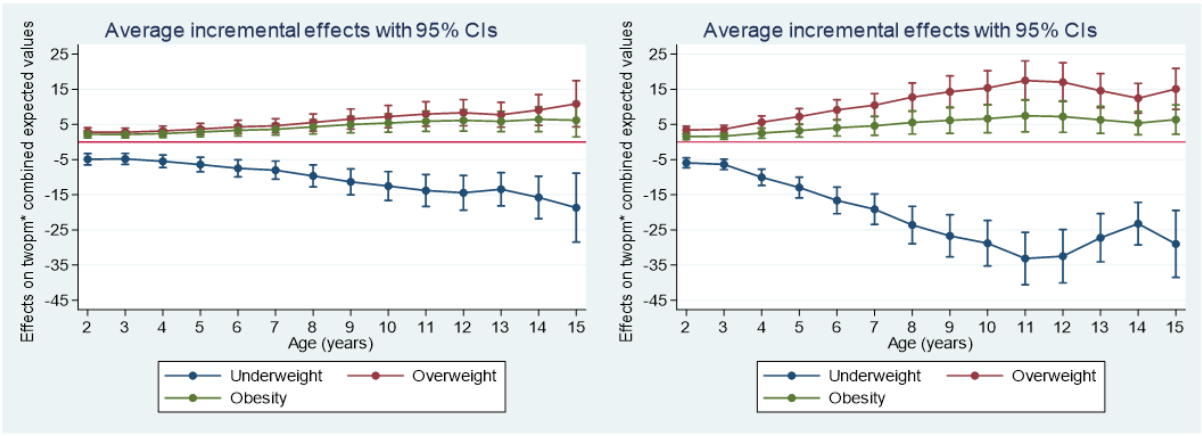

Figure 27 The relationship between test costs (£) and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

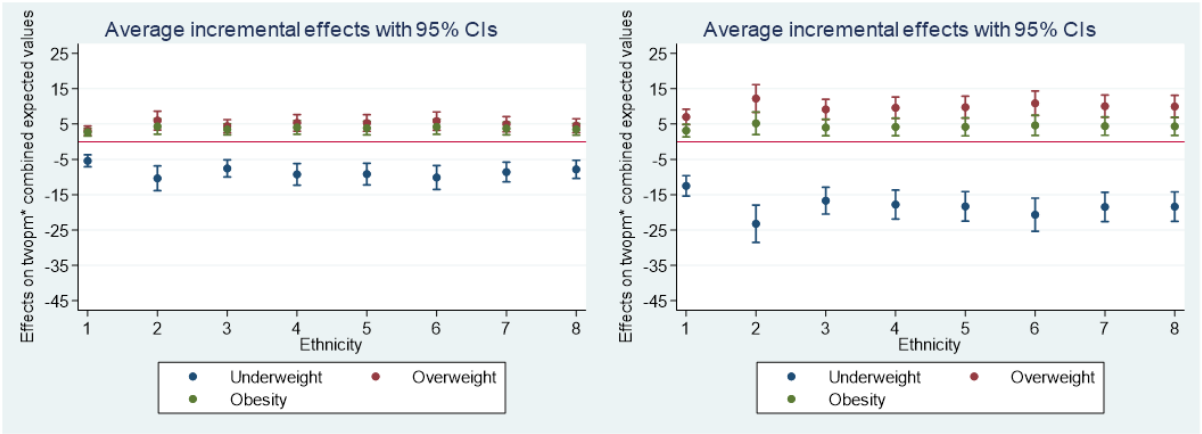

Figure 28 The relationship between test costs (£) and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

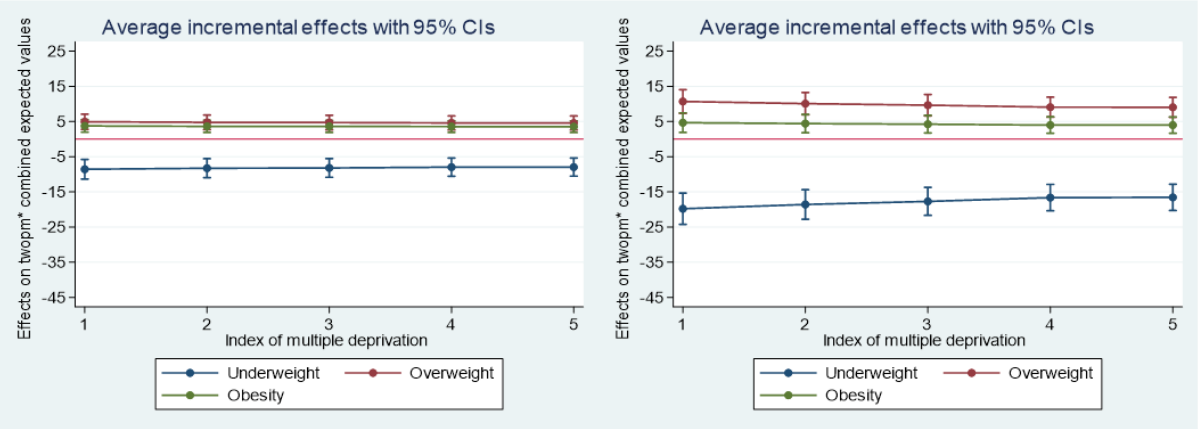

Figure 29 The relationship between test costs (£) and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

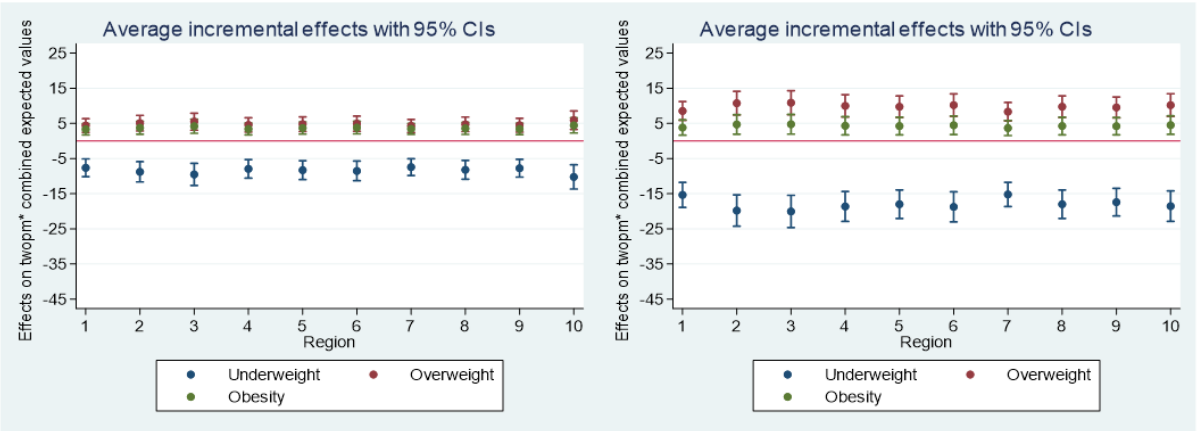

Figure 30 The relationship between test costs (£) and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

5.4 Discussion

5.4.1 Summary and interpretation of main findings

To my knowledge, this study is the first to estimate the all-cause resource use and costs associated with childhood excess weight in England at the primary care level using EHR. An earlier English study with a focus similar to my research limited its analysis to the EHR records of a cohort of children born in Bradford, a city in the North of

England.[494] In a previous England-wide survey that estimated the impact of childhood obesity on health outcomes and health service use, economic costs were not estimated.[495]

My main findings were that childhood obesity, compared with healthy weight, is associated with increased costs across all the three types of primary healthcare use I investigated (consultations, prescriptions and tests) both in the year preceding and the year following the index BMI measurement. The biggest contributors to these excess costs were consultations and prescriptions. The average prescription cost per child, as estimated in this study of 268,231 children with available EHRs—£18.23 for the year preceding and £20.12 for the year following the index BMI measurement—is substantially lower than the average per capita prescription cost in the English population for 2020/21 (£171).[496] This lower prescription cost for children is expected, as research has shown that the healthcare costs associated with excess weight are significantly higher among adults.[497] Additionally, in the year following the index BMI measurement, children categorised as underweight incurred higher average primary care costs for consultations and prescriptions than those in any other weight status category, including children with obesity. Elevated primary care costs for children living with underweight may indicate their greater need for medical intervention compared to children in other weight categories.

Test costs had the least impactful effect on excess costs associated with childhood obesity. The average (absolute) resource use and costs were generally higher in the year after the index BMI measurement than the year before across all weight status categories for consultations, prescriptions and tests. This finding is likely because many visits to primary care services requiring a BMI measurement may indicate serious health concerns, warranting follow-ups with more extensive care. Results were comparable across all statistical models applied in this study when convergence was achieved.

For the comparison between obesity and healthy weight, the utilisation of primary care resources generally aligned with costs, except in the case of tests where lower resource use counts in children with obesity relative to those in the healthy weight category contradicted the estimated excess costs. This discord was due to the difference in the unit costs of test categories and the distribution of test resource use by weight status. For instance, diagnostic tests were by far the most expensive test category, and children with excess weight had higher chances of undergoing a diagnostic test than they did the most frequently administered test categories

(haematology and biochemistry). On the other hand, children in the healthy weight category were less likely to have a diagnostic test compared to haematology and biochemistry tests.

In the year before the index BMI measurement, underweight children were less likely to attend a consultation and incurred lower consultation costs than their healthy-weight counterparts. However, this relationship reversed during the year after the index BMI measurement. The higher costs in the year after were potentially due to the increased provision of healthcare following the diagnosis. The incremental costs of prescriptions were higher in the underweight and obesity categories relative to healthy weight in the year after the index BMI measurement than the year before.

Consultation counts and costs did not differ considerably between the overweight and healthy weight categories. The absence of significant differences in consultation counts and costs between the overweight and healthy weight categories may indicate that children classified as overweight at the primary care level experience fewer substantial health complications compared to those with underweight or obesity. The average cost of prescriptions was higher in the overweight category relative to healthy weight. These differences showed varying statistical significance in the year before and after the index BMI measurement.

For the underweight and overweight categories, estimates of relative resource use counts and costs moved in opposite directions or were statistically insignificant across measures of primary healthcare use (particularly prescriptions and tests) and between the year before and after the index BMI measurement. The mean counts of tests were relatively higher and lower in underweight and overweight children, respectively, in the two years encompassing the index BMI measurement. These relationships reversed for costs and were statistically significant: underweight children incurred lower test costs, while overweight children had higher test costs than healthy-weight children. As explained previously, these inverse relationships between resource use and costs were due to the differences in unit costs of test categories and the varying distributions of their uptake across bodyweight categories.

Most covariates had statistically significant associations with counts of resource use and costs relative to the referent covariate level. Girls recorded more visits to the GP with associated incremental costs but fewer primary care prescriptions and lower costs than boys. Girls accrued higher test costs than boys in the year before the

index BMI measurement but lower test costs in the year after. I also reported statistically significant reductions in both counts and costs for consultations with age and a reversal of this trend for prescriptions and tests. For ethnicity, the highest counts and costs of resource utilisation generally occurred in children of Bangladeshi and Pakistani origin, regardless of the measure of primary healthcare utilisation. These elevated costs and frequency of resource use may be attributed to the higher prevalence of childhood excess weight observed among South Asian children in England[498], as well as the differing patterns of healthcare utilisation exhibited by South Asian populations in comparison to White individuals.[499] Consultation visits and costs were significantly higher in the most disadvantaged children, but similar comparisons for prescriptions and tests were mixed or statistically insignificant. Lastly, regional differences in mean costs of consultations were statistically significant, with the highest costs in London compared to other regions. Conversely, children in London incurred one of the lowest prescription and test costs.

The results of the covariates summarised above do not highlight differences based on weight status categories. Therefore, I conducted further analyses to better illustrate the complex relationships between the exposure variable (BMI category), covariates, and the outcome. I found that between weight status categories, the incremental costs of childhood obesity (relative to healthy weight) were statistically significant across all covariates for consultations, prescriptions and costs. However, within-category differences in costs were mostly statistically insignificant. An exception was observed in age, where two-year-old children with obesity incurred higher consultation costs compared to seven- to ten-year-olds in the same weight category. However, two-year-olds classified as overweight had lower test costs than children over nine years old in the overweight category. Additionally, two-year-olds with underweight experienced higher test costs compared to children over nine years old in the same weight category.

5.4.2 Comparison with the literature

As noted earlier, this is the first England-wide study to estimate resource use and costs associated with childhood weight status using EHR at the primary care level. Therefore, comparisons of results from this chapter with results reported elsewhere in the literature are limited. I discuss a more robust comparison in Chapter 7, in which I report aggregated primary and secondary health service resource use and costs.

The study by Hasan[494] conducted in Bradford, the 5th most income-deprived district in England, consisting of 9,397 children, differed remarkably from my study of 268,231 children in many other ways. For instance, in the Bradford study[494], children of Pakistani origin constituted the largest ethnic group at 46%, followed by whites (40%). This distribution contrasted with my study, which had a majority white population (63%) but also large sizes of children from other ethnicities. Hasan's analyses are also limited to children aged 4/5 years.

In alignment with my study, Hasan calculated statistically significantly higher mean annual costs for primary care associated with obesity compared to the healthy weight category. Hasan further estimated statistically significantly higher primary care costs for individuals in the underweight category in comparison to those with a healthy weight, which aligns with my findings, particularly regarding the higher costs for consultations and prescriptions. Furthermore, my findings that, independent of weight status, higher primary healthcare costs are linked to resource utilisation by ethnicity, while the relationship between weight status and primary healthcare costs remains unmodified by ethnicity, are consistent with Hasan's results.

5.4.3 Strengths and limitations

This study's core strength lies in using a large, country-wide sample size from EHRs, providing new insights into the association of childhood weight status and primary care utilisation and costs segregated by sex, age, ethnicity, IMD and region in England. The substantial study population is essential for generalisability, ensuring that my findings can be meaningfully applied nationally. It also gives me the confidence to examine trends within typically underserved and underrepresented subgroups such as children with underweight and children of minority ethnic backgrounds. For instance, in comparison to the National Child Measurement Programme (NCMP), the higher representation of children in the underweight category within my dataset—an often overlooked form of unhealthy weight[500]—may provide enhanced statistical power for identifying trends in this underrepresented weight status category.

My analysis indicates that resource counts do not always predict costs, emphasising the need for a more detailed understanding of their relationships. Moreover, my estimation of resource use and costs separately for the year preceding and the year following the index BMI measurement enhances the understanding of health-seeking behaviours and healthcare services associated with a BMI assessment. My results suggest that BMI

measurements lead to heightened medical attention in the following year, likely driven by concerns about the health risks associated with BMI. This increase in costs and resource use after the measurement could also imply that healthcare providers may be using BMI as a key metric to guide treatment decisions and health management, and parents or carers of the affected children may be more proactive in seeking care after BMI is measured.

The potential selection bias arising from BMI measurements not being routinely collected in the English primary healthcare setting posed a challenge, suggesting that the children in my analysis cohort may not sufficiently represent the distribution of children accessing primary healthcare in England. As van Jaarsveld and Gulliford pointed out, BMI measurements may be more likely to be taken when children are ill or in those in the tail distributions of weight status.[465] However, I demonstrated that my dataset's distribution of BMI categories at ages 4-5 (reception) and 10-11 years (year 6), particularly in the excess weight categories, is consistent with the BMI prevalences reported in the NCMP yearly surveys conducted between 2006/07 and 2022/23.[493] While these similarities in weight status distribution do not necessarily rule out the possibility of bias, they validate earlier studies which have shown comparable distributions between CPRD and other UK databases, such as the Health Survey for England and the NCMP.[465,501]

Another potential limitation of this study emanates from the choice of covariates included. There is a compelling argument in the literature that omitting relevant variables introduces more bias than including irrelevant ones.[477,492] Therefore, the literature on childhood excess weight and data availability informed my selection of covariates. However, I may have inevitably excluded vital covariates such as family history of chronic conditions and gestational age or included inappropriate ones. Unfortunately, these variables are available for only a limited number of children in the CPRD dataset.

5.5 Conclusions

In my scoping review (Chapter 2), I underscored the need for research estimating the economic burden of childhood excess weight, particularly in the UK. This chapter has addressed the absence of primary care estimates of excess costs associated with weight status in the childhood population of England. The derived estimates from this research can serve as parameter inputs in models estimating the cost-effectiveness of interventions targeting

childhood excess weight. In Chapter 6, I extend the research question to secondary healthcare service utilisation and costs associated with childhood excess weight.

Chapter 6: Secondary Care Resource Use and Costs Associated with Childhood Weight Category

6.1 Introduction

The research question in this chapter is a natural next step from the research question addressed in Chapter 5. The main goal is to investigate the relationship between childhood weight status categories (underweight, healthy weight, overweight and obesity) and annual secondary care (services generally requiring a referral from a general practice, usually in a hospital[455]) resource utilisation and costs. The study also disaggregates incremental costs (difference in costs) by weight status, gender, age groups, and cost/resource use category. Like Chapter 5, the study design is a retrospective cross-sectional analysis of Clinical Practice Research Datalink (CPRD) Aurum-linked Hospital Episode Statistics (HES) data. CPRD is an anonymised database of primary care medical records collected in general practice surgeries in the United Kingdom.[60,456] The HES dataset, available through NHS Digital, provides a comprehensive resource for hospital admissions records (admitted patient care), outpatient visits, and accident and emergency attendances.[466] In this chapter, I focus on HES data and I estimate mean annual secondary care resource use and costs before and after the index BMI measurements during visits to general practice surgeries. The methods applied in this chapter are broadly similar to those described and employed in the preceding chapter, although the focus is on secondary care rather than primary care.

6.2 Methods

6.2.1 Data sources

Linkage of the CPRD Aurum database with HES data (specifically, admitted patient care, outpatient visits, and accident and emergency attendances) was a precondition for eligibility in this secondary care healthcare utilisation and costing study. This requirement ensured that I had a common study population for all the Chapters 5-7 analyses. Descriptive information on CPRD and HES databases regarding their systems, data, and geographical coverages was provided in Chapter 5, section 5.2.1 Data sources for Chapters 5-7: CPRD and HES databases.

Secondary care provided by the NHS in England is curated through HES, a database containing clinical and administrative information on various aspects of hospital service provision. Ultimately, HES data may be used to

estimate secondary care costs, a comprehensive process involving several steps.[468] Each patient's interaction with the secondary care system is considered individually when costing secondary care. In my study, these unique secondary care interactions are covered under three categories of service provision: admitted patient care, outpatient visits, and accident and emergency attendances. Unique secondary care interactions are classified into Health Resource Groups (HRGs), representing grouped healthcare services that utilise similar amounts of healthcare resources. HRGs are "clinically meaningful groupings of patient activity, derived primarily from procedure (OPCS Classification of Interventions and Procedures Version 4.9) and diagnosis (International Statistical Classification of Diseases and Related Health Problems 10th Edition 5th Revision (ICD-10)) codes within patient records".[502] The current version of HRG codes was fully implemented in 2014/15.[469,502] The grouping of unique care interactions into respective HRGs is systematically conducted through the HRG Grouper software[503] using input variables from the appropriate secondary care service provision category. Subsequently, individual HRG-linked unique care interactions derived using the Grouper software can be quantified in cost terms by a National Average Unit Cost (NAUC) published annually in the National Cost Collection Data.[504] My costing approaches are described in subsection 6.2.5. The focus of this chapter is on the utilisation of secondary healthcare resources for all causes and their costs.

6.2.2 Study population

The study population in this chapter is the same as the one defined in Chapter 5. To summarise, eligible children were aged at least two years and had a BMI measurement during a visit to a GP surgery between the 1st of January 2015 and the 30th of March 2019, and their primary care data were linked to HES data. The analyses in this chapter are based on HES data collected from 2014 to 2020. The focus on data from 2014 onwards is premised on the rationale that the latest version of Healthcare Resource Groups (HRGs) in England (HRG4+) was not fully implemented until 2014/15.[469] Significant differences in the categorisation of resources in the previous version render comparisons with the current classification system unreliable. Applying the HRG4+ Grouper to recent data curtails methodological inconsistency and bias and produces contemporaneous policy-relevant estimates of resource use and costs.[65]

6.2.3 Study design

This chapter retains the retrospective cross-sectional study design applied in Chapter 5. Healthcare resource use (admitted patient care, outpatient visits, and accident and emergency attendances) and costs at the secondary care level were similarly estimated over two distinct periods, namely:

I. one year before the date of the last height and weight measurement in a calendar year (date of exposure, alternatively defined as the date of index BMI measurement)
II. one year after the date of the last height and weight measurement in a calendar year (date of exposure, alternatively defined as the date of index BMI measurement)

Descriptive information on the general model specification for this chapter was provided in Chapter 5, section 5.2.3 Study design for Chapters 5-7. The analytical approach to estimation is reported in detail in Chapter 5 (5.2.7 Analytical Approach for Chapters 5-7) and later in this chapter (6.2.7 Analytical Approach).

6.2.4 Exposure: weight status category

The methods used to determine the exposure category (namely, the weight status category) are fully described in Chapter 5. In summary, I categorised children in the study according to bodyweight categories for each BMI record based on the UK cut-offs for population monitoring. The levels of exposure are as follows: underweight (less than or equal to the 2nd centile), healthy weight (greater than the 2nd and less than the 85th centile), overweight (greater than or equal to the 85th and less than the 95th centile), and obesity (greater than or equal to the 95th centile).[22]

6.2.5 Use of secondary care and associated costs

My focus in this research is on all-cause use of secondary resources.

Admitted patient care

I generated HRG codes at the Full Consultant Episode (FCE) level using the HRG4+ 2021/22 Reference Cost Grouper.[503] An FCE is the time a patient spends in the continuous care of one consultant.[505] To avoid double counting episodes[466], I checked that there were no duplicates in my dataset in terms of the episode key uniquely identifying an episode of care ('epikey') and the encrypted unique key given to a patient in CPRD Aurum ('patid'). Further, only episodes with a start date ('epistart') and an end date ('epiend') were included. The complete list of

HES admitted patient care variables needed for deriving HRG codes and a guide for using the Grouper software are provided in the Grouper User Manual[503] and reported in Appendix F.

After deriving HRG codes through the grouping process, a further step was required to link HRGs to national average unit costs (NAUCs) effectively because HRG codes may be associated with multiple department descriptions (namely, day cases, elective inpatients, non-elective inpatient-long stays, non-elective inpatient-short stays and regular day or night admissions)[506] and thus multiple unit costs (NAUCs). I determined the appropriate department descriptions by checking the patient classification variable ('classpat') provided with the raw HES data[506] against the method of admission ('admimeth'), the intended management (for elective inpatients only) and the duration of the episode in days ('epidur').[62] Since my study population did not include newborns, observations indicating childbirth as the admission method were excluded. The algorithm I applied for deriving department descriptions and additional steps taken to estimate unit costs (NAUCs) are reported in Appendix F. The unit costs (NAUCs) of hospital admissions were obtained from the 2021/22 National Cost Collection Data[504] after generating the HRGs and verifying the department descriptions. Where relevant, costs were adjusted to 2021/22 prices using the NHS Cost Inflation Index (NHSCII).[471]

I categorised admitted patient care as occurring during the year before or after a BMI measurement based on the dates associated with the start of an episode (‘epistart’) and the end of the episode (‘epiend’) (see Appendix F).

Outpatient care

I provide the complete list of outpatient variables needed to derive HRG codes (also listed in Grouper User Manual [503]) using the Grouper software in Appendix F. After deriving HRG codes, two additional steps were required to link them to the appropriate unit costs (NAUCs) in the 2021/22 National Cost Collection Data.[504] The first step was to link the HRG codes to the outpatient care unit costs (NAUCs) using the patient's attendance status (variable 'attended'), the medical staff type seeing the patient ('stafftyp'), and the treatment speciality ('tretspef').[63] I excluded observations from my dataset if the patient's attendance status was cancelled by, or on behalf of, the patient or cancelled or postponed by the health care provider. The second step involved deriving the unit costs (NAUCs) if they were associated with outpatient procedures (OPROC). For this step, only the treatment speciality and the HRG variables were required to match the appropriate unit costs (NAUCs). When

unit costs (NAUCs) were missing in either step due to missing 'stafftyp' or department descriptions, I estimated the weighted average of costs for HRGs with the same service and currency descriptions. In a minority of cases, unit costs (NAUCs) could also be missing because the service description was not costed even though it was reported, for example, service code of 700 (Learning Disability Service).[507] In such cases, I estimated the total weighted average costs for outpatient care and outpatient procedures combined and used them as the proxy unit costs (NAUCs). I categorised outpatient care as occurring during the year before or after a BMI measurement based on the appointment date (‘apptdate’) (see Appendix F).

Accident and emergency care

A complete list of accident and emergency care variables I used to derive HRG codes (also listed in Grouper User Manual[503]) using the Grouper software is reported in Appendix F. Unit costs for outpatient care were obtained from the 2021/22 National Cost Collection Data[504] after generating the Health Resource Group (HRG) non-admitted care codes from the HRG4+ 2021/22 Reference Cost Grouper[503] based on the classification of accident and emergency department type according to the activity carried out ('aedepttype').[64,508] If unit costs (NAUCs) for accident and emergency attendance were not available in the NHS Reference Cost 2021/22 schedule, I applied the weighted national average costs across all Service codes. I categorised accident and emergency care as occurring during the year before or after a BMI measurement based on the arrival date of a patient in the accident and emergency department (‘arrivaldate’) (see Appendix F).

6.2.6 Covariates

The five covariates included in the regression models of this chapter are the same as those included in the analyses conducted in Chapter 5, i.e. sex; age; ethnicity; region; and the English Index of Multiple Deprivation (IMD).[66] Chapter 5 fully describes the rationale behind covariate selection.

6.2.7 Analytical Approach

The descriptive statistics for the study population's BMI distribution, weight status categories, and sociodemographic characteristics remain the same as previously reported and can be found in Chapter 5 (Subsection 5.3.1). A summary of my analytical approaches is reported in the following paragraph. In this chapter,

I reported the mean and total resource use and costs for my study population for measures of secondary care (admitted patient care, outpatient care and accident and emergency care) and graphed the cost distributions.

Given the similar characteristics of the datasets, particularly the high proportions of zero counts, the rationale for my model specifications for estimating mean and incremental secondary care resource use and costs remained the same, as described in Chapter 5 (Subsection 5.2.7). For resource use counts, I applied the zero-inflated negative binomial regression (ZINB) estimator and the zero-inflated Poisson regression (ZIP) estimator.[97,479,480] To estimate costs, I applied the two-part model, specifically the generalised linear model (GLM) with log link and gamma distribution.[88,92,93,97] I applied the appropriate diagnostic approaches for all models, as detailed in Chapter 5 (Subsection 5.2.7). In summary, these approaches included using the Park test to assess the candidate family distributions and the Box-Cox transformation to evaluate the link function of the GLM distribution.[491] I also used the outputs of AIC and BIC to guide my model selection.[477,489,490] I performed clustered regression analyses at the patent level to effectively account for within-patient correlation in resource utilisation.[484] I ran all models using Stata 17 statistical software.[481]

6.3 Results

6.3.1 Study Population

The study population in this chapter consists of the same 268,231 children as reported in Chapter 5. Therefore, Chapter 5 (subsection 5.4.1) details this study population's sociodemographic and socioeconomic characteristics. In summary, boys comprised a larger percentage of the study population (55.26%) than girls. The number of children in the study population decreased significantly during mid-childhood and early adolescence, dropping from 12,393 children at 11 years to 2,234 children at 12 years old. Children in the healthy weight category represented 67.27% of all sample; underweight 4.10%; overweight 11.54%; and obesity 17.09%.

6.3.2 Model specification

Similar to Chapter 5, I applied the negative binomial regression (ZINB) estimator and the zero-inflated Poisson regression (ZIP) estimator to model outputs for secondary care resource use counts. Based on AIC and BIC comparisons (with lower values indicating better fit: see Appendix F), the ZINB model tended to fit the data better than the ZIP model. However, unlike the ZIP model, the ZINB iterations did not converge for some covariates in

one resource use type when estimating the whole model. Specifically, the ZINB model did not converge for only the accident and emergency care dataset the year after the index BMI measurement. Given the similarities in the predicted means (margins) and standard errors produced by both models, I report ZIP model estimates for that instance.

For costs, I conducted the diagnostic tests laid out in Chapter 5. The Gamma family with a log link function was strongly favoured in all models. Therefore, I derived model outputs using a two-part model with a logit first part and GLM second part with the log link and gamma distribution for the primary analysis of costs. Model estimates are reported in Subsections 6.3.1, 6.3.2 and 6.3.4 of this chapter. Statistical significance is set at a threshold of $p < 0.05$ throughout the results and discussion sections.

6.3.3 Admitted patient care – descriptive results and model estimates for resource use counts and costs

The Grouper software processed 129,439 admitted patient care records or observations. Of these, 128,936 (99.61%) were grouped. I excluded the ungrouped records, representing less than 1% of my dataset. The ungrouped records (undefined HRG codes) were typically due to missing data items on diagnosis or procedures.

In the year before the index BMI measurement, 37,050 children experienced a total of 71,289 admitted patient care episodes. In the year after the index BMI measurement, 31,279 children experienced 57,647 admitted patient care episodes cumulatively. The mean numbers of episodes across the entire study population are reported in Table 30.

Table 30 Mean number of admitted patient care episodes per child in the study population of 268,231 children

	Mean	Standard deviation	Min	Max*	Lower 95% CI	Upper 95% CI
One year before the BMI measurement	0.266	1.553	0	171	0.260	0.272
One year after the BMI measurement	0.215	1.392	0	171	0.210	0.220

*The maximum number of episodes the year before and after the BMI measurement pertains to two different children.

The mean numbers of admissions per child predicted with margins and adjusted for childhood weight status and all covariates in the years before and after the index BMI measurement were 0.266 (95% CI: 0.260-0.272) and 0.215 (95% CI: 0.210-0.220), respectively. These predicted numbers represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two

parts of the model are reported in Appendix F. Table 31 shows the estimated predicted mean number of admitted patient care episodes by weight status category (while holding all covariates at average values) and individual covariates (while holding all other covariates at average values), as well as the incremental effects with respect to the referent levels of individual covariates.

On average, children in the obesity category experienced an additional 0.041 and 0.032 more episodes than children in the healthy weight status category in the year before and after an index BMI measurement, respectively (Table 31, column "Incremental effects"). Girls were less likely to have admitted care episodes than boys (0.012 and 0.011 fewer episodes in the year before and after an index BMI measurement, respectively). These differences were statistically significant. Admitted care episodes were higher for children older than two years and tended to increase with age. Children of Pakistani ethnicity experienced the highest number of admitted care episodes relative to white children. Only children in the most deprived quintile had statistically significantly more admitted care episodes than the least deprived children in the year before the index BMI measurement. In the year after the index BMI measurement, differences between the IMD quintiles were not statistically significant. Children in the East of England and the Southwest had the lowest number of episodes (statistically significant) compared to their peers in London in both the year before and after the index BMI measurement.

Table 31 Mean and incremental number of admitted patient care episodes one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean number of admitted patient care episodes	Standard error	Incremental effects	Standard error	Mean number of admitted patient care episodes	Standard error	Incremental effects	Standard error
BMI								
Underweight	0.219***	0.009	-0.038***	0.010	0.209***	0.008	0.002	0.009
Healthy weight (referent)	0.256***	0.003	-	-	0.207***	0.003	-	-
Overweight	0.295***	0.010	0.039***	0.011	0.231***	0.008	0.024***	0.008
Obesity	0.297***	0.010	0.041***	0.010	0.239***	0.009	0.032***	0.009
Sex								
Boys (referent)	0.271***	0.004	-	-	0.22***	0.004	-	-
Girls	0.259***	0.005	-0.012**	0.006	0.209***	0.004	-0.011**	0.005
Age								

Variable	Year before				Year after			
	Mean number of admitted patient care episodes	Standard error	Incremental effects	Standard error	Mean number of admitted patient care episodes	Standard error	Incremental effects	Standard error
2 years (referent)	0.521***	0.014	-	-	0.371***	0.013	-	-
3 years	0.369***	0.011	-0.152***	0.018	0.284***	0.010	-0.087***	0.016
4 years	0.325***	0.009	-0.196***	0.016	0.253***	0.007	-0.119***	0.015
5 years	0.259***	0.008	-0.261***	0.016	0.205***	0.008	-0.166***	0.015
6 years	0.25***	0.009	-0.271***	0.016	0.201***	0.007	-0.17***	0.015
7 years	0.201***	0.007	-0.32***	0.016	0.166***	0.006	-0.205***	0.014
8 years	0.188***	0.006	-0.333***	0.015	0.164***	0.006	-0.207***	0.014
9 years	0.185***	0.007	-0.335***	0.016	0.178***	0.009	-0.193***	0.016
10 years	0.181***	0.007	-0.34***	0.016	0.164***	0.006	-0.207***	0.015
11 years	0.235***	0.016	-0.286***	0.021	0.205***	0.011	-0.166***	0.017
12 years	0.213***	0.030	-0.308***	0.033	0.181***	0.018	-0.19***	0.022
13 years	0.205***	0.039	-0.316***	0.041	0.272***	0.049	-0.099**	0.051
14 years	0.21***	0.041	-0.311***	0.043	0.17***	0.031	-0.202***	0.034
15 years	0.143***	0.055	-0.378***	0.057	0.207**	0.092	-0.164*	0.093
Ethnicity								
Other/Unknown	0.093***	0.007	-0.196***	0.008	0.088***	0.006	-0.139***	0.007
Bangladeshi	0.269***	0.031	-0.02	0.031	0.229***	0.020	0.002	0.020
Black	0.288***	0.011	-0.001	0.012	0.254***	0.010	0.027***	0.011
Chinese/Other Asian	0.333***	0.022	0.044**	0.022	0.286***	0.028	0.059**	0.028
Indian	0.28***	0.015	-0.009	0.016	0.231***	0.012	0.004	0.013
Pakistani	0.373***	0.025	0.084***	0.025	0.306***	0.022	0.079***	0.022
White (referent)	0.289***	0.004	-	-	0.227***	0.003	-	-
Mixed	0.322***	0.018	0.033*	0.019	0.251***	0.016	0.024	0.016
IMD								
Fifth quintile: least deprived (referent)	0.255***	0.007	-	-	0.203***	0.006	-	-
Fourth quintile	0.264***	0.007	0.009	0.010	0.214***	0.007	0.011	0.009
Third quintile	0.26***	0.007	0.006	0.010	0.214***	0.006	0.011	0.008
Second quintile	0.268***	0.006	0.013	0.009	0.218***	0.005	0.015*	0.008
First quintile: most deprived	0.274***	0.006	0.019**	0.009	0.219***	0.005	0.016*	0.008
Region								
North East	0.289***	0.018	0.031	0.020	0.264***	0.016	0.059***	0.017
North West	0.325***	0.007	0.066***	0.010	0.257***	0.006	0.051***	0.008
Yorkshire and The Humber	0.232***	0.010	-0.026**	0.013	0.216***	0.014	0.01	0.015
East Midlands	0.22***	0.014	-0.038**	0.016	0.187***	0.017	-0.019	0.018
West Midlands	0.265***	0.008	0.007	0.010	0.206***	0.006	0	0.008
East of England	0.223***	0.011	-0.035***	0.013	0.166***	0.008	-0.04***	0.010
London (referent)	0.258***	0.007	-	-	0.206***	0.005	-	-
South East	0.262***	0.008	0.004	0.011	0.224***	0.008	0.018*	0.010
South West	0.226***	0.007	-0.032***	0.010	0.186***	0.006	-0.019**	0.008
Missing	0.278***	0.066	0.019	0.067	0.176***	0.012	-0.03**	0.014

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

Only 213 retained observations had missing unit cost (NAUC) values in the 2021/22 National Cost Collection Data, for which I applied the weighted averages of unit costs (NAUCs) associated with their respective department descriptions. For day cases, elective inpatients, non-elective inpatient-long stays, non-elective inpatient-short stays, and regular day or night admissions, the weighted average unit costs (NAUCs) were £1,038.17, £5,963.55, £4,376.51, £800.75, and £401.19, respectively.

The total costs of admitted patient care episodes recorded among children who experienced an episode one year before and after the index BMI measurements were £125,139,122 and £107,750,668, respectively. The mean costs per child in the study population of 268,231 children were £466.53 and £401.71, respectively, in the year before and after the index BMI measurement (**Table 32**).

Table 32 Mean admitted patient care episode costs per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before the BMI measurement	466.53	3,259.40	0	279,495.90	454.20	478.87
One year after the BMI measurement	401.71	3,374.82	0	377,893.80	388.94	414.48

depicts the distribution of admitted patient care episode costs, showing the frequency of data points in bins and kernel density plots with smoothed estimates of the distribution. It can be observed that admitted patient care costs are heavily right-skewed.

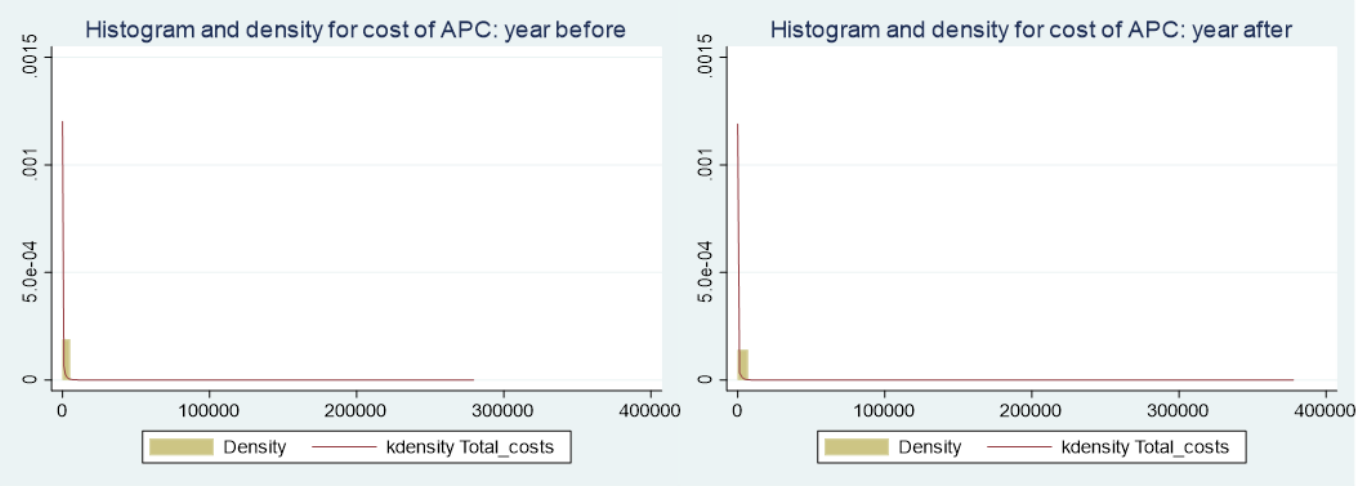

Figure 31 Combined histogram and kernel density plot of admitted patient care episode costs in the years before and after the index BMI measurement (APC: admitted patient care)

The adjusted mean costs of admitted patient care episodes per child predicted with margins the year before and after the index BMI measurement were £466.69 (95% CI: 454.35-479.02) and £401.72 (95% CI: 388.95-414.49), respectively. These predicted cost estimates derived from the two-part GLM regression model represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix F. Table 33 presents the modelled mean costs of admitted patient care episodes by weight status category (while holding all covariates at average values) and individual covariates (while holding all other covariates at average values), as well as the incremental effects with respect to the referent levels of individual covariates.

In the year before a BMI measurement, the mean total costs of admitted patient care episodes were highest in children with obesity. Compared to healthy weight, childhood obesity cost an additional £59.68 and an additional £52.11 (statistically significant) for admitted patient care in the year before and after an index BMI measurement, respectively (Table 33, column “Incremental costs”). In the year after the index BMI measurement, underweight accounted for the highest admitted patient care costs relative to healthy weight at £96.65, and this difference was statistically significant. On average, girls accrued lower annual admitted patient care costs in the years that straddled an index BMI measurement by £25.77 and 28.84, a statistically significant cost difference. Costs for older children were higher compared to two-year-olds. Children of Pakistani origin incurred the highest costs relative to white children. Only children in the Southwest had statistically significant differences in costs in the

year before the index BMI measurement compared to children in London. Differences in the year after were not statistically significant.

Table 33 Mean and incremental costs of admitted patient care costs one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean costs of admitted patient care	Standard error	Incremental costs	Standard error	Mean costs of admitted patient care	Standard error	Incremental costs	Standard error
BMI								
Underweight	440.45***	28.016	-10.52	28.887	484.16***	31.937	96.65***	32.832
Healthy weight (referent)	450.97***	7.163	-	-	387.51***	7.527	-	-
Overweight	506.23***	20.027	55.26***	21.165	401.73***	16.849	14.22	18.335
Obesity	510.64***	18.034	59.68***	19.353	439.62***	19.577	52.11**	20.942
Sex								
Boys (referent)	478.13***	8.469	-	-	414.53***	9.023	-	-
Girls	452.36***	9.095	-25.77**	12.241	385.69***	9.119	-28.84**	12.682
Age								
2 years (referent)	928.59***	35.340	-	-	690.83***	30.082	-	-
3 years	607.5***	22.236	-321.09***	41.502	488.23***	20.574	-202.6***	36.273
4 years	563.03***	20.614	-365.56***	40.682	469.59***	20.358	-221.25***	35.811
5 years	423.71***	15.107	-504.88***	38.290	376.49***	19.873	-314.34***	35.765
6 years	422.11***	14.563	-506.48***	38.135	389.83***	18.280	-301***	35.152
7 years	367.85***	17.489	-560.75***	39.364	328.36***	19.512	-362.47***	35.763
8 years	344.53***	16.266	-584.06***	38.783	298.91***	14.149	-391.92***	33.236
9 years	324.12***	14.362	-604.47***	38.213	328.3***	18.629	-362.54***	35.432
10 years	350.08***	18.163	-578.51***	39.755	322.15***	17.673	-368.68***	35.058
11 years	450.2***	29.993	-478.39***	46.461	404.92***	25.641	-285.91***	39.679
12 years	429.57***	68.260	-499.03***	77.112	400.51***	62.647	-290.32***	69.767
13 years	380.4***	98.754	-548.19***	104.831	416.33***	85.821	-274.51***	91.012
14 years	570.15***	204.271	-358.44*	207.521	243.73***	49.803	-447.1***	58.152
15 years	153.36**	67.416	-775.23***	76.071	269.74**	134.883	-421.09***	138.069
Ethnicity								
Other/Unknown	153.33***	12.349	-369.83***	15.281	148.98***	12.870	-294.11***	16.246
Bangladeshi	433.98***	59.152	-89.18	60.311	369.93***	39.113	-73.16*	40.435
Black	502.45***	27.463	-20.71	29.640	472.38***	31.193	29.29	33.359
Chinese/Other Asian	539.66***	37.479	16.5	38.763	465.24***	42.840	22.15	43.836
Indian	466.5***	35.436	-56.66	36.578	385.95***	33.396	-57.14*	34.650
Pakistani	597.78***	33.035	74.62**	34.072	512.21***	29.353	69.13**	30.734
White (referent)	523.16***	8.581	-	-	443.09***	8.824	-	-
Mixed	497.58***	27.596	-25.58	29.064	440.97***	39.442	-2.12	40.683
IMD								
Fifth quintile: least deprived (referent)	439.76***	16.505	-	-	357.62***	15.955	-	-
Fourth quintile	460.39***	14.589	20.64	21.830	404.31***	16.050	46.69**	22.044

Variable	Year before				Year after			
	Mean costs of admitted patient care	Standard error	Incremental costs	Standard error	Mean costs of admitted patient care	Standard error	Incremental costs	Standard error
Third quintile	452.43***	13.984	12.67	21.552	387.56***	14.162	29.94	21.145
Second quintile	468.74***	12.723	28.99	20.855	407.03***	12.113	49.41**	20.307
First quintile: most deprived	492.42***	12.370	52.67**	20.776	428.65***	14.448	71.03***	22.299
Region								
North East	473.72***	35.618	4.01	39.968	471.84***	42.690	70.62	46.352
North West	536.31***	15.470	66.6***	21.953	440.36***	14.781	39.14*	21.417
Yorkshire and The Humber	446.75***	27.859	-22.96	32.056	441.66***	49.737	40.43	51.595
East Midlands	434.75***	40.542	-34.96	43.361	433.63***	55.919	32.4	57.827
West Midlands	450.57***	14.743	-19.14	21.039	378.64***	15.026	-22.58	20.854
East of England	448.75***	36.604	-20.97	39.553	342.96***	30.885	-58.27*	34.294
London (referent)	469.72***	14.756	-	-	401.23***	14.531	-	-
South East	459.52***	14.397	-10.2	21.408	407.22***	16.111	6	22.411
South West	407.68***	16.868	-62.04***	22.631	356.37***	18.417	-44.86*	23.666
Missing	450.77***	66.231	-18.95	68.020	376.03***	46.089	-25.2	48.580

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

The relationships between the exposure variable (BMI category), covariates, and the outcome variable (admitted patient care costs) are more complex than what is captured by the average incremental effects presented in **Table 33.** To enhance the interpretation of results by exploring potential effect modification by covariates, I separately calculated the incremental effects of the BMI category on costs for each covariate (point estimates and their 95% CIs are reported in Appendix F). The calculations are visually represented in **Figure 32**-**Figure 36.** For each covariate level, an error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Compared to healthy weight, incremental costs associated with obesity weight status persisted across all covariates in the year before or after the index BMI measurement. However, in the year after the index BMI measurement, these additional costs were lower than those of children in the underweight category. Both findings were statistically significant. In the year before the index BMI measurement, the underweight category recorded the lowest costs for all covariates. Admitted patient care costs in the overweight category, compared to healthy weight, were not statistically significant neither the year before nor after the index BMI measurement, but were lower in magnitude the year after.

In the obesity category, girls appeared to incur a lower cost than boys, but the difference was not statistically significant. Costs tended to be highest for two-year-olds with the overweight and obesity categories, but these

differences were not statistically significant. Differences in costs were statistically insignificant for the remaining covariates at all weight status categories.

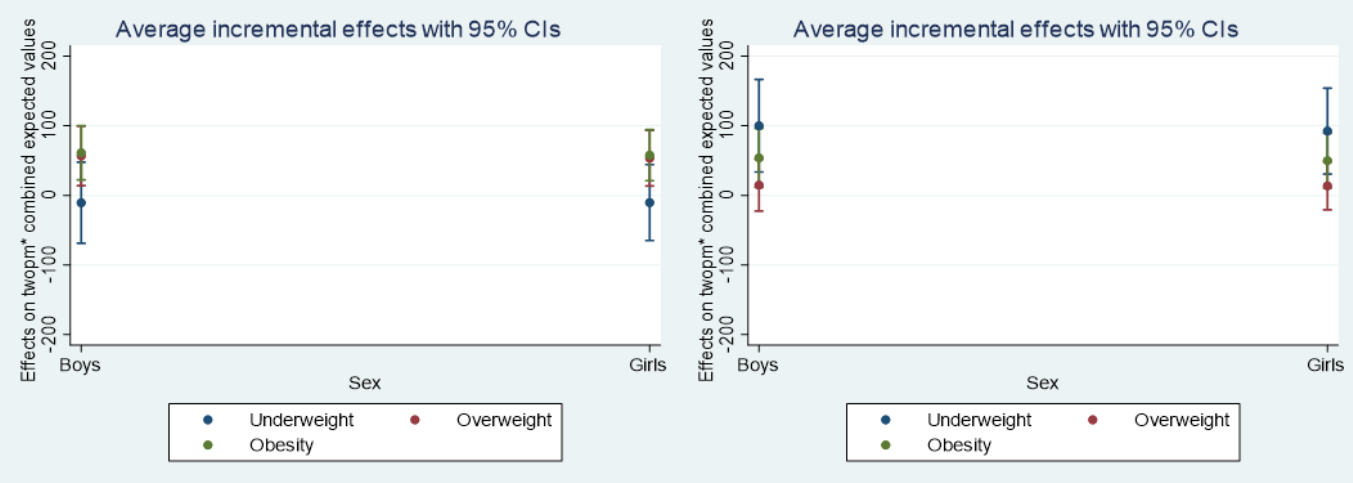

Figure 32 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

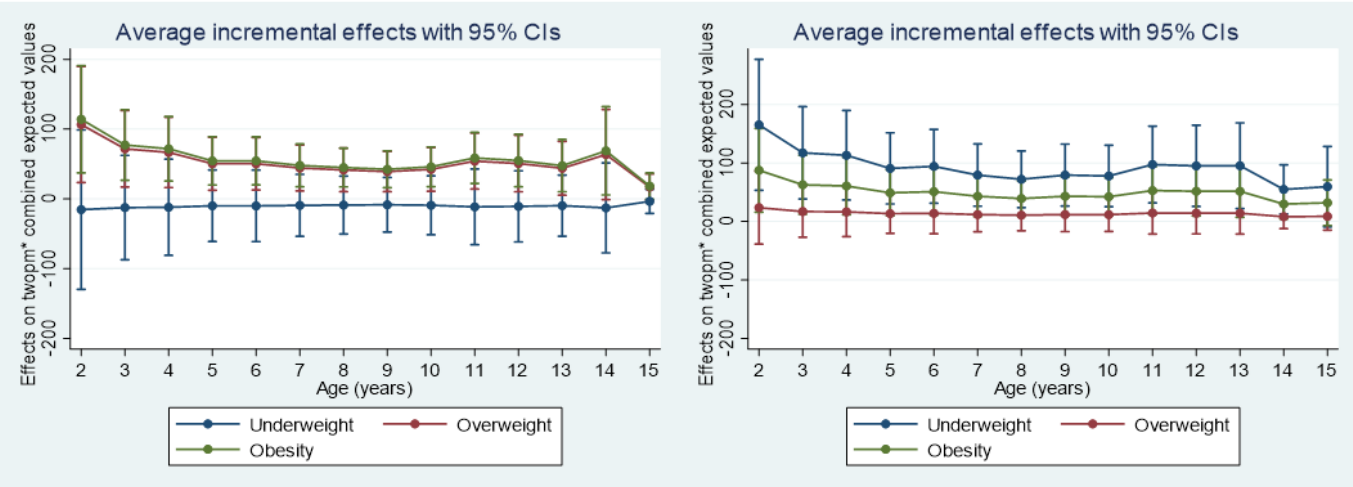

Figure 33 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

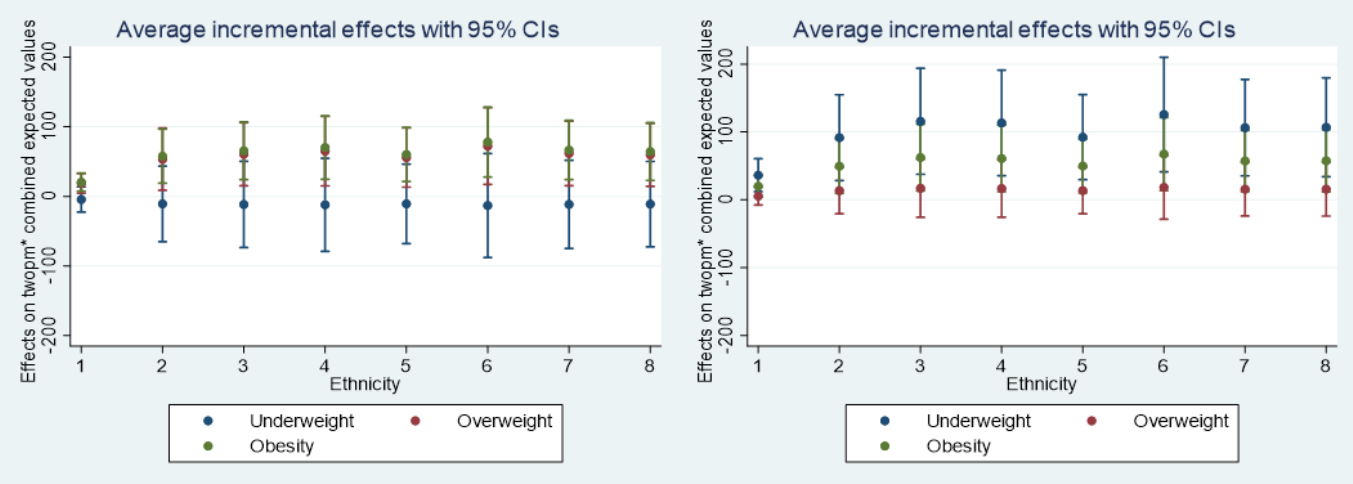

Figure 34 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

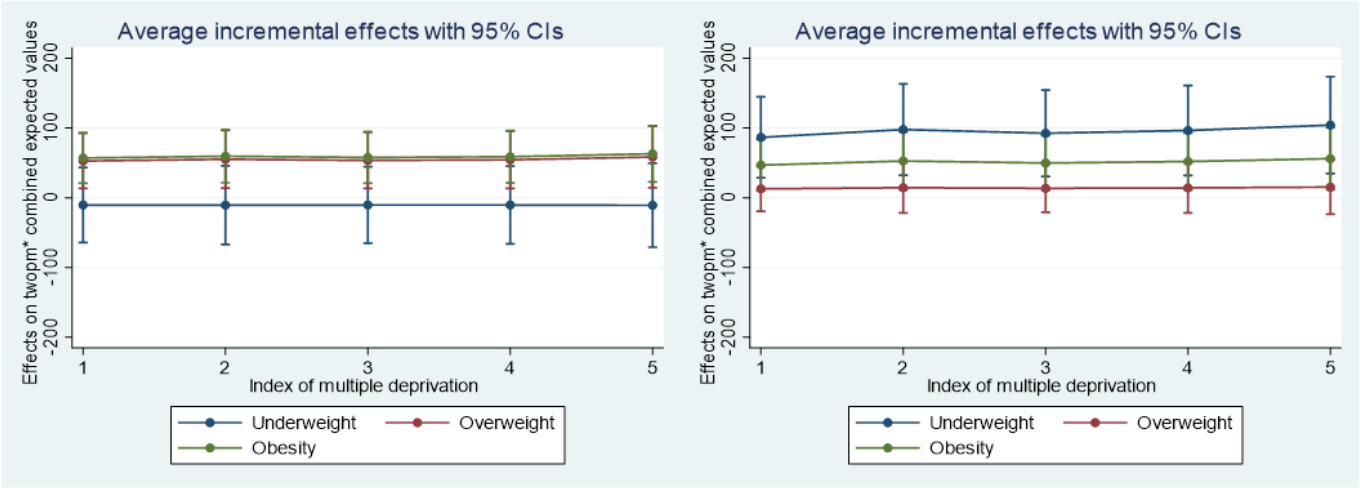

Figure 35 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

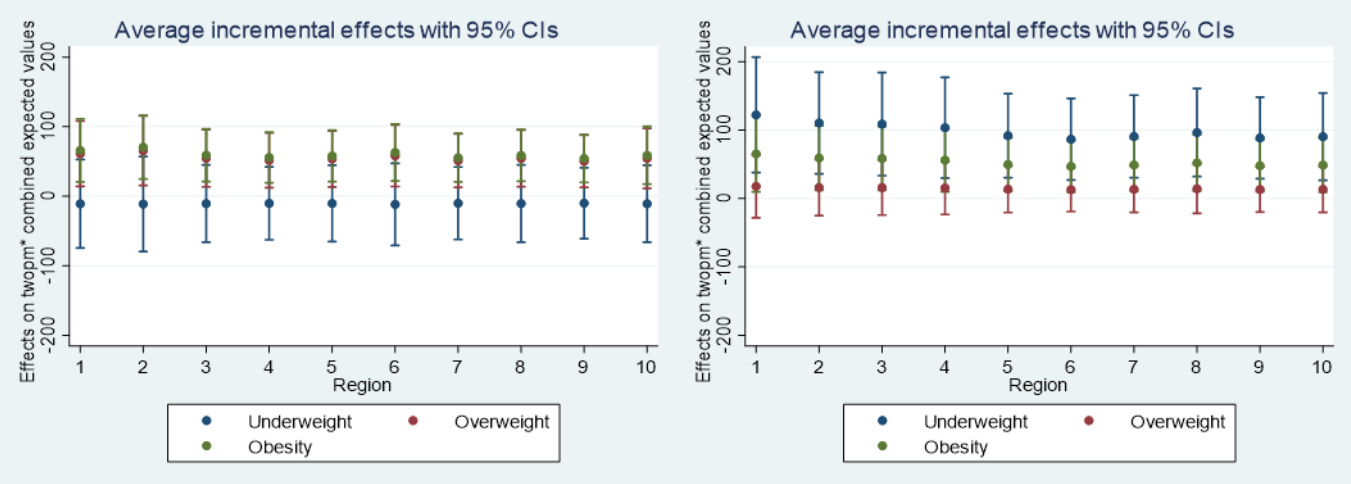

Figure 36 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

6.3.4 Outpatient care – descriptive results and model estimates for resource use counts and costs

In the year before the BMI measurement, 117,585 children had a total of 497,441 outpatient care visits. In the year after the BMI measurement, 136,210 children had 570,075 outpatient care visits cumulatively. The mean number of outpatient care visits across the study population is reported below.

Table 34 Mean number of outpatient care attendances per child in the study population of 268,231 children

	Mean	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	1.855	5.045	0	851	1.835	1.874
One year after BMI measurement	2.125	5.157	0	1121	2.106	2.145

The predicted mean outpatient care visitations per child in the years before and after the index BMI measurement were 1.854 (95% CI: 1.835-1.873) and 2.125 (95% CI: 2.105-2.145), respectively. Regression coefficients (marginal effects) for the two parts of the model with a logit first part and GLM second part with the log link and gamma distribution are reported in Appendix F. Table 35 shows the estimated mean number of outpatient care visitations by weight status category and covariates, as well as the incremental effects with respect to the referent levels of individual covariates. On average, children in the obesity categories utilised an

additional 0.204 and 0.229 (statistically significant) more outpatient care visitations than children in the healthy weight status category in the year before and after an index BMI measurement, respectively. Girls were less likely to attend outpatient care than boys (0.151 and 0.115 fewer attendances in the year before and after an index BMI measurement, respectively). These differences were statistically significant. The mean number of outpatient care visits was lower in older children compared to children aged 2. In the year before an index BMI measurement, children of Pakistani origin recorded the highest number of outpatient care visits (2.102), but the comparative difference was not statistically significant. On the other hand, statistically significantly lower outpatient care visits were estimated for Bangladeshi, black and Indian children relative to their white peers. The children from the least socioeconomically deprived areas had the lowest number of outpatient care visits, and the lower estimates relative to other quintiles of deprivation were statistically significant. Children from the most socioeconomically deprived areas tended to experience the highest number of outpatient care visits. Children in the East of England had the lowest number of outpatient care visits compared to their peers in London (the reference group for region). This difference was statistically significant in the year before an index BMI measurement but not statistically significant in the year after.

Table 35 Mean and incremental number of outpatient care attendances one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean number of outpatient care attendance	Standard error	Incremental effects	Standard error	Mean number of outpatient care attendance	Standard error	Incremental effects	Standard error
BMI								
Underweight	1.813***	0.050	0.008	0.052	2.186***	0.046	0.12***	0.047
Healthy weight (referent)	1.805***	0.011	-	-	2.065***	0.011	-	-
Overweight	1.93***	0.027	0.125***	0.029	2.204***	0.028	0.139***	0.030
Obesity	2.009***	0.029	0.204***	0.030	2.295***	0.034	0.229***	0.035
Sex								
Boys (referent)	1.922***	0.012	-	-	2.177***	0.012	-	-
Girls	1.77***	0.015	-0.151***	0.019	2.061***	0.016	-0.115***	0.020
Age								
2 years (referent)	2.407***	0.042	-	-	2.669***	0.037	-	-
3 years	1.904***	0.029	-0.503***	0.051	2.233***	0.030	-0.436***	0.048
4 years	1.931***	0.026	-0.476***	0.049	2.333***	0.028	-0.336***	0.046
5 years	1.811***	0.026	-0.596***	0.049	2.049***	0.025	-0.62***	0.045
6 years	1.861***	0.025	-0.546***	0.049	2.079***	0.027	-0.59***	0.046
7 years	1.737***	0.034	-0.67***	0.052	1.941***	0.040	-0.729***	0.052
8 years	1.614***	0.024	-0.793***	0.048	1.864***	0.024	-0.805***	0.044

Variable	Year before				Year after			
	Mean number of outpatient care attendance	Standard error	Incremental effects	Standard error	Mean number of outpatient care attendance	Standard error	Incremental effects	Standard error
9 years	1.691***	0.025	-0.716***	0.049	1.956***	0.027	-0.713***	0.046
10 years	1.812***	0.034	-0.595***	0.054	2.07***	0.032	-0.599***	0.050
11 years	2.055***	0.050	-0.352***	0.065	2.311***	0.046	-0.358***	0.059
12 years	1.78***	0.084	-0.627***	0.094	2.277***	0.100	-0.393***	0.106
13 years	2.01***	0.150	-0.397**	0.155	2.948***	0.234	0.279	0.237
14 years	2.453***	0.352	0.046	0.355	2.759***	0.272	0.089	0.275
15 years	1.578***	0.343	-0.829**	0.346	2.118***	0.619	-0.551	0.620
Ethnicity								
Other/Unknown	0.814***	0.021	-1.274***	0.025	1.13***	0.030	-1.23***	0.033
Bangladeshi	1.576***	0.066	-0.512***	0.068	1.751***	0.064	-0.61***	0.066
Black	1.789***	0.042	-0.299***	0.045	2.104***	0.040	-0.257***	0.043
Chinese/Other Asian	1.968***	0.071	-0.121*	0.073	2.279***	0.071	-0.081	0.072
Indian	1.882***	0.057	-0.206***	0.058	2.155***	0.055	-0.206***	0.057
Pakistani	2.102***	0.056	0.013	0.058	2.329***	0.053	-0.032	0.055
White (referent)	2.088***	0.013	-	-	2.36***	0.012	-	-
Mixed	2.034***	0.056	-0.055	0.057	2.275***	0.050	-0.085*	0.051
IMD								
Fifth quintile: least deprived (referent)	1.755***	0.022	-	-	2.006***	0.022	-	-
Fourth quintile	1.835***	0.022	0.08***	0.030	2.105***	0.022	0.099***	0.030
Third quintile	1.821***	0.020	0.066**	0.029	2.106***	0.022	0.1***	0.030
Second quintile	1.85***	0.021	0.095***	0.030	2.123***	0.020	0.117***	0.030
First quintile: most deprived	1.945***	0.020	0.19***	0.029	2.22***	0.021	0.214***	0.030
Region								
North East	3.12***	0.125	1.448***	0.131	3.215***	0.153	1.258***	0.160
North West	1.914***	0.018	0.242***	0.029	2.197***	0.019	0.24***	0.030
Yorkshire and The Humber	1.891***	0.041	0.219***	0.046	2.15***	0.045	0.193***	0.050
East Midlands	1.631***	0.049	-0.041	0.053	1.947***	0.054	-0.01	0.059
West Midlands	1.928***	0.031	0.257***	0.038	2.186***	0.028	0.229***	0.036
East of England	1.558***	0.035	-0.113***	0.041	1.825***	0.035	-0.132***	0.042
London (referent)	1.672***	0.021	-	-	1.957***	0.022	-	-
South East	2.021***	0.024	0.35***	0.033	2.329***	0.024	0.372***	0.034
South West	1.619***	0.020	-0.053*	0.030	1.919***	0.023	-0.038	0.032
Missing	1.635***	0.054	-0.037	0.059	1.798***	0.057	-0.159***	0.062

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

The mean costs per child of outpatient care were £440.73 (95% confidence interval [CI]: £436.18-445.29) and £516.58 (95% CI: £511.97-521.18) in the year before the index BMI measurement. The total outpatient care costs were £118,218,543 and £138,561,461 in the year after the index BMI measurement.

Table 36 Mean outpatient care costs per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	440.73	1,203.61	0	142,763.50	436.18	445.29
One year after BMI measurement	516.58	1,217.88	0	177,178.30	511.97	521.18

depicts the distribution of outpatient care costs, showing the frequency of data points in bins and kernel density plots with smoothed estimates of the distribution. It can be observed that costs are heavily right-skewed.

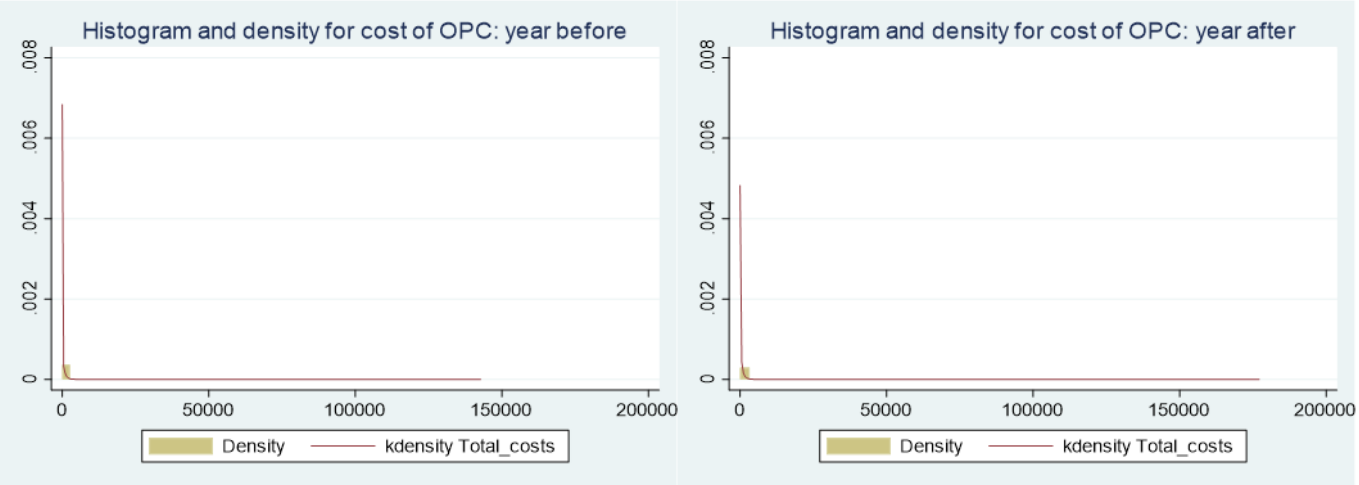

Figure 37 Combined histogram and kernel density plot of outpatient care costs in the years before and after the index BMI measurement (OPC: outpatient care)

The predicted mean costs of outpatient care visits per child in the years before and after the index BMI measurement were £440.76 (95% CI: 436.23-445.29) and £516.61 (95% CI: 512.02-521.20), respectively. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix F. Table 37 shows the estimated mean costs of outpatient care visits by weight status category and other covariates, as well as the incremental effects with respect to the referent levels of individual covariates. On average, children in the obesity categories incurred an additional £38.86 and £41.49 outpatient care visits than children in the healthy weight status category in the year before and after an index BMI measurement, respectively (Table 37, column "Incremental costs"). Girls incurred lower outpatient care costs of £42.93 and £39.18 than boys in the year before and after an index BMI measurement, respectively. These differences were statistically significant. The mean cost of outpatient care visits was lower in older children compared to children aged 2. In the year before the index

BMI measurement, white children recorded the highest mean costs of outpatient care visits (£497.13), and the incremental costs compared to their peers of other ethnicities were mostly statistically significant.

Costs tended to increase with worsening socioeconomic status, and children from the most socioeconomically deprived areas incurred the highest outpatient care visit costs. These were statistically significant increments (relative to children in the highest quintile) of £47.92 and £48.83, respectively, in the year before and after the index BMI measurement. Children in the Southwest had the lowest outpatient care visit costs compared to their peers in London, and this difference was statistically significant in the year before an index BMI measurement but not statistically significant in the year after.

Table 37 Mean and incremental costs of outpatient care attendance one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean cost of outpatient care attendance	Standard error	Incremental costs	Standard error	Mean cost of outpatient care attendance	Standard error	Incremental costs	Standard error
BMI								
Underweight	403.62***	9.856	-27.83***	10.214	515.91***	10.871	10.89	11.191
Healthy weight (referent)	431.45***	2.726	-	-	505.01***	2.692	-	-
Overweight	463.69***	6.778	32.24***	7.288	539.85***	6.960	34.84***	7.450
Obesity	470.31***	6.278	38.86***	6.838	546.5***	6.951	41.49***	7.492
Sex								
Boys (referent)	459.82***	3.048	-	-	534.02***	3.109	-	-
Girls	416.89***	3.433	-42.93***	4.527	494.84***	3.503	-39.18***	4.649
Age								
2 years (referent)	573.75***	9.625	-	-	645.46***	8.849	-	-
3 years	451.63***	7.101	-122.12***	11.935	532.34***	6.901	-113.12***	11.198
4 years	454.06***	6.259	-119.69***	11.449	546.44***	6.700	-99.03***	11.073
5 years	410.51***	5.952	-163.24***	11.269	473***	5.639	-172.46***	10.453
6 years	426.58***	6.121	-147.17***	11.415	501.56***	6.902	-143.9***	11.218
7 years	409.7***	7.337	-164.05***	11.924	479.31***	8.243	-166.16***	11.928
8 years	386.55***	5.880	-187.2***	11.280	462.82***	5.979	-182.64***	10.687
9 years	413.72***	6.102	-160.03***	11.388	491.61***	6.624	-153.85***	11.051
10 years	456.16***	9.210	-117.59***	13.317	527.38***	8.708	-118.08***	12.425
11 years	516.16***	13.031	-57.59***	16.191	589.97***	12.772	-55.49***	15.558
12 years	442.38***	21.632	-131.37***	23.667	567.95***	25.992	-77.51***	27.463
13 years	494.95***	37.813	-78.8**	39.015	698.18***	55.086	52.72	55.797
14 years	576.11***	75.169	2.36	75.804	650.31***	60.537	4.84	61.188
15 years	366.18***	92.184	-207.57**	92.706	448.45***	135.897	-197.01	136.184
Ethnicity								
Other/Unknown	183.9***	4.471	-313.23***	5.585	260.1***	5.709	-314.73***	6.685

Variable	Year before				Year after			
	Mean cost of outpatient care attendance	Standard error	Incremental costs	Standard error	Mean cost of outpatient care attendance	Standard error	Incremental costs	Standard error
Bangladeshi	355.46***	14.365	-141.67***	14.835	406.75***	15.495	-168.08***	15.926
Black	419.97***	9.267	-77.16***	10.056	502.33***	9.356	-72.51***	10.107
Chinese/Other Asian	464.11***	17.868	-33.02*	18.277	545.99***	17.235	-28.84	17.616
Indian	442.67***	13.174	-54.46***	13.629	512.96***	12.899	-61.88***	13.372
Pakistani	491.89***	13.207	-5.24	13.647	559.88***	12.853	-14.96	13.291
White (referent)	497.13***	3.100	-	-	574.83***	3.087	-	-
Mixed	492.8***	14.275	-4.33	14.681	560.24***	12.310	-14.59	12.760
IMD								
Fifth quintile: least deprived (referent)	417.76***	5.487	-	-	491.18***	5.699	-	-
Fourth quintile	432.94***	5.318	15.18**	7.542	508.32***	5.453	17.15**	7.780
Third quintile	432.55***	4.929	14.79**	7.326	512.18***	5.169	21***	7.623
Second quintile	438.59***	4.907	20.83***	7.407	515.51***	4.890	24.34***	7.626
First quintile: most deprived	465.68***	4.685	47.92***	7.186	540.01***	4.775	48.83***	7.402
Region								
North East	668.13***	21.612	274.8***	22.922	711.64***	24.616	246.84***	25.990
North West	465.57***	4.472	72.24***	6.980	547.26***	4.654	82.46***	7.109
Yorkshire and The Humber	456.78***	9.627	63.44***	11.029	540.86***	11.367	76.06***	12.594
East Midlands	407.99***	12.270	14.66	13.331	501.25***	13.529	36.45**	14.489
West Midlands	449.95***	7.201	56.62***	8.967	516.73***	6.461	51.93***	8.289
East of England	391.15***	9.509	-2.19	10.918	473.89***	9.769	9.09	11.164
London (referent)	393.33***	5.062	-	-	464.8***	5.136	-	-
South East	498.95***	6.396	105.62***	8.368	586.83***	6.568	122.03***	8.525
South West	357.5***	4.695	-35.83***	7.084	437.77***	5.116	-27.03***	7.422
Missing	403.2***	13.710	9.87	14.783	456.85***	14.776	-7.95	15.764

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

Point estimates and their 95% CIs of the incremental effects of the BMI category on mean outpatient care visit costs by covariate are reported in Appendix F and graphically depicted below (**Figure 38**-**Figure 42**). An error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Among all covariates, outpatient care visit costs were highest for children in the obesity category one year before and after the index BMI measurement. These differences were statistically significant. While children in the underweight category had the lowest incremental costs compared to their peers in the overweight and obesity categories, these differences were statistically significant in the year before the index BMI measurement but not in the year after. For children in the overweight category, incremental outpatient care costs were statistically significant both in the year before and after the index BMI measurement. Incremental outpatient care costs in the

obesity category were lower in girls than boys but the differences were not statistically significant. Outpatient care costs in the obesity subgroup seemed to drop with age until age 9, but the increments were not statistically significant. Similarly, the cost differences within other weight status categories for other covariates were not statistically significant.

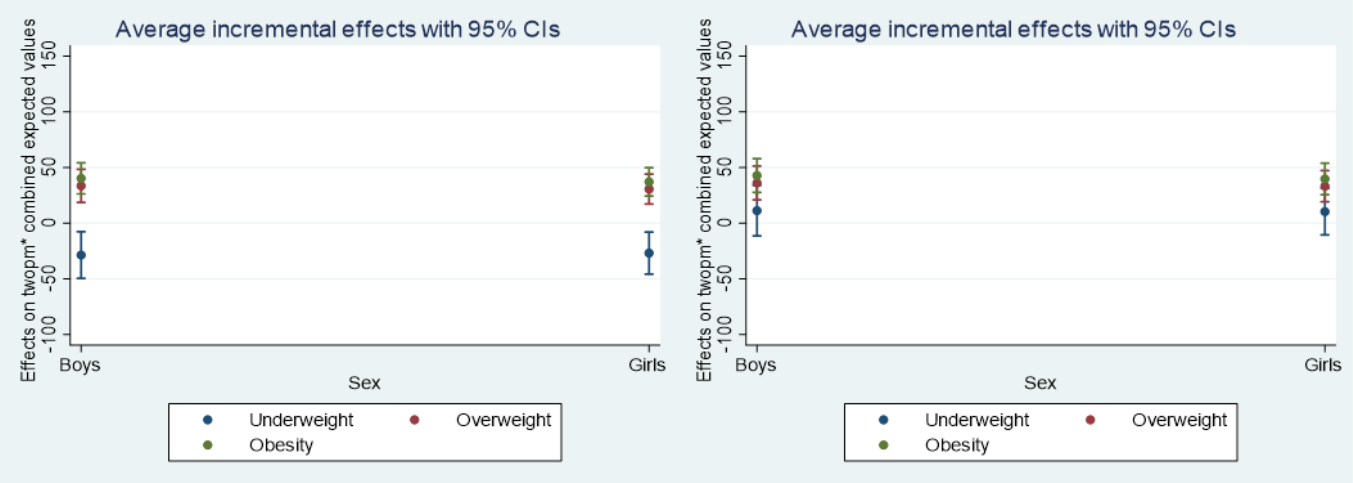

Figure 38 The relationship between outpatient care costs and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

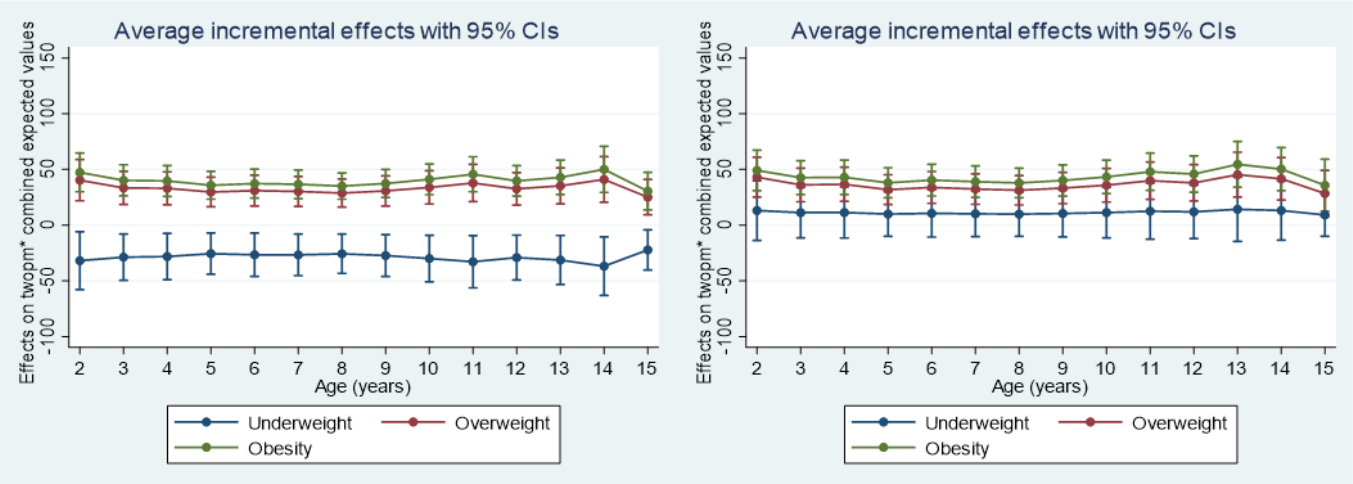

Figure 39 The relationship between outpatient care costs and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

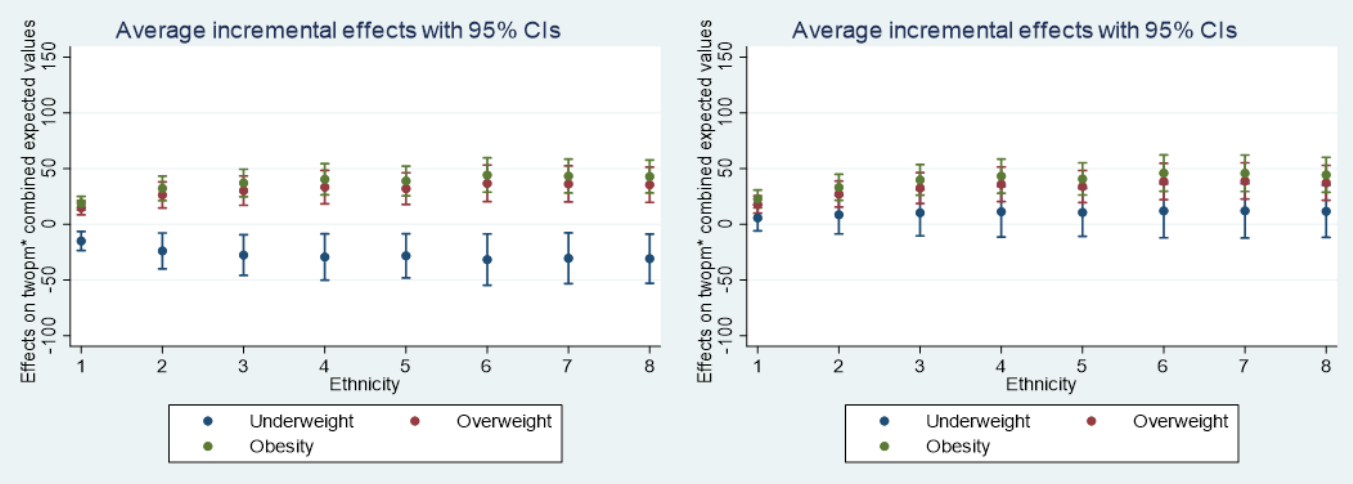

Figure 40 The relationship between outpatient care costs and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

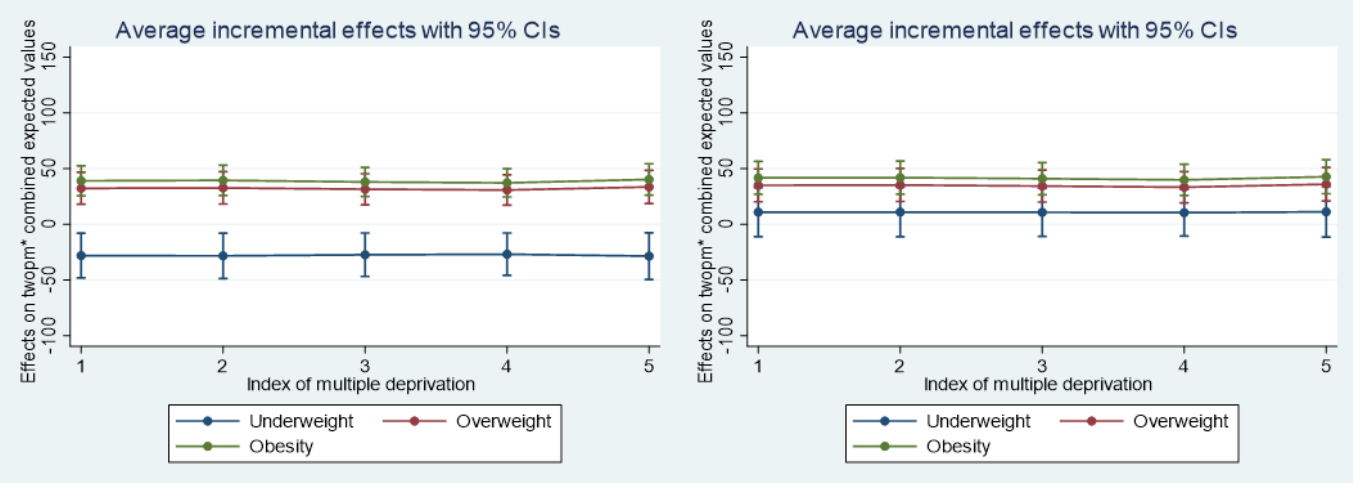

Figure 41 The relationship between outpatient care costs and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

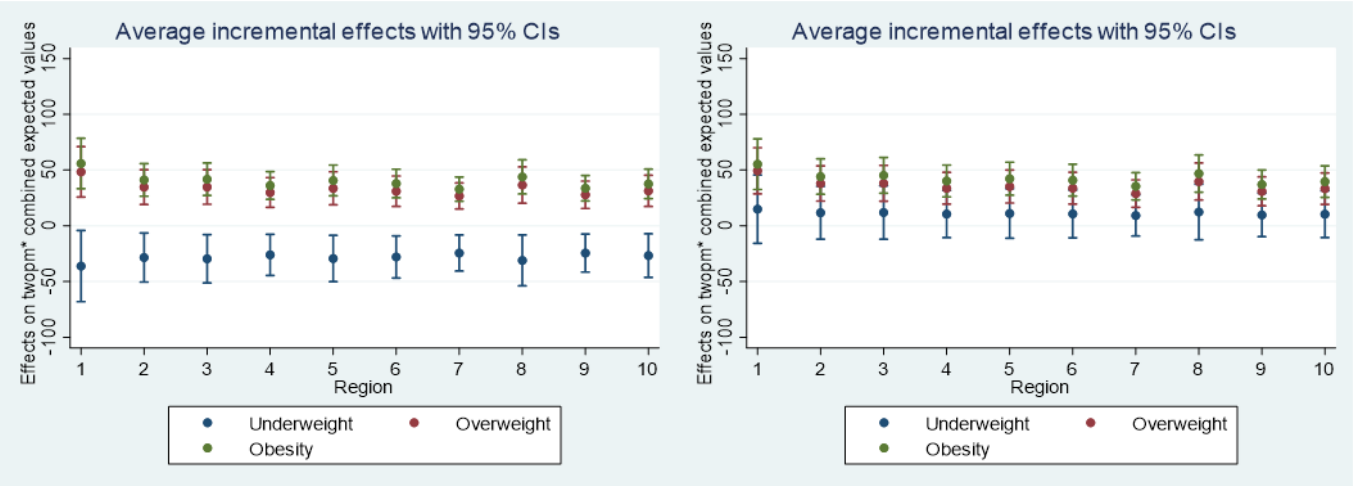

Figure 42 The relationship between outpatient care costs and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

6.3.5 Accident and Emergency Care – descriptive results and model estimates for resource use counts and costs

In the year before the index BMI measurement, 81,299 children made a total of 142,193 accident and emergency attendances, while 150,646 children did not receive outpatient care. In the year after the BMI measurement, 70,883 children made 118,918 accident and emergency attendances cumulatively. The mean number of accident and emergency attendances across the study population is reported in Table 38.

Table 38 Mean number of accident and emergency attendances per child in the study population of 268,231 children

	Mean	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	0.530	1.123	0	111	0.526	0.534
One year after BMI measurement	0.443	1.023	0	148	0.440	0.447

The predicted mean accident and emergency attendances per child in the years before and after the index BMI measurement were 0.530 (95% CI: 0.526-0.534) and 0.443 (95% CI: 0.440-0.447), respectively. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix F. Table 39 shows the estimated mean accident and emergency attendance by weight status category and covariates, as well as the incremental effects with respect to the referent levels of individual covariates.

On average, children in the obesity category had an additional 0.057 and 0.062 more accident and emergency attendance than children in the healthy weight status category in the year before and after an index BMI measurement, respectively. Girls were less likely to visit an accident and emergency department than boys (0.040 and 0.029 fewer visits in the year before and after an index BMI measurement, respectively). These differences were statistically significant.

The mean number of accident and emergency attendances followed a U-shape, reaching its lowest rate at age 7 (0.399 and 0.361 visits in the year before and after the index BMI measurement) and then rising again with age. In the year before an index BMI measurement, children of black and Bangladeshi origins were the least likely to visit accident and emergency departments relative to white children. These decrements were statistically significant. Accident and emergency attendance increased with worsening socioeconomic status and was statistically significant. Children in the Northeast had more accident and emergency attendances than their peers in London (the reference group for region) and the highest of all the regions. The incremental differences were statistically significant in the year before (0.236) and the year after (0.142) the index BMI measurement.

Table 39 Mean and incremental number of accident and emergency attendances one year before and after the index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after‡			
Variable	Mean number of accident and emergency attendances	Standard error	Incremental effects	Standard error	Mean number of accident and emergency attendances	Standard error	Incremental effects	Standard error
BMI								
Underweight	0.481***	0.010	-0.038***	0.010	0.42***	0.009	-0.01	0.009
Healthy weight (referent)	0.518***	0.003	-	-	0.43***	0.002	-	-
Overweight	0.551***	0.006	0.033***	0.007	0.459***	0.006	0.029***	0.006
Obesity	0.575***	0.006	0.057***	0.007	0.492***	0.006	0.062***	0.006
Sex								
Boys (referent)	0.548***	0.003	-	-	0.456***	0.003	-	-
Girls	0.508***	0.003	-0.04***	0.004	0.427***	0.003	-0.029***	0.004
Age								
2 years (referent)	0.935***	0.011	-	-	0.68***	0.009	-	-
3 years	0.709***	0.008	-0.226***	0.013	0.543***	0.006	-0.137***	0.011
4 years	0.614***	0.007	-0.321***	0.013	0.477***	0.006	-0.203***	0.011
5 years	0.509***	0.006	-0.426***	0.012	0.406***	0.005	-0.274***	0.010
6 years	0.446***	0.005	-0.49***	0.012	0.376***	0.005	-0.305***	0.010

Variable	Year before				Year after‡			
	Mean number of accident and emergency attendances	Standard error	Incremental effects	Standard error	Mean number of accident and emergency attendances	Standard error	Incremental effects	Standard error
7 years	0.399***	0.006	-0.537***	0.012	0.361***	0.007	-0.32***	0.011
8 years	0.411***	0.005	-0.525***	0.012	0.38***	0.005	-0.3***	0.010
9 years	0.426***	0.006	-0.509***	0.013	0.403***	0.006	-0.277***	0.011
10 years	0.458***	0.007	-0.477***	0.013	0.433***	0.007	-0.247***	0.011
11 years	0.506***	0.010	-0.429***	0.015	0.479***	0.010	-0.201***	0.013
12 years	0.543***	0.025	-0.392***	0.027	0.496***	0.024	-0.184***	0.026
13 years	0.544***	0.047	-0.392***	0.048	0.513***	0.040	-0.168***	0.041
14 years	0.536***	0.053	-0.4***	0.054	0.512***	0.058	-0.169***	0.059
15 years	0.852***	0.203	-0.083	0.204	0.402***	0.135	-0.278**	0.135
Ethnicity								
Other/Unknown	0.309***	0.005	-0.262***	0.006	0.314***	0.006	-0.158***	0.006
Bangladeshi	0.522***	0.015	-0.049***	0.015	0.44***	0.014	-0.032**	0.014
Black	0.53***	0.008	-0.04***	0.009	0.429***	0.007	-0.043***	0.008
Chinese/Other Asian	0.645***	0.014	0.074***	0.015	0.494***	0.012	0.022*	0.012
Indian	0.576***	0.013	0.005	0.013	0.473***	0.011	0.001	0.012
Pakistani	0.554***	0.011	-0.016	0.011	0.451***	0.009	-0.021**	0.010
White (referent)	0.571***	0.003	-	-	0.472***	0.003	-	-
Mixed	0.606***	0.011	0.035***	0.012	0.463***	0.010	-0.009	0.010
IMD								
Fifth quintile: least deprived (referent)	0.443***	0.005	-	-	0.365***	0.004	-	-
Fourth quintile	0.483***	0.005	0.04***	0.007	0.4***	0.004	0.035***	0.006
Third quintile	0.511***	0.005	0.068***	0.007	0.431***	0.004	0.066***	0.006
Second quintile	0.549***	0.004	0.106***	0.007	0.46***	0.004	0.095***	0.006
First quintile: most deprived	0.598***	0.005	0.155***	0.007	0.503***	0.004	0.138***	0.006
Region								
North East	0.84***	0.019	0.236***	0.021	0.645***	0.019	0.142***	0.020
North West	0.557***	0.005	-0.047***	0.008	0.449***	0.005	-0.054***	0.007
Yorkshire and The Humber	0.463***	0.010	-0.142***	0.012	0.39***	0.009	-0.113***	0.010
East Midlands	0.483***	0.013	-0.122***	0.015	0.402***	0.012	-0.102***	0.013
West Midlands	0.456***	0.005	-0.148***	0.007	0.395***	0.004	-0.108***	0.007
East of England	0.418***	0.008	-0.186***	0.010	0.353***	0.007	-0.151***	0.009
London (referent)	0.604***	0.006	-	-	0.503***	0.005	-	-
South East	0.483***	0.005	-0.121***	0.008	0.419***	0.005	-0.085***	0.007
South West	0.492***	0.006	-0.112***	0.008	0.423***	0.005	-0.081***	0.008
Missing	0.395***	0.016	-0.209***	0.017	0.308***	0.014	-0.195***	0.015

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10; ‡ Estimates based on ZIP model as ZINB model did not converge.

The mean annual costs of accident and emergency attendances per child in the years straddling the index BMI measurement were £103.43 (95% CI: 102.52-104.33) and £86.43 (95% CI: 85.59-87.27), respectively (Table 40). The study's total accident and emergency costs attributable to children were £27,742,991 and £23,182,688 in the year before and after the index BMI measurement.

Table 40 Mean accident and emergency costs per patient in the study population of 268,231 children

	Mean (£)	Standard deviation	Min (£)	Max (£)	Lower 95% CI	Upper 95% CI
One year before BMI measurement	103.43	239.02	0	27,671.74	102.52	104.33
One year after BMI measurement	86.43	221.87	0	38,079.31	85.59	87.27

illustrates the distribution of accident and emergency costs, displaying the frequency of data points in bins and kernel density plots with smoothed distribution estimates. The costs exhibit a strong right-skew in their distribution.

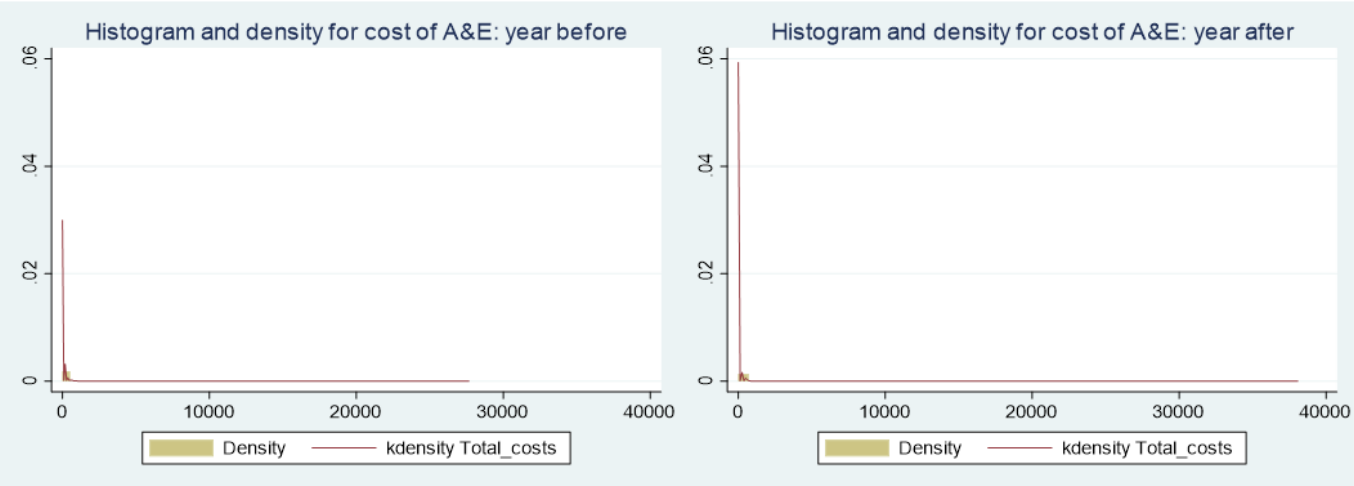

Figure 43 Combined histogram and kernel density plot of accident and emergency costs in the years before and after a BMI measurement

The predicted mean costs of accident and emergency attendance per child in the years before and after the index BMI measurement were £103.43 (95% CI: 102.54-104.32) and £86.43 (95% CI: 85.60-87.27), respectively. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix F. Table 41 shows the estimated mean costs of accident and emergency attendance by weight status category and covariates, as well as the incremental effects with respect to the referent levels of individual covariates.

On average, the additional costs of accident and emergency attendance for children in the obesity categories were £10.5 and £12.42 more than children in the healthy weight category in the year before and after an index

BMI measurement, respectively. Accident and emergency attendance costs were lower for girls than boys by £8.93 and £5.81 in the year before and after an index BMI measurement, respectively. These differences were statistically significant. The mean and incremental accident and emergency attendance costs were U-shaped, reaching the highest costs in the oldest children. In the year before and after the index BMI measurement, children of Chinese/Other Asian origins incurred the highest accident and emergency attendance costs relative to white children, and these increments were statistically significant. The accident and emergency attendance costs increased with worsening socioeconomic status and were statistically significant. Compared to white children, only children in the Northeast had higher accident and emergency attendance costs. The incremental costs were statistically significant in the year before (£41.47) and the year after (£24.66) the index BMI measurement.

Table 41 Mean and incremental costs of accident and emergency attendances one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean cost of accident and emergency attendances	Standard error	Incremental costs	Standard error	Mean cost of accident and emergency attendances	Standard error	Incremental costs	Standard error
BMI								
Underweight	92.45***	2.054	-8.83***	2.119	82.07***	1.930	-1.58	1.985
Healthy weight (referent)	101.28***	0.532	-	-	83.65***	0.475	-	-
Overweight	107.66***	1.310	6.38***	1.412	89.62***	1.183	5.98***	1.274
Obesity	111.78***	1.290	10.5***	1.397	96.07***	1.353	12.42***	1.435
Sex								
Boys (referent)	107.41***	0.603	-	-	89.02***	0.543	-	-
Girls	98.48***	0.676	-8.93***	0.896	83.22***	0.658	-5.81***	0.840
Age								
2 years (referent)	184.5***	2.371	-	-	132.73***	1.918	-	-
3 years	138.31***	1.621	-46.19***	2.865	104.18***	1.352	-28.55***	2.338
4 years	118.85***	1.461	-65.65***	2.779	89.91***	1.206	-42.81***	2.262
5 years	97.21***	1.150	-87.29***	2.633	75.64***	0.981	-57.09***	2.150
6 years	85.91***	1.120	-98.59***	2.621	71.9***	1.012	-60.83***	2.166
7 years	77.16***	1.270	-107.33***	2.665	70.08***	1.482	-62.65***	2.387
8 years	79.51***	1.085	-104.99***	2.608	75.14***	1.054	-57.59***	2.189
9 years	84.3***	1.211	-100.2***	2.664	81.26***	1.277	-51.47***	2.306
10 years	91.05***	1.494	-93.45***	2.804	89.02***	1.512	-43.71***	2.443
11 years	101.42***	2.122	-83.07***	3.183	99.19***	2.113	-33.53***	2.856
12 years	111.7***	5.407	-72.8***	5.909	101.28***	5.076	-31.44***	5.430
13 years	114.35***	11.026	-70.14***	11.285	116.07***	9.856	-16.65*	10.044
14 years	110.15***	11.351	-74.34***	11.599	108.63***	12.367	-24.1*	12.517
15 years	169.46***	44.899	-15.04	44.968	79.34***	21.133	-53.38**	21.225
Ethnicity								

Variable	Year before				Year after			
	Mean cost of accident and emergency attendances	Standard error	Incremental costs	Standard error	Mean cost of accident and emergency attendances	Standard error	Incremental costs	Standard error
Other/Unknown	57.17***	1.072	-53.28***	1.267	58.29***	1.181	-33***	1.353
Bangladeshi	108.05***	3.317	-2.4	3.396	89.24***	3.019	-2.05	3.093
Black	110.13***	1.892	-0.33	2.038	90.09***	1.747	-1.2	1.879
Chinese/Other Asian	127.14***	3.052	16.69***	3.133	98.92***	2.623	7.63***	2.703
Indian	109.27***	2.597	-1.18	2.676	90.65***	2.376	-0.64	2.450
Pakistani	114.38***	2.378	3.93	2.458	91.54***	2.050	0.25	2.131
White (referent)	110.45***	0.601	-	-	91.29***	0.550	-	-
Mixed	122.31***	2.459	11.86***	2.540	94.2***	2.159	2.91	2.237
IMD								
Fifth quintile: least deprived (referent)	88.2***	1.037	-	-	71.98***	0.931	-	-
Fourth quintile	95.13***	1.064	6.94***	1.448	78.43***	0.930	6.45***	1.281
Third quintile	98.92***	1.014	10.72***	1.432	83.62***	0.954	11.64***	1.323
Second quintile	106.34***	0.937	18.14***	1.419	88.7***	0.843	16.72***	1.277
First quintile: most deprived	116.53***	0.970	28.34***	1.438	98.47***	0.934	26.49***	1.318
Region								
North East	158.51***	4.413	41.47***	4.677	121.79***	4.690	24.66***	4.948
North West	105.06***	1.027	-11.98***	1.544	85.8***	0.916	-11.33***	1.385
Yorkshire and The Humber	89.86***	2.160	-27.18***	2.461	76.93***	1.928	-20.2***	2.200
East Midlands	93.93***	2.869	-23.1***	3.080	77***	2.565	-20.13***	2.759
West Midlands	93.13***	1.021	-23.91***	1.512	81.04***	0.970	-16.09***	1.395
East of England	82.17***	1.735	-34.87***	2.087	67.49***	1.482	-29.65***	1.816
London (referent)	117.04***	1.101	-	-	97.13***	0.991	-	-
South East	97.19***	1.093	-19.85***	1.587	82.98***	1.045	-14.16***	1.477
South West	96.12***	1.267	-20.92***	1.709	81.76***	1.154	-15.37***	1.559
Missing	77.11***	3.297	-39.92***	3.501	58.74***	2.884	-38.4***	3.065

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

The average incremental effects presented in **Table 41** do not fully capture the intricate relationships between the exposure variable (BMI category), covariates, and the outcome or dependent variable (accident and emergency costs). To improve the interpretation of results, I separately calculated the incremental costs of the BMI category on costs for each covariate. I reported the estimated point estimates and their 95% CIs in Appendix F. These calculations are expressed graphically in **Figure 44**-**Figure 48**. For each covariate level, an error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Across all covariates, the incremental accident and emergency costs associated with overweight and obesity were sustained in the year preceding or following the index BMI measurement. These findings were statistically

significant. The underweight category recorded the lowest incremental costs for all covariates in the year before and after the index BMI measurement. However, these increments were statistically significant only in the year before.

In the overweight and obesity categories, girls appeared to incur higher accident and emergency attendance costs than boys. However, this within-category difference was not statistically significant. Costs tended to follow a U-shape, with the lowest costs accrued between the ages of seven and nine in the overweight and obesity categories (statistically significant in the obesity category). These differences in costs within weight status categories were, however, largely statistically insignificant for other covariates.

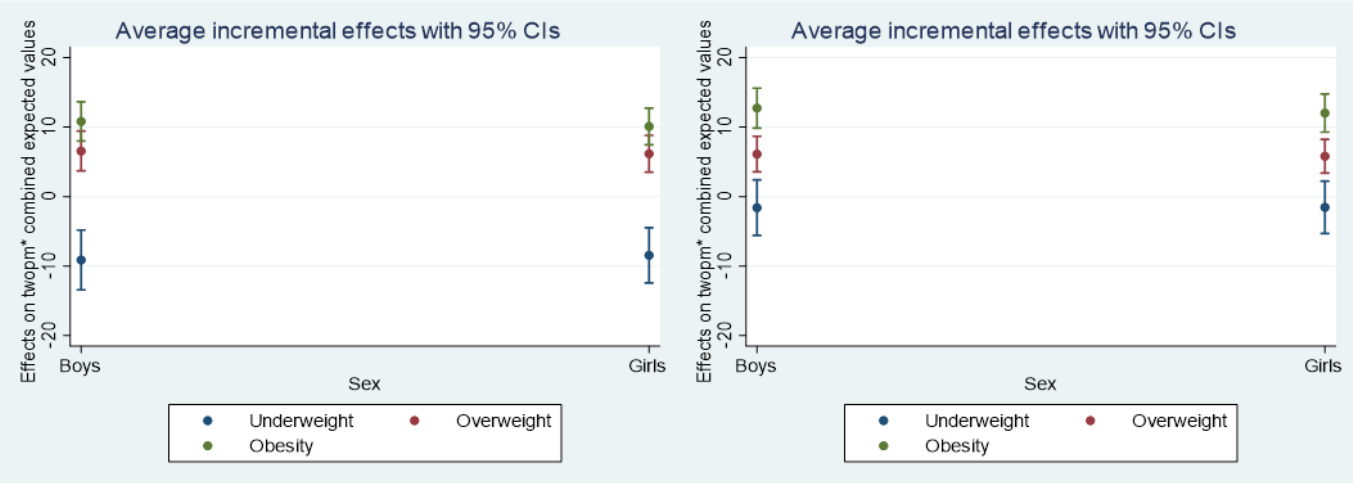

Figure 44 The relationship between accident and emergency attendance costs and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

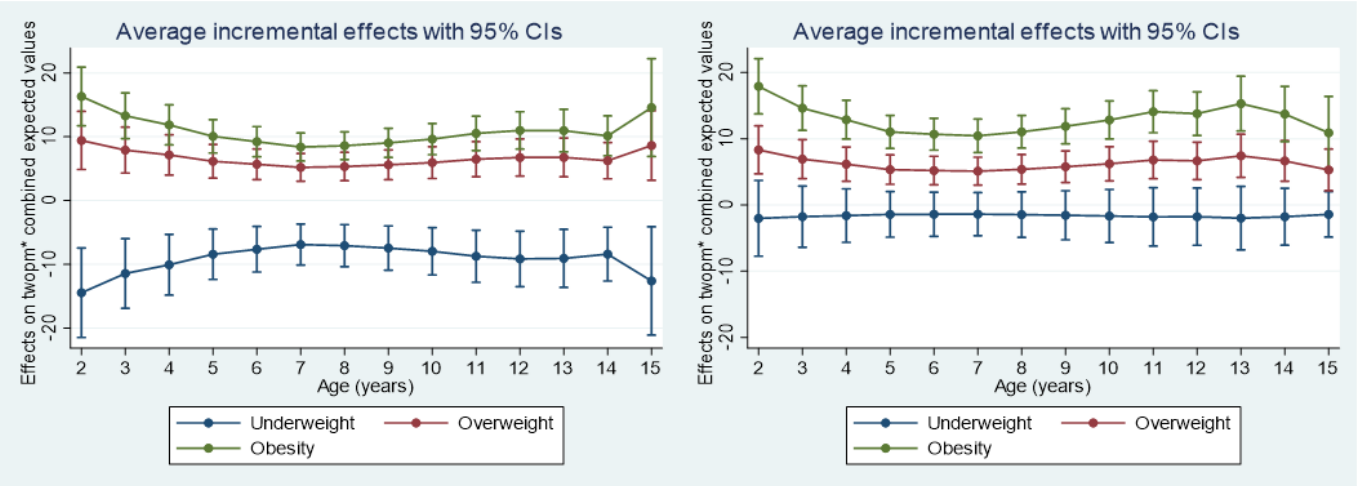

Figure 45 The relationship between accident and emergency attendance costs and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

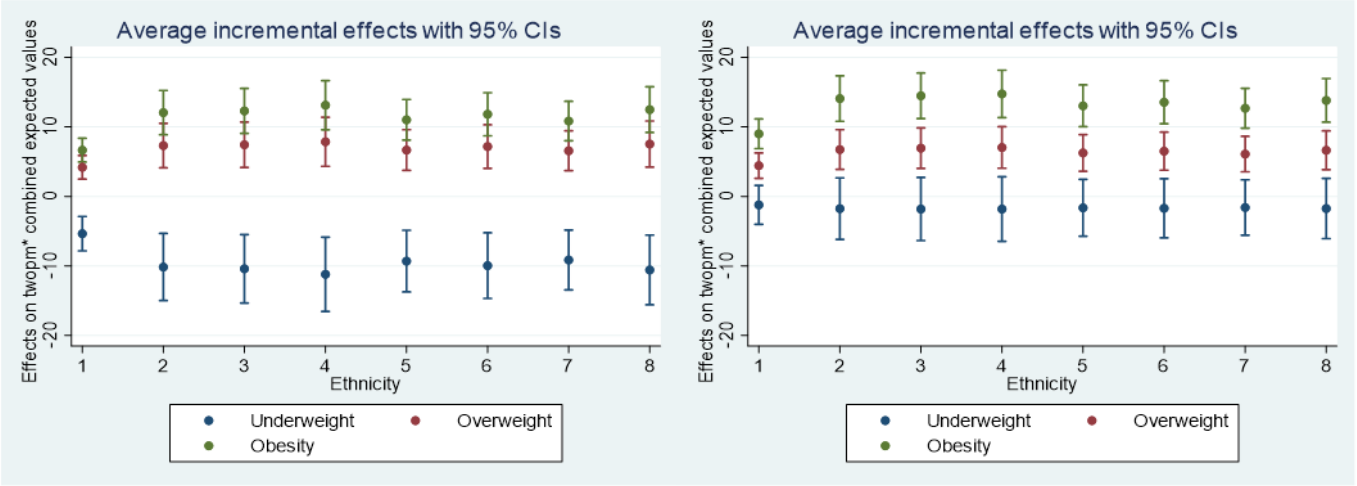

Figure 46 The relationship between accident and emergency attendance costs and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

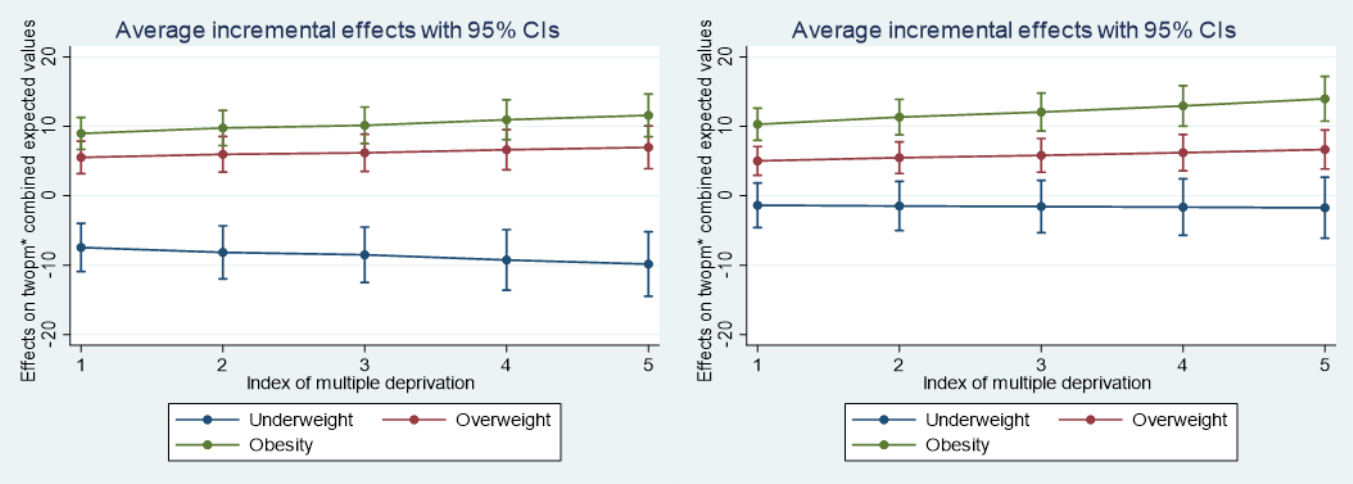

Figure 47 The relationship between accident and emergency attendance costs and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

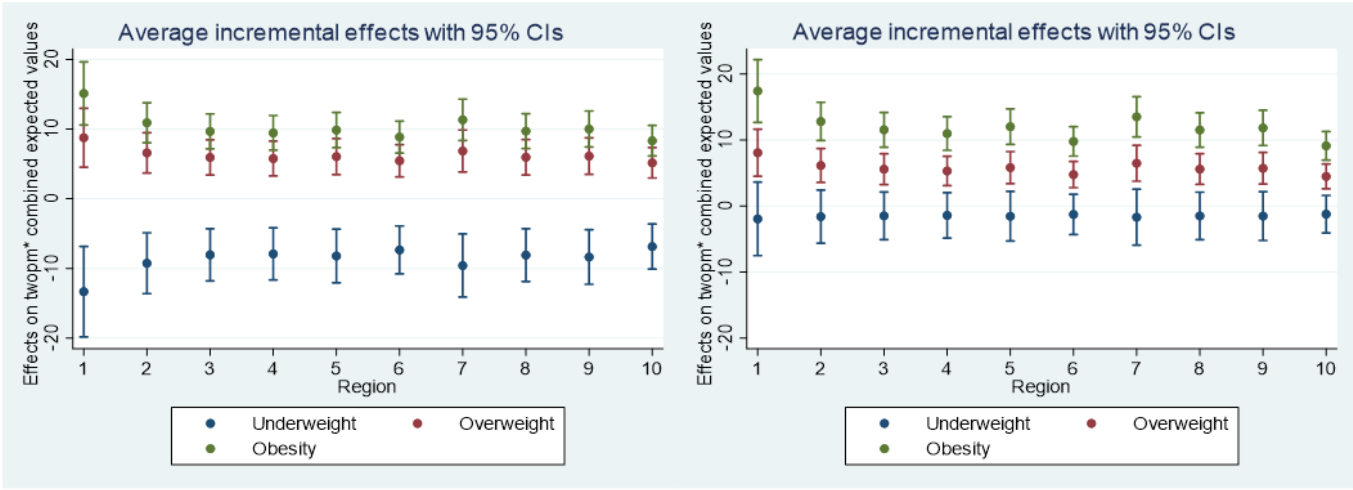

Figure 48 The relationship between accident and emergency attendance costs and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

6.4 Discussion

6.4.1 Summary and interpretation of main findings

This study is the first to estimate the resource use and costs associated with childhood excess weight in England at the secondary care level using electronic health records. The main findings of this chapter were that compared to healthy weight status, childhood overweight and obesity are associated with increased costs across the three types of secondary healthcare use I investigated (admitted patient care, outpatient care, and accident and

emergency care). The largest impacts of excess weight on incremental costs were observed in admitted patient care and outpatient care. Accident and emergency care was a less impactful yet statistically significant driver of incremental costs. Relative costs incurred by children in the underweight category tended to vary in direction before and after the index BMI measurement, with lower costs mainly in the year before and higher costs in the year after for admitted patient care and outpatient care. These elevated costs may indicate heightened medical attention following BMI measurement. The relative frequency of resource utilisation was a reliable indicator of incremental costs among children with obesity. Generally, the correlations between resource use count and costs were strongest in the underweight and overweight categories.

Most covariates showed statistically significant associations with resource use and costs compared to the reference covariate level. Independent of their weight status, girls incurred lower costs than boys for all secondary care resource use measures during the years before and after the index BMI measurement. Resource use and costs in admitted patient care, outpatient care, and accident and emergency care were lower in children older than two years. Children of Pakistani origin had the highest relative incremental costs in admitted patient care. In contrast, children of Chinese or other Asian origin recorded the highest costs in accident and emergency care. In outpatient care, white children incurred the highest costs, while Bangladeshi and black children had the lowest costs relative to their white peers. This disparity may indicate ethnic differences in healthcare-seeking behaviours at the secondary care level. Incremental costs were statistically significant and rose steadily with worsening socioeconomic status for outpatient and accident and emergency care. In terms of admitted patient care, incremental costs associated with socioeconomic status were statistically significant only for comparisons between children from the least and the most socioeconomically deprived areas in the year before the index BMI measurement. Only the Southwest had a decrement in outpatient care costs relative to London. The reverse was the case in accident and emergency care costs, with decrements in costs estimated for all regions relative to London. These decrements were statistically significant. In terms of admitted patient care, incremental costs associated with region were scarcely statistically significant. However, the year before the index BMI measurement, the Northwest region had the highest incremental costs, while the Southwest had the lowest costs relative to London. Both estimates were statistically significant.

The results of the covariates summarised above give insights into the economic costs that accrue before and after BMI measurement. Still, they do not consider the associations between incremental costs and weight status categories are modified by covariates. Therefore, I conducted additional analyses to elucidate the intricate relationships between the exposure variable (BMI category), covariates, and secondary care outcomes. The analyses indicated that, across all covariates, differences in admitted patient care, outpatient care, and accident and emergency care costs within the individual weight status categories were not statistically significant. This finding suggests that, in cost-effectiveness modelling, identical costs may be applied to population subgroups defined by the examined covariates within the same weight status category.

The incremental costs of childhood obesity (relative to healthy weight) were statistically significant across all covariates for admitted patient care, outpatient care, and accident and emergency care costs in the year before and after the index BMI measurement. For the underweight and overweight categories, whether costs associated with individual covariates were higher or lower depended on the year in consideration and the measure of secondary health care. Across all covariates, admitted patient care costs within the underweight category were statistically insignificant in the year before the index BMI measurement. In the year after the index BMI measurement, these costs became higher and statistically significant in comparison with healthy weight. Across all covariates, admitted patient care costs within the overweight category were higher than in the year before the index BMI measurement but insignificant in the year after. Similar to childhood obesity, the incremental costs of childhood overweight (relative to healthy weight) were statistically significant across all covariates for outpatient care and accident and emergency care costs. Relative to healthy weight, underweight costs for outpatient care and accident and emergency care were lower in the year before the index BMI measurement across all covariates but insignificant in the year after.

6.4.2 Comparison with the literature

As noted previously, this study is the first to estimate the use of resources and costs associated with childhood weight status across England using electronic health records at the secondary care level. Therefore, comparisons of this chapter's results with those reported in the literature are limited. An earlier English study by Hasan[494] with a focus similar to my research limited its analysis to the electronic health records of a cohort of children born in Bradford, England's fifth most income-deprived district. The study involved 9,397 children and differed

significantly from my study of 268,231 children in several respects. For example, in Hasan's study, children of Pakistani origin made up the largest ethnic group at 46%, followed by white children at 40%. This distribution contrasts with my study, where the majority were white (63%), alongside substantial numbers from other ethnic backgrounds. Furthermore, Hasan's analysis was limited to children aged 4 to 5 and omitted the assessment of outpatient care resource use or costs. Nevertheless, Hasan found a relationship between obesity and higher accident and emergency costs. The magnitude of this incremental cost relative to healthy weight (£6.60) was statistically significant and similar to what I found (£10.50 and £12.42 in the year before and after the index BMI measurement, respectively). However, unlike my study, Hasan found no statistically significant association between weight status and hospital admissions (admitted patient care) costs. These differences in findings between the two studies may be attributed to variations in methodological approaches and demography of the study populations highlighted above.

Another study by Griffiths and colleagues analysed linked hospital admissions of children living in Wales and Scotland using data from the Millennium Cohort Study, a prospective cohort study of children born between 2000 and 2002 in the United Kingdom.[509] However, the study did not investigate the healthcare costs associated with childhood excess weight. Griffiths and colleagues found that overweight and obesity were not associated with higher rates of subsequent all-cause hospital admissions among children living in Wales and Scotland.[509] The researchers examined the relationship between weight status at age five and hospital admissions by age 14, concluding that excess weight did not increase hospital admissions. However, their study differs from mine, which focused on secondary care utilisation in the year preceding or following BMI measurement. Additionally, Griffiths and colleagues did not explore the association between childhood weight status and healthcare costs. In contrast, my study found evidence linking excess weight to higher hospital admissions and associated costs, highlighting the need to conduct similar research across a broader range of time horizons.

6.4.3 Strengths and limitations

The core strength of this study lies in its use of a large, nationwide sample from electronic health records, offering new insights into the association between childhood weight status and primary care utilisation and costs, categorised by sex, age, ethnicity, IMD, and region in England. The substantial study population enhances the generalizability of the findings, ensuring their applicability on a national scale. This large sample size also provides

the confidence to examine trends within typically underserved and underrepresented subgroups, such as underweight children and children from minority ethnic backgrounds. For example, compared to the National Child Measurement Programme (NCMP), the dataset's greater representation of underweight children offers improved statistical power to analyse trends in this less-represented weight category.

Similar to Chapter 5, I found that resource counts do not always predict costs. This finding is significant because it highlights the need for caution when interpreting conclusions from studies that only examine the association between childhood weight status and resource use. Additionally, estimating resource use and costs separately for the year before and after a BMI measurement enhances the understanding of health-seeking behaviours and healthcare services associated with a BMI measurement. The strengths and weaknesses of this chapter and its companion Chapter on primary care resource use (Chapter 5) are revisited in detail in the concluding chapter on the association between healthcare resource use and costs and childhood excess weight (Chapter 7).

6.5 Conclusions

This chapter extends the research from Chapter 5, focusing on the relationship between secondary healthcare resource use and costs related to childhood excess weight. This research is inspired by my finding in Chapter 2 that there was a vast knowledge gap regarding the economic burden of childhood excess weight, particularly in the UK. Estimates derived from this chapter can be used to inform data inputs for decision-analytic modelling-based economic evaluations. I conclude the research on the direct healthcare costs linked to childhood excess weight in Chapter 7, where I estimate the total direct healthcare costs, encompassing both primary and secondary care, and discuss the broader implications of my findings for policy and practice.

Chapter 7: Total Primary and Secondary Care Costs Associated with Childhood Weight Category

7.1 Introduction

Chapters 5 and 6 focused on the resource use and costs associated with childhood excess weight for disaggregated components of primary (general practice consultations, prescriptions, tests) and secondary healthcare use (admitted patient care, outpatient care, accident and emergency care), respectively. This chapter estimates the relationships between childhood excess weight and aggregated (overall) primary and secondary healthcare costs, separately, as well as the total direct healthcare costs (the sum of overall primary and secondary healthcare costs). The aim of this chapter is to provide estimates of the magnitude of the association between childhood weight status and direct healthcare costs in the UK. The methods applied in this chapter remain identical to those in Chapters 5 and 6, except for additional analyses described in detail in the methods section of this chapter.

7.2 Methods

7.2.1 Data sources

This chapter is based on linked CPRD-HES data identical to Chapters 5 and 6. The requirement for data linkage ensures that I have a consistent study population for the analyses in Chapters 5-7. Chapters 5 and 6 provide detailed information about the CPRD and HES databases, including their systems, data, and geographical coverages.

7.2.2 Study population

The study population in this chapter is the same as the one defined in Chapters 5 and 6.

7.2.3 Study design

This chapter uses the same retrospective cross-sectional study design as Chapters 5 and 6. Aggregated primary and secondary healthcare costs, as well as combined primary and secondary healthcare costs, were similarly estimated over two distinct periods, namely:

I. one year before the date of height and weight measurements (date of exposure, alternatively defined as the date of index BMI measurement)

II. one year after the date of height and weight measurements (date of exposure, alternatively defined as the date of index BMI measurement)

Descriptive information on the general model specification for this chapter was provided in Chapter 5, section 5.2.3 Study design for Chapters 5-7. The analytical approach to estimation is reported in detail in Chapter 5 (5.2.7 Analytical Approach for Chapters 5-7) and later in this chapter (7.2.7 Analytical Approach). In this chapter, I focus on three outcomes: aggregated primary healthcare costs, aggregated secondary healthcare costs and total direct healthcare costs (combined primary and secondary healthcare costs).

7.2.4 Exposure: weight status category

The methods for determining exposure levels (weight status category) are thoroughly explained in Chapter 5. In summary, I categorised children in the study based on body weight using UK cut-offs for BMI population monitoring and defined the same levels of exposure as per Chapters 5, i.e. underweight, healthy weight, overweight, and obesity.[22]

7.2.5 Total direct healthcare costs

The outcomes in this chapter are aggregated primary healthcare costs (general practice consultations, prescriptions, tests), aggregated secondary healthcare costs (admitted patient care, outpatient care, accident and emergency care) and combined primary and secondary healthcare costs. I derived the datasets for the first two outcomes by adding child-level costs across the primary and secondary healthcare constituent measures, respectively. The methods I employed to derive the constituent datasets for primary (general practice consultations, prescriptions and tests) and secondary (admitted patient care, outpatient care and accident and emergency care) healthcare costs are fully described in Chapter 5. Similarly, I derived the dataset for the combined primary and secondary healthcare costs (direct healthcare costs) by summing up child-level aggregate primary and secondary healthcare costs.

7.2.6 Covariates

In my models I use the same covariates as presented in Chapter 5, i.e. sex; age; ethnicity; region; the English Index of Multiple Deprivation (IMD).[66]

7.2.7 Analytical Approach

The descriptive statistics describing the study population's BMI distribution, weight status categories, and sociodemographic characteristics remain unchanged from the previously reported data and can be found in Chapter 5 (Subsection 5.3.1). However, in this chapter, I reported the mean and total costs for my study population for the three aggregated costs (aggregated primary care costs, aggregated secondary care costs and total direct healthcare costs combining aggregated primary and secondary care costs) and graphed their distributions.

The rationale for my model specifications in estimating the mean and incremental costs (difference in costs) remains consistent with the approach detailed in Chapter 5 (Subsection 5.2.7). To estimate mean costs, I applied the two-part model, specifically the generalised linear model (GLM) with log link and gamma distribution.[88,92,93,97] I employed the appropriate diagnostic techniques for all models, as detailed in Chapter 5 (Subsection 5.2.7). Specifically, these techniques included utilising the Park test to evaluate the candidate family distributions and applying the Box-Cox transformation to assess the link function of the GLM distribution.[491] Additionally, I considered the outputs of the AIC and BIC to inform my model selection.[477,489,490]

Finally, I estimated total national costs attributable to childhood overweight and obesity using the population of children with excess weight recently reported by the Royal College of Paediatrics and Child Health (RCPCH)[510] and NHS England[511], which reported that 2.5 million children in England are affected by excess weight, with 1.22 million in the obesity category, along with the adjusted mean incremental costs associated with excess weight categories. To estimate the national costs attributable to excess weight, I multiplied the above-stated populations of children living with overweight or obesity by the corresponding adjusted mean incremental costs attributable to childhood excess weight estimated in this chapter, assuming these costs were nationally representative of the English childhood population.

In a separate comparative analysis, I also applied the proportions of children with excess weight from my dataset, estimating the total national costs attributable to childhood excess weight by first projecting the cumulative prevalence of childhood excess weight in my dataset to the population of children (from ages 0 to 18 years) in England as derived by the Office for National Statistics.[512] I then multiplied the estimated population of children living with overweight or obesity by the adjusted mean incremental costs attributable to childhood excess weight estimated in this chapter, assuming these costs were nationally representative of the English childhood population. This second approach to estimating the total national costs relied on the observation that the prevalence estimates derived from my data for children in Reception (age 4-5) and Year 6 (age 10-11) align closely with those reported by the National Child Measurement Programme (NCMP)[493], a national survey in England, as substantiated in Chapter 5. I then designated the most conservative estimate of national costs from the two approaches as my base case estimate. Using prevalence estimates from the NCMP, I also estimated the national costs attributable to childhood excess weight in Reception and Year 6 children.

The method I applied is similar to that used by Ward and colleagues[497] to estimate population-level excess costs associated with BMI and healthcare expenditures in the US. More recently, Altunkaya and colleagues[513] employed a similar approach to estimate the national COVID-19 hospitalisation costs associated with BMI categories, utilising QResearch, an electronic healthcare record database in the UK comparable to CPRD.

7.3 Results

7.3.1 Study Population

The study population remains consistent with the 268,231 children previously described in Chapter 5, and the sociodemographic and socioeconomic characteristics are elaborated upon there.

7.3.2 Model specification

I adhered to the diagnostic tests detailed in Chapter 5. The Gamma family with a log link function was consistently preferred or comparable across all models. Consequently, I derived the model outputs using a two-part model, comprising a logit model for the first part and a Generalized Linear Model (GLM) with a log link and Gamma distribution for the second part for the primary analysis of costs. The model estimates are presented in the

subsequent sections of this chapter. Statistical significance is set at a threshold of $p < 0.05$ throughout the results and discussion sections.

7.3.3 Aggregated primary care costs – descriptive results and model estimates

In this section, I replicated my Chapter 5 analyses of primary care costs, this time focusing on the total costs of consultations, prescriptions, and tests.

The mean annual primary care costs (cumulative costs of consultations, prescriptions, and tests) per child in the years straddling the index BMI measurement were £306.43 (95% CI: 299.04-313.83) in the year before and £380.98 (95% CI: 373.17-388.79) in the year after (Table 42). The total primary care costs attributable to children in the study were £82,195,233.00 and £102,190,182.95 in the year before and after the index BMI measurement, respectively. These costs were incurred by 268,231 children in the year preceding the index BMI measurement and by 249,405 children in the subsequent year.

Table 42 Mean aggregate primary care costs (consultations, prescriptions, tests) per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	306.43	1,954.78	0	867,324.90	299.04	313.83
One year after BMI measurement	380.98	2,063.63	0	876,853.20	373.17	388.79

Figure 49 shows heavily skewed box plot distributions of total primary care costs with outliers in the year before and after the index BMI measurement.

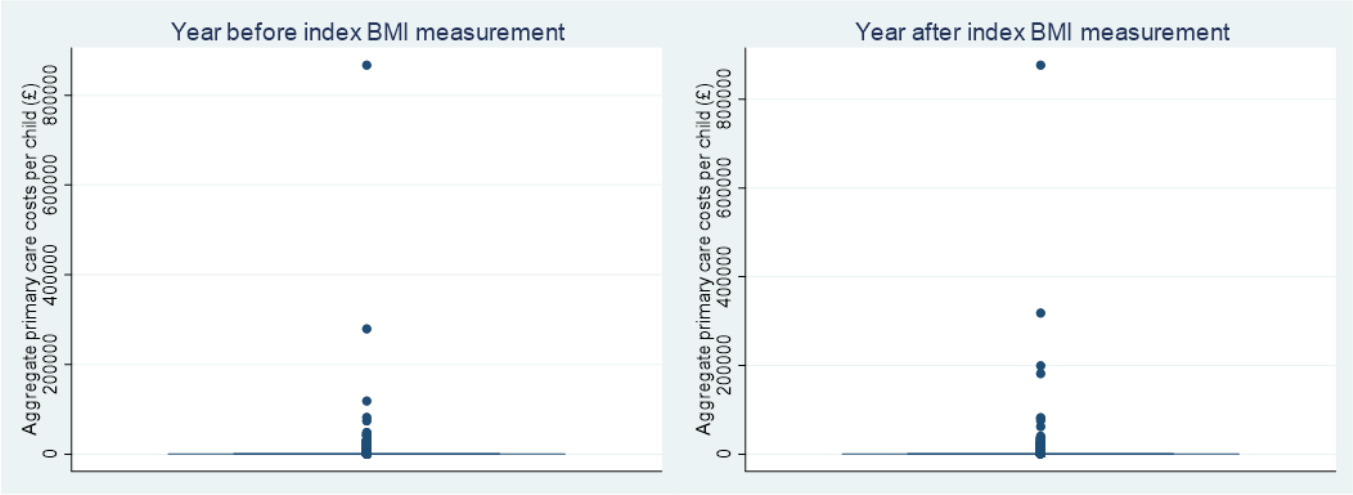

Figure 49 Box plots showing distributions of aggregate primary care costs (consultations, prescriptions, tests) one year before and after index BMI measurement

The adjusted primary care costs (consultations, prescriptions, tests) per child predicted with margins in the years before and after a BMI measurement were £306.22 (95% CI: 299.52-312.92) and £381.12 (95% CI: 373.40-388.83), respectively. These predicted cost estimates derived from the two-part GLM regression model (described in detail in Chapter 5, Model specification for healthcare costs) represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix G. Table 43 reports the predicted mean primary care costs by weight status category (while holding all covariates at average values) and individual covariates (while holding all other covariates at average values), as well as the incremental effects with respect to the referent levels of individual covariates.

Children with obesity recorded higher costs than their peers in the healthy weight category on combined primary care costs by an additional £8.30 the year before and £44.90 the year after the index BMI measurement (Table 43, column “Incremental costs”). This difference was statistically significant only in the year after the index BMI measurement. Underweight also had a relative incremental cost of £41.82 in the year following the index BMI measurement, which was statistically significant. Incremental costs associated with overweight were not statistically significant. The cost differences between girls and boys were not statistically significant. The mean primary care costs tended to increase with age in the year after the index BMI measurement. Children of Bangladeshi and Pakistani origin incurred the highest costs, which were statistically significant one year before and after the index BMI measurement, respectively. The mean primary care costs were lower and statistically significant in the most deprived IMD quintile compared to the least deprived by £34.60, but only in the year after the index BMI measurement. The lowest regional primary care costs relative to London (the reference group) one year before and after the index BMI measurement was observed in the South West (£36.94 and £51.10, respectively). Both differences were statistically significant.

Table 43 Mean and incremental aggregate primary care costs (consultations, prescriptions, tests) one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean primary care costs	Standard error	Incremental costs	Standard error	Mean primary care costs	Standard error	Incremental costs	Standard error
BMI								
Underweight	314.66***	14.501	12.9	14.905	412.4***	12.214	41.82***	12.512
Healthy weight (referent)	301.76***	2.958	-	-	370.57***	2.402	-	-
Overweight	322.98***	15.107	21.23	13.873	377.7***	4.860	7.13	5.093
Obesity	310.05***	4.220	8.3	5.080	415.47***	16.361	44.9***	15.792
Sex								
Boys (referent)	306.67***	4.765	-	-	382.16***	5.031	-	-
Girls	305.7***	2.810	-0.97	4.246	379.81***	4.304	-2.35	5.257
Age								
2 years (referent)	366.61***	7.950	-	-	347.01***	6.256	-	-
3 years	297.38***	4.495	-69.23***	8.948	316.15***	7.649	-30.86***	9.319
4 years	287.37***	4.249	-79.25***	8.799	316.26***	5.401	-30.75***	7.890
5 years	273.66***	8.572	-92.95***	11.405	324.77***	14.727	-22.24	14.493
6 years	272.73***	4.426	-93.88***	8.927	354.66***	6.849	7.65	8.896
7 years	269.61***	4.474	-97***	8.946	365.01***	4.513	17.99**	7.390
8 years	287.26***	4.540	-79.35***	9.012	412.68***	10.112	65.66***	11.303
9 years	340.13***	18.057	-26.48	18.476	451.84***	5.563	104.82***	8.109
10 years	354.78***	6.289	-11.83	10.007	482.22***	6.996	135.21***	9.141
11 years	396.52***	10.922	29.91**	13.383	544.64***	10.459	197.62***	12.095
12 years	418.97***	24.512	52.36**	25.673	567.81***	24.673	220.8***	25.321
13 years	401.81***	26.578	35.2	27.668	492.51***	32.578	145.49***	33.020
14 years	400.18***	28.858	33.57	29.838	424.79***	40.907	77.78*	41.214
15 years	451.4***	60.607	84.79	61.191	365.55***	51.604	18.54	51.931
Ethnicity								
Other/Unknown	167.32***	2.765	-150.13***	3.664	252.58***	2.767	-134.58***	4.128
Bangladeshi	408.89***	16.316	91.43***	16.621	557.35***	46.040	170.19***	46.232
Black	333.69***	19.121	16.24	19.550	399.98***	6.606	12.82*	7.382
Chinese/Other Asian	345.69***	8.794	28.24***	9.180	517.42***	95.914	130.26	95.309
Indian	358.39***	9.533	40.94***	9.878	429.37***	9.363	42.21***	9.767
Pakistani	491.6***	55.502	174.15***	54.968	527.68***	12.930	140.52***	13.134
White (referent)	317.45***	2.384	-	-	387.16***	3.105	-	-
Mixed	318.11***	7.960	0.66	8.238	403.42***	8.269	16.27*	8.740
IMD								
Fifth quintile: least deprived (referent)	301.2***	4.559	-	-	408.02***	17.397	-	-
Fourth quintile	304.34***	5.124	3.14	6.179	382.72***	6.730	-25.31	15.955
Third quintile	312.92***	4.418	11.72**	5.631	380.91***	4.112	-27.11	16.732
Second quintile	300.55***	3.609	-0.65	5.281	372.32***	5.646	-35.7*	18.745
First quintile: most deprived	310.42***	6.639	9.22	6.309	373.43***	3.923	-34.6**	16.941
Region								
North East	308.37***	8.539	3.01	9.587	357.13***	12.788	-38.79***	14.146
North West	319.44***	4.012	14.07**	6.362	395.12***	7.738	-0.79	10.322
Yorkshire and The	308.29***	8.360	2.93	9.506	392.24***	23.987	-3.68	25.080

Variable	Year before				Year after			
	Mean primary care costs	Standard error	Incremental costs	Standard error	Mean primary care costs	Standard error	Incremental costs	Standard error
Humber								
East Midlands	311.72***	11.175	6.36	12.174	385.39***	9.968	-10.53	13.491
West Midlands	320.4***	11.455	15.03	12.160	392.03***	6.049	-3.89	9.389
East of England	301.07***	8.108	-4.3	9.222	366.87***	8.201	-29.05**	13.155
London (referent)	305.36***	4.707	-	-	395.92***	9.411	-	-
South East	306.95***	5.466	1.59	6.950	372.96***	4.358	-22.95**	10.824
South West	268.42***	3.601	-36.94***	5.371	344.81***	4.946	-51.1***	8.677
Missing	305.85***	10.414	0.48	11.330	326.31***	14.140	-69.61***	15.978

*Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.*

The relationships between BMI category, covariates, and primary care costs are more complex than what is conveyed by the average incremental effects reported in **Table 43**. To better interpret these interactions, I separately calculated the incremental effects of the BMI category and on costs for each covariate (see Appendix G for point estimates and their 95% CIs). These calculations are expressed graphically in **Figure 50**-**Figure 54**. For each covariate level, an error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Among all covariates, primary care costs were highest (relative to healthy weight) for children in the underweight category one year before the index BMI measurement, but these differences were not statistically significant. In the year after the index BMI measurement, the highest costs compared to healthy weight were observed among children living with obesity across all covariates, and these differences were statistically significant. For children in the overweight category, incremental primary care costs were not statistically significant in the year before or after the index BMI measurement. Within-category cost differences for all covariates were not statistically significant.

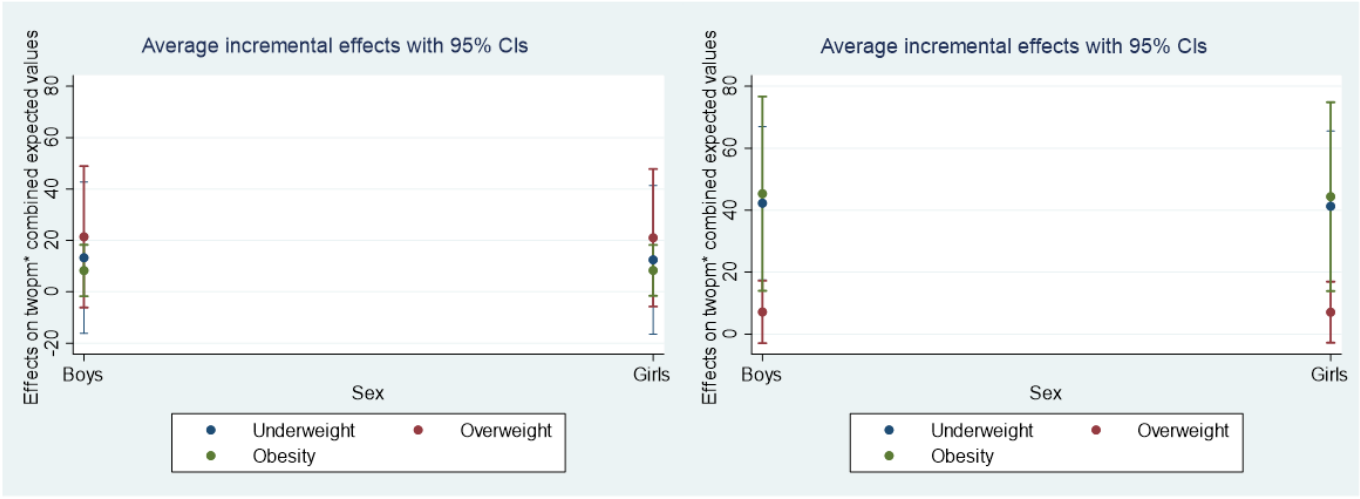

Figure 50 The relationship between primary care costs (consultations, prescriptions, tests) and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

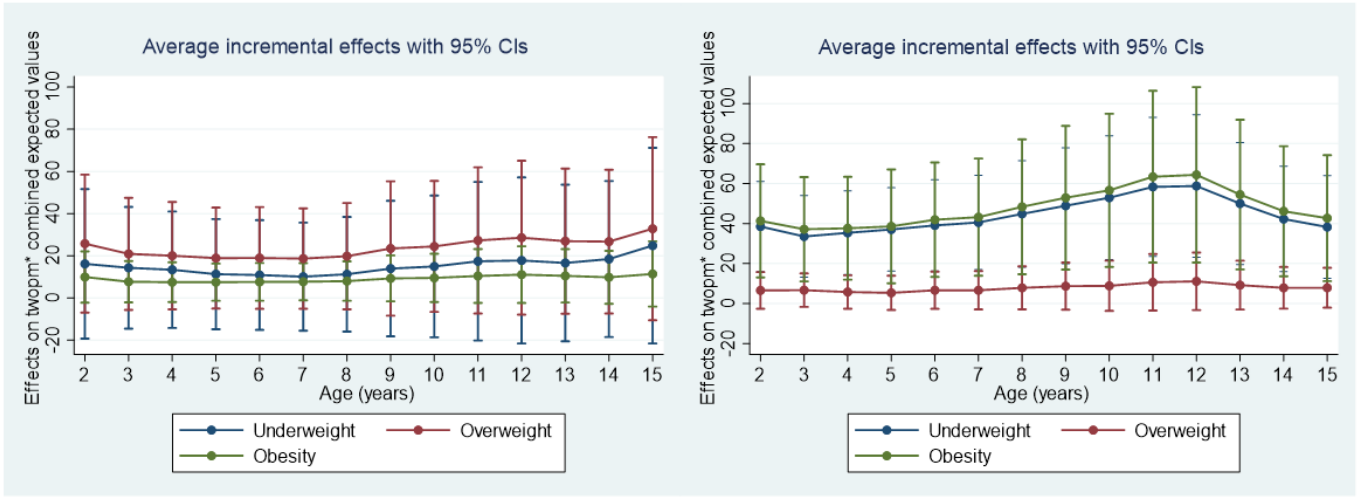

Figure 51 The relationship between primary care costs (consultations, prescriptions, tests) and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

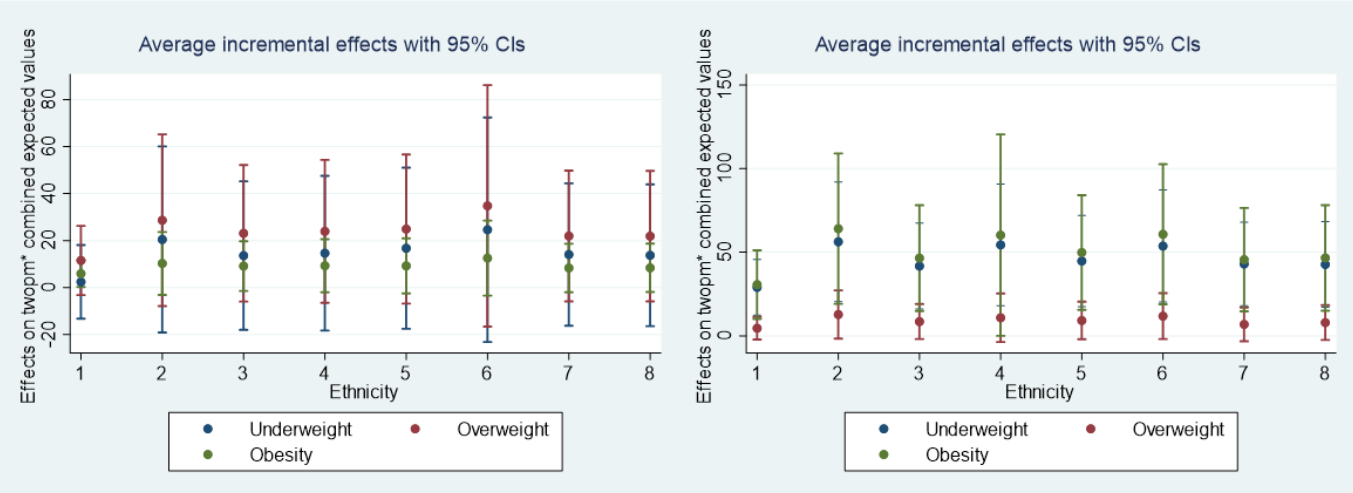

Figure 52 The relationship between primary care costs (consultations, prescriptions, tests) and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

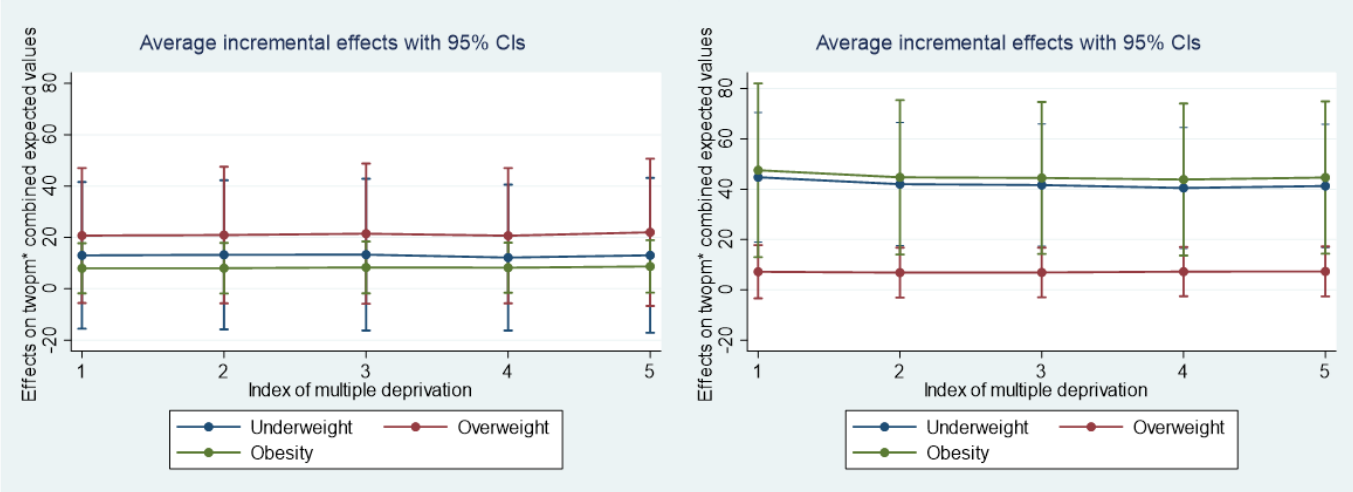

Figure 53 The relationship between primary care costs (consultations, prescriptions, tests) and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

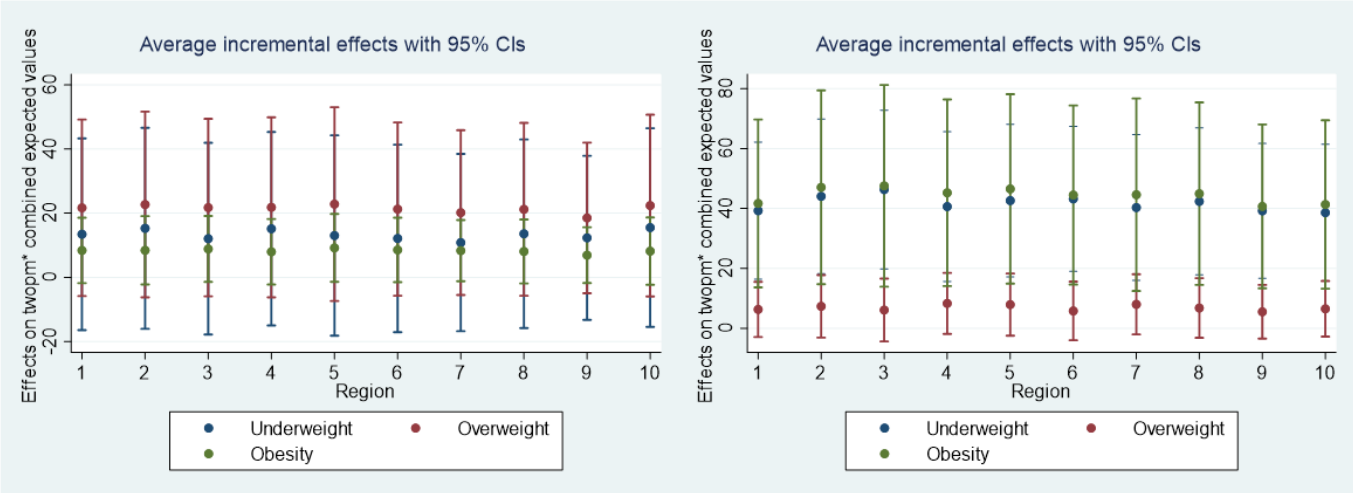

Figure 54 The relationship between primary care costs (consultations, prescriptions, tests) and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

7.3.4 Aggregated secondary care costs – descriptive results and model estimates

In this section, I have conducted all analyses related to the total secondary care costs, which include costs for admitted patient care, outpatient care, and accident and emergency care.

The mean annual secondary care costs per child in the years straddling the index BMI measurement were £1,010.70 (95% CI: 995.51-1,025.89) and £1,004.71 (95% CI: 989.20-1,020.23), respectively (Table 44). The total secondary care costs attributable to children in the study were £271,100,656.02 and £269,494,817.36 in the year before and after the index BMI measurement. These costs were incurred by 152,772 children in the year prior to the index BMI measurement and 162,774 children in the following year.

Table 44 Mean aggregate secondary care costs (admitted patient care, outpatient care, and accident, emergency care) per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	1,010.70	4,014.37	0	449,931.20	995.51	1,025.89
One year after BMI measurement	1,004.71	4,099.36	0	583,757.30	989.20	1,020.23

Figure 55 depicts the box plot distributions of aggregate secondary care costs. The costs demonstrate a strong right-skew in their distribution.

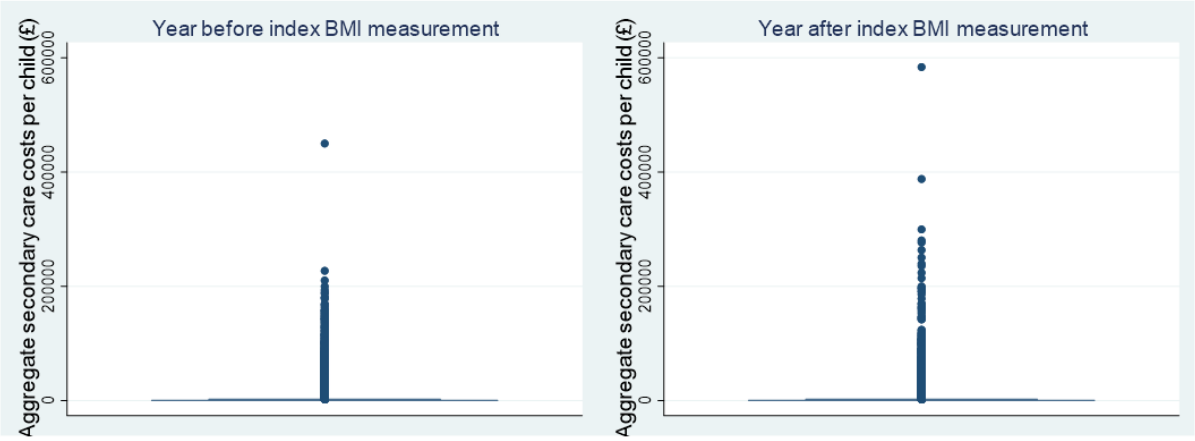

Figure 55 Box plots of aggregate secondary care costs (admitted patient care, outpatient care and accident and emergency care) in the years before and after the index BMI measurement

The adjusted mean costs of secondary care costs (admitted patient care, outpatient care and accident and emergency care) per child predicted with margins the year before and after the index BMI measurement were £1,010.68 (95% CI: 995.50-1,025.86) and £1,004.81 (95% CI: 989.22-1,020.41), respectively. These predicted cost estimates derived from the two-part GLM regression model represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix G. Table 45 presents the modelled mean costs of admitted patient care episodes by weight status category (while holding all covariates at average values) and individual covariates (while holding all other covariates at average values), as well as the incremental effects with respect to the referent levels of individual covariates.

In the year before a BMI measurement, the mean total costs of secondary care were highest in children with obesity, and compared to healthy weight children, cost an additional £107.31 and an additional £107.44 (statistically significant) in the year before and after an index BMI measurement, respectively (Table 45, column "Incremental costs"). On average, girls accrued lower secondary care costs in the years that straddled an index BMI measurement by £75.03 and £70.37, which were statistically significant cost differences. Costs for older children were lower compared to two-year-olds. Children of Pakistani origin incurred the highest costs relative to white children. Only children in the Southwest had decrements in secondary care costs compared to children in

London, which were statistically significant in the year before (£136.35) and after (£90.3) the index BMI measurement.

Table 45 Mean and incremental aggregate secondary care costs (admitted patient care, outpatient care, and accident, emergency care) one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Mean secondary care costs	Standard error	Incremental costs	Standard error	Mean secondary care costs	Standard error	Incremental costs	Standard error
BMI								
Underweight	930.52***	33.190	-52.76	34.287	1087.32***	38.390	111.72***	39.459
Healthy weight (referent)	983.27***	8.861	-	-	975.6***	9.063	-	-
Overweight	1082.68***	26.118	99.41***	27.749	1031.8***	21.681	56.2**	23.531
Obesity	1090.58***	23.280	107.31***	25.034	1083.04***	25.961	107.44***	27.774
Sex								
Boys (referent)	1044.05***	10.323	-	-	1036.11***	10.771	-	-
Girls	969.02***	11.726	-75.03***	15.625	965.74***	11.852	-70.37***	16.043
Age								
2 years (referent)	1679.37***	41.461	-	-	1468.3***	35.905	-	-
3 years	1193.15***	27.043	-486.22***	49.315	1120.82***	24.199	-347.48***	43.181
4 years	1132.27***	24.516	-547.1***	47.984	1101.11***	23.848	-367.19***	42.753
5 years	928.05***	18.366	-751.33***	45.219	924.15***	22.764	-544.15***	42.227
6 years	936.64***	18.999	-742.73***	45.531	964.76***	22.396	-503.54***	42.283
7 years	860.93***	25.949	-818.45***	48.634	882.95***	28.260	-585.35***	45.332
8 years	817.88***	21.190	-861.49***	46.590	837.18***	17.460	-631.12***	39.916
9 years	824.07***	18.095	-855.3***	45.301	905.34***	24.720	-562.96***	43.819
10 years	898.54***	23.549	-780.83***	47.739	940.06***	22.957	-528.23***	42.774
11 years	1064.35***	36.830	-615.02***	55.600	1093.03***	32.754	-375.26***	48.764
12 years	972.31***	71.027	-707.06***	82.386	1061.4***	72.875	-406.9***	81.412
13 years	983.84***	120.139	-695.53***	127.143	1232.79***	117.526	-235.51*	122.859
14 years	1224.58***	241.981	-454.79*	245.778	1006.01***	102.452	-462.29***	108.556
15 years	698.31***	151.448	-981.06***	157.022	878.27***	292.038	-590.03**	294.181
Ethnicity								
Other/Unknown	397.38***	16.244	-735.38***	19.610	468.83***	18.089	-642.42***	21.888
Bangladeshi	881.6***	62.937	-251.17***	64.398	855.26***	47.334	-255.99***	48.904
Black	1024.38***	32.153	-108.39***	34.827	1064.87***	36.902	-46.38	39.431
Chinese/Other Asian	1120.5***	50.006	-12.27	51.506	1104.42***	55.443	-6.83	56.604
Indian	1014.34***	44.178	-118.42***	45.547	986.17***	40.732	-125.08***	42.285

Variable	Year before				Year after			
	Mean secondary care costs	Standard error	Incremental costs	Standard error	Mean secondary care costs	Standard error	Incremental costs	Standard error
Pakistani	1207.5***	43.263	74.74*	44.526	1160.97***	38.033	49.71	39.629
White (referent)	1132.77***	10.399	-	-	1111.25***	10.534	-	-
Mixed	1119.5***	37.473	-13.27	39.181	1097.77***	45.244	-13.48	46.836
IMD								
Fifth quintile: least deprived (referent)	946.25***	19.625	-	-	919.06***	18.479	-	-
Fourth quintile	983.6***	17.676	37.35	26.146	987.64***	18.847	68.58***	25.772
Third quintile	984.74***	16.931	38.5	25.824	981.5***	16.887	62.44**	24.723
Second quintile	1017.84***	16.244	71.6***	25.630	1013.03***	15.005	93.97***	23.986
First quintile: most deprived	1073.17***	15.560	126.93***	24.993	1070.78***	18.356	151.72***	26.770
Region								
North East	1330.72***	75.551	336.44***	81.565	1334.69***	91.610	364.41***	96.893
North West	1099.79***	17.685	105.51***	26.210	1069.69***	17.278	99.41***	25.410
Yorkshire and The Humber	998.14***	34.476	3.86	39.774	1055.76***	54.444	85.48	56.914
East Midlands	938.31***	47.426	-55.98	51.071	1014.94***	63.495	44.66	65.754
West Midlands	984.16***	18.916	-10.12	26.541	969.67***	18.795	-0.61	25.570
East of England	929.62***	41.497	-64.66	45.454	897.59***	36.619	-72.69*	40.813
London (referent)	994.28***	18.590	-	-	970.28***	17.712	-	-
South East	1051.08***	17.830	56.8**	26.695	1071.46***	18.980	101.18***	26.638
South West	857.93***	19.246	-136.35***	26.944	879.98***	22.411	-90.3***	29.415
Missing	920.8***	70.826	-73.48	73.440	885.11***	53.543	-85.17	56.735

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

The relationships among the exposure variable (BMI category), covariates, and outcome variable (secondary care costs) are more intricate than what is captured by the average incremental effects presented in **Table 45**. To enhance the interpretation of results, I separately calculated the incremental effects of the BMI category on costs for each covariate (point estimates and their 95% CIs are reported in Appendix G). The calculations are visualised in **Figure 56**-**Figure 60**. For each covariate level, an error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Incremental costs associated with obesity and overweight were statistically significant and persisted across all covariates in the year before and after the index BMI measurement. In the year before the index BMI measurement, children in the underweight category recorded the lower secondary care costs for all covariates. However, in the year after the BMI measurement, secondary care costs for children with underweight were

higher and statistically significant across all covariates relative to the healthy weight category. The cost differences for all covariates within individual weight status categories were not statistically significant.

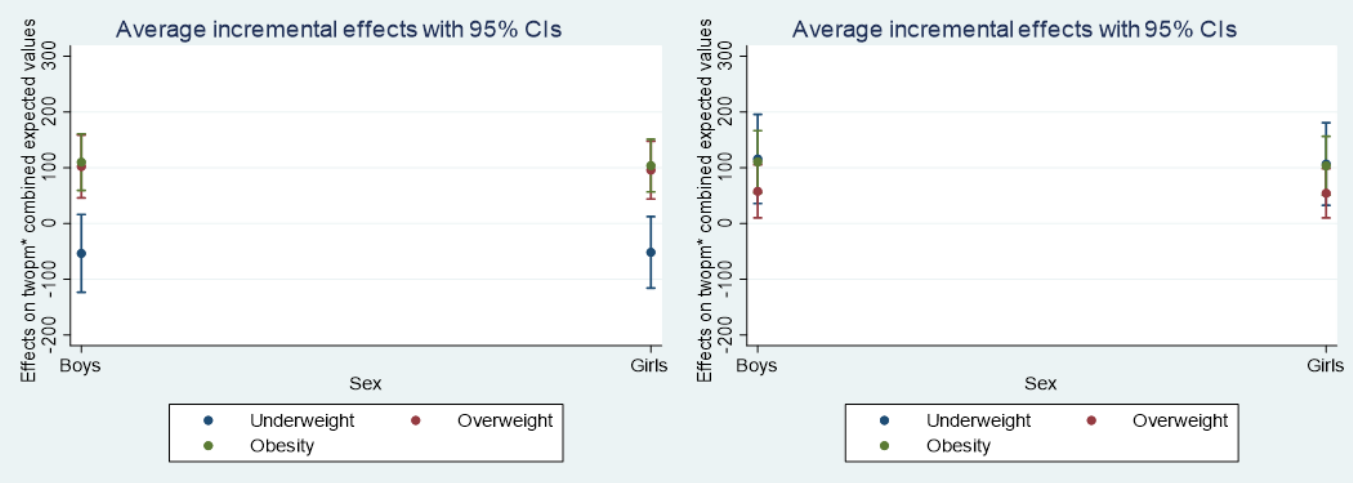

Figure 56 The relationship between secondary care costs (admitted patient care, outpatient care, and accident, emergency care) and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

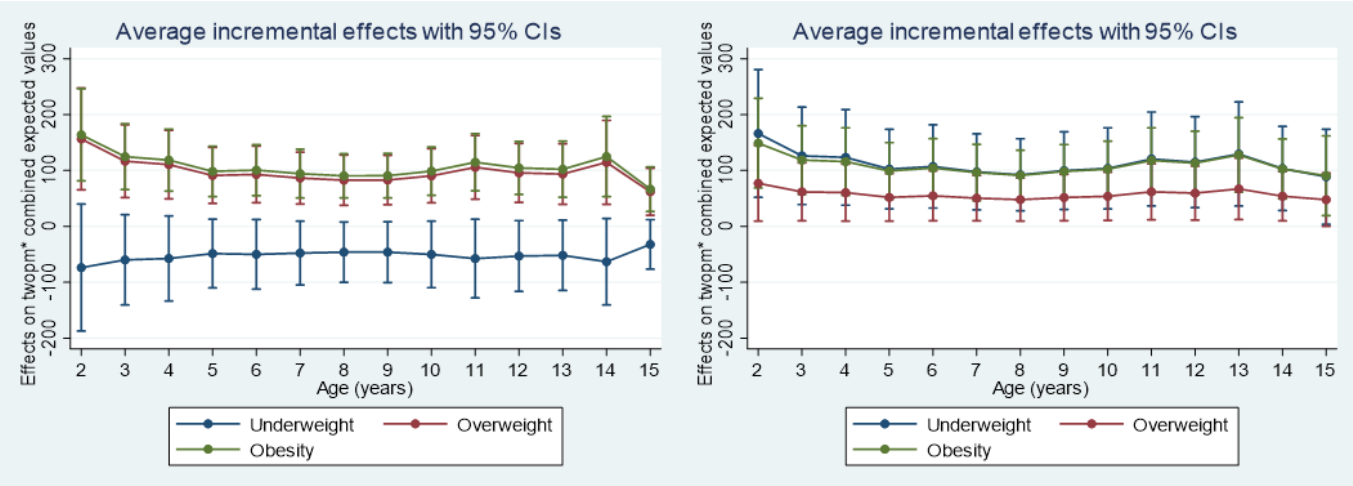

Figure 57 The relationship between secondary care costs (admitted patient care, outpatient care, and accident, emergency care) and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

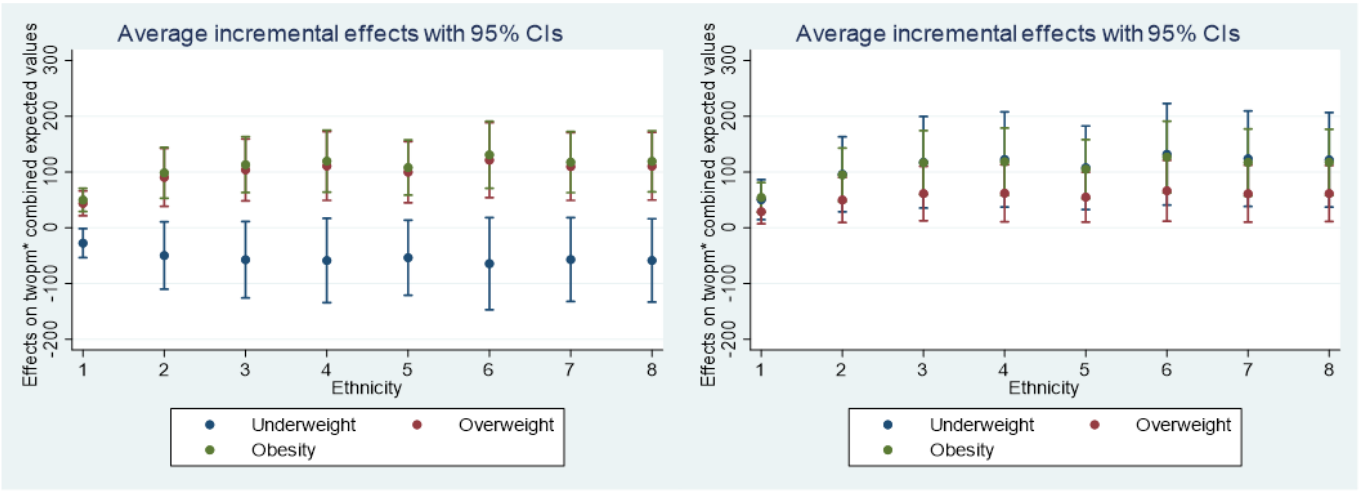

Figure 58 The relationship between secondary care costs (admitted patient care, outpatient care, and accident, emergency care) and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

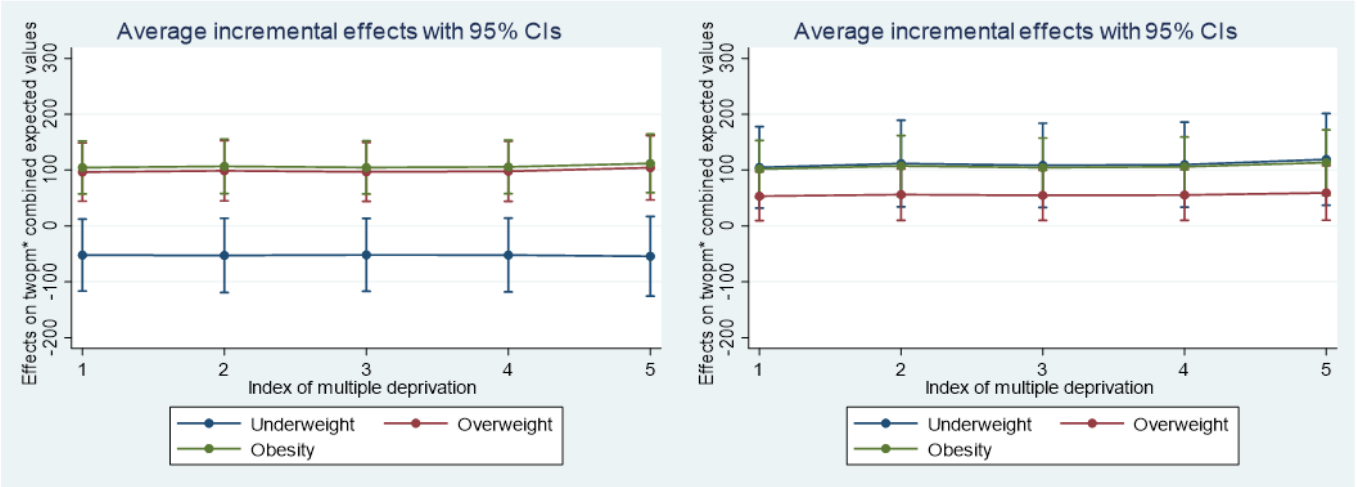

Figure 59 The relationship between secondary care costs (admitted patient care, outpatient care, and accident, emergency care) and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

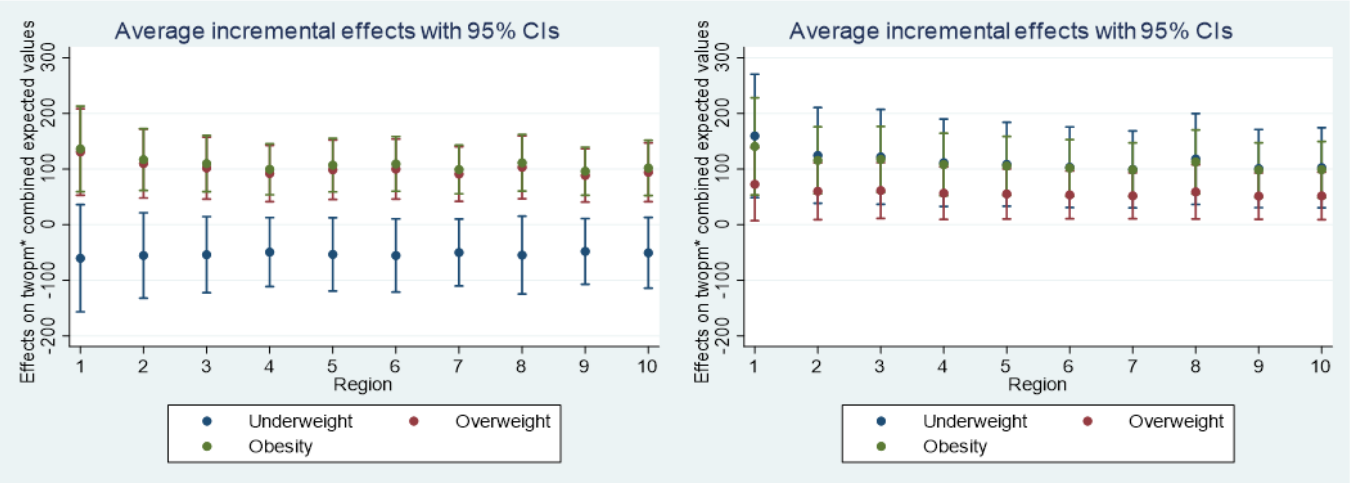

Figure 60 The relationship between secondary care costs (admitted patient care, outpatient care, and accident, emergency care) and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

7.3.5 Total direct healthcare costs (combined primary and secondary care costs)

The mean annual costs of total direct healthcare costs per child in the year before and after the index BMI measurement were £1,317.13 (95% CI: 1,299.40-1,334.87) and £1,385.69(95% CI: 1,367.65-1,403.74), respectively (Table 46). The total direct healthcare costs attributable to children in the study were £353,295,889.00 and £371,685,000.29 in the year before and after the index BMI measurement.

Table 46 Mean total direct healthcare costs per child in the study population of 268,231 children

	Mean (£)	Standard deviation	Min	Max	Lower 95% CI	Upper 95% CI
One year before BMI measurement	1,317.13	4,685.97	0	888,844.80	1,299.40	1,334.87
One year after BMI measurement	1,385.69	4,768.22	0	879,018.50	1,367.65	1,403.74

Figure 61 shows heavily skewed box plot distributions of annual total direct healthcare costs.

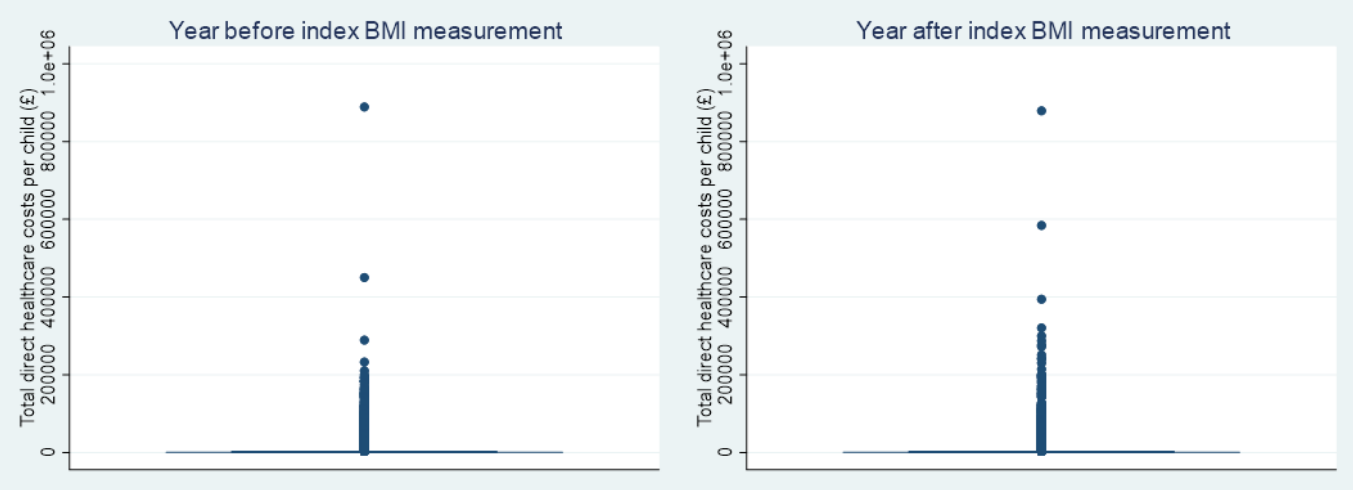

Figure 61 Box plots of total direct healthcare costs in the years before and after a BMI measurement

The adjusted total direct healthcare costs per child predicted with margins in the years before and after a BMI measurement were £1,317.37 (95% CI: 1,299.58-1,335.15) and £1,386.19 (95% CI: 1,367.87-1,404.51), respectively. These predicted cost estimates derived from the two-part GLM regression model (described in detail in Chapter 5) represent the marginal effects while holding childhood weight status and all covariates at average values. Regression coefficients (marginal effects) for the two parts of the model are reported in Appendix G. The predicted mean costs of direct healthcare costs by weight status category (while holding all covariates at average values) and individual covariates (while holding all other covariates at average values), as well as the incremental effects with respect to its referent levels of individual covariates, are reported in Table 47.

One year before and after the index BMI measurement, children with overweight and obesity recorded higher direct healthcare costs than their peers in the healthy weight category. The incremental direct healthcare costs for overweight and obesity relative to healthy weight were £133.93 and £115.47 one year before the index BMI measurement (Table 47, column “Incremental costs”). In the year after the index BMI measurement, incremental direct healthcare costs associated with obesity (£154.51) and underweight (£138.20) exceeded that associated with overweight (£66.32). These differences were statistically significant. These cost differences were all statistically significant. On average, girls incurred statistically significantly lower direct healthcare costs compared to boys at a difference of £78.08 and £77.02 in the years straddling the index BMI measurement. The mean direct healthcare costs tended to be lower with age in the year before and after the index BMI measurement, with

statistically significant differences for most age groups in comparison to 2-year-olds. Children of Pakistani origin incurred the highest direct healthcare costs, exceeding their white contemporaries by an additional £262.76 and £190.57 (statistically significant) one year after the index BMI measurement, respectively. The mean direct healthcare costs were highest in the most deprived IMD quintile in the year before and after the index BMI measurement (£137.63 and £112.00, respectively) relative to the least deprived IMD quintile, and these estimates were statistically significant. The lowest regional direct healthcare costs relative to London (the referent group) one year before or after the index BMI measurement (£185.43 and £131.67, respectively) was observed in the South West. Both differences were statistically significant.

Table 47 Mean and incremental total direct health care costs one year before and after index BMI measurement adjusted for covariates in the study population of 268,231 children

	Year before				Year after			
Variable	Total direct healthcare costs	Standard error	Incremental costs	Standard error	Total direct healthcare costs	Standard error	Incremental costs	Standard error
BMI								
Underweight	1234.9***	37.616	-49.4	38.812	1484.65***	41.676	138.2***	42.816
Healthy weight (referent)	1284.3***	9.821	-	-	1346.45***	9.899	-	-
Overweight	1418.23***	37.508	133.93***	38.497	1412.77***	23.580	66.32***	25.686
Obesity	1399.77***	25.111	115.47***	27.151	1500.95***	35.111	154.51***	36.763
Sex								
Boys (referent)	1352.13***	12.501	-	-	1420.38***	12.742	-	-
Girls	1274.05***	12.764	-78.08***	17.648	1343.36***	13.380	-77.02***	18.267
Age								
2 years (referent)	2048.56***	45.095	-	-	1817.67***	39.109	-	-
3 years	1485.3***	28.904	-563.25***	53.379	1432.77***	26.745	-384.9***	47.210
4 years	1415.52***	25.995	-633.04***	51.863	1413.53***	25.419	-404.14***	46.285
5 years	1199.02***	21.460	-849.54***	49.790	1254.27***	31.775	-563.4***	49.305
6 years	1211.54***	21.134	-837.01***	49.724	1320.4***	25.299	-497.28***	46.570
7 years	1133.81***	28.536	-914.74***	53.134	1246.58***	30.597	-571.09***	49.185
8 years	1108.36***	23.522	-940.2***	50.959	1247.41***	21.022	-570.26***	44.236
9 years	1167.54***	30.605	-881.02***	53.797	1360.02***	28.063	-457.65***	48.470
10 years	1256.33***	26.012	-792.23***	52.102	1426.29***	25.557	-391.38***	46.843
11 years	1460.59***	40.667	-587.97***	60.848	1642.15***	36.233	-175.52***	53.454
12 years	1383.9***	76.710	-664.65***	89.138	1615.53***	77.897	-202.14**	87.193

Variable	Year before				Year after			
	Total direct healthcare costs	Standard error	Incremental costs	Standard error	Total direct healthcare costs	Standard error	Incremental costs	Standard error
13 years	1381.95***	122.865	-666.61***	130.982	1733.94***	125.001	-83.74	130.885
14 years	1584.69***	236.679	-463.87*	241.230	1418.77***	120.334	-398.9***	126.463
15 years	1188.4***	204.232	-860.16***	209.178	1291.04***	327.354	-526.63	329.599
Ethnicity								
Other/Unknown	564.15***	16.197	-888.56***	19.703	714.31***	17.943	-784.59***	22.021
Bangladeshi	1276.09***	65.280	-176.62***	66.846	1403.89***	68.220	-95	69.716
Black	1348.58***	39.214	-104.13**	41.906	1455.28***	38.791	-43.62	41.439
Chinese/Other Asian	1462.3***	53.899	9.59	55.495	1629.93***	125.846	131.04	126.031
Indian	1368.89***	47.039	-83.82*	48.534	1413.37***	43.394	-85.53*	45.093
Pakistani	1715.47***	87.405	262.76***	87.931	1689.47***	44.291	190.57***	45.913
White (referent)	1452.71***	11.245	-	-	1498.9***	11.463	-	-
Mixed	1439.95***	41.224	-12.76	43.019	1505.69***	48.217	6.79	49.925
IMD								
Fifth quintile: least deprived (referent)	1247.45***	21.186	-	-	1330.61***	29.070	-	-
Fourth quintile	1281.5***	19.203	34.05	28.169	1367.04***	20.667	36.43	33.513
Third quintile	1298.9***	18.619	51.45*	28.033	1363.55***	18.197	32.93	33.763
Second quintile	1321.61***	18.066	74.16***	28.032	1386.72***	17.399	56.11	35.277
First quintile: most deprived	1385.08***	18.962	137.63***	27.759	1442.62***	20.159	112***	36.047
Region								
North East	1648.58***	93.024	338.23***	99.377	1715.77***	119.723	352.59***	125.736
North West	1412.21***	18.867	101.85***	28.278	1466.13***	20.077	102.94***	29.194
Yorkshire and The Humber	1312.72***	38.353	2.37	44.080	1446.52***	59.253	83.34	62.545
East Midlands	1242.03***	51.031	-68.32	55.160	1390.25***	64.044	27.06	67.345
West Midlands	1300.51***	24.987	-9.84	32.093	1352.78***	21.013	-10.4	29.634
East of England	1237.65***	44.525	-72.7	48.952	1275.42***	39.662	-87.77*	45.956
London (referent)	1310.35***	20.401	-	-	1363.19***	22.091	-	-
South East	1353.96***	19.820	43.6	29.350	1439.88***	20.396	76.7**	31.511
South West	1124.92***	20.170	-185.43***	28.599	1231.52***	24.972	-131.67***	33.688
Missing	1220.58***	73.656	-89.77	76.640	1206.77***	57.197	-156.41**	61.395

Significance codes: *** for p-values ≤ 0.01, ** for p-values ≤ 0.05, * for p-values ≤ 0.10.

Point estimates and their 95% CIs of the incremental effects of the BMI category on mean direct healthcare costs by covariate are reported in Appendix G and graphically depicted below (**Figure 62**-**Figure 66**). An error bar crossing zero indicates a lack of statistical significance at $p < 0.05$.

Among all covariates, incremental direct healthcare costs were highest for children in the obesity category relative to healthy weight one year before and after the index BMI measurement. These differences were statistically significant. Children in the underweight category had lower costs relative to healthy weight in the year before the index BMI measurement, and these differences were not statistically significant. In the year after the index BMI measurement, costs associated with underweight, overweight and healthy weight were higher than those for healthy weight across all covariates. Cost differences were statistically insignificant for all covariates at individual weight status categories.

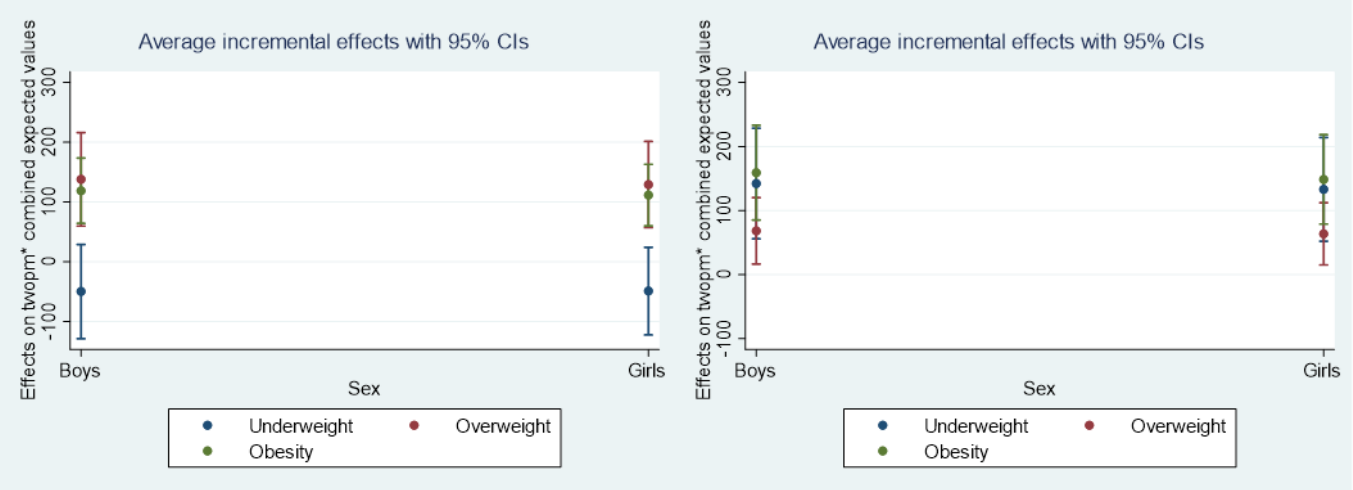

Figure 62 The relationship between the combined primary and secondary care costs and BMI category (with healthy weight as comparator) by sex one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

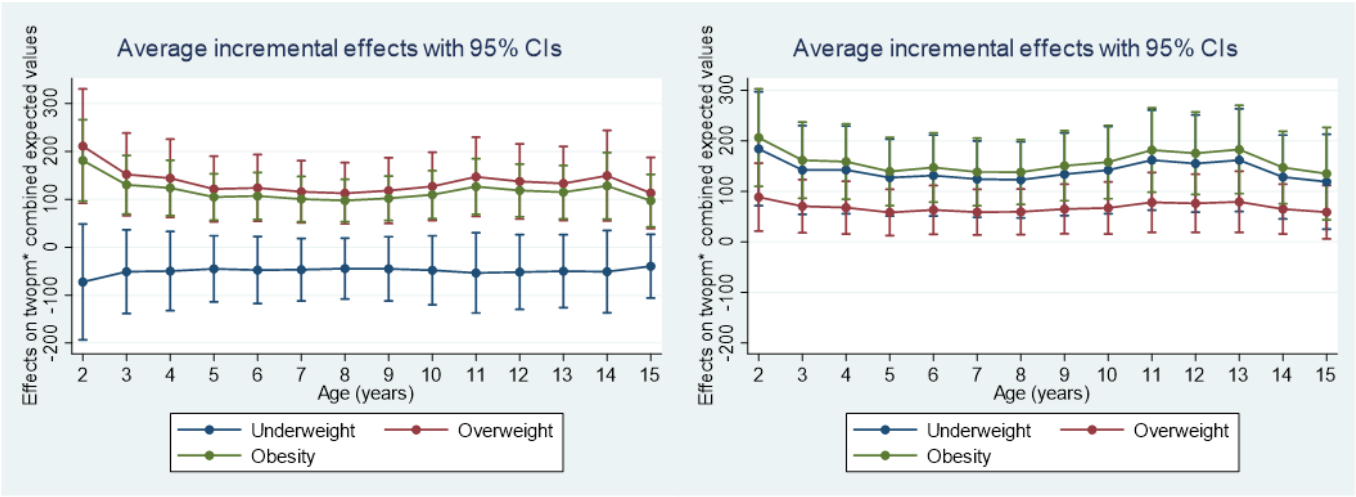

Figure 63 The relationship between the combined primary and secondary care costs and BMI category (with healthy weight as comparator) by Age one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part model]

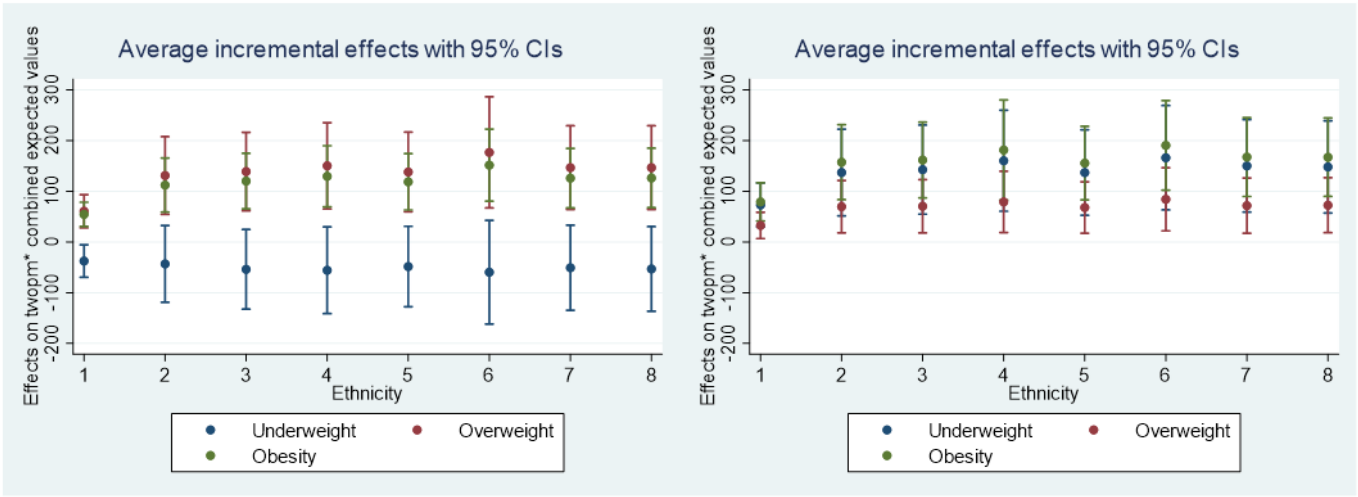

Figure 64 The relationship between the combined primary and secondary care costs and BMI category (with healthy weight as comparator) by ethnicity one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = model Other/Uknown, 2 = Bangladeshi, 3 = Black, 4 = Chinese/Other Asian, 5 = Indian, 6 = Pakistani, 7 = White, and 8 = Mixed]

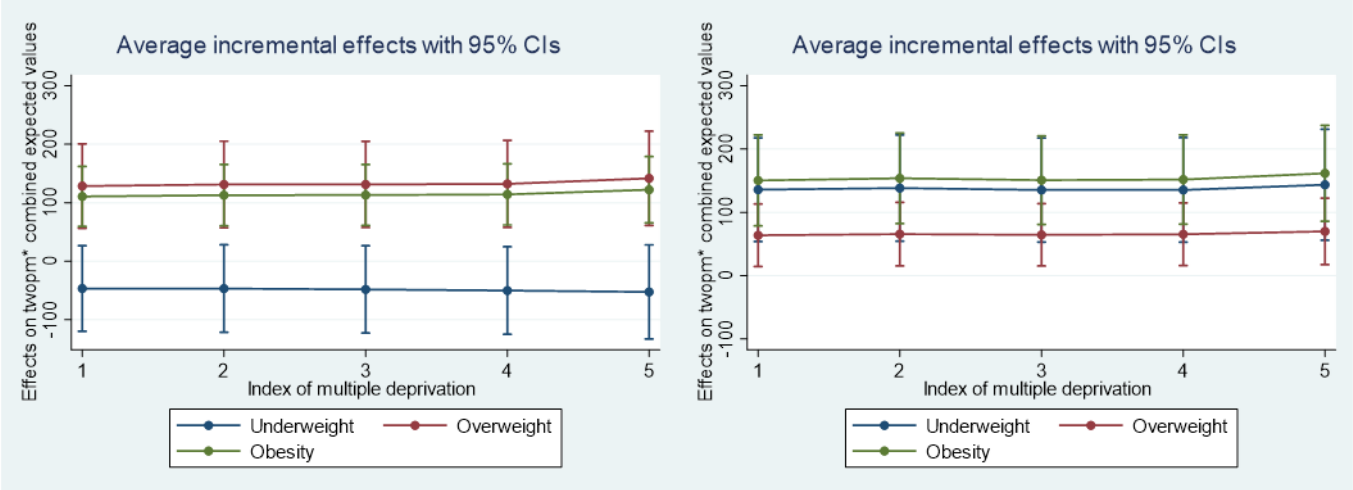

Figure 65 The relationship between the combined primary and secondary care costs and BMI category (with healthy weight as comparator) by index of multiple deprivation one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = Fifth quintile (lowest level of deprivation), 2 = Fourth quintile, 3 = Third quintile, 4 = Second quintile, 5 = First quintile (highest level of deprivation)]

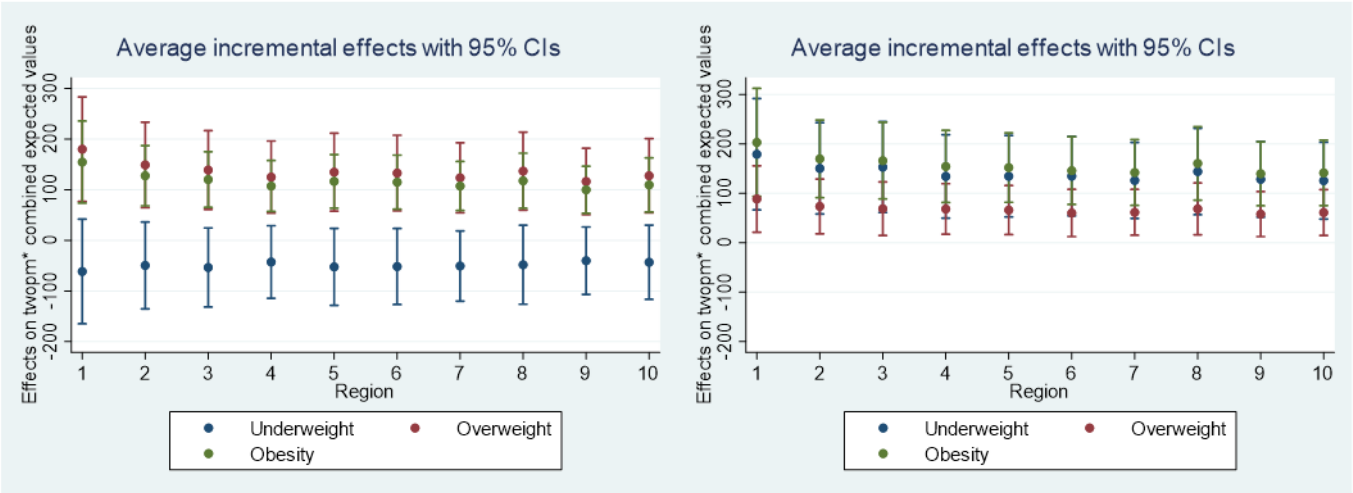

Figure 66 The relationship between the combined primary and secondary care costs and BMI category (with healthy weight as comparator) by region one year before (left half) and after (right half) the index BMI measurement

[twopm* = two-part, 1 = North East, 2 = North West, 3 = Yorkshire and The Humber, 4 = East Midlands, 5 = West Midlands, 6 = East of England, 7 = London, 8 = South East, 9 = South West, 10 = Missing]

7.3.6 Population projections of incremental total direct healthcare costs

Estimates based on RCPCH/NHS England population projections for excess weight

The Royal College of Paediatrics and Child Health (RCPCH)[510] and NHS England[511] have reported that 2.5 million children in England are affected by excess weight or obesity, with 1.22 million classified as eligible for treatment. I assumed that these 1.22 million children were in the obesity category and the remainder (1.28 million) were in the overweight category. The year when these figures were estimated, and the method of estimation was not explicitly stated in the reports, but the RCPCH report was published in 2024. In Table 48, I report the estimated mean incremental direct healthcare costs and 95% confidence intervals per child predicted with margins from my dataset for all children, children in Reception (4 and 5-year-olds) and Year 6 (10 and 11-year-olds) in the year before and after a BMI measurement.

Table 48 Incremental direct healthcare costs per child predicted with margins for study population of 268,231 children, children in Reception (4 and 5-year-olds) and Year 6 (10 and 11-year-olds), respectively

Group	Year before the index BMI measurement			Year after the index BMI measurement		
	Incremental cost (£)	Lower 95% CI	Upper 95% CI	Incremental cost (£)	Lower 95% CI	Upper 95% CI
Overweight						
All children in CPRD dataset	133.93	58.47	209.38	66.32	15.98	116.66
4 year olds	144.11	62.79	225.42	67.99	15.99	119.99
5 year olds	121.51	53.16	189.87	58.40	12.73	104.07
10 year olds	127.01	55.87	198.15	67.30	15.83	118.77
11 year olds	146.92	64.31	229.54	78.35	19.16	137.54
Obesity						
All children in CPRD dataset	115.47	62.25	168.68	154.51	82.45	226.56
4 year olds	123.77	66.02	181.51	158.89	84.55	233.23
5 year olds	104.79	56.44	153.15	139.41	71.92	206.89
10 year olds	109.67	59.72	159.61	157.94	85.42	230.46
11 year olds	126.59	68.55	184.62	181.72	98.18	265.27
Excess weight (overweight and obesity combined)						
All children in CPRD dataset	249.39	120.72	378.06	220.83	98.43	343.22
4 year olds	267.87	128.81	406.94	226.87	100.53	353.21
5 year olds	226.31	109.60	343.02	197.80	84.65	310.96
10 year olds	236.68	115.60	357.77	225.24	101.25	349.22
11 year olds	273.51	132.86	414.15	260.08	117.34	402.81

Table 49 reports the projected total incremental direct healthcare costs in England when the populations of children with excess weight (according to the RCPCH report) are multiplied by the corresponding incremental costs in Table 48.

Table 49 Projected total incremental direct healthcare costs in England for all children

Weight status	Year before the index BMI measurement			Year after the index BMI measurement		
	Incremental cost (£)	Lower 95% CI	Upper 95% CI	Incremental cost (£)	Lower 95% CI	Upper 95% CI
Overweight	171,425,536	74,845,325	268,005,888	84,890,266	20,450,624	149,329,920
Obesity	140,869,740	75,947,513	205,791,918	188,497,320	100,592,257	276,402,346
Excess weight	312,295,276	150,792,838	473,797,806	273,387,586	121,042,881	425,732,266

Based on population estimates of excess weight reported by the RCPCH and NHS England.

The total direct healthcare costs attributable to childhood excess weight in the English childhood population of children aged 0-18 years was estimated to be £312,295,276 (95% CI: 150,792,838-473,797,806) one year before the index BMI measurement and £273,387,586 (95% CI: 121,042,881-425,732,266) in the year after the index BMI measurement.

Estimates based on *proportions of children with excess weight from my dataset and the NCMP*

Estimates of the prevalence of childhood excess weight are crucial for extrapolating the predicted marginal effects (incremental costs) per child to the population of children in England. However, contemporary prevalence data for the entire childhood population in England are sparse and not readily available. In Chapter 5 (5.3.1 Study Population), I showed that the prevalence of overweight and obesity in my dataset for children in Reception (ages 4-5) and Year 6 (ages 10-11) was comparable to those estimated by the National Child Measurement Programme (NCMP) between 2006/07 and 2022/23.[493]

The highest prevalence estimates in the NCMP were recorded in the 2020/21 survey. My estimates fall roughly between this peak in 2020/21 and the drop in the latest NCMP data in 2022/23. For instance, the prevalence of excess weight in my dataset is 23.55% and 38.58%, respectively, for children in Reception (ages 4-5) and Year 6 (ages 10-11). In the NCMP surveys, the prevalence of excess weight was 27.70% and 40.90%, respectively, for children in Reception and Year 6 in the year 2020/21. These NCMP estimates dropped to 21.40% and 36.60%, respectively, for children in Reception and Year 6 in the year 2022/23. Therefore, to estimate the national costs

attributable to overweight and obesity, I assumed that my prevalence estimates for other age groups not considered in the NCMP were also nationally representative.

Table 50 details the 2023 mid-year population of children in England for all children (ages 0-18 years), and the subgroups of children in Reception (ages 4-5) and Year 6 (ages 10-11). It also reports the prevalence of overweight, obesity, and excess weight in these groups of children, as per my study (0-18 years) and the NCMP (Reception and Year 6). The number of children with overweight, obesity and excess weight, estimated by multiplying prevalence and population, are further reported.

Table 50 Mid-year population estimates for children in England in 2023 and number with excess weight

Ages (years)	Population in England	Prevalence	Number with excess weight
		Overweight	
0-18*	12,669,854	11.54%	1,462,101
4-5‡	1,289,206	12.20%	157,283
10-11‡	1,410,531	13.90%	196,064
		Obesity	
0-18*	12,669,854	17.09%	2,165,278
4-5‡	1,289,206	9.20%	118,607
10-11‡	1,410,531	22.70%	320,191
		Excess weight (overweight and obesity combined)	
0-18*	12,669,854	28.63%	3,627,379
4-5‡	1,289,206	21.40%	275,890
10-11‡	1,410,531	36.60%	516,254

*Prevalence based on CPRD study dataset of 268,231; ‡prevalence based on NCMP 2022/23 survey.

Table 51 reports population estimates of incremental direct healthcare costs in England for all children, children in Reception (4 and 5-year-olds) and Year 6 (10 and 11-year-olds). These estimates are the products of the relevant numbers of the English childhood population with overweight, obesity or excess weight (Table 50) and the respective mean incremental direct healthcare costs per child (Table 48). The total direct healthcare costs attributable to childhood excess weight in the English childhood population of children aged 0-18, 4-5 and 10-11 years one year before the index BMI measurement was estimated to be £441,415,352, £34,350,872 and £64,680,417, respectively. In the year after the index BMI measurement, these direct healthcare costs were £427,241,115, £27,559,778 and £68,659,225 for the corresponding English childhood population. The more conservative estimates derived from the RCPCH population projections are highlighted in the discussion section.

Table 51 Projected total incremental direct healthcare costs in England for all children, children in Reception (4 and 5-year-olds) and Year 6 (10 and 11-year-olds), respectively

Ages (years)	Year before the index BMI measurement			Year after the index BMI measurement		
	Incremental cost (£)	Lower 95% CI	Upper 95% CI	Incremental cost (£)	Lower 95% CI	Upper 95% CI
			Overweight			
	193,873,8	84,646,4	303,101,5	96,006,7	23,128,6	168,884,8
0-18*	99	03	55	40	56	38
	20,832,5	9,093,5	32,571,4	9,913,4	2,251,4	17,575,4
4-5‡	21	86	48	63	57	70
	26,855,6	11,782,2	41,929,0	14,279,1	3,431,0	25,127,3
10-11‡	26	19	16	80	19	36
			Obesity			
	247,541,4	133,457,7	361,625,0	331,234,3	176,764,3	485,704,2
0-18*	52	44	75	76	89	98
	13,518,3	7,243,5	19,793,1	17,646,3	9,254,6	26,038,0
4-5‡	51	82	22	15	09	22
	37,824,7	20,537,4	55,112,1	54,380,0	29,393,4	79,366,6
10-11‡	91	05	58	45	02	58
			Excess weight (overweight and obesity combined)			
	441,415,3	218,104,1	664,726,6	427,241,1	199,893,0	654,589,1
0-18*	52	47	30	15	45	36
	34,350,8	16,337,1	52,364,5	27,559,7	11,506,0	43,613,4
4-5‡	72	68	71	78	66	92
	64,680,4	32,319,6	97,041,1	68,659,2	32,824,4	104,493,9
10-11‡	17	23	74	25	20	94

*Prevalence based on CPRD study dataset of 268,231; ‡prevalence based on NCMP 2022/23 survey.

7.4 Discussion

7.4.1 Summary and interpretation of main findings

This study estimates the direct healthcare costs associated with childhood excess weight in England, encompassing both primary and secondary care using electronic health records. In this chapter, I found that childhood overweight and obesity are associated with increased direct healthcare costs relative to healthy weight. The order of magnitude in direct healthcare costs (aggregated primary and secondary healthcare costs) is obesity (£1,500.95), underweight (£1,484.65), overweight (£1,412.77) and healthy weight (£1,346.45) in the year following the index BMI measurement. This order persists across age, region, and ethnicity. The incremental costs of underweight and excess weight (relative to healthy weight) were predominantly driven by secondary care resource utilisation, which, on a per-child basis, was nearly three times that of primary care utilisation.

In general, costs were higher in the year following the index BMI measurement compared to the preceding year, especially in the underweight and obesity categories. This finding is anticipated, as it suggests a logical increase in care subsequent to a visit to a general practice, diagnosis, or referral to secondary care. Another major

contribution of this chapter is the estimation of total healthcare costs attributable to childhood excess weight in England. These estimates expand knowledge on the global economic burden of childhood excess weight and are valuable for English healthcare decision-making, aiding in the assessment of future general practice and hospital resource utilisation tailored to various population subgroups and BMI profiles.

The covariates considered in this study showed statistically significant associations with costs compared to the referent covariate level. Girls, for instance, tended to incur lower costs than boys one year before and after the index BMI measurement at primary and secondary care levels. A further step in my analysis contextualises the relationship between healthcare costs and childhood weight status by examining potential effect modifications across various covariates. The overall observation indicated that cost differences between weight status categories were statistically significant but insignificant when stratified by covariates. For instance, two-year-old children in the underweight category incurred lower direct healthcare costs compared to their counterparts in the healthy weight category, while direct healthcare costs increased incrementally for two-year-olds with overweight and obesity, relative to those in the healthy weight category. However, within individual weight status categories, cost differences by age were not statistically significant. Given that covariates generally did not moderate the relationship between weight status and total healthcare costs, this suggests that uniform cost weights may be applied in cost-effectiveness modelling, even when accounting for targeted strategies aimed at particular subgroups, such as ethnic groups at greater risk of elevated childhood BMI.

7.4.2 Comparison with the literature

To my knowledge, this is the first nationwide study in England to estimate costs associated with childhood weight status using electronic health records. Further, studies that estimate the costs attributable to childhood excess weight from other data sources or using other methods in the English context are scarce. An earlier English study that estimated costs linked to excess weight limited its analysis to the electronic health records of a cohort of children born in Bradford, a city in the North of England.[494] My updated search of a systematic review by Hamilton and colleagues[72] and subsequent structured review of economic costs associated with childhood excess weight in Chapter 2 of this thesis did not identify any UK-based study. Similarly, a recent systematic review examining the global economic impact of childhood overweight and obesity did not identify any studies originating from England or the UK that met the inclusion criteria.[81]

Hasan's study[494] was set in Bradford, the 5th most income-deprived district in England, consisting of 9,397 children aged 4/5 years. It differed remarkably from my study of 268,231 children in many other ways, including its majority Pakistani and white populations of 46% and 40%, respectively. Despite methodological differences, Hasan estimated the incremental costs associated with underweight and obesity categories in comparison to healthy weight. Hasan's analysis also indicated that ethnicity did not modify these effects. However, Hasan found that independent of weight status, Pakistani children exhibited significantly higher healthcare costs compared to white children. Similarly, my study found no evidence of effect modification by ethnicity or other covariates in relation to direct healthcare costs, with Pakistani children incurring the highest incremental costs relative to their white counterparts.

Studies reporting the economic burden of childhood excess weight are predominantly of US origin and tend to exclude underweight from analysis. Of the 48 studies included in the systematic review and meta-analysis by Ling and colleagues[81], 29 were conducted in the US, with only seven conducted in Europe, none of which included the UK. The meta-analysis, which quantitatively estimates the total medical costs (consisting of all medical direct costs of inpatient care, outpatient care, and prescriptions), non-hospital healthcare costs (including costs of outpatient care and prescriptions), outpatient visit costs, prescribed medication costs, and hospitalisation costs, was fraught with high levels of heterogeneity across all domains of healthcare. Disparities reported between the meta-analysed studies were to be anticipated due to the variation in economic outcomes across diverse geographical jurisdictions, with a preponderance of studies reporting expenditures or charges rather than costs among studies conducted in the US.[67] Between-study variations also arose from the differences in age groups considered. To facilitate comparisons, I extracted cost outcomes from individual studies and adjusted them using the CCEMG—EPPI-Centre Cost Converter, a web-based tool for updating cost estimates.[514] All costs are expressed in British pounds sterling (£) and adjusted to 2022 prices. The converter uses national price indices for inflation and purchasing power parities (PPPs) from the International Monetary Fund (IMF) for currency conversions.

Ling and colleagues found that living with childhood overweight and obesity resulted in per capita incremental total medical costs of £132.40 and £213.87 (relative to healthy weight), respectively and in combination, a per capita increase of £165.10. These meta-analysis estimates are comparable with the total incremental direct healthcare costs estimated in this chapter (£133.93 and £115.47 for overweight and obesity, respectively in the

year before the index BMI measurement, and in the year after, £66.32 and £154.51 for overweight and obesity, respectively). Of all measures of healthcare examined by Ling and colleagues, hospitalisation costs accounted for the highest costs. The cause of primary diagnosis (predominantly related to respiratory conditions) varied considerably across studies, resulting in high heterogeneity.

Due to the significant heterogeneity observed in the systematic review by Ling and colleagues, it is reasonable to assess recent studies that estimate the national economic impact of childhood obesity on an individual basis. Recently, Biener and colleagues investigated the medical costs of childhood obesity and severe obesity in a national sample of children aged 11-17 years in the US.[93] They estimated that obesity and severe obesity in this age group elevated total annual medical expenditures by £766.36 and £1259.32, respectively. Upon decomposition into third-party and out-of-pocket expenditures, the influence of obesity on third-party payer costs was significantly magnified. This highlights the considerable externalities of childhood obesity, an argument favouring governmental intervention.[68] Ward and colleagues also recently estimated healthcare expenditures associated with excess weight in children aged 6-19.[497] They found that childhood excess weight was associated with an incremental cost of £91.32 per child. The elevated estimates reported by Biener et al.[93] may be attributed to their use of an instrumental variable (IV) approach. This perspective is supported by findings from a related study, which demonstrated that IV estimates were significantly higher than those obtained through non-IV methods.[92]

Separated by sex, estimates of incremental annual medical expenditures reported by Biener and colleagues were slightly lower for girls than boys (£803.30 versus £804.90 for obesity and £1319.44 versus £1340.15 for severe obesity).[93] However, these differences were not statistically significant. Ward and colleagues found that overall per capita spending was lower in girls than boys, but no incremental obesity-related costs were estimated between girls and boys. These findings are consistent with the results of my study, which indicated that sex did not modify the association between healthcare costs and weight status.

Recent studies conducted in Europe and Australia on childhood excess weight within specific age groups have yielded results consistent with the incremental cost estimates from my research. In Australian children aged 2 to 5, obesity was found to increase 3-year healthcare costs by £500.44 for general patients and £807.98 for

concession card holders.[90] Similarly, another Australian study estimated additional annual Medicare non-hospital costs of £38.19 and £62.88 for children aged 6 to 13 classified as overweight and obese, respectively, compared to those of healthy weight.[92] In Dutch children aged 14 to 15, the incremental healthcare costs for overweight were estimated at £246.70.[91]

A systematic review by Kent and colleagues determined that adults with underweight experience a 13% increase in total annual healthcare costs compared to individuals of healthy weight.[515] This conclusion is consistent with the results of my research, which revealed that total direct healthcare costs for children living with underweight were 10.26% higher than for those with a healthy weight in the year following the index BMI measurement. However, in the year preceding the index BMI measurement, my estimates indicated lower healthcare costs for children living with underweight compared to those of healthy weight. Furthermore, Kent et al. estimated that adults living with overweight and obesity experienced elevated total annual healthcare costs in the region of 12% and 36%, respectively, when compared to healthy-weight individuals. My corresponding estimates of cost differences for children living with overweight and obesity (10.43% and 8.99% in the year preceding the index BMI measurement and 4.93% and 11.47% in the year following the index BMI measurement) are, in some instances, less than half of those observed in adults. These differences may be attributable to the fact that the complications associated with unhealthy weight status, such as increased risks of metabolic and cardiovascular diseases, tend to manifest in adulthood, imposing substantial costs on society.[11]

Few studies estimated total population costs attributable to childhood excess weight. The most recent projections of population costs in the US come from two studies.[93,497] Biener and colleagues estimate that for children aged 11-17 years, the total direct cost associated with obesity from 2001 to 2015 averaged $7.71 billion per year. On the other hand, Ward and colleagues estimated an incremental annual medical spending attributable to childhood obesity of $1.32 billion in the US. Projections of additional annual medical costs associated with childhood excess weight among 6–13-year-olds in Australia were much lower, at $AUD 43 million, than those estimated in the US and in my study (£0.8 billion in the year before the index BMI measurement and £1 billion in the year after the index BMI measurement). In England, NHS costs attributable to elevated BMI were projected to be about £6.1 billion in 2015[516], £8.3 in 2025 and £9.7 billion in 2050.[517,518] Conservative estimates of the aggregate population costs of childhood excess weight from this chapter (£0.8 billion in the year before the index

BMI measurement and £1 billion in the year after the index BMI measurement) suggest that childhood excess weight accounts for about one-sixth of NHS population-wide costs associated with overweight and obesity. Preventing and treating childhood excess weight will yield positive cascading benefits in the reduction of healthcare costs since childhood overweight is a predictor of obesity in adulthood.

Caution should be exercised when making direct comparisons between my study on the economic costs of childhood excess weight and other cost of illness studies due to methodological differences, some of which have been previously mentioned in the discussion. The difference in cost structure between the UK and healthcare settings in other jurisdictions and the variation in weight status distribution are additional sources of methodological variation.

7.4.3 Strengths and limitations

The primary strength of this study is its utilisation of an extensive national sample derived from electronic health records, offering novel insights into the relationship between childhood weight status and direct healthcare costs comprising primary and secondary healthcare costs. The analysis is disaggregated by sex, age, ethnicity, Index of Multiple Deprivation, and geographic region within England. The substantial size of the study population is crucial for achieving generalisability, ensuring that my findings can be appropriately extrapolated to a national level. Additionally, it provides the confidence to explore trends within typically marginalised and underrepresented subgroups, such as children in the underweight category and those from minority ethnic backgrounds. For example, in contrast to the NCMP, my dataset's higher proportion of children classified as underweight could enhance statistical power in discerning trends within the least represented weight category.

Forecasting healthcare resources and costs holds paramount importance in budgetary and planning considerations from the perspective of decision-makers. This study offers tailored assessments of the relationship between childhood weight status and economic costs in England. These findings are invaluable for UK healthcare planners as they evaluate optimal resource allocation strategies for specific weight status categories within subgroups of the population. Further, absolute and relative cost estimates can serve as model parameters in economic evaluation of interventions targeting childhood excess weight.

This cost of illness study is not without weaknesses, some of which were noted in Chapters 5 and 6. The omission of routine BMI measurements in the English primary healthcare system posed a potential selection bias issue, implying that the children in my study cohort may not adequately reflect the broader population of children accessing primary healthcare in England. As van Jaarsveld and Gulliford noted, BMI measurements might be more frequently obtained during periods of illness or among individuals at the extremes of weight distribution status.[465] I have shown that the distribution of BMI categories in my dataset at ages 4-5 (Reception) and 10-11 years (year 6), especially in the categories related to excess weight, aligns with the BMI prevalences reported in the NCMP annual surveys from 2006/07 to 2022/23.[493] While these resemblances in weight status distribution do not definitively dismiss the potential for bias, they confirm earlier findings that have observed similar distributions between CPRD and other prominent UK databases like the Health Survey for England and the NCMP.[465,501] My study joins a growing, but still limited, stream of research work using electronic health records to assess the economic costs of illness linked to excess weight in the UK.[513]

An additional potential limitation of this study arises from the selection of covariates. The literature suggests that omitting pertinent variables introduces greater bias than including irrelevant ones.[477,492] Therefore, my choice of covariates was guided by both the existing research on childhood excess weight and data availability. Nonetheless, essential covariates such as mother's BMI and family history of chronic conditions may have been unintentionally omitted. For example, it has been proposed that residual confounding may exist due to unobserved variables, such as physical activity.[497]

My population-wide estimates of healthcare costs attributable to childhood excess weight hinge on the assumption that every child affected by overweight or obesity will visit their general practice due to their weight status or related complications. However, this assumption may not always be realistic, especially in less severe cases of excess body fat accumulation. Several factors, including parental preparedness to facilitate healthcare contact, may impede timely access to healthcare for children afflicted with excess weight.[519,520]

Due to time constraints, this study does not investigate the lifetime costs or indirect, non-healthcare costs associated with childhood excess weight. While substantial evidence links childhood excess weight to the epidemiological development of obesity-related diseases in adulthood, the enduring economic repercussions of

childhood obesity are currently insufficiently researched.[89] Existing studies estimating longer-term or lifetime economic impacts are predominantly non-UK-based, potentially limiting their generalisability and applicability. Similarly, research on indirect costs linked to childhood excess weight is scarce, with no UK-specific studies identified in Chapter 2 or recent systematic reviews.[67,81] However, research suggests that indirect costs contribute a significant portion of the total economic burden attributable to excess weight, exceeding direct healthcare costs.[74,517] Incorporating these long-term costs and indirect costs—such as sickness absences, loss of earnings, reduced productivity, and premature mortality from diseases linked to overweight and obesity—would enhance the comprehensiveness of economic impact assessments concerning childhood excess weight.[70,497]

The confidence intervals for the aggregate "Excess Weight" category were estimated by summing the upper and lower confidence intervals of the "overweight" and "obesity" categories, which likely overestimates their width. While more sophisticated methods, such as Monte Carlo analysis, could provide more accurate estimates, their implementation was not feasible within the time constraints of this thesis. Future research could address this limitation by applying these advanced techniques.

Finally, my cost estimates rely on the cross-sectional relationship observed between BMI and the domains of healthcare resource use. Applying longitudinal or panel data that tracks changes in childhood BMI and resource utilisation over time would strengthen the establishment of a causal link between BMI and healthcare costs.[497]

7.5 Conclusions

This study demonstrates the potential for cost savings and underscores the imperative for childhood intervention through both prevention and treatment, given the well-documented long-term impacts of childhood excess weight. Chapters 5, 6, and this current chapter collectively provide a critical foundation for resource allocation aimed at reducing the prevalence of childhood excess weight. The cost estimates derived from this research can serve as crucial parameter inputs for models assessing the cost-effectiveness of interventions targeting childhood excess weight. These cost estimates can be consistent across different subgroups of covariates, as there is no evidence suggesting that the incremental costs associated with overweight and obesity varied among various ethnic groups, Index of Multiple Deprivation groups, and other covariates. Future research endeavours can

further enhance understanding in this area by exploring the lifetime and indirect costs associated with childhood excess weight.

Chapter 8: Final Discussion, Reflections and Conclusions

8.1 Summary of findings

8.1.1 Overview of research objectives

The overarching aim of this thesis was to investigate and derive parameters and economic outcomes that could provide guidance to researchers and policymakers in the allocation of resources for competing interventions aimed at addressing childhood excess weight. Accordingly, at the outset of this DPhil research, a fundamental objective was to delineate and investigate four research strands underpinning health economic aspects of excess weight among children, namely: (1) economic costs associated with childhood excess weight; (2) health utility values associated with childhood excess weight; (3) economic evaluations of preventive and treatment interventions targeting children with excess weight; and (4) economic determinants and broader consequences of childhood excess weight. These research strands were examined in **Chapter 2** through structured literature reviews or by synthesising evidence from existing reviews. The findings and recommendations in this foundational chapter helped establish new objectives and served as the impetus for the subsequent chapters, each of which played a crucial role in achieving the research objectives. Having accomplished the initial objective of setting forth and examining these four research strands, the following objectives were developed based on the identified knowledge gaps:

1. Undertake a systematic review to critically appraise and synthesise evidence from economic evaluations of interventions targeting childhood excess weight **(Chapter 3)**.
2. Estimate the hazards of transitioning between childhood weight status categories in the UK and explore the impact of child, maternal, and sociodemographic characteristics on these transition hazards **(Chapter 4)**.
3. Estimate the economic costs associated with childhood excess weight from a health service perspective for the English childhood population **(Chapters 5, 6 and 7)**.

The following three subsections summarise the foremost findings from my research. First, the review studies presented in Chapters 2 and 3 are summarised, followed then by a synthesis of the empirical analysis of childhood

weight status transitions, as conducted in Chapter 4. The final subsection summarises the results of my estimation of healthcare utilisation and costs associated with childhood weight status, as detailed in Chapters 5, 6, and 7.

8.1.2 Summary of review studies

My updated searches, building upon a previous systematic review[74], along with a structured review of the costs associated with childhood excess weight[67], revealed that childhood excess weight imposes significant short- and long-term costs in certain high-income countries. The included studies were predominantly of American origin. Primary research studies specific to the United Kingdom, many other European nations, and most low-income countries were either non-existent or sparse. A recent related systematic review[81] has also confirmed the absence of national studies of British origin. The research presented in Chapters 5, 6 and 7 was conducted to address this knowledge gap, specifically in the English childhood population.

To address my second research strand in Chapter 2, I updated the search for a systematic review and meta-analysis[124] to evaluate the health utility values (HSUVs) linked to childhood excess weight. In the included studies, I found significant methodological variations, such as differences in valuation protocol (utility instrument, population preferences for weight-related health states, and methods of valuation) and sample sizes, which potentially impact the quality of estimated utility values associated with weight status categories. Furthermore, I ascertained that inadequately powered sample sizes, the lack of sensitivity of the instruments used in children of young ages, and the weak relationship between BMI and utility could have diminished the statistical significance of estimated utility values associated with a given weight status. I also emphasised the importance of longitudinal studies to explore reverse causal relationships between childhood body weight status and HSUVs and the need for rigorous consideration of the appropriateness of included utility measures.

My updated searches and structured literature review on economic evaluations of interventions targeting childhood excess weight revealed a substantial upward trend in the volume of recent studies, indicating a heightened interest among the public and policymakers in the cost-effectiveness of prevention and treatment interventions. However, both the initial systematic review conducted by Zanganeh and colleagues[154] and my search were constrained in scope, necessitating a comprehensive systematic review detailed in Chapter 3 and summarised later in this subsection.

The last research strand in Chapter 2 assessed economic determinants and broader consequences of childhood excess weight. I focused on two key economic factors influencing childhood excess weight: socioeconomic status (SES) and food pricing. The analysis revealed mixed evidence concerning specific SES metrics; however, it emphasised that taxes on unhealthy and energy-dense foods are effective in reducing demand. Furthermore, my analysis of the broader economic implications of childhood excess weight on educational attainment and labour market outcomes reinforced existing evidence regarding the adverse effects of excess weight on human capital outcomes.

In Chapter 3, my systematic review of economic evaluations of interventions targeting childhood excess weight included 151 studies, nearly four times as many studies as included in the review by Zanganeh and colleagues published in 2019.[154] I categorised studies into three groups based on the intervention approach: prevention-only (13 studies), prevention and treatment (100 studies), and treatment-only (38 studies). This classification of studies was crucial, as the predominant setting and study design differed considerably among the three groups. Compared with usual care, most interventions were deemed cost-effective, regardless of grouping. The study participants' ages, sex, and socioeconomic status were crucial to intervention cost-effectiveness. Interventions whose effects were projected beyond childhood tended to be cost-effective. However, cost-effectiveness was sensitive to the assumptions underlying the persistence and intensity of such effects.

8.1.3 Summary of weight status transitions based on the UK Millennium Cohort Study

The findings in Chapter 3, which emphasised the frequent use of decision-analytic models, specifically state transition models (STMs), for conducting health economic evaluations of interventions targeting childhood excess weight, motivated my study in Chapter 4, where I estimated transition probabilities and hazard ratios for changes in weight status categories among children aged three to 17 years. A further rationale for this study was the absence of UK-specific estimates. I tested the validity of the underlying assumption in the literature that transitions between childhood bodyweight categories are time-homogeneous. I also examined the influence of child, maternal, and sociodemographic factors on transitions between weight status categories.

Transition rates were found to be time heterogeneous, with younger children (ages 3–5 and 5–7 years) displaying significantly higher annual transition probabilities of moving from healthy weight to overweight/obesity compared to older children. However, the resolution of unhealthy weight was more strongly age-dependent than transitions from healthy weight to non-healthy weight states.

Subgroup results – sex

The hazards of transiting between weight status categories varied significantly by sex across all five age groups. All transition hazard ratios for sex in children aged 3-5 years were statistically significant at the 0.05 alpha level. Boys were less likely to transition from underweight or overweight to healthy weight and from obesity to overweight but more likely to transition from healthy weight to underweight or overweight and from overweight to obesity. Some sex-based transition hazard ratios were not statistically significant for other age groups, and the patterns observed among children aged 3-5 years did not necessarily carry over to the remaining age groups. For instance, for children aged 11-14 years, boys were less likely to transition from healthy weight to overweight and from overweight to obesity.

Subgroup results – maternal and birth characteristics

Higher maternal body mass index, lower maternal educational attainment, and lower socioeconomic status drove the transition from healthy weight to overweight. Additionally, higher maternal BMI and lower socioeconomic status were associated with increased rates of progression from overweight to obesity. The resolution of excess weight was statistically significant among the least deprived children compared to their counterparts from lower socioeconomic backgrounds.

8.1.4 Summary of healthcare utilisation and costs associated with weight status

Chapters 5, 6, and 7 were developed to address a key knowledge gap identified in Chapter 2, namely the absence of national estimates in the UK regarding the costs attributable to childhood weight status (underweight, healthy weight, overweight, and obesity) derived from electronic healthcare records. My analyses were based on electronic health records for children from the Clinical Practice Research Datalink (CPRD) database linked with Hospital Episode Statistics (HES), employing a retrospective cross-sectional analysis study design. I also estimated resource use and costs disaggregated by sex, age, ethnicity, socioeconomic status and region.

Chapter 5 focused on annual healthcare resource utilisation and costs from a primary care perspective (general practice consultations, prescriptions and tests) in the UK. The main findings of this study indicate that childhood obesity, compared to a healthy weight, is linked with increased costs across all measures of primary healthcare usage both one year before and one year after the index BMI measurement. Underweight was also associated with significantly higher consultation and prescription costs than healthy weight. The examined covariates generally did not modify the relationship between primary care costs and weight status, with the exception of age, where variations in consultation and test costs were statistically significant within certain weight status categories.

When comparing overweight or obesity to healthy weight, primary care resource use tended to align with costs, except for tests. Here, lower resource use in children with overweight or obesity, compared to healthy weight, contradicted the higher estimated incremental costs. This unexpected trend arose from variations in the distribution of test categories by weight status. In a similar vein, although the utilisation of primary care resources and costs of consultations among children in the underweight category aligned relative to healthy-weight children, the frequency of tests and prescriptions in primary care settings diverged from costs in children with underweight. This discrepancy arises from the greater number of low-cost tests administered to children with underweight, in contrast to the fewer but more costly tests given to their healthy-weight counterparts. Additionally, children with underweight were prescribed fewer yet more expensive prescriptions compared to those of healthy weight.

In Chapter 6, the focus shifted to estimating resource use and costs in the UK's secondary care settings (admitted patient care, outpatient care, and accident and emergency care). The main findings showed that childhood overweight and obesity lead to higher costs in the three measures of secondary healthcare use as compared to healthy weight status. The most significant impacts on incremental costs were observed in admitted patient care and outpatient care. Accident and emergency care had a smaller but still significant impact on increased costs.

In the year following the index BMI measurement, admitted patient care costs were higher (relative to healthy weight) for children with obesity but not for those who were overweight. Incremental outpatient and accident and emergency costs were higher for all children with excess weight compared to their peers in the healthy

weight category. Costs for children in the underweight category varied, with lower costs primarily observed before the index BMI measurement and higher costs in the year after relative to healthy weight, potentially indicating increased provision of healthcare following diagnosis. Overall, the frequency of resource utilisation reliably indicated incremental costs relative to healthy weight for children living with underweight, overweight and obesity. Besides accident and emergency costs, which varied by age in the obesity category, cost differences were not statistically significant for the remaining covariates in all weight status categories.

In Chapter 7, I estimated the relationships between childhood excess weight and aggregate primary and secondary healthcare costs (total direct healthcare costs). I also estimated the overall direct healthcare costs, encompassing both aggregate primary and secondary healthcare costs and extrapolated the estimates nationally. As anticipated, childhood overweight and obesity were linked to higher direct healthcare costs compared to healthy weight. However, the additional costs associated with underweight status surpassed those of overweight in the year following the initial BMI measurement. These incremental costs were largely attributable to secondary care resource utilisation, which, on a per-child basis, was nearly three times greater than that of primary care.

Relative to healthy weight, direct healthcare costs were higher for children in the overweight category (by £133.93 and £66.32 in the year before and after the index BMI measurement, respectively) and for the obesity category (by £115.47 and £154.51 in the year before and after the index BMI measurement, respectively). These cost differences were statistically significant. The incremental direct healthcare cost for the underweight category in the year after the index BMI measurement was £138.20, which was also statistically significant. My conservative estimates for the total direct healthcare costs attributable to childhood excess weight in the English childhood population of children aged 0-18 years one year before and after the index BMI measurement were estimated to be £312,295,276 and £273,387,585, respectively.

Subgroup results

The initial step in untangling the relationships between covariates and costs associated with various healthcare services given a BMI measurement involved estimating the predicted mean costs by individual covariates while holding all other covariates at their average values for the year preceding and the year following the index BMI measurement. These cost estimates, independent of BMI status, are considered first.

On average, girls incurred significantly lower total direct healthcare costs compared to boys. Direct healthcare costs were lower for older children compared to 2-year-olds. Children of Pakistani origin had the highest costs, which were significantly greater than those of white children. The most deprived IMD quintile bore substantially higher healthcare costs than the least deprived. Regionally, the South West had the lowest healthcare costs relative to London, while the North East and North West experienced the highest incremental costs. These incremental costs were statistically significant one year before and after the index BMI measurement.

A subsequent subgroup analysis was conducted to determine whether the covariates (sex, age, ethnicity, region and socioeconomic status) modified the relationship between childhood weight status and healthcare costs. Following the index BMI measurement, incremental direct healthcare costs were found to be statistically significant across all covariates for children in the underweight, overweight, and obesity categories compared to those with a healthy weight. However, cost differences across covariates were not statistically significant within individual weight status categories.

8.2 Comparisons with the literature and interpretation of results

8.2.1 Weight status transitions based on the UK Millennium Cohort Study

Chen and colleagues conducted a study in the United States involving 1,653 children who underwent 11 consecutive BMI measurements between the ages of five and 12 years.[413] The study found that weight status generally remained consistent across the 11 BMI measurements. Consequently, Chen and colleagues presented a single transition matrix in their main findings, which they considered representative across all ages, with variations only by season. Similarly, other studies have reported generalisable transition matrices that do not explicitly differentiate by age during childhood.[414,415,417,422] I examined the assumption that transition probabilities remain homogeneous by age during childhood and found this implausible. Consequently, the findings of the aforementioned studies differ from mine. For example, children aged three to seven in my study had transition probabilities from overweight to healthy weight at least two times higher than the annual probabilities observed for similar transitions in older children.

Prior research primarily concentrated on the influence of covariates such as sex, ethnicity, and socioeconomic status, consistently demonstrating that these factors significantly affect transitions in weight status.[413,414,417,422]

While my study included these subgroups and came to similar conclusions, it also explored a broader range of sociodemographic characteristics and risk factors associated with changes in childhood weight status for very young children. These factors included the mode of delivery, gestational age, maternal alcohol consumption during pregnancy, and the mother's BMI category during pregnancy. Moreira and colleagues limited their analysis to vaginal and caesarean modes of delivery without distinguishing between planned and emergency caesarean sections.[415] Nevertheless, similar to my findings, these investigators observed that the mode of delivery did not have a statistically significant impact on the likelihood of transitioning from one weight status to another during early childhood.

8.2.2 Healthcare utilisation and costs associated with weight status

As previously mentioned, no national studies of UK origin that estimate the associations between childhood excess weight and primary or secondary care costs were identified in the summarised reviews. Kinge and Morris[495] assessed the impact of childhood obesity on health outcomes and health service utilisation based on a survey conducted across England, while Griffiths and colleagues[509] examined linked hospital admissions for children residing in Wales and Scotland using data from the Millennium Cohort Study. However, neither study explored the relationship between childhood weight status and costs, which was the central focus of my research.

A previous English study by Hasan, which pursued research objectives closely aligned with mine, focused its analysis on the electronic health records (EHR) of a cohort of children born in Bradford, England's 5th most income-deprived district.[494] The most notable demographic distinctions when compared to my study population pertained to ethnic and age distributions: the study was limited to children aged 4/5 to 8 years, the sample size was nearly 30 times smaller and children of Pakistani origin constituted the largest ethnic group at 46%, followed by whites (40%).

Nevertheless, my study and the research by Hasan yielded several common findings and differences that merit discussion. The absolute costs associated with different weight status categories in Hasan's study were notably lower than those estimated in mine. This discrepancy may be attributed to Hasan’s exclusion of certain healthcare domains (such as primary care tests and outpatient care) and variations in methodological approaches. However, Hasan’s incremental cost estimates relative to healthy weight were similar to those I estimated. In terms of

covariates, Hasan found that ethnicity significantly influenced healthcare costs independent of weight status, such that Pakistani children incurred higher costs than their white peers independent of their weight status. Hasan further reported that ethnicity did not modify the associations between childhood weight status and healthcare costs. These findings align with the results of my analysis.

Adopting an international perspective and making comparisons between the UK and healthcare systems in other jurisdictions presents significant challenges due to numerous methodological differences across studies. These challenges include differences in health system contexts, variations in economic measures and cost structures—such as expenditures and charges in the US compared to costs in the UK—and demographic differences. Nevertheless, valuable insights can still be gained by extending comparisons of my findings to studies conducted in other countries.

Ling and colleagues[81] assessed 35 studies cutting across several countries and found that excess weight led to incremental total medical costs of £132.40 and £213.87 annually per child for overweight and obesity, respectively, compared to healthy weight (costs are expressed in British pounds sterling (£) and adjusted to 2022 prices to aid comparison with my estimates[514]). These findings are consistent with my estimates of incremental direct total healthcare costs corresponding to overweight and obesity in England, which are £133.93 and £115.47 for the year preceding the index BMI measurement and £66.32 and £154.51 for the year following, respectively. In the US[93,497], Europe[91] and Australia[90,92], recent studies on childhood excess weight in restricted age groups also aligned with incremental costs estimated in my study. Research on adult populations[515] indicates that the healthcare costs associated with underweight, overweight, and obesity categories are significantly higher than those identified in my findings for children, reflecting the delayed onset of weight-related complications which typically emerge in adulthood.[11]

In England, estimates of NHS costs attributed to elevated BMI, including both children and adults, were £6.1 billion in 2015, rising to £9.7 billion by 2050.[516-518] Chapter 7 of this thesis estimates conservative incremental healthcare costs of £0.3 billion annually. These figures suggest that childhood excess weight might contribute at least 5% of the overall avoidable costs incurred by the NHS related to excess weight. The total incremental healthcare cost estimated in this thesis is up to 0.2% of public funding for health services in England, which was

£181.7 billion in 2022/23.[521,522] While this figure may appear modest, it underscores a significant and noteworthy allocation within the overall budget for healthcare.

8.3 Implications of results and recommendations for research and policy

Childhood excess weight is a major public health issue that has garnered considerable attention from academics, funding bodies, and political leaders alike. In 2023 and 2024, government initiatives to combat childhood obesity were critically examined during policy debates in both the House of Commons[523] and the House of Lords.[524] The discussions revolved around questions about opportunity cost. For example, Lord Brooke of Alverthorpe raised concerns regarding the government's decision to allocate £40 million to a trial of the anti-obesity drug Wegovy® while opting not to pursue reformulation policies for sugar-sweetened beverages.[524] My thesis findings have important implications for both research and policy, particularly regarding the economic evaluation of interventions targeting the prevention and treatment of childhood excess weight and healthcare resource allocation.

My systematic review demonstrated that the number of economic evaluations of interventions addressing childhood excess weight has grown considerably in recent years, reflecting increasing public interest and the evolving complexity of weight management strategies. I found that age, sex, and socioeconomic status play pivotal roles in determining the cost-effectiveness of interventions. Notably, preventive interventions targeting early childhood emerged as cost-effective, with many of these programmes initiated during pregnancy or aimed at newborns. The strong correlation between maternal factors—such as maternal BMI and educational attainment—and childhood weight status transitions that I estimated further underscores the importance of early intervention, potentially even before birth. The research in this thesis showed that healthcare costs associated with childhood excess weight are much lower than those linked to adult excess weight. Since childhood excess weight increases the risk of developing obesity in adulthood[8-10], this finding also makes a compelling case for prioritising early intervention strategies to tackle childhood weight issues, with the aim of reducing potential future healthcare costs.

As interventions expand beyond traditional settings to encompass innovative approaches, such as online and mobile app-based platforms and pharmaceutical treatments, existing methods for assessing cost-effectiveness

will require careful re-examination. Researchers and policymakers should consider emerging challenges, including the generalisability of findings, equity, and the valuation of quality of life. Thoughtful selection of outcome measures and benefits is essential, ensuring that instruments and valuation protocols are age-appropriate and account for the potential impacts on health-related quality of life for both the child and family members or caregivers. The choice of comparators in economic evaluations should be thoroughly justified, and a fully incremental analysis should be conducted for all included interventions.

Identifying substantial age-dependent variations in transition probabilities between weight status categories and the pattern of these variations challenges the assumption that these probabilities can be treated as consistent throughout childhood. This indicates that some existing economic models, which do not account for age differentiation, may oversimplify the dynamics of childhood weight status transitions, potentially leading to inaccurate estimates of the cost-effectiveness of interventions. The parameter outputs estimated from the models developed in this thesis, which include cost weights, form the foundation of a health economic model that accounts for age-specific transitions in weight status. Incorporating utility values for weight status would render it a complete health economic model for evaluating interventions targeting childhood excess weight. Future research should prioritise the development of age-specific transition models that more precisely capture the complexities of weight status changes during childhood. Such models would better inform targeted intervention strategies and resource allocation in health service initiatives.

Additionally, identifying further sociodemographic and maternal factors—such as ethnicity, family income, gestational age, and maternal BMI during pregnancy—as influential in childhood weight status transitions underscores the necessity for a more comprehensive approach in research and policymaking. These findings suggest that policies addressing childhood obesity must move beyond generic interventions and adopt tailored strategies that account for these diverse influencing factors. For instance, policymakers could prioritise funding economic evaluations alongside randomised trials of interventions targeting nutritional support and healthcare access to socioeconomically disadvantaged families, implementing culturally sensitive health programmes, and offering specialised postnatal care to children based on gestational age and maternal BMI status.

A more nuanced understanding of the costs associated with childhood weight status profiles can enhance health planning and more efficient resource allocation, thereby ensuring the effective implementation of interventions. This thesis demonstrates that measures of healthcare utilisation frequency do not always correlate with actual costs, and annual cost outcomes may differ substantially depending on when they were estimated relative to BMI measurement, highlighting the necessity for detailed temporal cost assessments in future studies. Policies should target services or patient populations that contribute disproportionately to healthcare costs, even if their utilisation frequency is low. For instance, children with excess weight may use fewer medical testing services overall but still generate higher testing costs than healthy-weight children. On the other hand, children with underweight status may receive fewer prescriptions for more expensive medications than their healthy-weight peers. Since costs may vary over time, especially around events such as BMI measurement or diagnosis, researchers need to assess annual costs at different time points to capture fluctuations. Further, this thesis has demonstrated that the incremental costs associated with underweight and excess weight (relative to healthy weight) are predominantly driven by the utilisation of secondary care resources, which, on a per-child basis, are nearly three times greater than those of primary care. Considering that the costs incurred at the primary care level are significantly lower than those at the secondary care level, it may be both practical and cost-effective to prioritise prevention interventions targeting unhealthy weight within primary care settings, thereby reducing referrals and the overall healthcare economic burden.

No evidence was found in this thesis to suggest variations in incremental costs associated with underweight, overweight and obesity across different ethnic groups, IMD quintiles or regions, indicating that uniform cost weights can be applied in budgeting and cost-effectiveness modelling. Therefore, my findings provide essential evidence to guide commissioning, budgeting and service delivery by Integrated Care Boards (ICBs) and NHS England in formulating primary care, public health, and specialist services for children and young people affected by excess weight.[525-527]

The findings of this thesis, which highlight the significant contribution of childhood excess weight to overall healthcare costs in England, underscore the considerable negative externalities (borne, to a large extent, by public taxation in the UK) and provide a compelling rationale for urgent government intervention.[68,528] Despite the economic implications of my findings, government obesity policies in England have predominantly adopted a less

interventionist approach or have been proposed in ways that do not readily facilitate implementation.[529] Lord Darzi's recently published report on the state of the National Health Service in England highlighted a significant lack of bold action in addressing obesity and regulating the food industry.[530] Policymakers should carefully consider the long-term economic benefits of early childhood interventions to prevent as well as treat childhood excess weight. Taxation policies on unhealthy, energy-dense foods, potentially supplemented by fiscal incentives such as tax breaks on healthy products and bans on unhealthy alternatives, should be meticulously designed in collaboration with all stakeholders.[68,528,529] Given that excess weight arises from an imbalance between energy intake and energy expenditure[1], investment in cost-effective interventions aimed at maintaining optimal energy balance (prevention) or reversing energy imbalance (treatment)—typically through the promotion of healthy eating and physical activity—could substantially reduce the future healthcare burden associated with excess weight. The quantitative estimates presented in this thesis serve as valuable parameters for conducting economic evaluations of interventions targeting childhood excess weight, thereby informing policy and practice.

8.4 Strengths

This thesis provides unique evidence of childhood excess weight parameters using extensive national datasets. The analysis of transitions between weight status categories was notably enhanced by the large, nationally representative sample size provided by the Millennium Cohort Study. Similarly, the research on healthcare costs associated with childhood excess weight was novel as it leveraged a substantial, country-wide sample derived from Clinical Practice Research Datalink with Hospital Episode Statistics data linkage. These extensive sample sizes enabled a comprehensive investigation of trends across a broader range of covariates and typically underserved and underrepresented subgroups, including children with underweight and those from minority ethnic backgrounds. Moreover, reporting error stemming from self-reported or proxy-reported measures of height and weight was minimised in my datasets, as BMI records were objectively measured and derived from administrative records.

8.5 Limitations

The primary limitation of the research presented in this thesis is its reliance on the analysis of observational data, which may introduce risks of bias from confounding factors, BMI measurement errors, and the lack of routine BMI

measurements. First, in the MCS, bodyweight status was interval-censored between adjacent surveys, meaning the exact timings of transitions were often unknown. For instance, if the observed transitions between two distinct time points are from a healthy weight to obesity, the child must have initially transitioned from a healthy weight to overweight. Nevertheless, this intermediate step is not recorded and, therefore, censored.

In some instances, when estimating hazard rates for explanatory variables, the model estimates failed to converge due to the absence of observed transitions within the data. This limitation necessitated merging affected levels for specific covariates, such as ethnicity, thereby reducing the granularity required to investigate all subgroups of interest thoroughly. I recommend applying a half-cycle correction[453] when using my transition estimates to design Markov-type cost-effectiveness models to mitigate this issue.

The intervals between MCS waves were uneven, leading to less accurate estimates of annual transition probabilities for adjacent waves with wider time gaps. Moreover, as BMI measurements are not routinely gathered in the English primary healthcare setting, the CPRD-HES-linked data did not include regularly collected BMI data, raising the possibility of selection bias. I recommend that future cohort studies on related topics incorporate routine BMI measurements during childhood, with a minimum frequency of biennial assessments.

Childhood weight status is associated with healthcare use, but this relationship is influenced by factors such as reverse causation—where underlying illnesses contribute to weight changes—and healthcare utilisation driven by BMI measurement rather than weight-related conditions. Illnesses like endocrine or psychological disorders may cause weight gain or loss, increasing healthcare visits for diagnosis or treatment.[2,515] Additionally, BMI screening can lead to further healthcare use, such as referrals or interventions, even without comorbidities. For instance, the U.S. Preventive Services Task Force (USPSTF) recommends referring children aged six or older with high BMI to intensive behavioural interventions.[531]

The cost estimates presented in this thesis are derived from the cross-sectional relationship observed between body weight status and healthcare resource utilisation. Employing longitudinal or panel data that tracks changes in childhood BMI and resource use over time would enhance the ability to establish a causal relationship between BMI and healthcare costs.[497] Reverse causality may occur if general practice visits lead to interventions that inadvertently reduce physical activity or alter dietary habits, resulting in excess weight accumulation and

distorting the perceived causal relationship between BMI and healthcare costs.[92] Another mechanism that may interfere with or underestimate the causal effect is omitted variable bias. For instance, unobserved factors related to socioeconomic status, such as maternal education and unobserved health conditions, such as family history of cardiovascular disease, may introduce such bias.[93] The literature suggests that omitting relevant variables can introduce more bias than including irrelevant ones.[477,492] Thus, as the literature on childhood excess weight and data availability informed my selection of covariates, it is possible that I may have inadvertently excluded critical covariates or included inappropriate ones.

To address reverse causation, instrumental variable frameworks, which use variables correlated with weight status but not directly with healthcare use or its confounders—such as genetic predispositions or parental BMI—are increasingly employed to reduce bias in estimating healthcare costs associated with childhood weight status.[93,495] Although it was not possible to apply this approach in my research, studies using instrumental variables have reported higher healthcare costs or expenditures associated with childhood excess weight.[93,495] Using relevant national data, further research employing an appropriate instrumental variable could explore the extent to which differences in incremental costs by weight status observed in the year before versus the year after the index BMI measurement are driven by reverse causality and BMI measurement.

Due to time constraints, this thesis did not investigate the lifetime costs and indirect, non-healthcare costs associated with childhood excess weight. Incorporating the full range of costs into analyses can strengthen the case for investing in early intervention programmes and preventive strategies to reduce long-term economic and social burdens associated with childhood obesity. While substantial evidence links childhood excess weight to the development of obesity-related diseases in adulthood, the long-term economic consequences of childhood obesity are currently under-researched.[89] Existing studies that estimate longer-term or lifetime economic impacts are predominantly based outside the UK, which may limit their generalisability and applicability. Similarly, research on the indirect costs associated with childhood excess weight is scarce, with no UK-specific studies identified in Chapter 2 or recent systematic reviews.[67,81] However, evidence suggests that indirect costs contribute significantly to the total economic burden of excess weight, often surpassing direct healthcare costs.[74,517] Including these long-term and indirect costs—such as sickness absences, loss of earnings, reduced productivity, and

premature mortality due to overweight and obesity—would provide a more comprehensive assessment of the economic impact of childhood excess weight.[70,497]

8.6 Future research

In this thesis, BMI was employed as a proxy for adiposity. Although alternative methods, such as hydrometry, dual-energy X-ray absorptiometry, and magnetic resonance imaging, provide more accurate adiposity assessments, they require advanced expertise and costly equipment.[38] Recent studies suggest that the waist circumference-to-height ratio may serve as a more precise indicator of excess fat mass compared to BMI without incurring additional expenses or requiring specialised skills.[37] Where available in extensive cohort studies, objective measures of adiposity should be analysed to validate the findings of this research.

This thesis estimated annual healthcare costs incurred before and after the BMI measurement. Although this one-year timeframe effectively captures the short-term economic burden associated with childhood excess weight, it does not account for health conditions that gradually develop or manifest with consequences typically in adulthood. Furthermore, this research did not consider the non-NHS costs associated with childhood excess weight. However, there are strong indications that longer-term and non-NHS costs may contribute to an even more significant economic burden than healthcare costs.[70,497] Future research should prioritise these areas.

To validate the cost estimates derived from this research, it is recommended that, if available, adequately powered longitudinal data with multiple BMI records over clinically meaningful time intervals be analysed.[497] Instrumental variable estimators should be considered to address concerns of residual confounding due to unobserved variables.[92,93] These approaches may more robustly establish the causal relationship between BMI and medical costs.

8.7 Conclusions

This thesis presents transition estimates of body weight status within a representative childhood population in the UK, revealing pronounced age-related gradients in transitions between various childhood weight profiles. My analysis demonstrates that the likelihood of shifts between weight status categories varies significantly by age and is influenced by a range of child, maternal, and sociodemographic factors. Additionally, this thesis establishes

that the frequency of resource utilisation and associated costs in primary and secondary healthcare settings are substantially elevated due to childhood underweight and excess weight.

The findings of this research are novel from a UK perspective and have important implications for both research and policy, particularly concerning childhood weight status transitions and economic burden. The transition estimates and the excess costs associated with childhood overweight and obesity generated in this thesis can be utilised as input parameters in cost-effectiveness modelling for interventions targeting childhood excess weight. Furthermore, the absence of evidence for differing incremental costs associated with underweight, overweight and obesity across different ethnic groups, IMD quintiles or regions suggests that uniform cost weights can be applied in budgeting and cost-effectiveness analyses. This thesis, therefore, provides a crucial foundation for budgetary planning and resource allocation aimed at reducing the prevalence of childhood excess weight in England and across the UK.

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Appendix A

Associated published work

1. Onyimadu, O., Violato, M., Astbury, N. M., Jebb, S. A., & Petrou, S. (2022). Health economic aspects of childhood excess weight: a structured review. Children, 9(4), 461. https://www.mdpi.com/2227-9067/9/4/461
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3. Onyimadu, O., Astbury, N. M., Achana, F., Petrou, S., & Violato, M. (2024). Childhood Transitions Between Weight Status Categories: Evidence from the UK Millennium Cohort Study. PharmacoEconomics, 42(6), 649-661. https://link.springer.com/article/10.1007/s40273-024-01361-3

Conference presentations

1. I delivered a presentation on my DPhil research at the Lady Margaret Hall Graduate Subject Seminar and Dinner on 8th March 2023, where I served as the invited speaker.
2. A draft paper based on Chapter 4 was accepted and presented at the Health Economists' Study Group (HESG) conference on 23rd June, 2023, where it was subsequently discussed. www.hesg.org.uk/wp-content/uploads/2023/05/HESG-booklet_Summer-2023_11May23.pdf
3. I presented the findings of Chapter 4 at the Economics of Children's Health and Wellbeing (E-CHW) Special Interest Group of the International Health Economics Association (iHEA) on 7th September, 2023. https://healtheconomics.org/news/august-newsletter/

Appendix B

Table B 1 Medline via Ovid search strategy and search outputs for studies on economic costs in childhood excess weight

#	Searches	Results
1	exp Obesity/	218,633
2	Overweight/	25,790
3	obes*.mp.	371,839
4	exp Body Mass Index/	130,190
5	(bmi or adipos*).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	299,231
6	1 or 2 or 3 or 4 or 5	597,405
7	exp Child/	1,938,185
8	(child* or school children or schoolchildren or pediatr* or paediatr* or boys or girls).mp.	2,619,724
9	7 or 8	2,619,724
10	exp “Costs and Cost Analysis”/	241,514
11	economic.ti,ab.	223,686
12	10 or 11	429,383
13	6 and 9 and 12	3061
14	exp animals/not humans/	4,775,603
15	13 not 14	3059
16	limit 15 to (english language and yr=“2016 -Current”)	1042

Table B 2 Medline via Ovid search strategy combinations for studies on utilities in childhood excess weight

Name of Strategy/Strategy Combination	Strategy
S1	“Health utilit*” OR “utilit* based” OR “utilit*-based” OR “utility* weight” OR “quality of life” OR QOL OR “health state valu*” OR “standard gamble” OR “time tradeoff” OR “time trade off” OR “time trade-off” OR “multi-attribute utilit*” OR CHU-9D OR CHU9D OR “child health utilit*” OR “short form 12” OR “short form 36” OR “EURoQoL 5D” OR “health utilit* index” OR HUI OR “quality of well being” OR “quality of well-being” OR “quality of wellbeing” OR QWB OR “assessment of quality of life 6D” OR AQoL-6D OR AQoL6D
S2	Child* OR adolescen* OR teen* OR youth OR pediatric OR paediatric
S3	“weight status” OR “body mass index” OR obes* OR BMI OR overweight OR adipos*
S4	“Cost-effectiv*” OR “cost effectiv*” OR “cost utilit*” OR “economic evaluation” OR “economic model*” OR “quality adjusted life year” OR QALY
S5	“discrete choice” OR “best worst scal*” OR “best-worst scal*” OR “multi attribute utilit*”

Name of Strategy/Strategy Combination	Strategy
	OR “EQ-5D*” OR “EQ 5D*” OR “EQ5D” OR “Euroqol” OR “Euro qol” OR HUI2 OR “HUI 2” OR HUI3 OR “HUI 3” OR “short form survey-6D” OR “short form 6D” OR “SF 6D” OR SF6D OR “16D health related quality of life” OR “16D HRQOL” OR “17D health related quality of life” OR “17D HRQOL” OR “adolescent health utility measure” OR AHUM
S1 AND S2 AND S3	
S2 AND S3 AND S4	
S2 AND S3 AND S5	
	Searches conducted January 2021 (limit year = “2017–Current”)

Table B 3 Medline via Ovid search strategy and search outputs for studies on utilities in childhood excess weight

#	Searches	Results
1	Health utilit*.mp.	2278
2	utilit* based.mp.	386
3	utilit*-based.mp.	386
4	utility* weight.mp.	40
5	exp Quality of Life/	202,778
6	QOL.mp.	41,029
7	health state valu*.mp.	433
8	standard gamble.mp.	861
9	time tradeoff.mp.	254
10	time trade off.mp.	1221
11	time trade-off.mp.	1221
12	multi-attribute utilit*.mp.	202
13	(CHU-9D or CHU9D).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	66
14	child health utilit*.mp.	75
15	(short form 12 or short form 36 or EURoQoL 5D).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	13,985
16	health utilit* index.mp.	940
17	HUI.mp.	1289
18	(quality of well being or quality of well-being or quality of wellbeing).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	454
19	QWB.mp.	205
20	(assessment of quality of life 6D or AQoL-6D or AQoL6D).mp.	33
21	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20	224,146
22	Child*.mp.	2,494,923
23	adolescen*.mp.	2,144,223

#	Searches	Results
24	teen*.mp.	31,736
25	youth.mp. or Adolescent/	2,088,008
26	(pediatric or paediatric).mp. [mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]	368,716
27	22 or 23 or 24 or 25 or 26	3,677,277
28	weight status.mp.	6287
29	body mass index.mp.	250,234
30	obes*.mp.	372,189
31	BMI.mp.	153,467
32	overweight.mp. or Overweight/	77,716
33	adipos*.mp.	161,116
34	28 or 29 or 30 or 31 or 32 or 33	661,534
35	Cost-effectiv*.mp.	143,070
36	cost effectiv*.mp.	143,070
37	cost utilit*.mp.	5119
38	economic evaluation.mp. or Cost-Benefit Analysis/	88,002
39	(economic model* or quality adjusted life year or QALY).mp.	14,791
40	35 or 36 or 37 or 38 or 39	191,039
41	(discrete choice or best worst scal* or best-worst scal* or multi attribute utilit*).mp.	2678
42	(EQ-5D* or EQ 5D* or EQ5D or Euroqol or Euro qol or HUI2 or HUI 2 or HUI3 or HUI 3).mp.	12,491
43	(short form survey-6D or short form 6D or SF 6D or SF6D or 16D health related quality of life or 16D HRQOL).mp.	890
44	(17D health related quality of life or 17D HRQOL or adolescent health utility measure or AHUM).mp.	4
45	41 or 42 or 43 or 44	15,419
46	21 and 27 and 34	2408
47	limit 46 to yr = “2017–Current”	732
48	27 and 34 and 40	898
49	limit 48 to yr = “2017–Current”	288
50	27 and 34 and 45	127
51	limit 50 to yr = “2017–Current”	46

Table B 4 Medline via Ovid search strategy and search outputs for studies on economic evaluation of childhood excess weight interventions

#	Searches	Results
1	exp Obesity/	218,810
2	Obese.mp.	133,484
3	exp Overweight/	225,402
4	(BMI or body mass index).af.	298,964
5	Weight gain/	31,929
6	(Overweight or over weight or obesity or adipose).af.	480,218
7	exp Child/	1,939,453
8	exp Infant/	1,154,053
9	(Child* or adolescen* or infant*).af.	4,432,218
10	Schoolchild*.mp.	14,335
11	exp Adolescent/	206,1603
12	(Boys or girls or youth or youths).af.	212,956

#	Searches	Results
13	(Teenage* or young person).af.	23,280
14	(Nutrition adj2 intervent*).af.	3851
15	((Obesity adj2 prevent*) or treat*).af.	6,246,518
16	Counsel?ing.mp.	124,432
17	exp support groups/	10,290
18	(Health Behaviour or Behaviour).mp.	213,262
19	exp Life Style/	96,462
20	exp Delivery of Health Care/	1,103,679
21	exp Social Support/	72,736
22	exp Family Practice/	65,410
23	exp Parent-Child Relations/	57,206
24	Food Habits.mp.	2151
25	exp Diet therapy/	55,529
26	exp Food Preferences/	14,714
27	exp Exercise therapy/	52,680
28	Physical activit*.mp.	120,934
29	Economic Evaluat*.mp.	13,208
30	Cost*.ti.	125,266
31	Cost?Benefit*.mp.	95
32	Cost?Utilit*.mp.	11
33	Cost?Effective*.mp.	214
34	exp “costs and cost analysis”/	241,658
35	1 or 2 or 3 or 4 or 5 or 6	690,604
36	7 or 8 or 9 or 10 or 11 or 12 or 13	4,454,419
37	14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28	7,630,669
38	29 or 30 or 31 or 32 or 33 or 34	296,105
39	35 and 36 and 37 and 38	1015
40	limit 39 to yr = “2017–Current”	282

Appendix C

Systematic searches were conducted from inception of each search engine to the 5th of August 2021 and updated on the 19th of April 2023 in the following 11 databases: Medline (OvidSP)[1946-present]; Embase (OvidSP)[1974-present]; PsycINFO (OvidSP)[1806-present]; CINAHL (EBSCOHost)[1982-present]; EconLIt (Proquest)[1969-present]; Cochrane Database of Systematic Reviews (Cochrane Library, Wiley)[Issue 4 of 12, April 2023]; Cochrane Central Register of Controlled Trials (Cochrane Library, Wiley)[Issue 3 of 12, March 2023]; NHS Economic Evaluation Database & Health Technology Assessment (via https://www.crd.york.ac.uk/CRDWeb/)[up to 31/03/2015]; Science Citation Index; Social Science Citation Index; and Conference Proceedings Citation Index - Science (Web of Science Core Collection)[1900-present].

A subject-specific librarian and information scientist assisted with the development of search keywords and Medical Subject Headings. The searches were built using title/abstract keywords, subject headings, or MeSH terms, where available, for the following key concepts: obesity/overweight and exercise/dietary interventions and childhood terms and economic/cost terms.

The search strategy for Medline (Ovid MEDLINE® Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE® Daily and Ovid MEDLINE®) 1946 to present is presented in Table C1. Searches conducted in other databases were modified accordingly.

Table C 1 Medline search strategy

Search number	Search terms
1	adolescent/ or exp child/ or infant/
2	(infant* or preschooler* or pre-schooler* or child* or schoolchild* or p?ediatric* or boys or girls or adolescen* or teen* or youth? or young people).ti,ab,kw.
3	1 or 2
4	exp *Exercise/
5	*Diet/ or *Diet, Healthy/
6	Sedentary Behavior/
7	(exp Exercise/ or exp Diet/) and (Health Promotion/ or Health Behavior/)
8	((exercise? or active or activity or activities) adj2 (improv* or promot* or encourag* or increas* or more or chang* or behavi*)).ti,ab,kw.
9	((exercise? or active or activity or activities) and (improv* or promot* or encourag* or increas* or more or chang* or behavi*)).ti.
10	((exercise? or physical* activ* or physical* educat* or physical* fit*) adj2 (intervention? or program*)).ti,ab,kw.
11	((exercise? or physical* activ*) adj2 (time? or level?)).ti,ab,kw.
12	(diet* adj2 (improv* or promot* or encourag* or participat* or increas* or more or chang* or behavi*)).ti,ab,kw.
13	(diet* and (improv* or promot* or encourag* or participat* or increas* or more or chang* or behavi*)).ti.
14	(diet* adj2 (intervention? or program*)).ti,ab,kw.
15	((health* lifestyle? or health* lifestyle? or health* eating or health* behavi*) adj2 (improv* or promot* or encourag* or participat* or increas* or more or chang* or behavi*)).ti,ab,kw.
16	((health* adj2 (lifestyle? or life style? or eating or behavi*)) and (improv* or promot* or encourag* or participat* or increas* or more or chang* or behavi*)).ti.
17	((health* lifestyle? or health* lifestyle? or health* eating or health* behavi*) adj2 (intervention? or program*)).ti,ab,kw.
18	((sedentary or sitting) adj2 (reduc* or decreas* or less or chang* or behavi*)).ti,ab,kw.
19	((sedentary or sitting) and (reduc* or decreas* or less or chang* or behavi*)).ti.

Search number	Search terms
20	((sedentary or sitting) adj2 (time? or level?)).ti,ab,kw.
21	((sedentary or sitting) adj2 (intervention? or programme?)).ti,ab,kw.
22	exp weight gain/ or exp weight loss/ or exp overweight/
23	body mass index/
24	(obes* or overweight or body weight or fat or fatness or body mass index or bmi).ti,ab,kw.
25	(weight adj (loss or losing or lose or manage* or reduc* or control)).ti,ab.
26	4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25
27	3 and 26
28	Pediatric Obesity/
29	27 or 28
30	economics/ or exp economics, hospital/ or exp economics, medical/
31	Value of Life/
32	exp health care costs/
33	quality-adjusted life years/
34	economic evaluation*.ti,ab.
35	(Cost* adj2 (Effective* or analysis* or Utility* or Benefit* or Minimi*)).ti,ab.
36	(pharmacoeconomic* or pharmaco-economic*).ti,ab.
37	economic*.ti.
38	("Value of life" or "quality adjusted life year*" or qaly* or qald* or qale* or "disability adjusted life year*" or daly).ti,ab.
39	(sf6 or short form 6 or shortform6 or euroqol or euro quality of life or eq5d or eq-5d).ti,ab.
40	(hye or health* year equivalent*).ti,ab.
41	(health utilit* or disutilit*).ti,ab.
42	willingness to pay.ti,ab.
43	standard gamble.ti,ab.
44	(time trade off or time tradeoff or tto).ti,ab.
45	(vas or visual analog*).ti,ab.
46	((economic adj2 model*) or markov or monte carlo method).ti,ab.
47	(decision* adj (tree* or model* or analysis)).ti,ab.
48	(resource* adj (use* or utilisation)).ti,ab.
49	((healthcare or health care or direct service or hospital or drug*) adj cost*).ti,ab.
50	30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49
51	29 and 50
52	(2021* or 2022* or 2023*).ed,ez,yr.
53	51 and 52

Table C 2 CHEERS checklist item

Section/item	Item No	Recommendation	Reported on page number
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study.	
		Present the study question and its relevance for health policy or practice decisions.	
Methods			
Target population and subgroups	4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated.	
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen.	

Section/item	Item No	Recommendation	Reported on page number
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate.	
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed.	
Measurement of effectiveness	11a	*Single study-based estimates:* Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data.	
	11b	*Synthesis-based estimates:* Describe fully the methods used for identification of included studies and synthesis of clinical effectiveness data.	
Measurement and valuation of preference based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes.	
Estimating resources and costs	13a	*Single study-based economic evaluation:* Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	
	13b	*Model-based economic evaluation:* Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	
Currency, price date, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	
Choice of model	15	Describe and give reasons for the specific type of decision-analytical model used. Providing a figure to show model structure is strongly recommended.	
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytical model.	
Analytical methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	
Results			
Study parameters	18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	
Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	
Characterising uncertainty	20a	*Single study-based economic evaluation:* Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	
	20b	*Model-based economic evaluation:* Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	
Characterising heterogeneity	21	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	
Discussion			
Study findings, limitations, generalisability, and current knowledge	22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	

Section/item	Item No	Recommendation	Reported on page number
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations.	

Table C 3 CHEERS scores for individual checklist items by study

Author, year of publication (country)	number and score for items 1-24																												
	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Prevention-only																													
Hayes, A., et al. 2014 (Australia)[192]	Y 1709	Y 1709	0.5 1709-10	0.5 1709-10	Y 1709-10	Y 1710	Y 1710	Y 1709-10	Y 1710	Y 1710	Y 1709-10	Y 1709-10	NA	NA	Y 1710-1	NA	Y 1710	NA	NA	Y 1710-1	Y 1710-1	Y 1711	Y 1710-3	NA	NA	Y 1711-4	Y 1709	Y 1709
Barber, S. E., et al. 2015 (UK)[286]	Y v	Y v	0.5 1	0.5 1	Y 30	Y 1	Y 21	Y 11	Y 21	NA	Y 15	Y 21	NA	Y 21	Y 82	NA	Y 21	NA	NA	Y 23, 85, 88	Y 89	Y 89	Y 89	NA	NA	Y 110	Y vi	Y i
Kolu, P., et al. 2016 (Finland)[283]	Y 1	Y 1	0.5 2	0.5 2	Y 4	Y 2	Y 4	Y 3	Y 2	No	Y 3-4	Y 3-4	NA	NA	Y 4	NA	Y 4	NA	NA	Y 5	Y 8	Y 9-10	Y 5	NA	NA	Y 13	Y 1	Y 2
Marsh, K., et al. 2016 (Mexico)[276]	Y 1	Y 1	0.5 2	0.5 2	Y 4	Y 2	Y 2	Y 2	Y 7	Y 3	Y 5-6	NA	Y sm	Y sm	NA	Y sm	Y 6	Y 3	Y 6-8 sm	Y 6-8 sm	Y 6-8 sm	Y 6-8	NA	Y 6-8 sm	NA	Y 9	Y 10	Y 10
Döring, N., et al. 2018 (Sweden)[218]	Y 1	Y 1	0.5 2	0.5 2	Y 1-2	Y 1-2	Y 2	Y 2	Y 2	No	Y 2	Y 2	NA	NA	Y 3-4	NA	Y 2	NA	NA	0.5	Y 3-4	Y 5	Y 4-6	NA	NA	Y 5-6	Y 7	Y 8
Gc, V. S., et al. 2019 (UK)[284]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 2	Y 1-2	Y 1	Y 3	Y 2	Y 2	Y 4	Y 8	NA	Y 4 and 5	NA	Y 5	Y 5	Y 3	Y 2	Y 5	Y 4-5	Y 6	NA	Y 6	NA	Y 8	Y 9	Y 9
Sonntag, D., et al. 2019 (Germany)[213]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1-2	NA	Y 5	Y 1-2	Y 4	Y 5	Y 4	Y 3-4	NA	Y 8	Y 4	NA	Y 4	Y 4 and ap	Y 4-7 and ap	Y 4-5 and ap	Y ap	Y 6	Y 6	NA	NA	Y 6-9	Y 8	Y 9
Tan, E. J., et al. 2020 (Australia)[199]	Y 2201	Y 2201	0.5 2202-3	0.5 2202-3	Y 2202-3	Y 2202-3	Y 2202	Y 2202	Y 2202	Y 2203	Y 2203	Y 2202-3	NA	Y 2207	Y 2202-3	NA	Y 2203	Y 2203	Y 2203	Y 2203	Y 2204	Y 2204-6	NA	Y 2205	NA	Y 2205-7	Y 2207	Y 2207
Taylor, R., et al. 2020 (Australia)[285]	Y	Y	0.5	0.5	Y	Y	Y	Y	Y	No	Y	Y	NA	No	No	NA	Y	No	No	No	No	Y	0.5	NA	NA	0.5	No	No
Kalita, N., et al. 2022 (UK)[287]	Y1	Y1	0.5 1	0.5 2	Y2	Y2	Y3	Y 2	Y4	Y6	Y4	Y2	NA	Y 4	Y 5	NA	Y 6	Y2	Y3	Y6	Y5	Y7	Y6	NA	Y 8	Y 8	Y 10	Y 10
Killedar, A., et al. 2022 (Australia)[288]	Y 2256	Y 2256	0.5 2257	0.5 2257	Y 2259	Y 2256	Y 2256	Y 2256	Y 2257	Y 2256	Y 2256	Y 2257	NA	NA	Y 2260	NA	Y 2256	NA	NA	Y 2258	Y 2259	Y 2260	Y 2261	NA	NA	Y 2260	Y 2263	Y 2263
Tran, H. N. Q., et al. 2022 (Australia)[289]	Y 1	Y 1	0.5 2	0.5 2	Y 3	Y 3	Y 1	Y 3	Y 1	Y 4	Y 3	Y 4	NA	Y 4	NA	Y5	Y 4	Y 4	Y 4	Y 4	Y 5	Y 6	NA	Y 6	NA	Y 22	Y 9	Y 9
Killedar, A., et al. 2023 (Australia)[290]	Y 193	Y 193	0.5 193	0.5 193	Y 193	Y 194	Y 193	Y 195	Y 193	Y 194	Y 195	Y 194	NA	Y 194	Y 196	NA	Y 196	Y 194	Y 194	Y 194	Y 197	Y 197	Y 198	NA	Y 198	Y 199-200	Y 200	Y 200

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Prevention and treatment																												
Wang, L. Y., et al. 2003 (US)[166]	Y 1313	Y 1313	0.5 1313-4	0.5 1313-4	Y: separate paper	Y 1313	Y 1313	Y 1314	Y 1314	Y 1314	Y 1314	NA	Y 1314-20	0.5	NA	Y 1314-20	Y 1319	Y 1314-20	Y 1314-20	Y 1314-20	Y 1316-17	Y 1320	NA	Y 1320	NA	Y 1321-2	Y 1322	No
Brown, H. S., et al. 2007 (US)[291]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 2	Y 2	Y 2	Y 2	Y 2	Y 2	Y 2	NA	Y 2-7	0.5	NA	Y 2-7	Y 2	Y 4-7	Y 4-7	Y 2-7	Y 2-7	Y 7-8	NA	Y 7-8	Y 7-8	Y 8-10	Y 10	No
Nixon, J., et al. 2008 (UK)[304]	Y	Y	0.5	0.5	No	Y	Y	0.5	No	No	Y	NA	No	No	NA	No	0.5	No	No	No	No	Y	NA	0.5	NA	No	No	No
Peterson, M., et al. 2008 (US)[168]	Y 426	0.5 426-7	0.5 426-7	0.5 426-7	Y 426-7	Y implied	No	Y 430	NA	NA	0.5	Y 429	NA	NA	Y 429	NA	0.5	NA	NA	No	Y 427-30	0.5	No	NA	NA	Y 430-32	No	No
Wang, L. Y., et al. 2008 (US)[169]	Y 619	Y 619	0.5 620	0.5 620	Y separate paper	Y separate paper	Y 620	Y 620	Y 619	NA	Y 620	Y separate paper	NA	NA	Y 620-2	NA	Y 620-22	NA	NA	Y 620-2	Y 620-2	Y 622	0.5	NA	NA	Y 622-3	Y 619	Y 619
Magnus, A., et al. 2009 (Australia)[187]	Y 1094	Y 1094	0.5 1095	0.5 1095	Y 1095	Y 1095	Y 1098	Y 1094-5	Y 1097	Y ap	Y ap	NA	Y ap	Y separate paper	NA	Y 1095-7	Y 1095	Y ap	Y ap	Y ap	Y ap	Y 1097-8	NA	Y 1097-8	NA	Y 1098-1101	Y 1101	Y 1101
Moodie, M., et al. 2009 (Australia)[319]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1-3	Y 1-3	Y 3	Y 1-3	Y 2	Y 2	Y 2	NA	Y 2-7	Y separate paper	NA	Y sm	Y 2	Y separate paper	Y sm	Y 7-8	Y 7	Y 4-9	NA	Y 7-8	NA	Y 8-11	Y 11	Y 11
Cecchini, M., et al. 2010 (Brazil, China, India, Mexico, Russia, South Africa, England)[277]	Y 1175	Y 1175	0.5 1175-6)	0.5 1175-6)	Y 1778	Y 1775-6	No	Y 1778	Y 1780	Y 1777	Y 1778	Y 1781	NA	0.5	Y ap	NA	Y 1777	Y 1776	Y 1777	Y 1781	Y ap	Y 1780	NA	Y 1781	Y 1781	Y 1781	No	Y 1783
McAuley, K. A., et al. 2010 (New Zealand)[210]	Y 131	Y 131	0.5 131-2	0.5 131-2	Y 131	Y 131-2	Y 132	Y 131	Y 134	Y 132	Y 132-3	Y separate study	NA	Y 133	Y 132-4	NA	Y 132	NA	NA	Y 132-4	Y 132-4	Y 134	0.5	NA	NA	Y 134-5	Y 135	Y 135
Mernagh, P., et al. 2010 (New Zealand)[336,379]	Y ii	Y iii-iv	0.5 1	0.5 1	Y 16	Y 4-6 and 16	Y 17	Y 18	Y 17	Y 19	Y 15	NA	Y 24	Y 19-20	NA	Y 27-29	Y 19	Y 17-19	Y 17-29	Y 17	0.5	Y 22	NA	0.5	Y 22	Y 30-32	Y ii	No
Moodie, M. L., et al. 2010 (Australia)[189]	Y 1585	Y 1585	0.5 1585-6	0.5 1585-6	Y 1586	Y 1586	Y 1588	Y 1586	Y 1586	Y 1586	Y 1585-7	NA	Y 1586-90	Y 1586	NA	Y 1586-9	Y 1586	Y separate paper	Y 1586-7 and	Y 1588	Y 1587-9	Y 1589-90	NA	Y 1589-9	NA	Y 1589-91	Y 1591	Y 1591

Author, year of publication (country)	number and score for items 1-24																												
	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Pringle, A., et al. 2010 (UK)[161]	Y 211	Y 211	0.5 213	0.5 213	Y 214	Y 212	Y 212	Y 215	No	No	Y 213	NA	No	No	Y 213	NA	Y 217	No	sm No	No	Y 217-9	Y 217-9	No	NA	NA	Y 221	Y 222	Y 222
Trasande, L. 2010 (US)[87]	Y 372	Y 372	0.5 373	0.5 373	Y 373	Y 373	Y 374	NA	Y 376	Y 375	Y 375	NA	NA	0.5	NA	Y 374	Y 376	Y 373	Y 376	Y 374	Y 374	NA	NA	No	NA	Y 376	No	No
Martínez, P. M., et al. 2011 (Spain)[330]	Y English version	Y English version	English version 0.5	English version 0.5	Y English version	Y English version	Y English version	Y English version	Y English version	NA	Y English version	Y English version	NA	NA	Y English version	NA	Y English version	NA	NA	Y English version	Y English version	No	0.5	NA	NA	Y English version	Y English version	No
Moodie, M., et al. 2011 (Australia)[190]	Y 503	Y 503	0.5 503-4	0.5 503-4	Y 503-7	Y 503-5	Y 503-5	Y 503-4	Y 503-4	Y 503-4	Y 503-4	NA	Y 511	Y 504	NA	Y 505-10	Y 504	Y separate paper	Y 511	Y 507-13	Y 511	Y 512	NA	Y 507-13	NA	Y 512-4	Y 514	Y 514
Ramos-Goñi JM, Valcárcel-Nazco C, Castilla-Rodríguez I. 2011 (Spain)[331]	Y	0.5	No	No	No	No	No	No	Y	Y	Y	NA	Y	No	NA	No	0.5	0.5	No	0.5	No	0.5	NA	0.5	NA	No	No	No
Te Velde, S., et al. 2011 (Netherlands)[33] 7,380	Y 14	Y 14	0.5 14 and 15	0.5 14 and 15	Y 15	Y 15	Y 17	Y 15	Y 16	Y 17	Y 15-16	NA	Y 15-16	Y 17	NA	Y 16-17	Y 21	Y 15	Ys 16-20	Ys 16-20	Ys 16-20	Ys 19-20	NA	Ys 19-20	NA	Ys 19-21	Y 21	Y 21
Wang, L. Y., et al. 2011 (US)[171]	Y 756	Y 756	0.5 756-7	0.5 756-7	Y 756	Y 756	Y 757	Y 756	Y 757	Y 757	Y 756-7	NA	Y 756-7	Y 759	NA	Y 756-9	Y 757	Y separate paper	Y 757-9	Y 757-9	Y 757-9	Y 760	NA	Y 759	NA	Y 759-61	Y 761	Y 761
Monsivais, P., & Rehm, C. D. 2012 (US)[292]	Y 459	Y 459	0.5 459	0.5 459	Y 460	Y 459	No	Y 461	Y 462	NA	0.5	Y 460	NA	NA	NA	Y 460	0.5	Y 460	Y 462	Y 461	Y 462	No	NA	No	NA	Y 462-3	Y 463	No
Gesell, S. B., et al. 2013 (US)[293]	No	Y 1	0.5 2	0.5 2	Y 5	Y 2	No	Y 2	Y 2	NA	0.5	Y 4	NA	NA	Y 4	NA	Y 5	NA	NA	Y 4	Y 5	Y 6	No	NA	NA	Y 7	Y 7	Y 7
Kesztyüs, D., et al. 2013 (Germany)[212]	Y 185	Y 185	0.5 185-9	0.5 185-9	Y 185-6	Y 185-6	Y 185	Y 185-6	Y 185	NA	Y 185-6	Y 185-6	NA	NA	Y 189	NA	Y 189	NA	NA	Y 189-93	Y 189-93	Y 190-2	Y 190-2	NA	NA	Y 192-4	Y 194	No
Meng, L., et al. 2013 (China)[163]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 4	Y 1	Y 3	Y 1-2	Y 2	NA	Y 3	Y 3	NA	NA	Y 3	NA	Y 6	NA	NA	Y 3	Y 3-5	0.5	No	NA	NA	Y 7-8	Y 1	Y 1

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Moodie, M. L., et al. 2013 (Australia)[191]	Y 2072	Y 2072	0.5 2072-3	0.5 2072-3	Y 2073	Y 2073	Y 2072	Y 2072-3	Y 2072	Y 2073	Y 2074	NA	Y 2074	Y 2074	NA	Y 2074	Y 2072-3	Y separate paper	Y 2075-6	Y 2074-6	Y 2075-7	Y 2078-9	NA	Y 2078-9	NA	Y 2078-9	Y 2072	Y 2072
Nelson, M. 2013 (England)[305]	Y 1006	Y 1006	0.5 1006-7	0.5 1006-7	Y 1008	Y 1007	No	Y 1007	Y 1008	No	No	NA	No	NA	Y 1007-8	NA	Y 1009	No	Y 1009	No	No	Y 1007-8	No	NA	NA	Y 1009-10	Y 1010	Y 1010
Tran, B., et al. 2013 (Canada)[334]	Y	Y	0.5	0.5	Y	Y	Y	Y	Y	Y	Y	Y	NA	No	NA	No	0.5	0.5	No	No	No	Y	NA	No	NA	0.5	No	No
Babey, S. H., et al. 2014 (US)[294]	Y S55	Y S55	0.5 S55-6	0.5 S55-6	No	Y S56	No	Y S56	No	No	0.5	Y S59	NA	NA	NA	Y S57	Y S56	No	No	No	Y S58	Y S57	NA	No	NA	Y S59	Y S59	Y S59
Rush, E., et al. 2014 (New Zealand)[209]	Y e115	Y e115-6	0.5 e115-6	0.5 e115-6	Y e115-6	Y e115-6	Y e116	Y e115-6	Y e117	Y e117	Y e117	NA	Y e117	Y e117	NA	Y e118	Y e117	Y e116-8	Y e116-8	Y e116-8	0.5	Y e118-9	NA	0.5	Y e118-9	Y e119-21	Y e121	No
Swinburn, B., et al. 2014 (Australia)[320]	No	Y 455	0.5 456	0.5 456	Y 458	Y 456	Y 457	Y 456	Y 456	No	Y 456-7	Y 461	NA	NA	Y 457	NA	0.5 457	NA	NA	Y 457	Y 458	0.5	No	NA	NA	Y 461	Y 461	Y 461
Tran, B. X., et al. 2014 (Canada)[335]	No	Y 1	0.5 1-2	0.5 1-2	Y 2	Y 2	Y 2	Y 2	Y 2	No	Y 2	Y 2	NA	NA	Y 2	NA	No	0.5	No	0.5	0.5	Y 3	NA	No	NA	Y 6-7	Y 1	Y 1
Barrett, J. L., et al. 2015 (US)[173]	Y 148	Y 148	0.5 148-9	0.5 148-9	Y 148-9	Y 148-9	Y 148-9	Y 148-9	Y 149	Y 149	Y 149	NA	Y 149-50	NA	NA	Y 149-50	Y 149	Y 149-50	Y 152-6	Y ap	Y 152	0.5	NA	Y 151-4	NA	Y 151-6	Y 156	Y 156
Gortmaker, S. L., et al. 2015 (US)[150]	Y 102	Y 102	0.5 102-3	0.5 102-3	Y 105	Y 102-3 and individual studies	Y 104	Y 102-3 and individual studies	Y 104	Y 104	Y 104	NA	Y 104	NA	NA	Y 104	Y 104	Y 104 and ap	Y ap	Y ap	Y ap and individual studies	0.5	NA	Y 104	NA	Y 105-9	Y 109	Y 109
Long, M. W., et al. 2015 (US)[174]	Y 112	Y 112	0.5 112-3	0.5 112-3	Y 112-3	Y 112-3	Y 114	Y 112-3	Y 114	Y 112	Y 114	NA	Y 114	NA	NA	Y 114	Y 117	Y 113	Y 115 and ap	Y 115 and ap	Y 117	Y 117	NA	Y 115 and ap	NA	Y 116-21	Y 121	Y 121
McCollister, K. E., et al. 2015 (US)[295]	No	Y 11	0.5 11	0.5 11	Y 12	Y 11	Y 12	Y 12	Y 12	No	Y 12	Y 12	NA	NA	NA	Y 12	Y 12	Y 12	No	No	0.5	Y 13	NA	No	NA	Y 14	Y 14	No
Mora, T., et al. 2015 (Spain)[332]	No	Y 190	0.5 190-1	0.5 190-1	Y 193	Y 190-1	Y 199	Y 191	Y 191	No	Y 195	Y 193	NA	NA	Y 198	NA	Y 198	Y 194	Y 194	Y 193-6	Y 195	Y 198	Y 195	NA	NA	Y 199	No	No
Sonneville, K.	Y	Y 124	0.5	0.5	Y 124-5	Y 124-	Y 127	Y 124-5	Y 127	Y	Y 126-	NA	Y 126-7	Y 127	NA	Y	Y 124	Y 127	Y	Y 127	Y 128	Y	NA	Y	NA	Y 129-	Y 132	Y

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
R., et al. 2015 (US)[175]	124		124-5	124-5		5				124	7					127			127-8			127-9		127-9		32		132
Wright, D. R., et al. 2015 (US)[176]	Y 135	Y 135	0.5 135-6	0.5 135-6	Y 135-6	Y 135-6	Y 137	Y 135-6	Y 136	Y 136	Y 137	NA	Y 137	NA	NA	Y 139	Y 136	Y 136	Y 139-40 and ap	Y 138-9 and ap	Y 139-40 and ap	Y 138-41	NA	Y 139-40 and ap	NA	Y 142-4	Y 144	Y 144
Jago, R., et al. 2016 (UK)[306]	0.5 47	Y v-vi	0.5 2	0.5 2	Y 27	Y 2	Y xxiii	Y 11	Y 47	NA	Y 15	Y 115	NA	Y 51	Y 50	NA	Y 48	NA	NA	0.5	Y 29	Y 50	0.5	NA	NA	Y 116	Y vi	Y i
Ladapo, J. A., et al. 2016 (US)[296]	Y 247	Y 247-8	0.5 247-8	0.5 247-8	Y 247	Y 247	Y 247-8	Y 248	Y 251	NA	0.5	Y 249	NA	NA	Y 250-1	NA	Y 249	NA	NA	0.5	Y 3-6	Y 6	0.5 251	NA	NA	Y 251-2	Y 252	Y 247
Lawlor, D. A., et al. 2016 (UK)[307]	0.5 21	Y vii-viii	0.5 2	0.5 2	Y 22	Y 2	Y 63	Y 6	Y 8	NA	0.5	Y 7	NA	NA	Y 17	NA	Y 17	NA	NA	Y 11	Y 22	Y 45	0.5	NA	NA	Y 65-67	Y 10	Y 3
Sutherland, R., et al. 2016 (Australia)[321]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 8	Y 1-2	Y 5	Y 1-2	Y 5	No	Y 5	Y 5	NA	NA	Y 5	NA	Y 5	NA	NA	Y 5	Y 7	Y 6-10	0.5	NA	NA	Y 8-14	Y 14	Y 14
Cradock, A. L., et al. 2017 (US)[178]	Y S17	Y S17	0.5 S17-9	0.5 S17-9	Y S17-9	Y S17-9	Y S18	Y S19	Y S19	0.5 S18	Y S19	NA	Y S18	NA	NA	Y ap	Y S18	Y separate article	Y in study ap	0.5	0.5	Y S22	NA	0.5	NA	Y S24-5	Y 25	Y 25
Crino, M., et al. 2017 (Australia)[322]	Y 1	Y 1	0.5 2	0.5 2	Y 11	Y 2	Y 7	Y 3	Y 1	Y 9	Y 9	Y 12	NA	Y 9	NA	Y 8	Y 9	Y 3	Y 5	Y 8	Y 11	Y 11	NA	Y 9	Y 11	Y 12-13	No	Y 14
Ekwaru, J. P., et al. 2017 (Canada)[216]	Y 1	Y 1	0.5 2	0.5 2	Y 3	Y 3	Y 3	Y 3	Y 2	Y 6	Y 5	NA	Y 3-5	Y 5	NA	Y 3-5	Y 5	Y 3-4	Y 3-5	0.5	0.5	Y 7	NA	Y 7	NA	Y 9	Y 2	Y 3
Graziose, M. M., et al. 2017 (US)[177]	Y 684	Y 684	0.5 684-5	0.5 684-5	Y 684-5	Y 684-5	Y 684-5	Y 684-5	Y 684-5	Y 684-5	Y 684-5	NA	Y 686	Y 685	Y 688-9	NA	Y 684-5	Y 685-6	Y 685-9	Y 685-9	Y 685-8	Y 689	0.5	NA	NA	Y 688-90	Y 690	Y 691
Hajizadeh, N., et al. 2017 (US)[297]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1	Y 1	Y 8	Y 1-2	Y 2	Y 8	Y 7	Y 7	NA	Y 8	NA	Y 8	Y 8	Y 3	Y 4-7	Y 9	Y 4-7	Y 8	NA	0.5 9-10	NA	Y 11	Y 12	Y 12
Kesztyüs, D., et al. 2017 (Germany)[333]	Y 1	Y 1	0.5 2	0.5 2	Y 8	Y 2	Y 6	Y 3	Y 4	NA	Y 4-5	Y 14	NA	NA	Y 6	NA	Y 3	NA	NA	Y 7	Y 9	Y 11	0.5 7	NA	NA	Y 14	Y 2	Y 2
Lee, B. Y., et al. 2017 (US)[179]	Y 902	Y 902	0.5 902-3	0.5 902-3	Y 903	Y 904	Y 903	Y 904	Y 904	Y 903	Y 903	NA	Y 903 and ap	Y ap	NA	Y 903 and	Y 903	Y 903 and ap	Y 906 and ap	Yap	Yap	No	NA	Y ap	NA	Y 906-7	Y 907	Y 907

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
																ap												
Moore, J. B., et al. 2017 (US)[298]	Y 364	Y 364	0.5 365	0.5 365	Y 365	Y 365	No	Y 365	Y 365	NA	0.5	Y 365	NA	NA	Y 365	NA	Y 366	NA	NA	Y 366	Y 367-8	No	No	NA	NA	Y 367-9	Y 364	Y 364
Wang, H., et al. 2017 (US)[299]	Y 278	Y 278	0.5 278-9	0.5 278-9	Y 279	Y 278-9	Y 278	Y 279	Y 279	NA	0.5	Y 279	NA	NA	Y 280	NA	Y 280	NA	NA	0.5 280-1	Y 282	Y 281	0.5 280-1	NA	NA	Y 283	Y 278	Y 278
An, R., et al. 2018 (US)[182]	Y 715	Y 715	0.5 715-6	0.5 715-6	Y 716-7	Y 716-7	Y 716	Y 723	Y 717	Y 718	Y 720	NA	Y 716-7	NA	NA	Y 716-7	Y 723	Y 716	Y 716-21	Y 716-21	Y 716-21	Y 717	NA	NA	Y 716-21	Y 719-21	Y 721	Y 721
Anokye, N., et al. 2018 (UK)[308]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 4	Y 1-2	Y 4	Y 2	Y 4	NA	Y 3	Y 8	NA	Y 5	Y 3-4	NA	Y 1	NA	NA	Y 3	Y 5	Y 6	Y 4	NA	NA	Y 7	Y 8	Y 8
Beets, M. W., et al. 2018 (US)[181]	Y 60	Y 60	0.5 60-1	0.5 60-1	Y 61	Y 60-1	Y 60	Y 61	Y 61	NA	0.5 61-2	Y 61-2	NA	NA	Y 61-2	NA	Y 61	NA	NA	0.5	0.5	Y 63	No	NA	Y 63	Y 64	Y 64	Y 64
Brown, V., et al. 2018 (Australia)[194]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 3	Y 3	Y 4	Y 3	Y 4	Y 4	Y 7	NA	Y 4-5	Y 5	NA	Y 4	Y 4	Y 5	Y 5-6	Y 4-6	Y 4-6	Y 7-8	NA	Y 4-6	Y 5-8	Y 8-11	Y 11	Y 11
Conesa, M., et al. 2018 (Spain)[215]	Y 477	Y 477	0.5 477	0.5 477	Y 477	Y 477	Y 478	Y 477	Y 477	NA	Y 477	Y 478	NA	NA	Y 478-9	NA	Y 479	NA	NA	0.5	0.5 479	Y 479	Y 479-80	NA	Y 478	Y 479-481	Y 481	Y 481
Reilly, K. L., et al. 2018 (Australia)[323]	Y 1	Y 1	0.5 2	0.5 2	Y 2-3	Y 2-3	Y 3	Y 3-4	Y 3-4	NA	0.5	Y 5	NA	NA	Y 5-6	NA	Y 3	NA	NA	Y 5	Y 5	Y 6	Y 5-7	NA	NA	Y 6-8	Y 8	Y 8
Wyatt, K., et al. 2018 (UK)[309]	Y vii	Y vii	0.5 1	0.5 1	Y 8 and 26	Y 30	Y 30	Y 8	Y 15	Y 56	Y 15	Y 15	NA	NA	Y 41	NA	Y 56	Y 72	Y 19	Y 30	Y 28	Y 56	No	NA	NA	Y 101-104	Y viii	Y cover
Amies-Cull, B., et al. 2019 (England)[203]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1-2	Y 1-2	Y 3	Y 1-2	Y 3	No	Y 1-2	NA	Y 3	NA	NA	Y 3	0.5	Y 3	Y 3-7	Y 3-4	0.5	Y 6-7	NA	Y 3	Y 4-5	Y 5-7	Y 7	Y 8
Ananthapavan, J., et al. 2019 (Australia)[324]	Y 1102	Y 1102	0.5 1102-3	0.5 1102-3	Y 1102-3	Y 1102-3	Y 1104	Y 1102-3	Y 1104	Y 1104	Y 1104	NA	Y 1103-4	Y 1104	NA	Y 1104	Y 1104	Y 1104	Y ap	Y 1104 and ap	Y ap	Y 1105	NA	Y 1105-9	NA	Y 1108-10	Y 1111	Y 1111
Basto-Abreu, A., et al. 2019 (Mexico)[279]	Y 1824	Y 1824	0.5 1824	0.5 1824	Y 1827	Y 1824	Y ap	Y 1824	Y 1826	Y 1826	Y 1825	NA	NA	Y 1826	NA	Y 1826	Y 1825	Y 1824	Y - ap	Y 1826	Y 1828	Y 1828	NA	Y 1826	NA	Y 1826	Y 1830	Y 1830
Brown, V., et al. 2019	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 3	Y 4-5	Y 5	Y 6	Y 3	Y 4	Y 6	NA	Y 3-6	Y 3	NA	Y 4	Y 4	Y 3	Y 5-7	Y 4-5	Y 4	NA	NA	Y 4-5	NA	Y 7-8	Y 8	Y 9

Author, year of publication (country)	number and score for items 1-24																										
	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
(Australia)[197]																												
Canaway, A., et al. 2019 (UK)[204]	Y 1	Y 1	0.5 2	0.5 2	Y 3	Y 5	Y 3	Y 3	Y 3	Y 3	Y 4	Y 4	NA	Y 4	Y 3-4	NA	Y 3	NA	Y 3-5	Y 3-5	NA	Y 5-7	Y 7-9	NA	NA	Y 9-11	Y 11	Y 2
Charles, J. M., et al. 2019 (UK)[310]	Y 1	Y 1	0.5 2	0.5 2	Y 10	Y 2	Y 5	Y 3	Y 5	Y 5	Y 5	Y 5	NA	Y 5	Y 3-4	NA	Y 3	NA	NA	Y 9	Y 11	Y 11	0.5 5-11	NA	NA	Y 12	Y 1	Y 2
Coffield, E., et al. 2019 (US)[300]	Y 1	Y 1	0.5 2	0.5 2	Y 2	Y 2	Y 2	Y 2	Y 2	Y 2	Y 4	NA	Y 2	NA	NA	Y 2	Y 2	0.5 ap	0.5 ap	Y 6	Y 4	Y 4	NA	Y 3	NA	Y 5	Y 6	Y 6
Gammon, C., et al. 2019 (UK)[311]	No	Y 1	0.5 2	0.5 2	Y 2	Y 2	No	Y 2-3	Y 1	NA	Y 4-8	Y 4-8	NA	Y 5	Y 5	NA	No	NA	NA	0.5	Y 10	0.5	No	NA	NA	Y 11	Y 12	Y 12
Harrington, D., et al. 2019 (UK)[312]	No	Y vii	0.5 1	0.5 1	Y 33	Y 1	Y xxvi	Y 3	Y 11	Y 19	0.5	Y 12	NA	NA	Y 18-19	NA	Y 16	NA	NA	Y 26	Y 37	Y 62	0.5 63	NA	NA	Y 113	Y i	Y i
Kenney, E. L., et al. 2019 (US)[184]	Y 2037	Y 2037	0.5 2037-8	0.5 2037-8	Y 2037-41	Y 2037-41	Y 2042	Y 2037-41	Y 2042	Y 2042	Y 2042	NA	Y 2042	NA	NA	Y 2042	Y 2042	Y 2044	Y 2041-2	Y 2044	Y 2040-1	No	NA	Y 2041	NA	Y 2044-5	Y 2037	Y 2037
Li, B., et al. 2019 (China)[278]	No	Y 1	0.5 3-4	0.5 3-4	Y 4	Y 2-3	Y 2	Y 4-5	Y 5	NA	Y 6	Y 15	NA	Y 6	Y 7	NA	Y 7	NA	NA	Y 15	Y 12-13	Y 14	Y 7	NA	Y 13	Y 15	Y 2	Y 2
Long, M. W., et al. 2019 (US)[301]	Y 1177	Y 1177	0.5 1177-8	0.5 1177-8	Y 1177-8 and sm	Y 1177-8	Y 1178	Y 1177-8	Y 1177	Y 1181	Y 1179	NA	Y 1179	No	NA	Y 1179	Y 1181	Y 1179	Y 1180-5 and sm	Y 1179-80 and sm	0.5	Y 1181	NA	Y 1179	NA	Y 1185	Y 1186	Y 1177
Sebire, S. J., et al. 2019 (UK)[313]	0.5 61	Y v	0.5 v-vi	0.5 v-vi	Y 11	Y 1	Y 37	Y 3	Y 8	NA	Y 35	Y 99	NA	Y 43	Y 43	NA	Y 43	NA	NA	Y 54	Y 54	Y 61	Y 43	NA	NA	Y 107	Y v	Y v
Vieira, M. & Carvalho, G.S. 2019 (Portugal)[219]	Y 1141	Y 1141	0.5 1141-2	0.5 1141-2	Y 1141-2	Y 1141-2	Y 1143	Y 1143	Y 1143	NA	NA	Y 1143-5	NA	NA	0.5	NA	Y 1143	NA	NA	0.5 1143	Y 1144-5	Y 1145	No	NA	NA	Y 1146-7	Y 1148	No
Ananthapavan, J., et al. 2020 (Australia)[325]	Y 1	Y 1	0.5 2	0.5 2	Y 3-5	Y 3-6	Y 3-6	Y 9-10	Y 9-10	Y 6	Y 6	NA	Y 3-6	Y 3-6	NA	Y 3-6	Y 6	Y 3-6	Y 3-6	Y 3-6	Y 3-6	Y 11-12	NA	Y 6	NA	Y 13-15	Y 1	Y 2
Breheny, K., et al. 2020 (UK)[314]	Y 812	Y 812	0.5 812-4	0.5 812-4	Y 812-4	Y 812-4	Y 815	Y 812-4	Y 815	NA	Y 815	Y 815	NA	Y 815	Y 815	NA	Y 815	NA	NA	Ysm	Y 817-20	Y 817	Y 817	NA	Y 817	Y 817-20	Y 821	Y 821
Clemes, S. A., et al. 2020 (UK)[315]	0.5 33	Y v	0.5 1	0.5 1	Y 8	Y 7	Y 33	Y 10	Y 33	Y 51	Y 13	NA	NA	Y 38	Y 39	NA	Y 39	Y 47	Y 50	Y 53	Y 124	Y 35	Y 54	NA	NA	Y 90	Y vi	Y i
Ferguson, M.	Y	Y	0.5	0.5	Y 1318	Y	Y:	Y 1318-	Y 1318	Y	Y	NA	Y 1318	No	NA	Y sm	Y sm	Y 1319	Y	Y 1318	Y sm	0.5	NA	0.5	NA	0.5	Y	Y

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
C., et al. 2020 (US)[302]	1317	1317	1317	1317		1318	implied	1319		sm	1318								1318			1321		1318			1324	1324
Finster, M.P. & Feldman, J. 2020 (US)[55]	Y 724	Y 724	0.5 724-5	0.5 724-5	0.5	Y 724-5	No	Y 724-5	Y 724-7	No	0.5	Y 726	NA	NA	Y 725	NA	0.5	NA	NA	NA	Y 727-8	Y 728	No	NA	NA	Y 728-9	Y 730	Y 730
Huse, O., et al. 2020 (Australia)[198]	Y 1011	Y 1011	0.5 1011-2	0.5 1011-2	Y 1013	Y 1011-2	Y 1011	Y 1013	Y 1013	Y 1015	Y 1013	NA	Y 1013	Y 1013	NA	Y 1013	Y 1015	Y 1013	Y 1014	Y 1013-5	Y 1014	Y 1015	NA	Y 1015	NA	Y 1016-9	Y 1019	Y 1019
Mytton, O. T., et al. 2020 (UK)[316]	No	Y 1	0.5 3-4	0.5 3-4	Y 5	Y 3-4	Y 3-4	Y 4	Y 9	0.5	Y 8	Y 14	NA	Y 9	NA	Y 4-5	Y 10	Y 4	Y 6-7	Y 8-9	Y 11	0.5	NA	Y 10	NA	Y 15-16	Y 2	Y 2
Oosterhoff, M., et al. 2020 (Netherlands)[208]	Y 1	Y 1	0.5 2	0.5 2	Y 2	Y 2	Y 2	Y 2	Y 2	Y 3	Y 3	Y 2-3	NA	Y sm	NA	Y 3-5	Y 3	Y 2	Y 4 and sm	Y 3-7	Y 4	Y 10	NA	Y 10-12	NA	Y 8-12	Y 14	Y 14
Oosterhoff, M., et al. 2020 (Netherlands)[328]	Y 1	Y 1	0.5 2	0.5 2	Y 2	Y 2	Y 9	Y 2	Y 2	Y sm	Y sm	Y sm	NA	NA	Y 2-4	NA	Y sm	NA	NA	Y 4	Y 5-6	Y 7-8	Y ap	NA	NA	Y 9-10	Y 10	Y 11
Xu, H., et al. 2020 (China)[164]	Y 1	Y 1	0.5 1-2	0.5 1-2	0.5	Y 2	Y 2	Y 2	Y 2	Y 2	Y 2	NA	0.5	0.5 3	NA	Y 2-3	Y 2	Y ap	0.5 ap	0.5	Y ap	Y 5	NA	Y 5-6	NA	Y 5-6	Y 6	Y 7
Corder, K. L., et al. 2021 (UK)[317]	No	Y v-vi	0.5 1	0.5 1	Y 29-31	Y 1	Y 9	Y 11-12	Y 29	Y 26	Y 29	Y 91	NA	Y 26	Y 53	NA	Y 25	Y 55	Y 54	Y 123	Y 33	Y 31	Y 54	NA	NA	Y 91	Y vi	Y i
Jago, R., et al. 2021 (UK)[318]	Y 1	Y 1-2	0.5 2	0.5 2	Y 7	Y 2	Y 1	Y 3	Y 2	NA	Y 3	Y 12	NA	Y 5	Y 5	NA	Y 5	NA	NA	Y 4	Y 8	Y 10	Y 5	NA	NA	Y 12	Y 12	Y 12
Kenney, E. L., et al. 2021 (US)[303]	Y 442	Y 442	0.5 443	0.5 443	Y sm	Y 443	Y 444	Y 443-444	Y 443	Y 444	Y 444	NA	Y 443	NA	NA	Y 444	Y 444	Y 444-445	Y 444	Y 444-445	Y sm	Y 445	NA	Y 444	NA	Y 446	Y 447	Y 447
Lonsdale, C., et al. 2021 (Australia)[326]	No	Y 680	0.5 681	0.5 681	Y 684	Y 681	Y 681	Y 681-682	Y 682	No	0.5	Y 682	NA	NA	0.5	NA	Y 683	NA	NA	Y 683	Y 685	Y 685	0.5	NA	NA	Y 686	Y 687	Y 686
Reeves, P., et al. 2021 (Australia)[327]	Y 1	Y 1	0.5 2	0.5 2	Y - described in RCT	Y 2	Y 3	Y 4	Y 3	NA	0.5	Y 4	NA	NA	Y 5	NA	Y 3	NA	NA	Y 6	Y 8	Y 8	Y 6	NA	NA	Y 9	Y 11	Y 11
van Schayck, C., et al. 2021 (Netherlands)[329]	Y	Y	0.5	0.5	Y - separate study	Y - separate	Y - implied	Y	Y - separate study	No	Y	Y	NA	NA	Y	NA	No	NA	NA	No	No	0.5	No	NA	NA	Y	No	No

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
[9]						study																						
Auerbach, J. D., Fitzhugh, E. C., & Zavisca, E. 2021 (US)[338]	No	No	0.5 1	0.5 1	Y 2	Y2	Y 4	Y 1-3	Y 5	No	Y 4	Y 3	NA	NA	Y 7	NA	0.5 4	0.5 2-4	0.5 sm	0.5 2-4	0.5 4-5	Y 7	No	NA	NA	Y 5-7	Y 8	No
Brown, A., et al. 2021 (Australia)[339]	Y 1	Y1	0.5 1	0.5 1	Y 3	Y3	Y 4	Y 3	Y 4	NA	Y 6	Y 4	NA	NA	Y 5	NA	Y 5	NA	NA	Y 5-6	Y 6	Y 7	Y 8	NA	NA	Y 10-11	Y 11	Y 11
Ekwaru, J. P., et al. 2021 (Canada)[340]	Y 1183	Y1	0.5 1184	0.5 1184	Y 1184	Y 1184	Y 1184	Y 1184	Y 1184	Y 1185	Y 1184	NA	Y 1184-5	Y 1185	NA	Y sm	Y 1187	Y 1184-5	Y 1184-5	NA	Y 1187	Y 1186	NA	Y 1186	NA	Y 1186	Y 1188	Y 1188
Kuvaja-Köllner, V., et al. 2021 (Finland)[341]	Y 1	Y 1	0.5 2	0.5 1	Y 2	Y 2	Y 1	Y 3	Y 3	Y 5	Y 4	Y 4-5	NA	NA	Y 6	NA	Y 4-6	NA	Y 4-5	Y 4-5	Y 5-6	Y 5	Y 6-7	NA	Y 817	Y 7-9	Y 10	Y 10
Sutherland, R., et al. 2021 (Australia)[342]	Y 1	Y 1	0.5 2	0.5 2	Y 3	Y 2	Y 1	Y 3	Y 1	No	NA	Y 3	NA	NA	Y 5-10	NA	0.5	NA	NA	Y 10	Y 13	Y 8	No	NA	Y 11	Y 15-17	Y 17	Y 17
Zanganeh, M., et al. 2021 (China)[280]	Y1	Y1	0.5 1	0.5 2	Y 2	Y2	Y1	Y 2	Y 2	NA	Y 6	Y2	NA	Y 3	Y sm	NA	Y3	NA	NA	Y 4	Y 6	Y 5	Y5	NA	Y 6	Y 6	Y 8	Y8
Cobiac, L. J., Law, C., & Scarborough, P. 2022 (UK)[343]	No	Y 3-4	0.5 5-6	0.5 5-6	Y 5-6	Y 5-6	Y 3	Y 5-6	Y 3	Y 19	Y 10	NA	Y 10	Y 18/sm	NA	Y 10/18	Y 18	Y 6	Y 14/sm	Y sm	Y sm	Y 23	NA	Y 14	NA	Y 25	Y 1	No
Derwig, M., et al. 2022 (Sweden)[344]	Y 77	Y 77	0.5 77	0.5 77	Y 79	Y 79	Y 80	Y 79	Y 80	NA	Y 80	Y 80	NA	NA	Y83	NA	Y 80	NA	NA	Y 82	Y83	Y 85	No	NA	Y 83	Y87	Y 88	Y88
Lane, C., et al. 2022 (Australia)[345]	Y1	Y1	0.5 2	0.5 2	Y 3	Y 3	Y 1	Y 4	Y 3	NA	Y 4	Y 3	NA	NA	Y 5	NA	Y4	NA	NA	Y 8	Y 5	Y 9	Y8	NA	NA	Y11	Y 14	Y 14
Lane, C., et al. 2022 (Australia)[56]	No	Y 1	0.5 2	0.5 2	Y 3	Y 3	Y 1	Y 3	Y 1	NA	Y 10	Y 3-8	NA	NA	Y 11	NA	Y 9	NA	NA	Y 9	Y	Y 11	Y 10	NA	NA	Y 11-14	Y 15	Y 15
Mahashabde, R., et al. 2022 (US)[346]	Y1	Y1	0.5 89	0.5 90	Y 90	Y 90	Y 90	0.5 90	No	No	0.5 90	No	NA	NA	0.5 90	NA	No	NA	NA	NA	No	Y 90	No	NA	NA	Y 90	Y 90	No
Alcaraz, A., et al. 2023 (Argentina, Brazil, El	0.5	Y 1	0.5 1-2	0.5 2	Y 3	Y 1	Y 1	Y 3	Y 1	NA	Y 6	Y 3	NA	NA	NA	Y 5-7	Y 4	Y 2	Y 3	Y 3	Y 5-7	No	NA	Y 5-7	Y 8	Y 8	No	Y 9

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Salvador, and Trinidad and Tobago)[281,381]																												
Jackson-Morris, A., & Meyer, C. L. 2023 (Mexico, China, Peru)[282]	No	Y1	0.5 1	0.5 1	Y1	Y1	Y1	0.5 1	Y1	No	Y1	NA	No	NA	NA	No	No	No	No	No	No	Y 1	NA	No	NA	Y 1	Y 1	Y 1
Mahdi, S., et al.2023 (UK)[347]	Y 1	Y 1	0.5 2	0.5 2	Y 5	Y 5	Y 6	Y 1	Y 1	NA	Y 9	Y 1	NA	Y 6	Y 6	NA	Y 7	Y 5	Y5	Y 5,6	Y 10	Y 10	Y 9/10	NA	NA	Y 1	Y 13	Y 13
Prevention -only																												
Goldfield, G., et al. 2001 (US)[165]	Y 1843	Y 1843	0.5 1843-4	0.5 1843-4	Y 1844	Y 1844	No	Y 1844	Y 1844	NA	Y 1846	Y 1846	NA	NA	Y 1846	NA	No	NA	NA	Y 1846	Y 1847	Y 1847	No	NA	NA	Y 1847-8	Y 1848	No
Raynor, H. A., et al. 2002 (US)[348]	No	Y 645	0.5 646	0.5 646	Y 646, 648	Y 646	No	Y 646	Y 647	NA	Y 647	Y 647	NA	NA	Y 649	NA	No	NA	NA	Y 648	Y 649	0.5	No	NA	NA	Y 655	Y 656	No
Moodie, M., et al. 2008 (Australia)[185]	Y 363	Y 363	0.5 363-4	0.5 363-4	Y 363	Y 364	Y 364	Y 364	Y 365	Y 364	Y 364	NA	Y separate paper	Y 365	NA	Y 368-70	Y 369	Y separate paper	Y 368-70	Y separate paper	Y 368-70	Y 372-4	NA	Y 371	NA	Y 374-5	Y 364	No
Wake, M., et al. 2008 (Australia)[186]	Y 336	Y 336	0.5 336-7	0.5 336-7	Y 336	Y 336-7	Y 340	Y 336-7	Y 336-7	NA	Y 336-7	Y 336-7	NA	NA	Y 337	NA	Y 337	NA	NA	Y 338	Y 337-9	Y 339	0.5 338-40	NA	NA	Y 340-1	Y 341	No
Janicke, D. M., et al. 2009 (US)[170]	Y 326	Y 326	0.5 326-7	0.5 326-7	Y 326	Y 326-8	No	Y 326-7	Y 328	NA	Y 328	Y 326-7	NA	NA	Y 326-8	NA	No	NA	NA	Y 328	Y 329	Y 329	No	NA	NA	Y 329-30	Y 326	No
Kalavainen, M., et al. 2009 (Finland)[220]	Y 606	Y 606	0.5 606-7	0.5 606-7	Y 607-8	Y 607-8	Y 607	Y 607-8	Y 607-8	NA	Y 606-7	Y 607	NA	NA	Y 607-9	NA	Y 607	NA	NA	Y 608	Y 607-9	Y 607-8	0.5	NA	NA	Y 609-10	Y 610	Y 610
Wake, M., et al. 2009 (Australia)[349]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 2	Y 1-2	Y 2	Y 3	Y 3	NA	Y 3	Y 3	NA	NA	Y 5	NA	Y 3	NA	NA	Y 3-4	Y 6-7	Y 5	0.5 4	NA	NA	Y 6	Y 7	Y 7
Ananthapavan, J., et al. 2010 (Australia)[350]	Y 377	Y 377	0.5 377-8	0.5 377-8	Y 378	Y 378	Y 378	Y 378	Y 378-9	Y 379	Y 378-9	NA	Y 378-9	Y 378	NA	Y 379	Y 378	Y 378	Y 378-380	Y 379-381	Y 378-380	Y 383	NA	Y 383	NA	Y 383-4	Y 377	Y 384
Nowicka, P., et al. 2010 (US)[351]	Y	Y	0.5	0.5	No	Y	0.5	Y	No	No	Y	Y	NA	No	0.5	NA	No	NA	NA	No	No	Y	No	NA	NA	No	No	No
Wang, L. Y., et al. 2010 (US)[84]	Y 467	Y 467	0.5 467-8	0.5 467-8	Y 469	Y 468	Y 468	NA	Y 468	Y 470	Y 469	NA	NA	0.5 468	NA	Y 471	Y 470	Y 468	Y 472	Y 470	Y 470	NA	NA	Y 470	Y 471	Y 472	0.5 467	0.5 467

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	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Hollingworth, W., et al. 2012 (UK)[71]	Y 559	Y 559	0.5 559-0	0.5 559-0	Y 559	Y 559	Y 559	Y 560	Y 560	Y 560	Y 559	NA	Y 559-1	NA	NA	Y 559-11	0.5	Y separate paper	Y 560-1	Y 560-3	0.5	Y 562-4	NA	No	Y 559-0	Y 562-5	Y 565	Y 565
Robertson, W., et al. 2012 (UK)[352]	No	Y 229	0.5 229-230	0.5 229-230	Y 231	Y 230	No	Y 230	Y 230	No	Y 230-1	Y 229-230	NA	NA	Y 230-1	NA	Y 232	NA	NA	Y 231	Y 233	Y 232	No	NA	NA	Y 233	Y 234	No
Epstein, L. H., et al. 2014 (US)[172]	Y 114	Y 114	0.5 114-5	0.5 114-5	Y 114-5	Y 119	Y 118	Y 114-6	Y 119	NA	Y 114-6	Y 114-6	NA	NA	Y 117	NA	0.5	NA	NA	Y 118	0.5	0.5	No	NA	NA	Y 118-20	Y 120	Y 120
Hollinghurst, S., et al. 2014 (UK)[353]	Y e26	Y e26	0.5 e27-28	0.5 e27-28	Y e27-30	Y e27-28	Y e31	Y e27-30	Y e30	NA	Y e27-30	Y e27-30	NA	NA	Y e27-30	NA	0.5	NA	NA	0.5	Y e27-30	0.5	Y e31-32	NA	NA	Y e30-33	Y e33	Y e33
Law, C., et al. 2014 (UK)[354]	No	Y v	0.5 1	0.5 1	Y 7	Y 1	Y 111	Y 7	Y 4	NA	Y 33	Y 33	NA	NA	NA	Y 63	Y 63	NA	NA	Y 32	Y 36	Y 167	0.5	NA	NA	Y 102	Y vi	Y i
Li, L. 2014 (US)[355]	Y 87	Y 87	0.5 88	0.5 88	Y 87	Y 89	0.5 92	Y 89	Y 91	Y 87	Y 93	NA	Y 91-2	0.5	NA	Y 91	Y 92	Y 91	Y 91	Y 94	Y 100	Y 100	NA	Y 94-95	NA	Y 96-7	No	No
Bairdain, S., & Samnaliev, M. 2015 (US)[356]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 3	Y 1-2	Y 2	Y 2	Y 2	Y 3	Y 2	Y 8	NA	0.5 4	Y 4	NA	Y 4	0.5 5	Y 2	Y 3	Y 5	Y 5	NA	Y 3	NA	Y 7-8	Y 8	Y 8
Kass, A. E. 2015 (US)[357]	Y	Y	0.5	0.5	0.5	0.5	No	Y	Y	No	Y	NA	Y	NA	NA	No	0.5	0.5	No	No	No	Y	NA	No	NA	0.5	No	No
Klebanoff M. J., et al. 2017 (US)[155]	Y 136	Y 136	0.5 137	0.5 137	Y 137	Y 137	Y 137	Y 137	Y 137	Y sm	Y 138	NA	Y 138	0.5 138	NA	Y 137-138	Y 137-138	0.5	0.5	0.5	Y 138	Y 139	NA	Y 138-139	NA	Y, 140	No	Y, 141
Larsen, K. T., et al. 2017 (Denmark)[217]	Y 666	Y 666	0.5 666-7	0.5 666-7	Y 667-8	Y 667	Y 667-8	Y 666-7	Y 667	No	Y 668	Y 668	NA	NA	Y 668	NA	Y 668	NA	NA	0.5	NA	Y 671-2	No	NA	NA	Y 671-3	Y 674	Y 673
Makkes, S., et al. 2017 (Netherlands)[206]	Y 458	Y 458	0.5 459	0.5 459	Y 459-462	Y 460	Y 459	Y 459-460	Y 459	Y 461	Y 460	Y 459-461	NA	Y 460	Y 461	NA	Y 461	NA	NA	Y 461	NA	Y 465-6	Y 462	NA	NA	Y 468-9	Y 470	Y 470
Quattrin, T., et al. 2017 (US)[180]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1-2	Y 1-2	Y 2	Y 2	Y 2	NA	Y 5	Y 2-5	NA	NA	Y 4-5	NA	Y 5	NA	NA	Y 5	NA	Y 6	Y 6	NA	NA	Y 6-7	Y 7	Y 7
Robertson, W., et al. 2017 (UK)[201]	Y title	Y xxvii-xxx	0.5 57	0.5 57	Y 57	Y xxvii-xxx	Y 57	Y 57	Y 57	NA	Y 58	Y 58	NA	Y 58	Y 58	NA	Y 58	NA	NA	Y 58-61	Y 61-67	Y 70-1	Y 71-5	NA	NA	Y 78-81	Y 120	Y first
Saelens, B. E., et al. 2017 (US)[358]	No	Y 314	0.5 314-5	0.5 314-5	Y 315	Y 314	Y 318	Y 315	Y 315	NA	Y 318	NA	Y 315-7	NA	Y 321	NA	Y 318	NA	NA	Y 318	Y 320	Y 321	No	NA	NA	Y 321-2	Y 322	Y 322

Author, year of publication (country)	number and score for items 1-24																											
	1	2	3a	3b	4	5	6	7	8	9	10	11a	11b	12	13a	13b	14	15	16	17	18	19	20a	20b	21	22	23	24
Sharifi, M., et al. 2017 (US)[359]	Y 1	Y 1	0.5 2	0.5 2	Y 2	Y 2	Y 2	Y 2-3	Y 3	Y 4	Y 2-3	Y 7	NA	NA	NA	Y 3	Y 3	Y 3	Y 4	Y 3	Y 5	Y 3	NA	Y 5	NA	Y 7	Y 8	Y 8
Anderson, Y. C., et al. 2018 (New Zealand)[211]	Y 293	Y 293	0.5 293-4	0.5 293-4	Y 294-5	Y 294-5	Y 294	Y 294-5	Y 294	NA	Y 294	Y 294-5	NA	NA	Y 294-5	NA	Y 295	NA	NA	Y 295	0.5 296	Y 297	Y 295	NA	NA	Y 64	Y 60	Y 64
Panca, M., et al. 2018 (England)[360]	Y 1	Y 1	0.5 1-2	0.5 1-2	Y 1-2	Y 1-2	Y 2	Y 2	Y 3	NA	Y 3	Y 2-4	NA	Y 3	Y 3	NA	Y 3	NA	NA	Y 3	Y 4-5	Y 6	Y 6	NA	NA	Y 6-8	Y 8	Y 8
Panca, M., et al. 2018 (UK)[156]	Y 105	Y 105	0.5 106	0.5 106	Y 108	Y 106	Y 106	Y 106	Y 107	Y 107	Y 107	NA	Y 107	Y 107	NA	Y 107-8	Y 107	Y 106	Y 107	Y 107	Y 109	Y 110	NA	Y 110	Y 109	Y 110-111	Y 112	Y 112
Vidmar, A. P., et al. 2019 (US)[183]	Y 1	Y 1	0.5 2	0.5 2	Y 2	Y 2	Y 3	Y 2	Y 6	NA	Y 5	Y 5	NA	NA	Y 4-5	NA	Y 3	NA	NA	Y 5	Y 4	Y 6	Y 6	NA	NA	Y 6-8	Y 8	Y 8
Bandurska, E., et al. 2020 (Poland)[221]	Y 487	0.5	0.5 488	0.5 488	Y 488-9	0.5	No	Y 490	Y 491	No	Y 493	Y 493	NA	NA	Y 491	NA	0.5	NA	NA	NA	Y 491	Y 493	No	NA	NA	Y 494-6	Y 496	Y 496
Lier, L., et al. 2020 (Germany)[361]	Y 185	Y 185	0.5 185-6	0.5 185-6	Y 186	Y 186	Y 189	Y 186	Y 186	Y 187	Y 186	NA	Y 186	NA	NA	Y 188	0.5 188	0.5 187	Y 189	Y 186	Y 187	Y 188-189	NA	No	NA	Y 189-190	Y 190	Y 190
Viner, R. M., et al. 2020 (UK)[362]	Y 63	Y 63	0.5 63	0.5 63	Y 41-45	Y 41-45	Y 63	Y 41-45	Y 63	NA	Y 67	Y 67	NA	Y 67	Y 64	NA	Y 64	NA	NA	Y 67	Y 63-70	Y 71	No	NA	NA	Y 71	Y 2	Y IV
Woolford, S. J., et al. 2022 (US)[363]	Y 2265	Y 2265	0.5 2265	0.5 2265	Y 2266	Y 2266	Y 2265	Y 2266	Y 2266	Y 2268	Y 2265	Y 2266	NA	NA	Y 2267	NA	0.5 2268	NA	NA	Y 2270	Y 2269-70	Y 2269	Y 2270	NA	NA	Y 2270-73	Y 2273	Y 2273
Zoellner, J. M., et al. 2022 (US)[364]	No	Y 1	0.5 2	0.5 2	Y 1	Y 3	Y 1	Y 6	Y 1	NA	Y 8	Y 6	NA	NA	Y 7/9	NA	0.5 10/sm	NA	NA	NA	Y sm	Y 10	Y9	NA	NA	Y 10	Y 12	Y 13
Carrello, J., et al. 2023 (Australia)[365]	Y 1	Y 1	0.5 1	0.5 2	Y 2	Y 3	Y 1	Y 2	Y 3	Y3	Y 4	NA	Y1	Y 4	NA	Y ap	Y 3	Y 3	Y3	Y4	Y ap	Y5	NA	Y 5	NA	Y5	Y 7	Y 7
Omorou, A. Y., et al. 2023 (France)[367]	Y 75	Y 75	0.5 75	0.5 76	Y 76	Y 76	Y 75	Y 77	Y 77	Y 78	Y 79	Y 76	NA	Y 76	Y 77	NA	0.5 77	NA	NA	NA	Y 76	Y 77	No	NA	NA	Y 80	Y 81	Y 81
Pryor, S., et al. 2023 (US)[366,369]	Y 1	Y 1	0.5 1	0.5 1	Y 2	Y 2	Y 1	Y 1	Y 1	Y 4	Y 1	NA	Y 1	NA	NA	Y 4	Y1	Y3	Y 3	Y 4	Y 4	Y4	NA	Y 7	NA	Y 4	Y 8	Y 8
Siegel, R., et al. 2023 (US)[368]	Y 1	Y 1	0.5 1	0.5 1	Y 2	Y2	Y 2	No	Y 2	NA	Y 2	Y2	NA	NA	Y 4	NA	0.5	Y3	Y4	Y5	Y6	Y6	Y6	NA	NA	Y 6-7	Y7	Y7

Table C 4 Data sources and key study assumptions

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
Hayes, A., et al. 2014 (Australia)[192]	Costs and effectiveness data were derived from the trial patient-level data	667 first time mothers and their infants: intervention n = 337 and control n = 330	Scenario analysis was used to test assumptions around travel times. PSA was performed using bootstrap sampling.
Barber, S. E., et al. 2015 (UK)[286]	The analysis was driven primarily by data collected during the trial	83 in intervention, 81 in control	Assessed sensitivity to changes in intervention component costs
Kolu, P., et al. 2016 (Finland)[283]	The analysis was driven primarily by data collected during the trial and at 7 years of follow-up	Intervention n = 85 women and their children, Usual care n = 88 women and their children	PSA was performed. Further sensitivity analysis standardised the productivity costs between groups and conducted a complete case analysis
Marsh, K., et al. 2016 (Mexico)[276]	Model based on descriptive statistics of the Mexican population and randomised controlled trials of the impact of 1pIF on childhood BMI	NA	Performed PSA using two models assuming different acceptable ICER thresholds. Conducted scenario analyses. Authors noted significant limitations surrounding the choice of many model parameters inputs
Döring, N., et al. 2018 (Sweden)[218]	The study was driven mainly by individual-level data on resource use and outcomes collected during the duration of the trial	1,355 families with 1,369 infants. Intervention CHCs (n = 31); control CHCs (n = 28)	Scenario analysis was carried out to test different assumptions on uptake reflected in intervention costs
Gc, V. S., et al. 2019 (UK)[284]	Model parameterised by previously published data	NA	PSA was performed. Scenario analysis varied the persistence of intervention effects (waning of effects) and time horizons.
Sonntag, D., et al. 2019 (Germany)[213]	A variety of data sources: Weight status transition probabilities from birth to age 6 were based on longitudinal data collected from the CHOP trial participants. Survey data on prevalence and life tables were used to estimate long term risks and transition probabilities	NA	Model parameters were tested in univariate sensitivity analysis and scenario analysis was used to test a range of assumptions around costs and rates of formula feeding. Base case analysis assumed that the intervention effect was maintained for 6 years
Tan, E. J., et al. 2020 (Australia)[199]	Data on intervention effects and costs of delivering the interventions came from the trial while EPOCH model furnished data on BMI trajectories and health care costs. Utility scores were derived from a systematic review and meta-analysis	802 pregnant women randomly assigned to one of four study arms: the FAB group (n = 205); the Sleep group (n = 192); the Combination group (both FAB and Sleep n = 196); or the control group (n = 209)	Uncertainty in costs and health outcomes were estimated using bootstrap sampling. One-way sensitivity analyses were used to test model parameters
Taylor, R., et al. 2020 (Australia)[285]	Based on a trial: insufficient information	192 intervention dyads, 209 controls dyads	Not stated
Kalita, N., et al. 2022 (UK)[287]	Multiple sources	NA	DSA, PSA and scenario analyses were performed extensively
Killedar, A., et al. 2022 (Australia)[288]	Trial-based	Control (n = 220), Telephone (n = 200), and SMS (n = 242)	Key sensitivity analysis involved re-estimating the ICER from a limited societal perspective (mothers' missed days of work). PSA was performed

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
Tran, H. N. Q., et al. 2022 (Australia)[289]	The Romp & Chomp quasi-experimental trial and national data sources	NA	Broad range of DSA varying intervention costs and discount rates were conducted. PSA was performed
Killedar, A., et al. 2023 (Australia)[290]	Data on intervention effects and costs of delivering the interventions came from the trial while EQ-EPOCH model furnished data on BMI trajectories and health care costs. Utility scores were derived from a systematic review and meta-analysis	NA	Uncertainty in costs and health outcomes were estimated using bootstrap sampling. One-way sensitivity analyses were used to test model parameters
Wang, L. Y., et al. 2003 (US)[166]	Data was derived from a variety of sources including the trial itself for determining proportions in weight categories and data from NHANES to estimate the probabilities of becoming overweight by 40 years of age	10 middle schools: 5 schools in Planet Health (310 girls) and 5 schools in control (317 girls)	Sensitivity analysis on key model parameters were conducted and PSA performed
Brown, H. S., et al. 2007 (US)[291]	Data was derived from a variety of sources including the CATCH/ El Paso trial itself for determining proportions in weight categories and data from NHANES to predict the number of adult obesity cases avoided for ages 40 to 64	4 intervention schools n = 423 (199 girls and 224 boys) and 4 matched control schools n = 473 (224 girls and 249 boys)	Sensitivity analysis on all model parameters were conducted and PSA performed. Subgroup analysis was done using Hispanic American parameters.
Nixon, J., et al. 2008 (UK)[304]	Based on a systematic review	NA	PSA was performed
Peterson, M., et al. 2008 (US)[168]	Intervention effectiveness was driven by data obtained from the 2004 Youth Tobacco Survey. Costs of the advertisements were obtained from the marketing firm that assisted with the campaign	3782 adolescents	No sensitivity analysis was reported. Only data on a self-reported BMI between 12 and 40 were included in the analysis
Wang, L. Y., et al. 2008 (US)[169]	The analysis was driven primarily by data collected during the trial	Nine elementary schools in each arm with a total of 601 children: Intervention n = 312; control n = 289	The per capita usual after-school care costs were varied across a plausible range
Magnus, A., et al. 2009 (Australia)[187]	Data was drawn from a mix of cross-sectional and longitudinal evidence including: an RCT for the effectiveness of a reduction in advertising and a prospective observational study for the impact of reduced sweetened beverages intake on BMI change	NA	A range of scenario analyses were performed such as varying the number of regulatory staff and the application of less conservative reductions in grams/day of EDNP beverages. PSA was performed. Changes in BMI were assumed to persist into adulthood
Moodie, M., et al. 2009 (Australia)[319]	Data was drawn from a mix of cross-sectional and longitudinal evidence including effectiveness data from the VicHealth program and cost data from the Australian Public Service Commission	NA	Due to the lack of data, several assumptions and estimates were applied for cost parameters and level of uptake of the intervention. PSA was performed
Cecchini, M., et al. 2010 (Brazil, China, India, Mexico, Russia, South Africa, England)[277]	Analysis used data reported elsewhere	NA	PSA was performed. Strategies targeting children were assumed to have some effects on adult behaviours
McAuley, K. A., et al.	The analysis was driven	7 primary schools (number of	A range of values for group

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
2010 (New Zealand)[210]	primarily by data collected during the trial	children): 4 intervention schools (n = 250) and 3 control schools (n = 219)	weight z-score were tested in sensitivity analysis
Mernagh, P., et al. 2010 (New Zealand)[336,379]			
Moodie, M. L., et al. 2010 (Australia)[189]	Data was drawn from a wide range of sources including the National Nutrition Survey 1995 (for height and weight of participants) and authors' estimates for uptake of the intervention.	NA	Due to the lack of data, several assumptions and estimates were applied for cost parameters and level of uptake of the intervention. PSA was performed
Pringle, A., et al. 2010 (UK)[161]	Data combined from seven separate intervention studies	Out of the 984 participants, 343 were 10-17 years old	Not reported
Trasande, L. 2010 (US)[87]	Characteristics of model population based on data collected in 2005	NA	DSA and scenario analyses were performed
Martínez, P. M., et al. 2011 (Spain)[330]	The analysis was driven primarily by data collected during the trial	10 intervention schools (691 children) and 10 control schools (718 children)	Scenario and one-way sensitivity analyses testing various assumptions around the intervention costs and resource use were carried out
Moodie, M., et al. 2011 (Australia)[190]	Data was drawn from a wide range of sources including the National Nutrition Survey 1995 (for height and weight of participants) and authors' estimates for several resource use and intervention costs	NA	Due to the lack of data, several assumptions and estimates were applied for cost and resource use parameters of the intervention. PSA was performed
Ramos-Goñi JM, Valcárcel-Nazco C, Castilla-Rodríguez I. 2011 (Spain)[331]	Multiple sources based on a literature review	NA	PSA was performed
Te Velde, S., et al. 2011 (Netherlands)[337,380])	Estimates of treatment costs and effect were derived from two trials.	(n = 735 for Dutch part of Pro Children study, n = 771 for the Schoolgruiten study)	Assumptions regarding the persistence and waning of intervention effects and the discount rates were critical drivers of cost-effectiveness
Wang, L. Y., et al. 2011 (US)[171]	Data on intervention effectiveness and medical treatment costs were estimated from the Planet Health RCT and multiple sources in the literature. Remission and relapse rates for bulimia nervosa were sources from several studies	254 girls in intervention schools and 226 girls in control schools	Univariate and multivariate sensitivity analyses were conducted on parameters such as medical treatment costs and progression probability
Monsivais, P., & Rehm, C. D. 2012 (US)[292]	Data extracted from the 2001-2004 NHANES and a national food prices database	7023 children	Assumed no compensatory increase in energy from other sources
Gesell, S. B., et al. 2013 (US)[293]	The analysis was driven primarily by data collected during the natural experiment	54 children attending community ASP and 37 children attending the school-based ASP	It was assumed that data was missing at random
Kesztyüs, D., et al. 2013 (Germany)[212]	Data on intervention effect sizes, intervention costs and teacher workload were sourced from the trial	Intervention group 20 schools (365 children) and control group 16 schools (354 children)	Selected parameters were tested in deterministic sensitivity analysis. PSA was performed using bootstrap sampling.
Meng, L., et al. 2013 (China)[163]	Data on intervention effect sizes and intervention costs were sourced from the trial	Total of 15 schools (8301 children): 3 in nutrition education intervention (615); 3 in PA intervention (590); 3 in nutrition education and PA intervention/comprehensive	None that was relevant to economic evaluations reported

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
		intervention (3356); and 6 in control (3,740)	
Moodie, M. L., et al. 2013 (Australia)[191]	Treatment effectiveness data came from the study. Cost and resource use data were derived from the several sources including the study and the Victorian Department of Education and Early.	Number of children: intervention n = 1001 and control n = 1183	Scenario analysis around the uptake of the intervention and other one-way sensitivity analyses were performed. PSA was performed.
Nelson, M. 2013 (England)[305]	longitudinal data collected from various sources	NA	Assumptions of the number of children who would attend a breakfast club
Tran, B., et al. 2013 (Canada)[334]	Insufficient information	NA	Not stated
Babey, S. H., et al. 2014 (US)[294]	Input values estimated based on results of other studies looking at the interventions separately	NA	Assumptions were made about length of school day and reach of intervention
Rush, E., et al. 2014 (New Zealand)[209]	Long term BMI classification was estimated using the New Zealand Ministry of Health's 2006/07 population survey data. Life-expectancy was estimated from the New Zealand lifetables and Dutch data. The cost of the intervention was estimated from the Project Energise trial	192 schools: 2474 younger and 2330 older children (36% Maori) attending Energise schools compared using mixed effect modelling with unEnergised comparison children from 2004 (124 schools) and 2006 (62 schools) from the same region	One-way sensitivity analyses were conducted for a range of parameters. A 1% annual decay was applied to the intervention effect after the first five years. The study did not state whether PSA was done
Swinburn, B., et al. 2014 (Australia)[320]	Analysis based on follow-up data collected three years after the end of the original non-randomised	660 students from intervention schools and 621 students from comparison provided follow-up data	Mixed linear models adjusting for the clustering in schools were used. PSA not reported
Tran, B. X., et al. 2014 (Canada)[335]	Data was based mainly on the APPLE schools intervention study and the NPHS 1996 - 2008	NA	Sensitivity analysis was not reported
Barrett, J. L., et al. 2015 (US)[173]	The relationship between a change in minutes of MVPA and change in BMI were estimated using a review of the literature. Costs and resource use were estimated from a variety of sources	NA	One-way sensitivity analyses were conducted for a range of parameters and PSA was performed. The full effect on BMI was assumed to occur after 2 years of the intervention
Gortmaker, S. L., et al. 2015 (US)[150]	Intervention effects on BMI were obtained from a review of the literature. Direct evidence linking behaviour change to BMI was available for all the interventions as well as additional econometric evidence linking increased price to lower consumption. Cost and resource use data were identified from multiple sources	NA	One-way sensitivity analyses were conducted for a range of parameters and PSA was performed. Effects on BMI change were assumed to occur after 1 year of exposure to the individual interventions
Long, M. W., et al. 2015 (US)[174]	The model's estimate of the relationship between SSB intake and BMI was based trial in youth and observational studies in adults. SSB consumption data was estimated from the NHANES 2011-2012 survey. The cost of intervention implementation	NA	One-way sensitivity analyses were conducted for a range of parameters and PSA was performed. Reductions in SSB intake and BMI were assumed to persist over the model time horizon

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	was taken from state administrative data		
McCollister, K. E., et al. 2015 (US)[295]	The analysis was driven primarily by data collected during the HC2 trial and lifetime projections were calculated based on estimates of incremental lifetime medical care costs	Intervention n = 726, Control n = 379	Not stated
Mora, T., et al. 2015 (Spain)[332]	The analysis was driven primarily by data collected during the trial with additional anthropometric measurements collected during follow-up	Intervention group (n = 272) and control group (n = 237)	Sensitivity analysis surrounding interaction terms in the regression equations
Sonneville, K. R., et al. 2015 (US)[175]	Differences in healthcare expenditures with and without the intervention, and impact of the intervention on QALYs among adults 18 years or older were based on the MEPS.	NA	One-way sensitivity analyses were conducted for a range of parameters and PSA was performed. A key model assumption was that the intervention effect was maintained through the 10-year time horizon
Wright, D. R., et al. 2015 (US)[176]	Data on baseline beverage consumption data for childcare settings was sourced from an observational study while an RCT was used to estimate the change in body weight that accrued from eliminating SSB consumption. Intervention costs were derived from multiple sources	NA	One-way sensitivity analyses were conducted for a range of parameters and PSA was performed. The model assumed that 73% of facilities would policy components of the intervention fully
Jago, R., et al. 2016 (UK)[306]	The analysis was driven primarily by data collected during the trial	Intervention n = 273, control n = 276	Sensitivity analysis investigated the effect of excluding the dance instructors' travel expenses
Ladapo, J. A., et al. 2016 (US)[296]	The analysis was driven primarily by data collected during the trial	2,606 in the intervention and 2,693 in the control group	Sensitivity analysis tested different purchasing prices and worker wages
Lawlor, D. A., et al. 2016 (UK)[307]	The analysis was driven primarily by data collected during the trial	1064 intervention children, 1157 control	Sensitivity analyses varied various assumptions, including about missing data
Sutherland, R., et al. 2016 (Australia)[321]	Effectiveness and intervention cost were estimated from trial data. Labour costs for personnel were estimated from the Australian Bureau of Statistics average earnings data	10 secondary schools: intervention 5 schools n = 645 and control 5 schools n = 505	Univariate sensitivity analyses were undertaken for various parameters including intervention cost and magnitude of effect size. PSA was not reported but results were presented with confidence intervals
Cradock, A. L., et al. 2017 (US)[178]	Several data sources for each of the six interventions as well as multiple national longitudinal surveys on population demographics and height and weight	A simulated a population of 1,000,000 individuals	The authors performed PSA. The model assumed that the intervention effects on BMI are maintained over the 10-year period of follow-up
Crino, M., et al. 2017 (Australia)[322]	Assumptions for input values derived from various published sources	entire 2010 Australian population	PSA and DSA were performed. Scenario analysis was conducted to reflect different implementation options
Ekwaru, J. P., et al. 2017 (Canada)[216]	Weight status transition probabilities were derived from two Canadian cohorts: National Population Health Survey	NA	The authors conducted various one-way sensitivity analyses, including varying the programme effect, discount rates and PSA

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	(NPHS) that follows participants 12 years of age or older; National Longitudinal Survey of Children and Youth (NLSCY) that follows children under 12 years of age		
Graziose, M. M., et al. 2017 (US)[177]	This study is a secondary analysis of effectiveness data from a trial. Data on costs of citywide implementation came from the New York City Department of Education. Published childhood-to-adulthood BMI trajectories were used to estimate adult obesity prevalence	Intervention schools (n = 20) and all New York City elementary schools (n = 728)	Scenario analysis was conducted to test model assumptions such as relapse rate into adulthood and subgroup intervention. PSA was performed
Hajizadeh, N., et al. 2017 (US)[297]	Model parameterised with data from RCTs investigating the effectiveness of ParentCorps	Assumed 72 pre-K students per school	Assumptions were made based on the cascading effect of shorter-term benefits of early childhood interventions persisting over time
Kesztyüs, D., et al. 2017 (Germany)[333]	The analysis was driven primarily by data collected during the trial	Intervention (n = 955), Control (n = 778)	Generalized linear models were used to test for potential clustering effect in schools
Lee, B. Y., et al. 2017 (US)[179]	The study included a wide range of longitudinal data sources such as the NHANES used for creating the model's initial distribution of heights and weights for each child; the CARDIA and the ARIC studies which tracked health outcomes in adults over several years	NA	The authors explored scenarios of varying proportions (50% to 100%) of participation in both interventions
Moore, J. B., et al. 2017 (US)[298]	Trial and financial reports from the granting organisation and grantees	2,138 youth	PSA was not conducted. The statistical analysis used to calculate the change in MVPA controlled for sex, grade, and race of the participating children
Wang, H., et al. 2017 (US)[299]	The analysis was driven primarily by data collected during the trial	445 students in 2 schools	Cost-effectiveness was evaluated under 4 different scenarios, such as management, school staff time, number of implementation days, student/school characteristics
An, R., et al. 2018 (US)[182]	The study is based on data presented in various observational studies, but the main data source is a quasi-experimental study that estimated the impact of water jets on BMI in elementary and middle school students	NA	The authors performed several one-way sensitivity analyses and a PSA. A major assumption of the model was that weight reductions due to the intervention were permanent
Anokye, N., et al. 2018 (UK)[308]	The analysis was driven primarily by data collected during the trial	246 participants	Deterministic and probabilistic sensitivity analyses to evaluate uncertainty
Beets, M. W., et al. 2018 (US)[181]	All resource use were recorded in diaries prospectively. Economic evaluation was driven by data collected during the trial	20 ASPs that served a total of 1,700 children: n = 10, immediate group and n = 10, delayed group	No sensitivity analysis was reported. Results are presented separately for boys and girls
Brown, V., et al. 2018 (Australia)[194]	The model used two main data sources: the Australian Health Survey 2011–2012 (cross-	NA	One-way sensitivity analysis carried out by varying key input parameters and the potential

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	sectional) and a Burden of Disease study for OECD countries. The model also used the Australian lifetable of the 2010 Australian population		loss of revenue to TV networks resulting from reduced advertising was tested in a sensitivity analysis. PSA was undertaken. Subgroup analysis in the most socioeconomically disadvantaged groups was also undertaken
Conesa, M., et al. 2018 (Spain)[215]	The study was driven mainly by individual-level data on resource use and outcomes collected during the duration of the trial	Intervention institutions: 24 schools of 36 classrooms and 1,550 pupils. Control institutions: 14 schools of 39 classrooms and 800 pupils	ICERs were only calculated for boys because the outcomes in girls were not significantly different between the intervention and control arms at the end of the trial. Scenario analysis focused on resource use and costs
Reilly, K. L., et al. 2018 (Australia)[323]	Cost-effectiveness was estimated based on data collected during the trials	High trial: 35 intervention and 35 control schools over a 12-to-14-month period; Medium trial: 28 intervention and 25 control schools over a 9-month period; Low trial: 36 intervention and 36 control schools over a 12-month period	The authors carried out univariate sensitivity analysis, varying the intervention costs and level of compliance to the policy
Wyatt, K., et al. 2018 (UK)[309]	The analysis was driven primarily by data collected during the trial	Intervention n = 628; control n = 616	Sensitivity analysis of the random-effects model used the worse-case scenario for missing data
Amies-Cull, B., et al. 2019 (England)[203]	The main data source of this study was the National Diet and Nutrition Survey (NDNS) waves 5 and 6, a cross-sectional survey capturing information on food consumption, nutrient intake and nutritional status	A modelled cohort representing 1508 participants in the NDNS waves 5 and 6	Sensitivity analyses involved assumptions of varied reductions in calorie intake, extended time horizons and exclusion of self-reported individuals. Missing data for body weight parameters were imputed
Ananthapavan, J., et al. 2019 (Australia)[324]	A variety of sources: Resource use came from trials that CBIs; effectiveness measures came from systematic review and meta-analysis; disability weights from the Global Burden of Disease 2010 Study were applied to health states to estimate health-adjusted life years	NA	One-way sensitivity analyses included variables such as the effect size, target population, and intervention intensity. Persistence of treatment effects over the lifetime was assumed
Basto-Abreu, A., et al. 2019 (Mexico)[279]	Data on health and nutritional status were collected from the National Health and Nutrition Survey	NA	PSA and DSA were performed. However, the study did not consider the impact of revenue generated from SSB taxation
Brown, V., et al. 2019 (Australia)[197]	Model parameters came were derived from several sources including the Australian Health Survey 2011 to 2012. Scoping review of a systematic review and meta-analysis studies informed parameter inputs for hypothetical reductions in BMI.	NA	PSA was conducted
Canaway, A., et al. 2019 (UK)[204]	Primary outcomes were collected at baseline and during follow-up. Resource use items were recorded during the trial and unit costs from several sources were applied. The control arm did not accrue any	Intervention: [n = 26 schools (pupils n = 660)]; Control: [n = 28 schools (pupils n = 732)]	Sensitivity analyses included testing different multiple imputation methods, including wider costs such as parents' time and travel costs, and reducing intervention costs

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	costs		
Charles, J. M., et al. 2019 (UK)[310]	Analysis used trial data	Intervention n = 570, Control n = 427	Complete case analysis at baseline was used. Sensitivity analysis tested the effect of varying the levels of accelerometer data
Coffield, E., et al. 2019 (US)[300]	Multiple sources including the 2008–2013 MEPS used to estimate healthcare costs associated with BMI z-score (children) or BMI (parents)	NA	PSA and DSA were performed
Gammon, C., et al. 2019 (UK)[311]	The analysis was driven primarily by data collected during the trial	96 students, 69 teachers and 2 assistant head teachers	None stated
Harrington, D., et al. 2019 (UK)[312]	The analysis was driven primarily by data collected during the trial	1211 students: 10 intervention schools and 9 to the control schools	sensitivity analysis assessed the effects of varying the population, the number of days valid and the season
Kenney, E. L., et al. 2019 (US)[184]	Multiple cross-sectional and longitudinal data sources including the US Census, the American Community Survey and the Early Childhood Longitudinal Study-kindergarten cohort	NA	PSA was used to account for model uncertainty. A sensitivity analysis varying the percentage eligibility of water jets was explored
Li, B., et al. 2019 (China)[278]	The analysis was driven primarily by data collected during the trial	832 children in the intervention, 809 in control	Assumptions were tested about average class sizes
Long, M. W., et al. 2019 (US)[301]	Data for model collected from a range of sources	NA	PSA was performed
Sebire, S. J., et al. 2019 (UK)[313]	The analysis was driven primarily by data collected during the trial	four PLAN-A schools (269 students) and two control schools (158 students)	Sensitivity analysis varied the pay of workers delivering the intervention
Vieira, M. & Carvalho, G.S. 2019 (Portugal)[219]	PHS-pro costs were calculated from the trial and data on direct medical costs attributable to obesity came from a study estimating Portuguese national data.	PHS-pro n = 219; control group n = 230	None that was relevant to economic evaluations reported
Ananthapavan, J., et al. 2020 (Australia)[325]	Data on costs and intervention effectiveness were obtained from multiple administrative databases	NA	Interventions that affected PA were assumed to affect BMI as well. The impact of regulatory interventions was assumed to be maintained over the model time horizon
Breheny, K., et al. 2020 (UK)[314]	Data on resource use and outcomes were collected during the trial	40 schools 1:1 allocation; intervention n = 1,153 participants; control n = 1,127	The base case analysis was based on ITT. Subgroup analysis (boys and girls) and PSA were carried out
Clemes, S. A., et al. 2020 (UK)[315]	The analysis was driven primarily by data collected during the trial	4 intervention schools, 4 control schools	PSA was performed. Sensitivity analysis adjusted for the differences in the activity at baseline.
Ferguson, M. C., et al. 2020 (US)[302]	Multiple data sources including data on the 2018 Girl Scouts Maryland cohort, the 2013-2014 NHANES, and transition parameters from the CARDIA and ARIC studies	250 simulated participants	DSA varied baseline prevalence of obesity/overweight to ensure the results can apply to different populations
Finster, M.P. & Feldman, J. 2020 (US)[55]	Cost-effectiveness was estimated based on data	128 schools: 64 onsite n = 64; online n = 64	None that was relevant to economic evaluations reported

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	collected during the study		
Huse, O., et al. 2020 (Australia)[198]	The main data sources were a Public Health England report sample of 30,000 British households estimating the reduction in take-home sugar for a range of 'high-sugar' products and Australian data on mean daily energy intake	NA	In the base case analysis, the authors assumed no decline in intervention effectiveness over time. This assumption was varied in a threshold analysis. Other scenario analyses were explored, including varying retail prices of SSBs.
Mytton, O. T., et al. 2020 (UK)[316]	Data collected from multiple sources: AC Nielsen and Broadcasters' Audience Research Board (2015); a meta-analysis on the effect of food advertising on adult caloric intake; the Human Mortality Database for the UK (2015); the Health Survey for England (2016); Global Burden of Disease Study; NHS England programme budgeting data	NA	Sensitivity analysis tested the effect of individual parameters e.g., different discount rates, classification of HFSS
Oosterhoff, M., et al. 2020 (Netherlands)[208]	BMI trajectory data and treatment effects came from a publication by the authors. Costs associated with the interventions were obtained from a published paper. Quality of life data was sourced from a published systematic review and meta-analysis	Number of participants = 1676: control n = 661; HPSF n = 537; PAS = 478	Scenario analyses varied around different assumptions of treatment effect and effect maintenance over time. A health care perspective was tested in sensitivity analysis.
Oosterhoff, M., et al. 2020 (Netherlands)[328]	Resource use, costs and monetary benefits captured in the study were used to carry out cost-benefit analysis	Number of participants = 1676: control n = 661; HPSF n = 537; PAS = 478	Sensitivity analysis tested assumptions such as spill over effects on caregiver's HRQOL and productivity, extended school day and discounting.
Xu, H., et al. 2020 (China)[164]	The data came from a variety of sources. The authors state that they sourced the probabilities of transitioning from a weight status and health state utilities from the literature. Intervention costs came from records kept during the trials and other costs were derived from the literature	Randomised trial 1: NE n = 3 schools, PA n = 3 schools and control n = 2 schools. Randomised trial 2: CNP n = 3 schools and control n = 3	Sensitivity analysis explored intervention effects and cost parameters
Corder, K. L., et al. 2021 (UK)[317]	The analysis was driven primarily by data collected during the trial	At baseline: intervention n = 1224; control n = 1414	Sensitivity analysis confirmed the data is unaffected by participants with missing data or by different approaches to data processing
Jago, R., et al. 2021 (UK)[318]	The analysis was driven primarily by data collected during the trial	Intervention n = 758, control n = 800	A multiple imputation approach yielded similar results. PSA was conducted using bootstrap replications
Kenney, E. L., et al. 2021 (US)[303]	Based on data from systematic reviews	NA	PSA was performed. The estimated effect of an hour of TV viewing on BMI was varied.
Lonsdale, C., et al. 2021 (Australia)[326]	The analysis was driven primarily by data collected during the trial	Intervention n = 557, Control n = 631, 11 schools in each arm	Bootstrapping sensitivity analyses produced similar results to the base case
Reeves, P., et al. 2021 (Australia)[327]	Data collected in RCT assessing the efficacy of the web-based menu planning intervention	54 childcare services were randomised into both groups	PSA and one-way sensitivity analysis were performed

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
van Schayck, C., et al. 2021 (Netherlands)[329]	Data was extracted from the study	Full intervention n = 600 children; partial intervention n = 600 children; control n = 1,200 children	Not stated in abstract
Auerbach, J. D., Fitzhugh, E. C., & Zavisca, E. 2021 (US)[338]	Student location data was provided by the county. Thoroughfare construction costs were based on government sources. Physical activity benefits were sourced from another study	NA	Monte Carlo sampling was used to estimate the mean and standard deviation for the optimal walking time for each school. PSA and DSA not reported
Brown, A., et al. 2021 (Australia)[339]	Trial-based	Intervention n = 778; control n = 991	DSA not reported. PSA performed
Ekwaru, J. P., et al. 2021 (Canada)[340]	Data on effectiveness was based on a systematic review and meta-analysis. Data source for cost not sufficiently reported	NA	Discount rate was varied. PSA performed
Kuvaja-Köllner, V., et al. 2021 (Finland)[341]	Trial-based	Intervention group (n = 306); Control group (n = 200)	DSA and scenario analyses were performed. PSA also performed
Sutherland, R., et al. 2021 (Australia)[342]	Trial-based	Intervention group (n = 23 schools); Control group (n = 25 schools)	Assumptions surrounding baseline levels of school PA practices made. DSA and PSA not reported
Zanganeh, M., et al. 2021 (China)[280]	The analysis was driven primarily by data collected during the trial	832 children in the intervention, 809 in control	Sensitivity analyses were conducted around implementation costs, the Chinese value set, class size, and missing data. CEAC was derived
Cobiac, L. J., Law, C., & Scarborough, P. 2022 (UK)[343]	Data was obtained from multiple sources in the literature specific to the UK population	NA	Multiple scenario analysis and PSA were performed
Derwig, M., et al. 2022 (Sweden)[344]	Data on effectiveness was trial-based. Cost data came from multiple Swedish sources	Intervention (healthy weight n = 2,278; with overweight n = 238), Control (healthy weight n = 2,233; with overweight n = 237)	BMI z-scores were adjusted for clustering, baseline, gender and CNI. DSA and PSA not reported
Lane, C., et al. 2022 (Australia)[345]	Trial-based	Intervention schools (n = 31) or a wait-list control schools (n = 30)	Sensitivity analysis incorporated a societal perspective, varied the cost of usual care and applied imputation to address missing data. PSA was conducted through bootstrapping
Lane, C., et al. 2022 (Australia)[56]	Trial-based	24 schools in both arms	Bootstrapping analysis was used to account for sampling variability
Mahashabde, R., et al. 2022 (US)[346]	Insufficient information	Insufficient information	Insufficient information
Alcaraz, A., et al. 2023 (Argentina, Brazil, El Salvador, and Trinidad and Tobago)[281,381]	Epidemiological data were sourced from multiple sources including national sources as well as from systematic reviews. Direct medical costs were country-specific	NA	Treatment effect sizes were varied in sensitivity analyses
Jackson-Morris, A., & Meyer, C. L. 2023 (Mexico, China, Peru)[282]	Costs and effectiveness data were sourced from the literature	NA	Insufficient information
Mahdi, S., et al.2023 (UK)[347]	Trial-based	App exposure condition (n = 62); control (n = 64)	Multiple imputation was used to account for missing data. Other sensitivity analyses involved removal of outliers and complete case analysis

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
Goldfield, G., et al. 2001 (US)[165]	The data was derived exclusively from the study	24 families: 12 children and 12 parents per group	No sensitivity analysis was reported
Raynor, H. A., et al. 2002 (US)[348]	The analysis was driven primarily by data collected during the trial	31 families randomised into either group	Pairwise comparisons using Bonferroni correction were conducted significant main effects
Moodie, M., et al. 2008 (Australia)[185]	Data on intervention efficacy and cost data were sourced mainly from the LEAP trial.	Intervention n = 82 and control n = 81; Cohort model of 9685 children	An outlier was removed to test trial efficacy and GP incentive payments were added in scenario analyses. PSA was performed
Wake, M., et al. 2008 (Australia)[186]	Data on intervention efficacy and cost data were sourced from the LEAP trial	Intervention n = 82 and control n = 81	A range of scenario analyses were explored around the costs
Janicke, D. M., et al. 2009 (US)[170]	The analysis was driven primarily by data collected during the trial	Family-based intervention n = 33 and parent-only intervention n = 34	No sensitivity analysis or assumptions were described
Kalavainen, M., et al. 2009 (Finland)[220]	The analysis was driven primarily by data collected during the trial	The group programme n = 35 and the routine programme n = 35	One-way sensitivity analyses varying clinical effectiveness were carried out.
Wake, M., et al. 2009 (Australia)[349]	The analysis was driven primarily by data collected during the trial	intervention: 139 children; control: 119 children	Sensitivity analysis accounted for the correlation between children interacting with the same GP, which yielded the same results
Ananthapavan, J., et al. 2010 (Australia)[350]	Data on costs and effectiveness were derived from a case series of 28 adolescents	NA	The change in BMI at 3 years was assumed to persist into the future. PSA was performed
Nowicka, P., et al. 2010 (US)[351]	Trial-based	NA	Not stated/insufficient information
Wang, L. Y., et al. 2010 (US)[84]	Data collected in the 2000 National Medical Expenditure Panel Survey and from published studies	NA	PSA and sensitivity analysis on BMI tracking probabilities, age, sex and BMI-specific medical costs
Hollingworth, W., et al. 2012 (UK)[71]	The study estimated a plausible range for intervention effect size and intervention costs from a literature review of RCTs of excess weight lifestyle interventions. The national programme budgeting data was used to estimate the annual NHS cost per case associated with five weight-related diseases	NA	A range of scenario analysis were reported for intervention effect size and costs. The changes in BMI z-score during the RCTs were assumed to be permanent and defined an individual's lifetime weight trajectory. PSA was not reported
Robertson, W., et al. 2012 (UK)[352]	The analysis was driven primarily by data collected during the trial	27 children from 21 families	To account for family clustering, the authors fitted linear mixed models with random family effects for change in BMI-z score
Epstein, L. H., et al. 2014 (US)[172]	Data on intervention effect sizes and intervention costs were sourced from the trial	50 children: PC n = 24 and FTB n = 26	The study imputed 12-month data based on a conservative baseline carried forward approach. No sensitivity analyses were described.
Hollinghurst, S., et al. 2014 (UK)[353]	Data was taken from two trials (the PC-COCO study and the Mandometer® study)	PC-COCO study: Primary care clinic n = 42 and Hospital clinic n = 26; Mandometer® study: Mandometer® training n = 54 and Hospital clinic n = 52	No DSA was reported. PSA was done using bootstrap sampling
Law, C., et al. 2014 (UK)[354]	Analysis based on data collected during the MEND 7–13 trial	>20,000 children referred to MEND	Sensitivity analysis adjusted for BMI at baseline
Li, L. 2014 (US)[355]	Model based on data collected	NA	PSA was performed. DSA:

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	from various studies reporting obesity averted and QALY gain in bariatric surgery and the costs associated with different health states		changing discount rate to 5% supported bariatric surgery as cost-effective
Bairdain, S., & Samnaliev, M. 2015 (US)[356]	The analysis was driven primarily by data collected during the trial and costs were estimated from the MEPS	11 patients	Main model assumptions were based on waning of treatment effects over time after the 12month follow-up
Kass, A. E. 2015 (US)[357]	Insufficient information	Intervention n = 59, control n = 57	Insufficient information
Klebanoff M. J., et al. 2017 (US)[155]	Longitudinal study called the Teen-LABS: 3-year BMI % decrease. Clinical trial called the Swedish Obese Subjects (SOS) study: Long-term (1-15 years) total body weight % decrease	NA	One-way sensitivity analysis over 3-year, 4-year and 5-year time horizons. Assumption: differences in weight loss persisted beyond three years. PSA was performed
Larsen, K. T., et al. 2017 (Denmark)[217]	Most of the data were collected from individual participants in the trial at baseline and one-year follow-up. Staff salaries were estimated using records of the Municipality of Odense	115 overweight or obese children: camp group n = 59 and standard group n = 56	The authors analysed a hypothetical scenario of full participation in both interventions
Makkes, S., et al. 2017 (Netherlands)[206]	Data on measures of effect (BMI z-scores and QALYs) were collected for individual participants at baseline and follow-up. Costs covering healthcare utilisation, transportation, and lost productivity were collected using cost diaries	Short-stay n = 40 and long-stay group n = 40	Multiple imputation was used for imputing missing data. Sensitivity Analyses were performed to test assumptions around discounting of costs and effects
Quattrin, T., et al. 2017 (US)[180]	Data on costs and outcomes were routinely collected as part of the trial. Weights were measured objectively by practice enhancement assistants while data on dietary intake, PA and expenses were collected using diaries and questionnaires	FBT n = 46 and IC n = 50	In addition to an ITT analysis, the authors also carried out a scenario analysis based on completers
Robertson, W., et al. 2017 (UK)[201]	The economic analysis was based on individual level cost and outcomes data collected over the 12-month time horizon of the trial	115 families (128 children): 'Families for Health' n = 56 families and usual-care n = 59 families	Several sensitivity and subgroup analyses were conducted, including the adopting a societal perspective and estimating cost-effectiveness based on sex of child. PSA was performed using bootstrap sampling
Saelens, B. E., et al. 2017 (US)[358]	Data collected from the EPICH and Parent Partnership trials	59 families	None stated
Sharifi, M., et al. 2017 (US)[359]	Analysis based on data collected as part of the STAR cluster-randomised clinical trial	NA	PSA and DSA were performed. Treatment effect was assumed maintained throughout the model time horizon in the base case and tested in sensitivity analysis
Anderson, Y. C., et al. 2018 (New Zealand)[211]	The study was driven mainly by individual-level data on resource use and outcomes collected during the trial or at follow-up	Intervention groups: high-intensity n = 100 and low-intensity n = 99. Conventional group: n = 44	No sensitivity analysis was reported. Subgroup analysis was performed for children under 10 years of age
Panca, M., et al. 2018 (England)[360]	The study was driven mainly by individual-level data on	HELP intervention n = 87; enhanced standard	Results were estimated in terms of complete cases

Author, year of publication (country)	Primary data sources	Sample size(s)	Sensitivity analyses and key model or study assumptions
	resource use and outcomes collected during the duration of the trial and the follow-up period	care n = 87	
Panca, M., et al. 2018 (UK)[156]	Model parameters taken from multiple sources, including the UK National Life tables	18 adolescents (9 RYGB, 9 sleeve gastrectomy)	The authors performed PSA and varied individual parameters in one-way sensitivity analyses
Vidmar, A. P., et al. 2019 (US)[183]	The data for the analysis were collected during the pilot study at baseline and 6 months follow-up	App n = 18; EMPOWER n = 17	None that was relevant to economic evaluations reported
Bandurska, E., et al. 2020 (Poland)[221]	The primary data used by the authors was the longitudinal data on the 12-month intervention	Sample sizes were not clearly defined for comparator groups	None that was relevant to economic evaluations reported
Lier, L., et al. 2020 (Germany)[361]	Analyses based on data previously collected from 249 children who participated in the Children's Health Interventional Trial	249 children	A linear relationship was assumed between cost and BMI-SDS reduction and persistence of treatment effect at 100% over 10 years
Viner, R. M., et al. 2020 (UK)[362]	Data was obtained predominantly from the trial	Intervention n=87; control n=87	Skewness of the cost data was accounted for using a generalised linear model. PSA and DSA not reported
Woolford, S. J., et al. 2022 (US)[363]	Trial-based	Intervention (n = 154); Usual care (n = 158)	Costs, the number of visits and the number of missed workdays were varied in sensitivity analysis. PSA was performed
Zoellner, J. M., et al. 2022 (US)[364]	Trial-based	iChoose (children = 44); Family Connections (n= 58)	Assumptions surrounding costs were tested
Carrello, J., et al. 2023 (Australia)[365]	Treatment effects (reduction in BMI) were sourced from systematic reviews. Costs were estimated from studies of web-based or telephone-delivered interventions	NA	Multiple one-way sensitivity analyses and PSA were performed. Intervention effect size was applied once at baseline
Omorou, A. Y., et al. 2023 (France)[367]	Trial-based	Intervention (n = 1,687); usual care (n = 1851)	None that was relevant to economic evaluations reported. Effect maintenance scenarios were tested in the budget impact analysis
Pryor, S., et al. 2023 (US)[366,369]	Multiple sources including the Bright Bodies RCT and the National Longitudinal Survey which was uses to estimate BMI trajectories	NA	PSA was performed. Scenarios of varying effect maintenance were tested
Siegel, R., et al. 2023 (US)[368]	Cross-sectional survey to estimate impact of framing on adherence to weight management programmes. Projected cost inputs were obtained from multiple sources	NA	The probability of adherence assumed to be dependent on keeping the 3-month clinic visit. A sensitivity analysis range of 10% was applied to the adherence rate. PSA not performed

Appendix D

Data availability

Millennium Cohort Study (MCS) datasets are publicly available via the UK Data Service (https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031#!/access-data) and further information about the MCS can be found at https://cls.ucl.ac.uk/cls-studies/millennium-cohort-study/. The seven datasets I used for my study can be found under the "GN 33359 Millennium Cohort Study – Survey and Biomeasures Data" Access data Tab at https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031#!/access-data. On the UK Data Service website, these datasets are titled: Millennium Cohort Study: Age 9 months, Sweep 1, 2001 (SN 4683), Millennium Cohort Study: Age 3, Sweep 2, 2004 (SN 5350), Millennium Cohort Study: Age 5, Sweep 3, 2006 (SN 5795), Millennium Cohort Study: Age 7, Sweep 4, 2008 (SN 6411), Millennium Cohort Study: Age 11, Sweep 5, 2012 (SN 7464), Millennium Cohort Study: Age 14, Sweep 6, 2015 (SN 8156), and Millennium Cohort Study: Age 17, Sweep 7, 2018 (SN 8682).

Observed prevalence

Table D 1 Weighted prevalence based on the observed data from Waves 2 to 7 for 5,486 children with complete data on covariates and valid BMI z-scores using the UK90 reference and the British cut-offs for population monitoring

Wave	Underweight	Healthy weight	Overweight	Obesity
Wave 2	0.78%	72.70%	15.90%	10.63%
Wave 3	0.59%	76.59%	13.86%	8.96%
Wave 4	0.87%	79.04%	10.65%	9.44%
Wave 5	1.40%	68.21%	14.79%	15.60%
Wave 6	1.65%	67.52%	14.70%	16.13%
Wave 7	1.69%	66.54%	14.12%	17.66%

Table D 2 Unweighted prevalence based on the observed data from Waves 2 to 7 for 5,486 children with complete data on covariates and valid BMI z-scores using the UK90 reference and the British cut-offs for population monitoring

Wave	Underweight	Healthy weight	Overweight	Obesity
Wave 2	1.13%	71.75%	16.24%	10.88%
Wave 3	0.98%	76.01%	13.60%	9.41%
Wave 4	1.17%	77.65%	11.36%	9.83%
Wave 5	1.60%	66.88%	14.86%	16.66%
Wave 6	1.62%	66.41%	14.78%	17.19%
Wave 7	1.93%	65.09%	14.27%	18.70%

Table D 3 Weighted prevalence based on the observed data from Waves 2 to 7 for 5,486 children with complete data on covariates and valid BMI z-scores using the WHO references and cut-offs

Wave	Underweight	Healthy weight	Overweight	Obesity
Wave 2	0.31%	88.23%	9.52%	1.94%
Wave 3	0.35%	71.07%	22.16%	6.42%
Wave 4	0.68%	75.18%	17.47%	6.67%
Wave 5	1.44%	66.34%	22.11%	10.10%
Wave 6	2.02%	70.61%	19.21%	8.16%
Wave 7	1.93%	70.64%	18.32%	9.11%

Table D 4 Unweighted prevalence based on the observed data from Waves 2 to 7 for 5,486 children with complete data on covariates and valid BMI z-scores using the WHO references and cut-offs

Wave	Underweight	Healthy weight	Overweight	Obesity
Wave 2	0.51%	87.81%	9.53%	2.15%
Wave 3	0.49%	70.65%	22.20%	6.65%
Wave 4	0.89%	74.04%	17.86%	7.20%
Wave 5	1.68%	65.07%	22.57%	10.68%
Wave 6	1.97%	69.60%	19.98%	8.46%
Wave 7	2.10%	69.23%	18.48%	10.19%

Predicted-to-observed prevalence ratios

Table D 5 British 1990 growth reference (UK90) and UK cut-offs for population monitoring: Ratio of predicted to observed prevalence in body weight status for the base case and scenario models (1 indicates complete agreement)

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
Underweight											
3	0.0078	0.0074, 0.0081	0.0078	0.0074, 0.0081	1.0000	0.0078	0.0074, 0.0081	1.0000	0.0078	0.0074, 0.0081	1.0000
4			0.0074	0.0071, 0.0078		0.0080	0.0076, 0.0083		0.0074	0.0071, 0.0078	
5	0.0059	0.0056, 0.0062	0.0072	0.0068, 0.0075	1.2207	0.0082	0.0078, 0.0085	1.3923	0.0072	0.0068, 0.0075	1.2207
6			0.0081	0.0078, 0.0085		0.0084	0.008, 0.0087		0.0070	0.0067, 0.0073	
7	0.0087	0.0083, 0.0091	0.0088	0.0084, 0.0092	1.0143	0.0086	0.0082, 0.0089	0.9830	0.0069	0.0065, 0.0072	0.7918
8			0.0093	0.0089, 0.0097		0.0087	0.0084, 0.0091		0.0068	0.0065, 0.0072	
9			0.0097	0.0093, 0.0101		0.0089	0.0085, 0.0093		0.0068	0.0064, 0.0071	
10			0.0101	0.0096, 0.0105		0.0091	0.0087, 0.0095		0.0067	0.0064, 0.0071	
11	0.0140	0.0135, 0.0145	0.0104	0.01, 0.0108	0.7442	0.0093	0.0089, 0.0097	0.6634	0.0067	0.0064, 0.0071	0.4821
12			0.0110	0.0106, 0.0114		0.0094	0.009, 0.0098		0.0067	0.0064, 0.0071	
13			0.0115	0.0111, 0.012		0.0096	0.0092, 0.01		0.0067	0.0064, 0.0071	
14	0.0165	0.0159, 0.017	0.0120	0.0116, 0.0125	0.7305	0.0098	0.0094, 0.0102	0.5927	0.0067	0.0064, 0.0071	0.4089
15			0.0127	0.0122, 0.0132		0.0099	0.0095, 0.0103		0.0067	0.0064, 0.0071	
16			0.0133	0.0128, 0.0138		0.0101	0.0097, 0.0105		0.0067	0.0064, 0.0071	
17	0.0169	0.0163, 0.0174	0.0138	0.0134, 0.0143	0.8200	0.0102	0.0098, 0.0106	0.6056	0.0068	0.0064, 0.0071	0.4000
Healthy weight											
3	0.7270	0.7251, 0.7288	0.7270	0.7251, 0.7288	1.0000	0.7270	0.7251, 0.7288	1.0000	0.7270	0.7251, 0.7288	1.0000
4			0.7343	0.7324, 0.7361		0.7266	0.7247, 0.7284		0.7343	0.7324, 0.7361	
5	0.7659	0.7641, 0.7676	0.7400	0.7382, 0.7418	0.9662	0.7262	0.7244, 0.728	0.9482	0.7400	0.7382, 0.7418	0.9662
6			0.7448	0.743, 0.7466		0.7258	0.724, 0.7277		0.7446	0.7428, 0.7464	
7	0.7904	0.7887, 0.7921	0.7478	0.746, 0.7496	0.9461	0.7254	0.7235, 0.7272	0.9178	0.7483	0.7465, 0.7501	0.9467
8			0.7394	0.7376, 0.7412		0.7250	0.7231, 0.7268		0.7514	0.7496, 0.7532	

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
9			0.7313	0.7294, 0.7331		0.7246	0.7227, 0.7264		0.7541	0.7523, 0.7558	
10			0.7234	0.7215, 0.7252		0.7241	0.7223, 0.726		0.7563	0.7545, 0.7581	
11	0.6821	0.6802, 0.6841	0.7157	0.7138, 0.7175	1.0492	0.7237	0.7218, 0.7255	1.0609	0.7582	0.7565, 0.76	1.1116
12			0.7129	0.7111, 0.7148		0.7232	0.7214, 0.7251		0.7599	0.7582, 0.7617	
13			0.7103	0.7085, 0.7122		0.7228	0.7209, 0.7246		0.7614	0.7596, 0.7632	
14	0.6752	0.6732, 0.6771	0.7078	0.7059, 0.7097	1.0483	0.7223	0.7204, 0.7242	1.0698	0.7627	0.7609, 0.7644	1.1296
15			0.7049	0.703, 0.7068		0.7218	0.72, 0.7237		0.7638	0.7621, 0.7656	
16			0.7019	0.7, 0.7038		0.7214	0.7195, 0.7232		0.7648	0.7631, 0.7666	
17	0.6654	0.6634, 0.6673	0.6988	0.6969, 0.7007	1.0503	0.7209	0.719, 0.7227	1.0834	0.7657	0.764, 0.7675	1.1508
Overweight											
3	0.1590	0.1575, 0.1605	0.1590	0.1575, 0.1605	1.0000	0.1590	0.1575, 0.1605	1.0000	0.1590	0.1575, 0.1605	1.0000
4			0.1527	0.1512, 0.1541		0.1580	0.1565, 0.1596		0.1527	0.1512, 0.1541	
5	0.1386	0.1372, 0.1401	0.1483	0.1468, 0.1498	1.0697	0.1571	0.1556, 0.1586	1.1336	0.1483	0.1468, 0.1498	1.0697
6			0.1369	0.1355, 0.1383		0.1563	0.1548, 0.1578		0.1452	0.1437, 0.1467	
7	0.1065	0.1052, 0.1077	0.1292	0.1278, 0.1306	1.2138	0.1554	0.1539, 0.1569	1.4602	0.1430	0.1415, 0.1444	1.3429
8			0.1320	0.1306, 0.1334		0.1547	0.1532, 0.1561		0.1413	0.1398, 0.1427	
9			0.1346	0.1332, 0.136		0.1539	0.1524, 0.1554		0.1400	0.1386, 0.1414	
10			0.1369	0.1355, 0.1383		0.1532	0.1517, 0.1547		0.1390	0.1376, 0.1404	
11	0.1479	0.1464, 0.1494	0.1390	0.1376, 0.1404	0.9397	0.1525	0.151, 0.154	1.0310	0.1382	0.1367, 0.1396	0.9342
12			0.1388	0.1374, 0.1403		0.1518	0.1503, 0.1533		0.1375	0.1361, 0.1389	
13			0.1387	0.1373, 0.1402		0.1512	0.1497, 0.1527		0.1369	0.1355, 0.1384	
14	0.1470	0.1455, 0.1485	0.1387	0.1373, 0.1401	0.9434	0.1506	0.1491, 0.1521	1.0244	0.1364	0.135, 0.1379	0.9281
15			0.1365	0.1351, 0.1379		0.1500	0.1486, 0.1515		0.1360	0.1346, 0.1374	
16			0.1347	0.1333, 0.1361		0.1495	0.148, 0.151		0.1357	0.1342, 0.1371	
17	0.1412	0.1397, 0.1426	0.1333	0.1319, 0.1347	0.9444	0.1490	0.1475, 0.1505	1.0552	0.1353	0.1339, 0.1368	0.9586
Obesity											
3	0.1063	0.105, 0.1076	0.1063	0.105, 0.1076	1.0000	0.1063	0.105, 0.1076	1.0000	0.1063	0.105, 0.1076	1.0000
4			0.1057	0.1044, 0.1069		0.1074	0.1061, 0.1087		0.1057	0.1044, 0.1069	

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
5	0.0896	0.0884, 0.0908	0.1046	0.1033, 0.1058	1.1665	0.1085	0.1072, 0.1098	1.2104	0.1046	0.1033, 0.1058	1.1665
6			0.1102	0.1089, 0.1115		0.1096	0.1083, 0.1109		0.1032	0.102, 0.1045	
7	0.0944	0.0932, 0.0957	0.1142	0.1128, 0.1155	1.2087	0.1106	0.1093, 0.1119	1.1712	0.1018	0.1006, 0.1031	1.0784
8			0.1193	0.1179, 0.1206		0.1116	0.1103, 0.1129		0.1005	0.0992, 0.1017	
9			0.1245	0.1231, 0.1258		0.1126	0.1113, 0.1139		0.0992	0.0979, 0.1004	
10			0.1297	0.1283, 0.1311		0.1136	0.1123, 0.1149		0.0980	0.0967, 0.0992	
11	0.1560	0.1545, 0.1575	0.1350	0.1335, 0.1364	0.8650	0.1146	0.1133, 0.1159	0.7344	0.0969	0.0956, 0.0981	0.6208
12			0.1372	0.1358, 0.1386		0.1155	0.1142, 0.1168		0.0959	0.0946, 0.0971	
13			0.1394	0.138, 0.1408		0.1164	0.1151, 0.1178		0.0949	0.0937, 0.0962	
14	0.1613	0.1598, 0.1629	0.1415	0.14, 0.1429	0.8768	0.1173	0.116, 0.1187	0.7272	0.0941	0.0929, 0.0953	0.5835
15			0.1460	0.1445, 0.1474		0.1182	0.1169, 0.1196		0.0934	0.0922, 0.0946	
16			0.1501	0.1486, 0.1516		0.1191	0.1177, 0.1204		0.0928	0.0916, 0.094	
17	0.1766	0.175, 0.1781	0.1540	0.1525, 0.1555	0.8722	0.1199	0.1186, 0.1213	0.6793	0.0922	0.091, 0.0934	0.5222

Sensitivity analysis

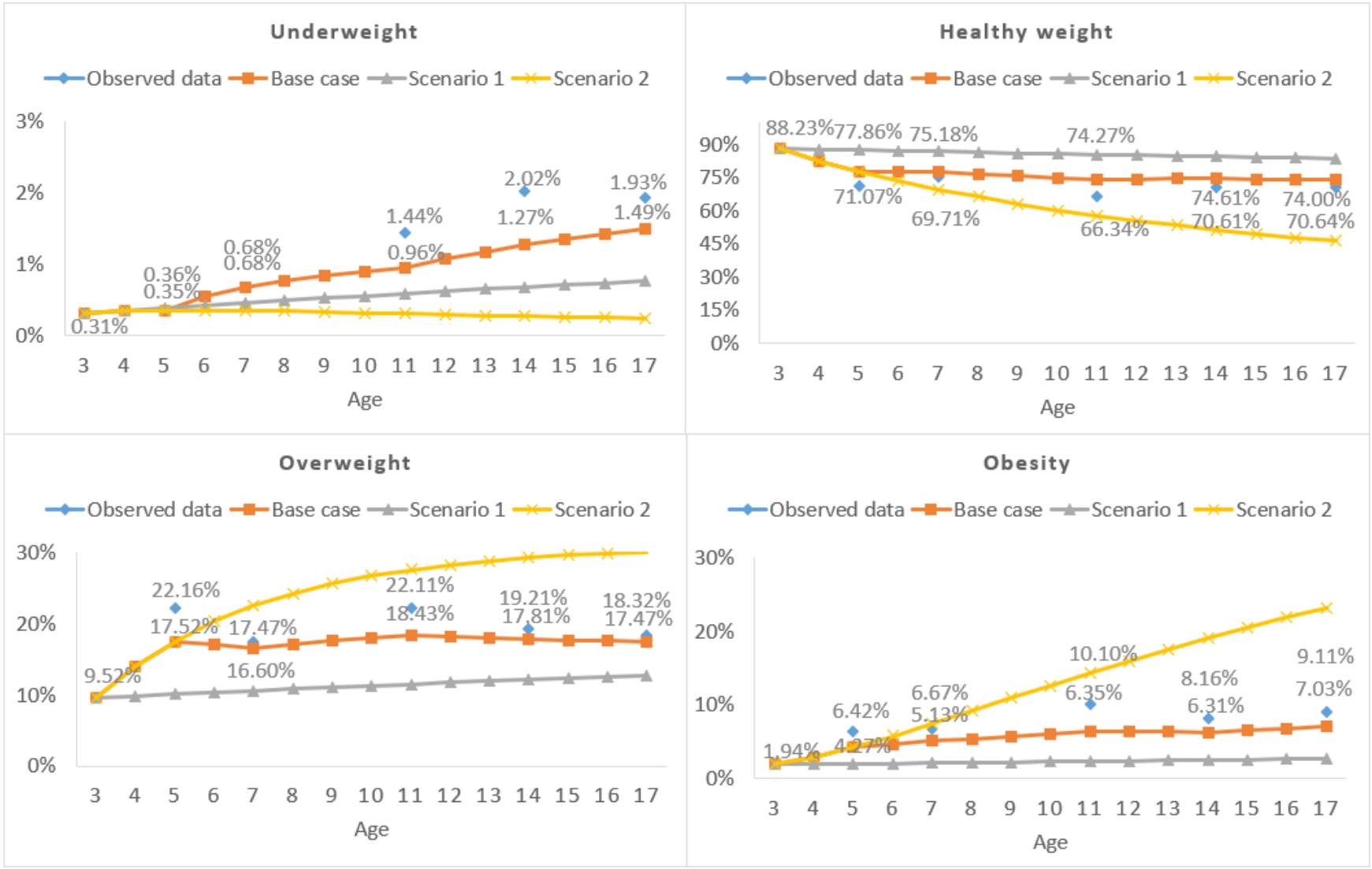

Figure D 1 WHO references and cut-offs: Observed and modelled projections for survey-weighted children followed from age 3 to 17 years

Table D 6 WHO references and cut-offs: Ratio of predicted to observed prevalence in body weight status for the base case and scenario models (1 indicates complete agreement)

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
Underweight											
3	0.0031	0.0029, 0.0034	0.0031	0.0029, 0.0034	1.0000	0.0031	0.0029, 0.0034	1.0000	0.0031	0.0029, 0.0034	1.0000
4			0.0035	0.0032, 0.0037		0.0035	0.0033, 0.0038		0.0035	0.0032, 0.0037	
5	0.0035	0.0032, 0.0037	0.0036	0.0033, 0.0038	1.0349	0.0039	0.0036, 0.0041	1.1166	0.0036	0.0033, 0.0038	1.0349
6			0.0055	0.0052, 0.0058		0.0042	0.004, 0.0045		0.0036	0.0034, 0.0039	
7	0.0068	0.0065, 0.0072	0.0068	0.0065, 0.0072	1.0050	0.0046	0.0043, 0.0049	0.6742	0.0036	0.0033, 0.0038	0.5210
8			0.0076	0.0073, 0.008		0.0049	0.0046, 0.0052		0.0035	0.0032, 0.0037	
9			0.0083	0.008, 0.0087		0.0053	0.005, 0.0056		0.0033	0.0031, 0.0036	
10			0.0090	0.0086, 0.0094		0.0056	0.0053, 0.0059		0.0032	0.003, 0.0034	
11	0.0144	0.0139, 0.0149	0.0096	0.0092, 0.01	0.6641	0.0059	0.0056, 0.0062	0.4110	0.0031	0.0029, 0.0033	0.2141
12			0.0107	0.0103, 0.0111		0.0062	0.0059, 0.0066		0.0030	0.0027, 0.0032	
13			0.0118	0.0113, 0.0122		0.0065	0.0062, 0.0069		0.0029	0.0026, 0.0031	
14	0.0202	0.0196, 0.0208	0.0127	0.0123, 0.0132	0.6303	0.0068	0.0065, 0.0072	0.3393	0.0027	0.0025, 0.003	0.1359
15			0.0135	0.013, 0.014		0.0071	0.0068, 0.0075		0.0026	0.0024, 0.0029	
16			0.0143	0.0138, 0.0148		0.0074	0.0071, 0.0078		0.0025	0.0023, 0.0028	
17	0.0193	0.0187, 0.0199	0.0149	0.0144, 0.0154	0.7724	0.0077	0.0073, 0.0081	0.3984	0.0025	0.0023, 0.0027	0.1273
Healthy weight											
3	0.8823	0.8809, 0.8836	0.8823	0.8809, 0.8836	1.0000	0.8823	0.8809, 0.8836	1.0000	0.8823	0.8809, 0.8836	1.0000
4			0.8271	0.8256, 0.8287		0.8787	0.8774, 0.8801		0.8271	0.8256, 0.8287	
5	0.7107	0.7088, 0.7126	0.7786	0.7769, 0.7803	1.0956	0.8753	0.8739, 0.8766	1.2316	0.7786	0.7769, 0.7803	1.0956
6			0.7773	0.7755, 0.779		0.8718	0.8705, 0.8732		0.7355	0.7337, 0.7373	
7	0.7518	0.75, 0.7536	0.7759	0.7741, 0.7776	1.0320	0.8685	0.8671, 0.8699	1.1552	0.6971	0.6952, 0.699	0.9272
8			0.7671	0.7654, 0.7689		0.8652	0.8638, 0.8666		0.6626	0.6607, 0.6646	
9			0.7587	0.7569, 0.7605		0.8619	0.8605, 0.8634		0.6316	0.6296, 0.6336	
10			0.7506	0.7488, 0.7523		0.8587	0.8573, 0.8602		0.6035	0.6015, 0.6055	
11	0.6634	0.6615, 0.6654	0.7427	0.7409, 0.7445	1.1194	0.8556	0.8542, 0.8571	1.2897	0.5780	0.5759, 0.58	0.8712

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
12			0.7438	0.742, 0.7457		0.8525	0.851, 0.854		0.5547	0.5527, 0.5568	
13			0.7450	0.7432, 0.7468		0.8495	0.848, 0.851		0.5335	0.5315, 0.5356	
14	0.7061	0.7042, 0.708	0.7461	0.7443, 0.7479	1.0566	0.8465	0.845, 0.848	1.1989	0.5141	0.512, 0.5162	0.7281
15			0.7440	0.7422, 0.7458		0.8435	0.842, 0.845		0.4963	0.4942, 0.4984	
16			0.7420	0.7402, 0.7438		0.8406	0.8391, 0.8422		0.4799	0.4778, 0.482	
17	0.7064	0.7045, 0.7083	0.7400	0.7382, 0.7419	1.0476	0.8378	0.8363, 0.8393	1.1860	0.4648	0.4628, 0.4669	0.6580
Overweight											
3	0.0952	0.094, 0.0964	0.0952	0.094, 0.0964	1.0000	0.0952	0.094, 0.0964	1.0000	0.0952	0.094, 0.0964	1.0000
4			0.1399	0.1385, 0.1413		0.0979	0.0966, 0.0991		0.1399	0.1385, 0.1413	
5	0.2216	0.2199, 0.2234	0.1752	0.1736, 0.1767	0.7904	0.1005	0.0992, 0.1017	0.4534	0.1752	0.1736, 0.1767	0.7904
6			0.1699	0.1684, 0.1715		0.1030	0.1018, 0.1043		0.2030	0.2013, 0.2046	
7	0.1747	0.1731, 0.1763	0.1660	0.1645, 0.1676	0.9504	0.1055	0.1042, 0.1068	0.6040	0.2250	0.2232, 0.2267	1.2877
8			0.1710	0.1694, 0.1725		0.1079	0.1067, 0.1092		0.2423	0.2405, 0.2441	
9			0.1757	0.1741, 0.1772		0.1103	0.109, 0.1116		0.2561	0.2543, 0.2579	
10			0.1801	0.1785, 0.1817		0.1126	0.1113, 0.1139		0.2670	0.2651, 0.2688	
11	0.2211	0.2194, 0.2229	0.1843	0.1826, 0.1859	0.8332	0.1149	0.1136, 0.1162	0.5195	0.2756	0.2738, 0.2775	1.2464
12			0.1820	0.1804, 0.1836		0.1171	0.1158, 0.1184		0.2825	0.2806, 0.2844	
13			0.1800	0.1784, 0.1816		0.1193	0.1179, 0.1206		0.2880	0.2861, 0.2899	
14	0.1921	0.1905, 0.1938	0.1781	0.1765, 0.1797	0.9269	0.1214	0.12, 0.1227	0.6316	0.2924	0.2905, 0.2942	1.5217
15			0.1768	0.1752, 0.1784		0.1234	0.122, 0.1248		0.2959	0.294, 0.2978	
16			0.1757	0.1741, 0.1772		0.1254	0.124, 0.1268		0.2987	0.2968, 0.3006	
17	0.1832	0.1816, 0.1848	0.1747	0.1731, 0.1763	0.9537	0.1274	0.126, 0.1288	0.6953	0.3009	0.299, 0.3028	1.6429
Obesity											
3	0.0194	0.0188, 0.02	0.0194	0.0189, 0.02	1.0000	0.0194	0.0189, 0.02	1.0000	0.0194	0.0189, 0.02	1.0000
4			0.0295	0.0288, 0.0302		0.0199	0.0193, 0.0205		0.0295	0.0288, 0.0302	
5	0.0642	0.0632, 0.0653	0.0427	0.0418, 0.0435	0.6641	0.0204	0.0198, 0.021	0.3173	0.0427	0.0418, 0.0435	0.6641
6			0.0473	0.0464, 0.0482		0.0209	0.0203, 0.0215		0.0579	0.0569, 0.0589	
7	0.0667	0.0657, 0.0677	0.0513	0.0503, 0.0522	0.7684	0.0214	0.0208, 0.022	0.3208	0.0744	0.0733, 0.0755	1.1155

Age in years	Observed data	95% CI	Annual prevalence (base case)	95% CI	Ratio (base case)	Annual prevalence (scenario 1)	95% CI	Ratio (scenario 1)	Annual prevalence (scenario 2)	95% CI	Ratio (scenario 2)
8			0.0542	0.0533, 0.0552		0.0219	0.0213, 0.0225		0.0916	0.0904, 0.0928	
9			0.0573	0.0563, 0.0582		0.0225	0.0219, 0.0231		0.1090	0.1077, 0.1103	
10			0.0604	0.0594, 0.0614		0.0230	0.0224, 0.0236		0.1263	0.125, 0.1277	
11	0.1010	0.0998, 0.1023	0.0635	0.0625, 0.0645	0.6286	0.0236	0.0229, 0.0242	0.2334	0.1433	0.1419, 0.1448	1.4188
12			0.0634	0.0624, 0.0644		0.0241	0.0235, 0.0248		0.1598	0.1583, 0.1613	
13			0.0633	0.0623, 0.0643		0.0247	0.0241, 0.0254		0.1756	0.1741, 0.1772	
14	0.0816	0.0805, 0.0828	0.0631	0.0621, 0.0641	0.7736	0.0253	0.0247, 0.026	0.3101	0.1908	0.1892, 0.1924	2.3374
15			0.0657	0.0647, 0.0667		0.0259	0.0253, 0.0266		0.2052	0.2035, 0.2069	
16			0.0681	0.067, 0.0691		0.0265	0.0259, 0.0272		0.2189	0.2171, 0.2206	
17	0.0911	0.0899, 0.0923	0.0703	0.0693, 0.0714	0.7723	0.0271	0.0265, 0.0278	0.2979	0.2317	0.23, 0.2335	2.5445

For further comparison, I present the unadjusted transition hazards before excluding children with incomplete data on the child, mother, and sociodemographic variables (Appendix D: Sensitivity analysis Table 7) alongside transition hazards for my base case analysis/complete case analysis (Appendix D: Sensitivity analysis Table 8) in my robustness check. The relevant comparison is between transition hazard point estimates of corresponding datasets, not the confidence intervals, since I did not derive replicate weights for this sensitivity analysis. As previously noted in the chapter subsection "Integrating complex survey design within models", the derivation and integration of replicate weights into variance estimation is computationally intensive. However, the point estimates of transition hazards estimated in both the base case analysis and the sensitivity analysis are unbiased because I applied the survey weights provided by MCS to account for the clustered sample design, the unequal probability of being sampled, and sample attrition. Examination of point estimates is sufficient to assess the effect of excluding children with missing data from my base case analysis. The similarity between the point estimates derived from the sensitivity and base case analyses is reassuring, as they lead to the same conclusions.

Table D 7 Sensitivity analysis: unadjusted estimates of transition hazards derived before excluding children with incomplete data on covariates

From \ To	Underweight		Healthy weight		Overweight		Obesity	
	MLE	95% CI	MLE	95% CI	MLE	95% CI	MLE	95% CI
Waves 2 (mean age 3) to 3 (mean age 5), n = 11,248								
Underweight	-0.6323	-0.7893, -0.5066	0.6323	0.5066, 0.7893	0	0, 0	0	0, 0
Healthy weight	0.0064	0.0048, 0.0084	-0.0869	-0.0952, -0.0796	0.0806	0.0748, 0.0868	0	0, 0
Overweight	0	0, 0	0.4669	0.4369, 0.4989	-0.714	-0.7739, -0.6589	0.2471	0.222, 0.275
Obesity	0	0, 0	0	0, 0	0.3669	0.3341, 0.4028	-0.3669	-0.4028, -0.3341
Waves 3 (mean age 5) to 4 (mean age 7), n = 11,629								
Underweight	-0.6308	-0.827, -0.4812	0.6308	0.4812, 0.827	0	0, 0	0	0, 0
Healthy weight	0.0093	0.0072, 0.0119	-0.0737	-0.0816, -0.0668	0.0645	0.0596, 0.0697	0	0, 0
Overweight	0	0, 0	0.4125	0.3831, 0.4441	-0.6558	-0.7128, -0.6034	0.2433	0.2203, 0.2687
Obesity	0	0, 0	0	0, 0	0.2116	0.1892, 0.2366	-0.2116	-0.2366, -0.1892
Waves 4 (mean age 7) to 5 (mean age 11), n = 10,490								
Underweight	-0.3013	-0.3864, -0.2349	0.3013	0.2349, 0.3864	0	0, 0	0	0, 0
Healthy weight	0.0061	0.0048, 0.0077	-0.0698	-0.0753, -0.065	0.0637	0.0602, 0.0675	0	0, 0
Overweight	0	0, 0	0.1086	0.096, 0.1229	-0.3266	-0.3581, -0.298	0.2179	0.2019, 0.2352
Obesity	0	0, 0	0	0, 0	0.0675	0.0578, 0.0787	-0.0675	-0.0787, -0.0578
Waves 5 (mean age 11) to 6 (mean age 14), n = 9,322								
Underweight	-0.3107	-0.3911, -0.2468	0.3107	0.2468, 0.3911	0	0, 0	0	0, 0
Healthy weight	0.0075	0.0059, 0.0095	-0.0634	-0.0702, -0.0574	0.0559	0.0515, 0.0607	0	0, 0

Overweight	0	0, 0	0.2464	0.2267, 0.2679	-0.4313	-0.4719, -0.3943	0.1849	0.1676, 0.204
Obesity	0	0, 0	0	0, 0	0.1229	0.111, 0.1361	-0.1229	-0.1361, -0.111
Waves 6 (mean age 14) to 7 (mean age 17) n = 7,701								
Underweight	-0.2532	-0.3345, -0.1917	0.2532	0.1917, 0.3345	0	0, 0	0	0, 0
Healthy weight	0.0071	0.0054, 0.0094	-0.0677	-0.0761, -0.0604	0.0606	0.055, 0.0668	0	0, 0
Overweight	0	0, 0	0.2639	0.2378, 0.2929	-0.493	-0.5496, -0.4422	0.229	0.2044, 0.2567
Obesity	0	0, 0	0	0, 0	0.1267	0.1109, 0.1447	-0.1267	-0.1447, -0.1109

MLE: Maximum likelihood estimate of transition hazard. Point estimates incorporate survey weights. British 1990 growth reference (UK90) and UK cut-offs for population monitoring

Table D 8 Base case analysis: unadjusted estimates of transition hazards derived after excluding children with incomplete data on covariates

From \ To	Underweight		Healthy weight		Overweight		Obesity	
	MLE	**95% CI**	**MLE**	**95% CI**	**MLE**	**95% CI**	**MLE**	**95% CI**
Waves 2 (mean age 3) to 3 (mean age 5), n = 10,399								
Underweight	-0.6503	-1.5159, -0.279	0.6503	0.279, 1.5159	0	0, 0	0	0, 0
Healthy weight	0.0057	0.0022, 0.0154	-0.0859	-0.1225, -0.0622	0.0802	0.06, 0.1071	0	0, 0
Overweight	0	0, 0	0.4661	0.3529, 0.6157	-0.7101	-0.9801, -0.5162	0.244	0.1633, 0.3644
Obesity	0	0, 0	0	0, 0	0.3694	0.2613, 0.5221	-0.3694	-0.5221, -0.2613
Waves 3 (mean age 5) to 4 (mean age 7), n = 10,729								
Underweight	-0.652	-1.8784, -0.2263	0.652	0.2263, 1.8784	0	0, 0	0	0, 0
Healthy weight	0.0093	0.0038, 0.0229	-0.073	-0.1068, -0.0521	0.0637	0.0483, 0.0839	0	0, 0
Overweight	0	0, 0	0.4138	0.3171, 0.5399	-0.6559	-0.892, -0.4836	0.2421	0.1665, 0.3521
Obesity	0	0, 0	0	0, 0	0.2164	0.1437, 0.3258	-0.2164	-0.3258, -0.1437
Waves 4 (mean age 7) to 5 (mean age 11), n = 9,685								
Underweight	-0.2795	-0.7281, -0.1073	0.2795	0.1073, 0.7281	0	0, 0	0	0, 0
Healthy weight	0.0059	0.0026, 0.0135	-0.0673	-0.0898, -0.052	0.0614	0.0494, 0.0763	0	0, 0
Overweight	0	0, 0	0.1062	0.0645, 0.1749	-0.3265	-0.4677, -0.2302	0.2203	0.1657, 0.2928
Obesity	0	0, 0	0	0, 0	0.0705	0.0402, 0.1234	-0.0705	-0.1234, -0.0402
Waves 5 (mean age 11) to 6 (mean age 14), n = 8,593								
Underweight	-0.3024	-0.8045, -0.1137	0.3024	0.1137, 0.8045	0	0, 0	0	0, 0
Healthy weight	0.0071	0.0029, 0.0178	-0.0638	-0.0948, -0.0447	0.0567	0.0418, 0.077	0	0, 0
Overweight	0	0, 0	0.2462	0.1742, 0.348	-0.4182	-0.6143, -0.2853	0.172	0.1111, 0.2663
Obesity	0	0, 0	0	0, 0	0.1253	0.0825, 0.1902	-0.1253	-0.1902, -0.0825

Waves 6 (mean age 14) to 7 (mean age 17) n = 7,085								
Underweight	-0.2549	-0.6035, -0.1077	0.2549	0.1077, 0.6035	0	0, 0	0	0, 0
Healthy weight	0.0073	0.002, 0.0267	-0.0675	-0.1134, -0.0438	0.0602	0.0418, 0.0867	0	0, 0
Overweight	0	0, 0	0.259	0.1749, 0.3834	-0.4931	-0.8057, -0.3047	0.2341	0.1298, 0.4223
Obesity	0	0, 0	0	0, 0	0.13	0.0782, 0.2161	-0.13	-0.2161, -0.0782

MLE: Maximum likelihood estimate of transition hazard. Point estimates incorporate survey weights, and confidence intervals were derived using replicate weights. British 1990 growth reference (UK90) and UK cut-offs for population monitoring.

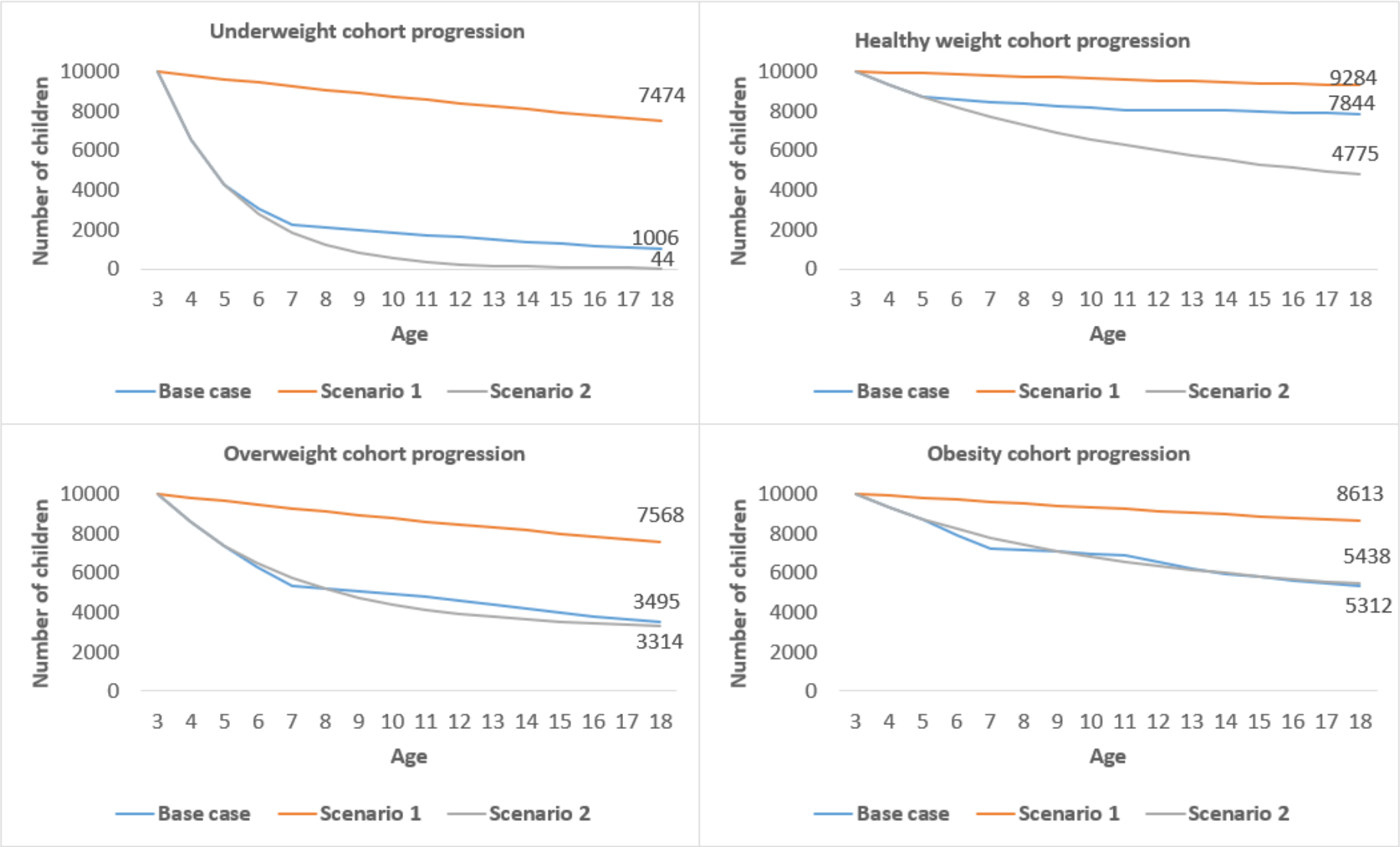

Figure D 2 WHO references and cut-offs: Modelled prevalence for four hypothetical cohorts of 10,000 children aged three at baseline in underweight, healthy weight, overweight, and obesity categories

Checking for model convergence

When estimating transition hazards, the model may not converge if there are no observed transitions within the data or if the number of transitions from one state to another is too small. This non-convergence and, ultimately, failure of the model to produce a maximum likelihood estimate is often due to the small sample size of the affected subgroup within an explanatory variable. Lack of convergence may not be evident from merely observing transition hazards. Therefore, it is necessary to calculate transition probabilities and their confidence intervals. If convergence is not achieved, the transition probabilities on a transition matrix row will not sum up to 1 (usually, they will exceed 1). A fix for non-convergence is to merge the levels of a variable. An example is ethnicity, where the model did not converge when assessing for the "Black/Black British" and "Indian/Pakistani/Bangladeshi" subgroups in the Waves 2 to 3 dataset, separately or when merged. As a result, I merged both subgroups with the "mixed or other" ethnicity subgroup, limiting my analysis for ethnicity to white and non-white subgroups. Jackson discusses other causes of non-convergence and ways of handling them in the MSM framework. [420]

Appendix E

CPRD data application protocol

Found here: https://www.cprd.com/approved-studies/economic-consequences-childhood-excess-weight-secondary-analyses-cprd

Consultations – results of data cleaning and processing

From 1st January 2014 to 30th March 2020, there were 68,835,092 childhood-related consultations in the CPRD Aurum dataset. After excluding consultations that did not meet my inclusion criteria, the number of consultations was reduced to 45,731,687. Upon further exclusion of consultations that did not occur within one year before or after the index BMI measurement, the number reduced to 15,872,715. 9,611,767 consultations were deemed duplicates and removed, leaving 6,260,948 consultations. These consultations spanned 79 activities or EMIS Medical dictionary terms (Table E 1 Distribution of EMIS Medical dictionary terms in the consultation dataset with the decision on inclusion/exclusion). The first seven terms in Table 17 capture 95% of the terms, with omitted or "Missing term", "GP surgery", and "Scanned documents" accounting for 4,610,565 of the 6,260,948 consultations. Terms such as "scanned document", "Awaiting clinical code migration to EMIS Web", and "Administration note" were not treated as patient-facing activities and were therefore excluded. Missing or null activities were included as they accounted for the largest consultation group, and their outright exclusion could lead to an underestimation of resource use. 39 of the 79 terms in Table E 1 Distribution of EMIS Medical dictionary terms in the consultation dataset with the decision on inclusion/exclusion were included, resulting in 3,488,799 remaining consultations.

Table E 1 Distribution of EMIS Medical dictionary terms in the consultation dataset with the decision on inclusion/exclusion

#	Term	Frequency	Percent	Cumulative	Include?
	Total	6,260,948	100.00		
1	Missing term	1,695,873	27.09	27.09	Yes
2	GP Surgery	1,478,933	23.62	50.71	Yes
3	Scanned document	1,435,759	22.93	73.64	No
4	Awaiting clinical code migration to EMIS Web	606,680	9.69	83.33	No
5	Administration note	369,724	5.91	89.24	No
6	Inbound document	208,002	3.32	92.56	No
7	Telephone consultation	178,809	2.86	95.42	Yes
8	Outbound referral	83,081	1.33	96.75	No
9	Third party consultation	27,671	0.44	97.19	Yes
10	Face to face consultation	23,874	0.38	97.57	Yes
11	Other note	14,573	0.23	97.8	No
12	Provision of general practitioner intermediate care	12,547	0.2	98	Yes
13	Clinic note	10,289	0.16	98.16	No
14	Telephone call to relative/carer	9,944	0.16	98.32	Yes

#	Term	Frequency	Percent	Cumulative	Include?
15	Hospital outpatient report	9,509	0.15	98.47	No
16	Externally entered note	9,508	0.15	98.62	No
17	Telephone triage encounter	9,293	0.15	98.77	Yes
18	Telephone call to a patient	8,745	0.14	98.91	Yes
19	Walk-in clinic	7,196	0.11	99.02	Yes
20	Routine consultation	7,109	0.11	99.13	Yes
21	Emergency consultation	6,564	0.1	99.23	Yes
22	Emergency appointment	5,874	0.09	99.32	Yes
23	Urgent consultation	5,596	0.09	99.41	Yes
24	Non-consultation data	3,918	0.06	99.47	No
25	Home visit note	3,911	0.06	99.53	No
26	Enterprise consultation	3,908	0.06	99.59	No
27	Telephone call from relative/carer	3,223	0.05	99.64	Yes
28	Seen in GP unit	2,795	0.04	99.68	Yes
29	Laboratory result	2,748	0.04	99.72	No
30	Discussion with colleague	2,061	0.03	99.75	No
31	Repeat prescription	1,746	0.03	99.78	No
32	Mail to patient	1,625	0.03	99.81	No
33	OOH report	1,296	0.02	99.83	No
34	Telephone call from a patient	1,280	0.02	99.85	Yes
35	Hospital inpatient report	838	0.01	99.86	No
36	Other consultation medium used	730	0.01	99.87	Yes
37	Non-consultation medication data	594	0.01	99.88	No
38	E-mail received from patient	564	0.01	99.89	No
39	Case conference	479	0.01	99.9	No
40	Face to face consultation with relative/carer	437	0.01	99.91	Yes
41	Group consultation	432	0.01	99.92	Yes
42	Medication requested	424	0.01	99.93	No
43	Same day appointment	396	0.01	99.94	Yes
44	Seen in urgent care centre	386	0.01	99.95	Yes
45	Telephone encounter	341	0.01	99.96	Yes
46	Extended hours consultation	321	0.01	99.97	Yes
47	Discussion with other professional	173	0	99.97	No
48	Consultation via SMS text message	133	0	99.97	Yes
49	School visit note	133	0	99.97	No
50	Nursing home visit note	125	0	99.97	No
51	Mail from patient	121	0	99.97	No
52	SMS text message sent to patient	85	0	99.97	No
53	E-mail consultation	75	0	99.97	Yes
54	Residential home visit note	69	0	99.97	No
55	Children's home visit note	67	0	99.97	No
56	Nurse telephone triage	59	0	99.97	Yes
57	Seen in rapid access clinic at GP surgery	59	0	99.97	Yes
58	Consultation via video conference	47	0	99.97	Yes
59	E-mail sent to patient	45	0	99.97	No
60	Twilight visit note	18	0	99.97	No
61	Progress report	17	0	99.97	No

#	Term	Frequency	Percent	Cumulative	Include?
62	Multidisciplinary team meeting without patient	16	0	99.97	Yes
63	Night visit note	14	0	99.97	No
64	Online communication	12	0	99.97	No
65	Hospital inpatient note	10	0	99.97	No
66	Seen in private clinic	10	0	99.97	Yes
67	Consultation via multimedia	9	0	99.97	Yes
68	Child protection core group meeting	7	0	99.97	No
69	Inbound referral	7	0	99.97	No
70	Seen in influenza vaccination clinic	7	0	99.97	Yes
71	First telephone consultation	5	0	99.97	Yes
72	Did not attend	4	0	99.97	No
73	Radiology result	4	0	99.97	No
74	District nurse visit	3	0	99.97	Yes
75	Seen in drug misuse clinic	3	0	99.97	Yes
76	Seen in hospital ward	2	0	99.97	Yes
77	Process notes	1	0	99.97	No
78	Seen by general practitioner with special interest in ear nose and throat disorders	1	0	99.99	Yes
79	Seen in baby clinic	1	0	100.00	Yes

Upon applying my second consultation inclusion/exclusion criteria, which involved examining the job category/description of the staff member who created the event, 52,584 consultations not linked to a staff member or job description were excluded, leaving 3,436,215 consultations. See Appendix E for a detailed report of 143 job descriptions and the decision to include or exclude them. "General Medical Practitioner" was the biggest category at 1,034,277 consultations. My conservative approach excluded entries relating to consultations with support staff and other non-healthcare professionals, such as "Receptionists" and "Clerical Workers". Thus, 94 of the 143 staff member job descriptions were included, covering 2,155,044 remaining consultations (See Table E 2 List of included job descriptions/staff and their frequency in the consultations dataset). 95% of these consultations were linked to 10 staff roles, namely, "General Medical Practitioner", "Community Practitioner", "Salaried General Practitioner", "Specialist Nurse Practitioner", "GP Registrar", "Health Care Support Worker", "Sessional GP", "Community Nurse", "Healthcare Assistant", "Staff Nurse", "Locum GP", "Pharmacist" and "Nurse Manager".

Table E 2 List of included job descriptions/staff and their frequency in the consultations dataset

#	Job description	Frequency	Percent	Cumulative	Included?
	Total	2,155,044	100.00		
1	General Medical Practitioner	1,034,277	47.99	47.99	Yes
2	Community Practitioner	234,068	10.86	58.85	Yes
3	Salaried General Practitioner	166,043	7.70	66.56	Yes
4	Specialist Nurse Practitioner	122,725	5.69	72.25	Yes
5	GP Registrar	79,017	3.67	75.92	Yes

#	Job description	Frequency	Percent	Cumulative	Included?
6	Health Care Support Worker	77,264	3.59	79.51	Yes
7	Sessional GP	76,644	3.56	83.06	Yes
8	Community Nurse	74,611	3.46	86.52	Yes
9	Healthcare Assistant	68,961	3.20	89.72	Yes
10	Staff Nurse	47,635	2.21	91.94	Yes
11	Locum GP	26,525	1.23	93.17	Yes
12	Pharmacist	23,889	1.11	94.27	Yes
13	Nurse Manager	17,435	0.81	95.08	Yes
14	Associate Practitioner - Nurse	16,146	0.75	95.83	Yes
15	Nurse Consultant	15,025	0.70	96.53	Yes
16	Sister/Charge Nurse	13,588	0.63	97.16	Yes
17	Associate Practitioner - General Practitioner	9,631	0.45	97.61	Yes
18	Phlebotomist	8,591	0.40	98.01	Yes
19	Enrolled Nurse	7,880	0.37	98.37	Yes
20	Paramedic	4,886	0.23	98.60	Yes
21	Paramedic Specialist Practitioner	3,319	0.15	98.75	Yes
22	Advanced Practitioner	3,068	0.14	98.89	Yes
23	Associate Practitioner	2,983	0.14	99.03	Yes
24	Consultant	2,491	0.12	99.15	Yes
25	Clinical Assistant	2,358	0.11	99.26	Yes
26	Associate Specialist	2,114	0.10	99.36	Yes
27	Assistant Practitioner	2,082	0.10	99.45	Yes
28	Practitioner	1,894	0.09	99.54	Yes
29	Physician Assistant	976	0.05	99.59	Yes
30	Staff Grade	699	0.03	99.62	Yes
31	House Officer - Post Registration	686	0.03	99.65	Yes
32	Assistant GP	589	0.03	99.68	Yes
33	Senior House Officer	551	0.03	99.70	Yes
34	Deputising Doctor	484	0.02	99.73	Yes
35	Radiologist	446	0.02	99.75	Yes
36	Child Protection worker	407	0.02	99.77	Yes
37	Nursery Nurse	402	0.02	99.78	Yes
38	Chiropodist/Podiatrist	382	0.02	99.80	Yes
39	Clinical Director - Medical	344	0.02	99.82	Yes
40	Other Community Health Service	318	0.01	99.83	Yes
41	Specialist Practitioner	288	0.01	99.85	Yes
42	Paramedic Consultant	269	0.01	99.86	Yes
43	Dietitian	253	0.01	99.87	Yes
44	Student Practice Nurse	227	0.01	99.88	Yes
45	Community Mental Health Nurse	225	0.01	99.89	Yes
46	Art Therapist	221	0.01	99.90	Yes
47	Trainee Practitioner	217	0.01	99.91	Yes
48	Midwife - Sister/Charge Nurse	208	0.01	99.92	Yes
49	Clinical Team Manager	194	0.01	99.93	Yes
50	Therapist	193	0.01	99.94	Yes
51	Researcher	173	0.01	99.95	Yes
52	Art Therapist Consultant	106	0.00	99.95	Yes

#	Job description	Frequency	Percent	Cumulative	Included?
53	Physiotherapist	105	0.00	99.96	Yes
54	Specialist Registrar	103	0.00	99.96	Yes
55	Community Team Manager	86	0.00	99.97	Yes
56	Student Nurse - Adult Branch	80	0.00	99.97	Yes
57	Patient Welfare Officer	77	0.00	99.97	Yes
58	Clinical Director	74	0.00	99.98	Yes
59	Modern Matron	53	0.00	99.98	Yes
60	Physiotherapist Manager	40	0.00	99.98	Yes
61	Art Therapist Specialist Practitioner	37	0.00	99.98	Yes
62	House Officer - Pre Registration	37	0.00	99.98	Yes
63	Osteopath	37	0.00	99.99	Yes
64	Physiotherapist Specialist Practitioner	33	0.00	99.99	Yes
65	Clinical Medical Officer	30	0.00	99.99	Yes
66	Other Community Health Service - Social Care Worker	30	0.00	99.99	Yes
67	Trust Grade Doctor - SHO level	25	0.00	99.99	Yes
68	Social Care Support Worker	23	0.00	99.99	Yes
69	Midwife	21	0.00	99.99	Yes
70	Trust Grade Doctor - Career Grade level	19	0.00	99.99	Yes
71	Paramedic Manager	17	0.00	99.99	Yes
72	Asst. Clinical Medical Officer	16	0.00	100.00	Yes
73	Radiographer	16	0.00	100.00	Yes
74	Healthcare Science Assistant	11	0.00	100.00	Yes
75	Technician - Healthcare Scientists	11	0.00	100.00	Yes
76	Dietitian Consultant	9	0.00	100.00	Yes
77	Healthcare Scientist	8	0.00	100.00	Yes
78	Student Community Practitioner	7	0.00	100.00	Yes
79	Counsellor	6	0.00	100.00	Yes
80	Clinical Psychologist	4	0.00	100.00	Yes
81	Director of Nursing	3	0.00	100.00	Yes
82	Physiotherapist Consultant	3	0.00	100.00	Yes
83	Trust Grade Doctor - House Officer level	3	0.00	100.00	Yes
84	Multi Therapist Specialist Practitioner	2	0.00	100.00	Yes
85	Art Therapist Manager	1	0.00	100.00	Yes
86	Community Learning Disabilities Nurse	1	0.00	100.00	Yes
87	Community Worker (children)	1	0.00	100.00	Yes
88	Dietitian Specialist Practitioner	1	0.00	100.00	Yes
89	Midwife - Specialist Practitioner	1	0.00	100.00	Yes
90	Nursing Cadet	1	0.00	100.00	Yes
91	Psychotherapist	1	0.00	100.00	Yes
92	Regional Dental Officer	1	0.00	100.00	Yes
93	Student Health Visitor	1	0.00	100.00	Yes
94	Trust Grade Doctor - Specialist Registrar level	1	0.00	100.00	Yes

Most job descriptions fell under the surgical consultation type during valuing and costing. However, 10 job descriptions (namely, "General Medical Practitioner", "Salaried General Practitioner", "GP Registrar", "Sessional GP", "Community Nurse", "Locum GP", "Associate Practitioner – Nurse", "Associate Practitioner - General

Practitioner", "Assistant GP", and "Deputising Doctor") had multiple consultation types. For these 10 job descriptions, GP Surgery, totalling 849,771 consultations, was the most predominant EMIS term. Consequently, the surgical consultation type was the most prevalent in my dataset. Only 4,899 consultation types costs were derived by taking the average of the surgical, home and phone types due to uncertainty in their classification. Appendix E reports a breakdown of the EMIS medical dictionary terms for the 10 job descriptions with multiple consultation types and their designated consultation types.

Prescriptions – results of data cleaning and processing

From 2014 onwards, there were 14,970,652 prescriptions. After excluding prescriptions that did not fall within my dataset of unique children, 12,106,362 prescriptions were left. When prescriptions not bound within a year of the BMI measurement were excluded, 3,675,263 prescriptions remained. With the removal of duplicates, 3,640,603 prescriptions remained. My conservative approach of excluding prescriptions with missing or conflicting SNOMED codes resulted in a final count of 3,326,081.

Categorisation of resource use and costs into the year before or after a BMI measurement

Consultations- categorisation of resource use and costs into the year before or after a BMI measurement

Figure 21 illustrates the algorithm used to allocate resource utilisation and associated costs to either the year preceding or the year following the index BMI measurement. This algorithm avoids double counting costs in the year before and after the index BMI measurement while including relevant cost data. Costs one year before the index BMI measurement were included if the date associated with the consultation (‘consdate’) was later than or equal to the date of the calendar year before the index BMI measurement and before the date of the index BMI measurement. Costs one year after the index BMI measurement were included if the date associated with the consultation (‘consdate’) was later than or equal to the date of the index measurement and before or equal to the date of the calendar year after the index measurement.

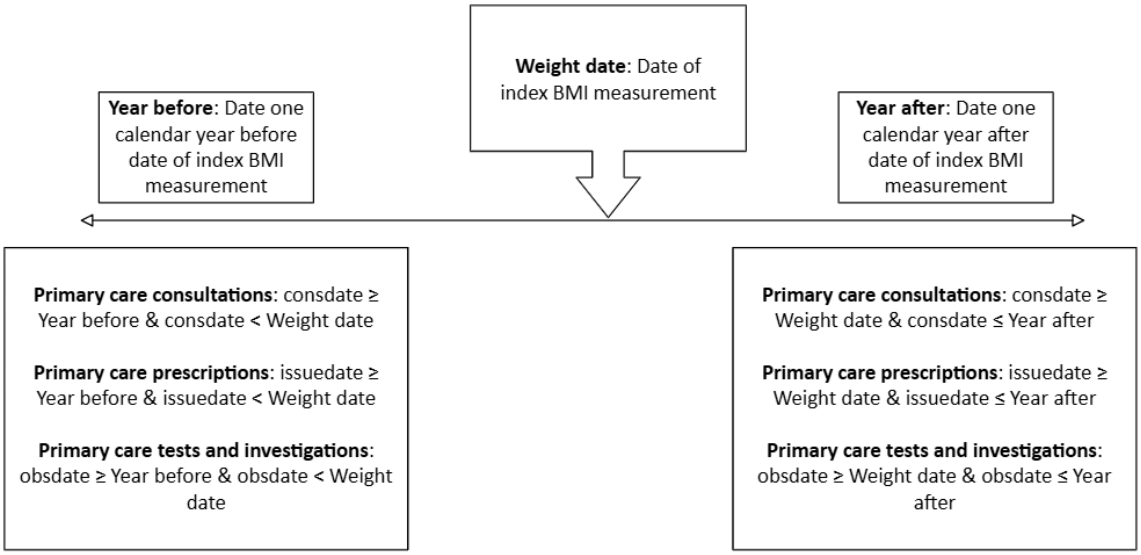

Figure E 1 Categorisation of resource use and costs (primary care consultations, prescriptions and tests) one year before and after the index BMI measurement

Prescriptions- categorisation of resource use and costs into the year before or after a BMI measurement

I used a formula similar to consultations to categorise prescription resource use and costs (see Figure 21). Costs one year before the index BMI measurement were included if the date associated with the prescription ('issuedate') was later than or equal to the date of the calendar year before the index measurement and before the date of the index measurement. Costs one year after the index BMI measurement were included if the date associated with the prescription ('issuedate') was later than or equal to the date of the index measurement and before or equal to the date of the calendar year after the index measurement.

Tests- categorisation of resource use and costs into the year before or after a BMI measurement

I used a formula similar to consultations to categorise tests resource use and costs (see Figure 21). Costs one year before the index BMI measurement were included if the date associated with the test or investigation request ('obsdate') was later than or equal to the date of the calendar year before the index measurement and before the date of the index measurement. Costs one year after the index BMI measurement were included if the date associated with the test or investigation request ('obsdate') was later than or equal to the date of the index measurement and before or equal to the date of the calendar year after the index measurement.

Table E 3 The relationship between consultation costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
Underweight										

	Year before					Year after				
	dy/dx	**std. error**	**P>z**	**[95% conf.**	**interval]**	**dy/dx**	**std. error**	**P>z**	**[95% conf.**	**interval]**
Sex										
Male	-4.83	1.50	0.001	-7.78	-1.88	17.83	1.48	0	14.93	20.72
Female	-5.40	1.66	0.001	-8.64	-2.15	19.62	1.64	0	16.41	22.83
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Sex										
Male	1.74	1.00	0.082	-0.22	3.69	-2.59	0.90	0.004	-4.34	-0.83
Female	1.90	1.10	0.084	-0.26	4.06	-2.88	1.00	0.004	-4.83	-0.93
Obesity										
Sex										
Male	9.48	0.90	0	7.71	11.25	11.80	0.83	0	10.17	13.42
Female	10.45	1.00	0	8.49	12.40	13.07	0.92	0	11.26	14.87
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
Age (years)										
2	-6.78	2.18	0.002	-11.04	-2.52	24.38	2.07	0	20.33	28.43
3	-5.60	1.92	0.004	-9.37	-1.83	21.17	1.86	0	17.53	24.81
4	-5.43	1.82	0.003	-9.00	-1.86	20.48	1.69	0	17.17	23.79
5	-5.23	1.61	0.001	-8.38	-2.08	18.88	1.54	0	15.86	21.89
6	-5.06	1.51	0.001	-8.02	-2.10	17.70	1.47	0	14.81	20.58
7	-4.68	1.35	0.001	-7.34	-2.03	17.15	1.42	0	14.37	19.92
8	-4.65	1.36	0.001	-7.32	-1.98	16.78	1.40	0	14.05	19.52
9	-4.53	1.34	0.001	-7.17	-1.90	16.71	1.39	0	13.98	19.44
10	-4.48	1.35	0.001	-7.12	-1.84	16.55	1.37	0	13.87	19.24
11	-4.38	1.34	0.001	-7.01	-1.75	17.28	1.45	0	14.43	20.12
12	-4.61	1.41	0.001	-7.37	-1.84	17.71	1.57	0	14.64	20.78
13	-5.04	1.57	0.001	-8.12	-1.95	18.20	1.69	0	14.88	21.52
14	-5.10	1.67	0.002	-8.36	-1.83	16.72	1.74	0	13.32	20.13
15	-5.64	2.24	0.012	-10.04	-1.25	14.24	2.91	0	8.54	19.95
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Age (years)										
2	2.54	1.44	0.078	-0.29	5.37	-3.63	1.26	0.004	-6.09	-1.17
3	2.29	1.28	0.072	-0.21	4.79	-3.28	1.14	0.004	-5.52	-1.05
4	2.16	1.21	0.074	-0.21	4.52	-2.94	1.02	0.004	-4.94	-0.94
5	1.84	1.07	0.084	-0.25	3.93	-2.66	0.92	0.004	-4.47	-0.85
6	1.71	1.00	0.089	-0.26	3.67	-2.57	0.89	0.004	-4.31	-0.83
7	1.50	0.90	0.095	-0.26	3.27	-2.46	0.85	0.004	-4.13	-0.79
8	1.52	0.91	0.092	-0.25	3.30	-2.44	0.84	0.004	-4.09	-0.78
9	1.51	0.89	0.09	-0.24	3.26	-2.43	0.84	0.004	-4.08	-0.78
10	1.53	0.89	0.088	-0.23	3.28	-2.38	0.82	0.004	-3.99	-0.76
11	1.53	0.89	0.085	-0.21	3.27	-2.53	0.88	0.004	-4.25	-0.81
12	1.60	0.93	0.086	-0.22	3.43	-2.64	0.92	0.004	-4.44	-0.84
13	1.79	1.04	0.084	-0.24	3.82	-2.72	0.95	0.004	-4.58	-0.86
14	1.91	1.09	0.08	-0.23	4.05	-2.49	0.87	0.004	-4.20	-0.77

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
15	2.57	1.44	0.073	-0.24	5.39	-2.10	0.82	0.011	-3.71	-0.48
Obesity										
Age (years)										
2	13.70	1.32	0	11.12	16.28	16.38	1.17	0	14.09	18.68
3	12.05	1.16	0	9.77	14.33	14.58	1.06	0	12.50	16.66
4	11.43	1.10	0	9.28	13.59	13.48	0.95	0	11.61	15.34
5	10.13	0.97	0	8.23	12.04	12.27	0.86	0	10.58	13.96
6	9.52	0.91	0	7.73	11.31	11.71	0.83	0	10.09	13.34
7	8.52	0.82	0	6.92	10.13	11.27	0.79	0	9.72	12.82
8	8.58	0.82	0	6.97	10.19	11.11	0.78	0	9.58	12.64
9	8.47	0.81	0	6.88	10.05	11.08	0.78	0	9.55	12.60
10	8.48	0.81	0	6.89	10.06	10.89	0.76	0	9.40	12.38
11	8.44	0.81	0	6.86	10.02	11.49	0.81	0	9.90	13.08
12	8.85	0.87	0	7.15	10.56	11.92	0.89	0	10.18	13.66
13	9.81	1.04	0	7.76	11.85	12.27	0.98	0	10.35	14.19
14	10.30	1.18	0	7.98	12.61	11.23	1.04	0	9.20	13.26
15	13.14	1.93	0	9.35	16.92	9.50	1.87	0	5.84	13.17
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
Ethnicity										
Other/Uknown	-4.75	1.22	0	-7.14	-2.35	17.05	1.42	0	14.27	19.83
Bangladeshi	-6.26	2.17	0.004	-10.51	-2.01	24.14	2.20	0	19.84	28.45
Black	-5.43	1.67	0.001	-8.71	-2.14	19.95	1.73	0	16.57	23.34
Chinese/Other Asian	-6.17	1.95	0.002	-10.00	-2.35	22.28	1.93	0	18.50	26.07
Indian	-6.20	2.04	0.002	-10.19	-2.21	22.89	1.97	0	19.02	26.76
Pakistani	-6.04	2.07	0.003	-10.09	-1.99	23.03	2.04	0	19.04	27.02
White	-4.92	1.56	0.002	-7.98	-1.85	18.01	1.48	0	15.11	20.91
Mixed	-5.38	1.70	0.002	-8.71	-2.06	19.81	1.68	0	16.51	23.10
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Ethnicity										
Other/Uknown	1.22	0.82	0.136	-0.38	2.82	-2.49	0.86	0.004	-4.18	-0.80
Bangladeshi	2.59	1.44	0.072	-0.23	5.40	-3.85	1.35	0.004	-6.50	-1.20
Black	1.92	1.11	0.083	-0.25	4.10	-3.04	1.06	0.004	-5.12	-0.97
Chinese/Other Asian	2.26	1.29	0.081	-0.28	4.80	-3.40	1.18	0.004	-5.71	-1.09
Indian	2.39	1.35	0.076	-0.25	5.03	-3.50	1.21	0.004	-5.88	-1.12
Pakistani	2.46	1.37	0.073	-0.23	5.14	-3.60	1.25	0.004	-6.06	-1.14
White	1.82	1.04	0.079	-0.21	3.85	-2.57	0.89	0.004	-4.32	-0.82
Mixed	1.97	1.13	0.081	-0.24	4.17	-2.94	1.02	0.004	-4.93	-0.94
Obesity										
Ethnicity										
Other/Uknown	7.52	0.75	0	6.06	8.99	11.32	0.80	0	9.76	12.89
Bangladeshi	13.55	1.32	0	10.97	16.13	16.92	1.26	0	14.44	19.39
Black	10.54	1.01	0	8.57	12.52	13.61	0.97	0	11.70	15.52
Chinese/Other	12.27	1.19	0	9.95	14.60	15.19	1.10	0	13.03	17.35

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
Asian										
Indian	12.77	1.23	0	10.35	15.19	15.63	1.14	0	13.40	17.85
Pakistani	12.93	1.25	0	10.49	15.38	15.94	1.17	0	13.65	18.23
White	9.84	0.94	0	8.00	11.68	11.80	0.83	0	10.18	13.42
Mixed	10.68	1.03	0	8.67	12.69	13.28	0.95	0	11.42	15.14
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
IMD										
Highest quintile	-4.91	1.53	0.001	-7.90	-1.92	18.25	1.50	0	15.32	21.18
Fourth quintile	-4.89	1.54	0.001	-7.91	-1.88	18.20	1.50	0	15.26	21.15
Third quintile	-5.02	1.57	0.001	-8.11	-1.94	18.54	1.54	0	15.52	21.56
Second quintile	-5.27	1.61	0.001	-8.43	-2.11	19.03	1.60	0	15.90	22.16
Lowest quintile	-5.17	1.59	0.001	-8.28	-2.07	18.81	1.58	0	15.72	21.90
Healthy weight	(base outcome)					(base outcome)				
Overweight										
IMD										
Highest quintile	1.76	1.01	0.083	-0.23	3.74	-2.59	0.90	0.004	-4.35	-0.83
Fourth quintile	1.78	1.02	0.081	-0.22	3.78	-2.62	0.91	0.004	-4.40	-0.84
Third quintile	1.82	1.04	0.082	-0.23	3.86	-2.70	0.93	0.004	-4.53	-0.87
Second quintile	1.85	1.07	0.085	-0.25	3.94	-2.81	0.97	0.004	-4.72	-0.90
Lowest quintile	1.82	1.05	0.084	-0.25	3.88	-2.78	0.96	0.004	-4.66	-0.89
Obesity										
IMD										
Highest quintile	9.62	0.92	0	7.81	11.43	11.92	0.84	0	10.27	13.56
Fourth quintile	9.69	0.93	0	7.87	11.51	11.98	0.84	0	10.32	13.63
Third quintile	9.91	0.95	0	8.05	11.77	12.29	0.87	0	10.59	13.98
Second quintile	10.17	0.97	0	8.26	12.07	12.73	0.90	0	10.97	14.49
Lowest quintile	10.00	0.95	0	8.13	11.86	12.58	0.89	0	10.84	14.32
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
Region										
North East	-4.96	1.53	0.001	-7.95	-1.96	16.43	1.35	0	13.78	19.08
North West	-4.76	1.57	0.002	-7.83	-1.69	17.06	1.41	0	14.29	19.84
Yorkshire and The Humber	-5.18	1.52	0.001	-8.16	-2.19	17.47	1.42	0	14.68	20.25
East Midlands	-4.55	1.56	0.004	-7.62	-1.49	18.13	1.61	0	14.98	21.28
West Midlands	-4.95	1.48	0.001	-7.84	-2.05	17.15	1.45	0	14.30	19.99
East of England	-5.60	1.66	0.001	-8.84	-2.35	21.14	1.71	0	17.79	24.49
London	-5.77	1.72	0.001	-9.14	-2.40	21.13	1.82	0	17.57	24.69
South East	-4.74	1.49	0.001	-7.65	-1.83	18.16	1.49	0	15.24	21.07
South West	-4.73	1.54	0.002	-7.75	-1.71	18.83	1.54	0	15.82	21.84
Missing	-4.68	1.58	0.003	-7.78	-1.59	16.00	1.36	0	13.33	18.67
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Region										

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
North East	1.75	1.01	0.084	-0.23	3.74	-2.32	0.81	0.004	-3.90	-0.74
North West	1.85	1.04	0.076	-0.19	3.88	-2.47	0.86	0.004	-4.15	-0.79
Yorkshire and The Humber	1.71	1.01	0.092	-0.28	3.69	-2.38	0.83	0.004	-4.01	-0.74
East Midlands	1.86	1.04	0.072	-0.17	3.89	-2.80	0.98	0.004	-4.72	-0.89
West Midlands	1.67	0.98	0.089	-0.25	3.59	-2.56	0.89	0.004	-4.30	-0.82
East of England	1.86	1.10	0.091	-0.30	4.02	-2.83	1.00	0.005	-4.78	-0.87
London	1.94	1.14	0.089	-0.30	4.18	-3.22	1.12	0.004	-5.41	-1.03
South East	1.72	0.99	0.081	-0.21	3.65	-2.58	0.89	0.004	-4.33	-0.82
South West	1.81	1.02	0.077	-0.19	3.81	-2.65	0.92	0.004	-4.46	-0.84
Missing	1.87	1.05	0.074	-0.18	3.92	-2.32	0.81	0.004	-3.90	-0.74
Obesity										
Region										
North East	9.62	0.92	0	7.81	11.43	10.69	0.75	0	9.21	12.17
North West	9.85	0.94	0	8.00	11.70	11.28	0.79	0	9.73	12.83
Yorkshire and The Humber	9.59	0.92	0	7.78	11.40	11.13	0.79	0	9.59	12.67
East Midlands	9.79	0.95	0	7.92	11.65	12.46	0.92	0	10.66	14.26
West Midlands	9.30	0.89	0	7.56	11.05	11.54	0.82	0	9.94	13.15
East of England	10.42	1.01	0	8.45	12.40	13.32	0.94	0	11.48	15.17
London	10.84	1.04	0	8.81	12.87	14.41	1.03	0	12.39	16.42
South East	9.37	0.90	0	7.61	11.12	11.85	0.83	0	10.22	13.48
South West	9.69	0.93	0	7.87	11.52	12.24	0.86	0	10.55	13.92
Missing	9.89	0.97	0	8.00	11.78	10.59	0.77	0	9.08	12.10

Diagnostic tests

Box-cox regression in Stata

boxcox Total_costs UK90_bmi Sex age_whole Ethnicity IMD Region if Total_costs > 0

Modified Park test in Stata

glm Total_costs UK90_bmi Sex age_whole Ethnicity IMD Region if Total_costs > 0, family(gamma) link(log) vce(robust)

* linear combination, lyhat is on log-scale */

predict lyhat if e(sample),xb

* expected value of y; y in raw scale, equal to exp(lyhat) with log link*/

predict yhat_g if e(sample), mu

* retransform yhat_g to raw scale and get the raw residuals

gen raw2 = (Total_costs - yhat_g)^2

* regress the squared raw residuals (est. variance)on a constant and the log-transformed predicted y (mean)

* For this, we are interested in the coefficient of the lyhat

glm raw2 lyhat, family(gamma) link(log) vce(robust)

* Guassian family, variance is constant, unrelated to mean

test lyhat - 0 = 0

* Poisson family, variance = mean

test lyhat - 1 = 0

* gamma family, variance > mean

test lyhat - 2 = 0

* Inverse family or Wald

test lyhat - 3 = 0

AIC and BIC test in Stata - Comparison of AIC and BIC outputs for ZINB and ZIP models

* Choose the model with the lowest outputs for AIC and BIC

Table E 4 Akaike's information criterion and Bayesian information criterion for ZINB and ZIP regression models - Primary care consultations one year before BMI measurement

Model	N	ll(null)	ll(model)	df	AIC	BIC
ZINB	268,231	-652782.7	-648592.5	77	1297339	1298148
ZIP	268,231	-810709.5	-794554.2	76	1589260	1590058

Table E 5 Akaike's information criterion and Bayesian information criterion for ZINB and ZIP regression models - Primary care prescriptions one year before BMI measurement

Model	N	ll(null)	ll(model)	df	AIC	BIC
ZINB	268,231	-699782.2	-697470.9	77	1395096	1395904
ZIP	268,231	-1444592	-1416409	76	2832969	2833767

Results

Consultations – results

Table E 6 Regression coefficients (marginal effects) for the two parts of the model- Consultation resource use

Total_Consultations	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	**Year before (ZIMB)**				**Year after (ZIP)**			
UK90_bmi								
Underweight	-0.043	0.001	-0.067	-0.019	0.041	0.000	0.024	0.059
Overweight	0.034	0.000	0.018	0.049	0.011	0.062	-0.001	0.023
Obesity	0.082	0.000	0.068	0.095	0.078	0.000	0.068	0.088
Sex								
Female	0.097	0.000	0.088	0.107	0.068	0.000	0.060	0.075
age_whole								
3	-0.091	0.000	-0.110	-0.071	-0.075	0.000	-0.090	-0.060
4	-0.109	0.000	-0.129	-0.089	-0.228	0.000	-0.245	-0.212
5	-0.307	0.000	-0.327	-0.286	-0.327	0.000	-0.343	-0.311
6	-0.391	0.000	-0.413	-0.370	-0.377	0.000	-0.393	-0.362
7	-0.508	0.000	-0.529	-0.486	-0.414	0.000	-0.430	-0.398
8	-0.496	0.000	-0.517	-0.474	-0.406	0.000	-0.422	-0.390
9	-0.504	0.000	-0.527	-0.482	-0.388	0.000	-0.405	-0.371
10	-0.486	0.000	-0.510	-0.462	-0.385	0.000	-0.403	-0.367
11	-0.480	0.000	-0.509	-0.452	-0.310	0.000	-0.331	-0.289
12	-0.431	0.000	-0.486	-0.377	-0.298	0.000	-0.341	-0.254
13	-0.320	0.000	-0.418	-0.223	-0.273	0.000	-0.337	-0.209
14	-0.281	0.000	-0.390	-0.172	-0.364	0.000	-0.458	-0.270
15	-0.085	0.425	-0.295	0.124	-0.619	0.000	-0.893	-0.346
Ethnicity								
Other/Uknown	-0.152	0.000	-0.169	-0.134	-0.071	0.000	-0.082	-0.060
Bangladeshi	0.292	0.000	0.259	0.325	0.276	0.000	0.251	0.301
Black	0.021	0.060	-0.001	0.044	0.029	0.000	0.013	0.045
Chinese/Other Asian	0.161	0.000	0.132	0.189	0.136	0.000	0.116	0.157
Indian	0.209	0.000	0.182	0.236	0.175	0.000	0.155	0.196
Pakistani	0.212	0.000	0.189	0.235	0.213	0.000	0.196	0.231
Mixed	0.042	0.001	0.017	0.066	0.050	0.000	0.031	0.068
IMD								
Fourth quintile	-0.005	0.600	-0.022	0.013	0.002	0.800	-0.012	0.015
Third quintile	0.026	0.002	0.009	0.043	0.024	0.000	0.011	0.037
Second quintile	0.048	0.000	0.031	0.065	0.038	0.000	0.025	0.051
Lowest quintile	0.054	0.000	0.038	0.071	0.069	0.000	0.056	0.082
Region								
North East	-0.016	0.279	-0.044	0.013	-0.136	0.000	-0.158	-0.114
North West	0.021	0.016	0.004	0.037	-0.064	0.000	-0.076	-0.051
Yorkshire and The Humber	0.031	0.034	0.002	0.060	-0.044	0.000	-0.066	-0.023
East Midlands	0.032	0.061	-0.001	0.065	0.013	0.302	-0.012	0.039
West Midlands	-0.039	0.000	-0.056	-0.022	-0.073	0.000	-0.085	-0.061

Total_Consultations Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
East of England	-0.002	0.895	-0.029	0.025	-0.010	0.321	-0.030	0.010
South East	-0.021	0.016	-0.038	-0.004	-0.036	0.000	-0.049	-0.023
South West	0.023	0.017	0.004	0.042	0.021	0.005	0.006	0.035
Missing	0.030	0.144	-0.010	0.071	-0.151	0.000	-0.185	-0.116
_cons	1.675	0.000	1.651	1.699	1.778	0.000	1.760	1.796
inflate								
UK90_bmi								
Underweight	0.113	0.037	0.007	0.218	-0.264	0.000	-0.338	-0.189
Overweight	0.084	0.015	0.017	0.152	0.024	0.247	-0.016	0.064
Obesity	0.023	0.454	-0.037	0.084	-0.078	0.000	-0.114	-0.042
Sex								
Female	0.261	0.000	0.217	0.305	-0.071	0.000	-0.096	-0.045
age_whole								
3	-0.733	0.000	-0.845	-0.621	-0.465	0.000	-0.532	-0.398
4	-0.422	0.000	-0.518	-0.325	0.275	0.000	0.217	0.334
5	-0.087	0.061	-0.179	0.004	0.408	0.000	0.352	0.463
6	0.019	0.686	-0.072	0.109	0.152	0.000	0.093	0.212
7	0.086	0.063	-0.005	0.177	0.245	0.000	0.186	0.304
8	-0.039	0.415	-0.133	0.055	0.119	0.000	0.059	0.180
9	-0.159	0.002	-0.259	-0.059	0.102	0.001	0.040	0.165
10	-0.264	0.000	-0.375	-0.153	0.202	0.000	0.138	0.266
11	-0.457	0.000	-0.602	-0.312	0.061	0.119	-0.016	0.137
12	-0.263	0.041	-0.515	-0.010	-0.192	0.022	-0.357	-0.028
13	-0.303	0.122	-0.687	0.081	-0.232	0.058	-0.472	0.008
14	-0.511	0.066	-1.057	0.034	-0.279	0.131	-0.641	0.083
15	-1.479	0.171	-3.596	0.638	-0.136	0.833	-1.407	1.134
Ethnicity								
Other/Uknown	1.594	0.000	1.532	1.655	-0.044	0.031	-0.083	-0.004
Bangladeshi	-0.321	0.004	-0.540	-0.101	-0.928	0.000	-1.077	-0.778
Black	0.176	0.001	0.069	0.283	-0.325	0.000	-0.392	-0.257
Chinese/Other Asian	0.234	0.001	0.092	0.375	-0.359	0.000	-0.448	-0.269
Indian	0.034	0.663	-0.118	0.186	-0.405	0.000	-0.495	-0.315
Pakistani	-0.420	0.000	-0.595	-0.245	-0.716	0.000	-0.802	-0.629
Mixed	0.116	0.084	-0.016	0.248	-0.192	0.000	-0.261	-0.123
IMD								
Fourth quintile	-0.036	0.451	-0.131	0.058	-0.021	0.341	-0.065	0.022
Third quintile	0.018	0.692	-0.073	0.109	-0.021	0.334	-0.065	0.022
Second quintile	0.219	0.000	0.133	0.305	-0.022	0.309	-0.066	0.021
Lowest quintile	0.302	0.000	0.221	0.384	-0.055	0.011	-0.098	-0.013

Total_Consultations Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
Region								
North East	0.031	0.631	-0.095	0.157	0.554	0.000	0.480	0.627
North West	-0.578	0.000	-0.665	-0.492	0.395	0.000	0.348	0.443
Yorkshire and The Humber	0.310	0.000	0.197	0.424	0.845	0.000	0.780	0.911
East Midlands	-0.986	0.000	-1.214	-0.757	-0.280	0.000	-0.406	-0.154
West Midlands	0.187	0.000	0.120	0.254	0.154	0.000	0.104	0.204
East of England	0.477	0.000	0.368	0.586	1.031	0.000	0.972	1.090
South East	-0.337	0.000	-0.421	-0.252	0.543	0.000	0.496	0.591
South West	-0.661	0.000	-0.773	-0.548	0.584	0.000	0.536	0.633
Missing	-1.037	0.000	-1.446	-0.628	0.297	0.000	0.168	0.426
_cons	-2.477	0.000	-2.602	-2.351	-2.417	0.000	-2.483	-2.350
/lnalpha	-0.132	0.000	-0.146	-0.118				
alpha	0.876		0.864	0.888				

Table E 7 Regression coefficients (marginal effects) for the two parts of the model- Consultation costs

Total_costs	Coefficient Year before (two-part GLM)	P>z	[95% conf.	interval]	Coefficient Year after (two-part GLM)	P>z	[95% conf.	interval]
logit								
UK90_bmi								
Underweight	-0.090	0.000	-0.135	-0.046	0.255	0.000	0.188	0.322
Overweight	0.001	0.955	-0.027	0.029	-0.015	0.431	-0.051	0.022
Obesity	0.054	0.000	0.030	0.079	0.104	0.000	0.072	0.137
Sex								
Female	-0.040	0.000	-0.058	-0.022	0.093	0.000	0.069	0.116
age_whole								
3	0.255	0.000	0.211	0.300	0.435	0.000	0.370	0.499
4	0.153	0.000	0.109	0.197	-0.309	0.000	-0.365	-0.252
5	-0.168	0.000	-0.210	-0.127	-0.461	0.000	-0.515	-0.407
6	-0.273	0.000	-0.315	-0.232	-0.252	0.000	-0.308	-0.196
7	-0.399	0.000	-0.440	-0.358	-0.358	0.000	-0.414	-0.303
8	-0.339	0.000	-0.380	-0.297	-0.239	0.000	-0.296	-0.183
9	-0.291	0.000	-0.333	-0.248	-0.216	0.000	-0.274	-0.158
10	-0.239	0.000	-0.284	-0.193	-0.301	0.000	-0.361	-0.241
11	-0.170	0.000	-0.223	-0.118	-0.139	0.000	-0.211	-0.068
12	-0.183	0.000	-0.284	-0.082	0.090	0.231	-0.057	0.237
13	-0.132	0.082	-0.281	0.017	0.140	0.202	-0.075	0.355
14	0.008	0.941	-0.213	0.229	0.125	0.421	-0.179	0.429
15	0.611	0.118	-0.154	1.376	-0.233	0.597	-1.096	0.630

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Ethnicity								
Other/Uknown	-0.897	0.000	-0.921	-0.873	0.009	0.599	-0.025	0.044
Bangladeshi	0.399	0.000	0.322	0.476	0.976	0.000	0.835	1.117
Black	-0.003	0.883	-0.042	0.036	0.311	0.000	0.251	0.371
Chinese/Other Asian	0.037	0.185	-0.018	0.092	0.388	0.000	0.305	0.471
Indian	0.175	0.000	0.118	0.231	0.448	0.000	0.363	0.532
Pakistani	0.311	0.000	0.261	0.361	0.752	0.000	0.671	0.832
Mixed	0.008	0.720	-0.038	0.055	0.196	0.000	0.133	0.259
IMD								
Fourth quintile	0.034	0.037	0.002	0.066	0.015	0.463	-0.025	0.054
Third quintile	0.042	0.009	0.010	0.073	0.028	0.169	-0.012	0.067
Second quintile	-0.032	0.039	-0.063	-0.002	0.037	0.062	-0.002	0.077
Lowest quintile	-0.070	0.000	-0.100	-0.040	0.077	0.000	0.039	0.116
Region								
North East	0.051	0.053	-0.001	0.102	-0.552	0.000	-0.618	-0.486
North West	0.303	0.000	0.273	0.334	-0.383	0.000	-0.426	-0.341
Yorkshire and The Humber	-0.101	0.000	-0.151	-0.052	-0.784	0.000	-0.845	-0.723
East Midlands	0.494	0.000	0.423	0.565	0.260	0.000	0.151	0.369
West Midlands	-0.062	0.000	-0.091	-0.033	-0.167	0.000	-0.211	-0.123
East of England	-0.181	0.000	-0.227	-0.136	-0.954	0.000	-1.009	-0.899
South East	0.123	0.000	0.093	0.154	-0.509	0.000	-0.551	-0.466
South West	0.259	0.000	0.225	0.293	-0.524	0.000	-0.569	-0.480
Missing	0.377	0.000	0.288	0.465	-0.342	0.000	-0.451	-0.233
_cons	1.267	0.000	1.221	1.313	2.350	0.000	2.288	2.413
glm								
UK90_bmi								
Underweight	-0.019	0.109	-0.042	0.004	0.109	0.000	0.089	0.129
Overweight	0.014	0.058	0.000	0.029	-0.020	0.006	-0.034	-0.006
Obesity	0.064	0.000	0.051	0.077	0.081	0.000	0.069	0.093
Sex								
Female	0.105	0.000	0.095	0.114	0.101	0.000	0.092	0.110
age_whole								
3	-0.152	0.000	-0.171	-0.132	-0.119	0.000	-0.138	-0.101
4	-0.192	0.000	-0.212	-0.172	-0.194	0.000	-0.214	-0.175
5	-0.275	0.000	-0.295	-0.256	-0.285	0.000	-0.304	-0.266
6	-0.324	0.000	-0.344	-0.304	-0.333	0.000	-0.352	-0.314
7	-0.413	0.000	-0.433	-0.393	-0.371	0.000	-0.390	-0.352
8	-0.410	0.000	-0.431	-0.390	-0.380	0.000	-0.399	-0.360

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
9	-0.428	0.000	-0.450	-0.407	-0.380	0.000	-0.400	-0.360
10	-0.433	0.000	-0.456	-0.409	-0.393	0.000	-0.414	-0.371
11	-0.443	0.000	-0.470	-0.415	-0.335	0.000	-0.360	-0.309
12	-0.388	0.000	-0.442	-0.335	-0.283	0.000	-0.336	-0.231
13	-0.288	0.000	-0.380	-0.195	-0.240	0.000	-0.316	-0.164
14	-0.259	0.000	-0.381	-0.138	-0.320	0.000	-0.440	-0.201
15	-0.086	0.434	-0.303	0.130	-0.541	0.003	-0.903	-0.179
Ethnicity								
Other/Uknown	-0.123	0.000	-0.139	-0.107	-0.091	0.000	-0.104	-0.077
Bangladeshi	0.235	0.000	0.203	0.268	0.288	0.000	0.257	0.318
Black	-0.003	0.757	-0.025	0.018	0.028	0.005	0.008	0.047
Chinese/Other Asian	0.159	0.000	0.132	0.187	0.170	0.000	0.145	0.194
Indian	0.210	0.000	0.184	0.235	0.229	0.000	0.205	0.254
Pakistani	0.240	0.000	0.218	0.262	0.290	0.000	0.269	0.311
Mixed	0.044	0.000	0.020	0.067	0.061	0.000	0.039	0.083
IMD								
Fourth quintile	-0.008	0.317	-0.025	0.008	-0.003	0.678	-0.019	0.012
Third quintile	-0.007	0.407	-0.023	0.009	-0.008	0.303	-0.024	0.007
Second quintile	0.009	0.288	-0.007	0.024	0.000	0.968	-0.015	0.015
Lowest quintile	0.021	0.007	0.006	0.037	0.039	0.000	0.025	0.054
Region								
North East	-0.144	0.000	-0.171	-0.118	-0.282	0.000	-0.307	-0.257
North West	-0.144	0.000	-0.160	-0.128	-0.237	0.000	-0.252	-0.222
Yorkshire and The Humber	-0.101	0.000	-0.128	-0.073	-0.224	0.000	-0.251	-0.196
East Midlands	-0.157	0.000	-0.192	-0.123	-0.134	0.000	-0.166	-0.102
West Midlands	-0.159	0.000	-0.176	-0.143	-0.222	0.000	-0.237	-0.208
East of England	-0.050	0.000	-0.074	-0.025	-0.060	0.000	-0.083	-0.037
South East	-0.157	0.000	-0.173	-0.141	-0.161	0.000	-0.176	-0.146
South West	-0.140	0.000	-0.158	-0.122	-0.127	0.000	-0.143	-0.110
Missing	-0.107	0.000	-0.148	-0.066	-0.256	0.000	-0.297	-0.215
_cons	5.454	0.000	5.431	5.476	5.312	0.000	5.291	5.333

Table E 8 The relationship between consultation costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Sex								
Male	-4.83	0.001	-7.78	-1.88	17.83	0	14.93	20.72
Female	-5.40	0.001	-8.64	-2.15	19.62	0	16.41	22.83
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	1.74	0.082	-0.22	3.69	-2.59	0.004	-4.34	-0.83
Female	1.90	0.084	-0.26	4.06	-2.88	0.004	-4.83	-0.93
Obesity								
Sex								
Male	9.48	0	7.71	11.25	11.80	0	10.17	13.42
Female	10.45	0	8.49	12.40	13.07	0	11.26	14.87
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Age (years)								
2	-6.78	0.002	-11.04	-2.52	24.38	0	20.33	28.43
3	-5.60	0.004	-9.37	-1.83	21.17	0	17.53	24.81
4	-5.43	0.003	-9.00	-1.86	20.48	0	17.17	23.79
5	-5.23	0.001	-8.38	-2.08	18.88	0	15.86	21.89
6	-5.06	0.001	-8.02	-2.10	17.70	0	14.81	20.58
7	-4.68	0.001	-7.34	-2.03	17.15	0	14.37	19.92
8	-4.65	0.001	-7.32	-1.98	16.78	0	14.05	19.52
9	-4.53	0.001	-7.17	-1.90	16.71	0	13.98	19.44
10	-4.48	0.001	-7.12	-1.84	16.55	0	13.87	19.24
11	-4.38	0.001	-7.01	-1.75	17.28	0	14.43	20.12
12	-4.61	0.001	-7.37	-1.84	17.71	0	14.64	20.78
13	-5.04	0.001	-8.12	-1.95	18.20	0	14.88	21.52
14	-5.10	0.002	-8.36	-1.83	16.72	0	13.32	20.13
15	-5.64	0.012	-10.04	-1.25	14.24	0	8.54	19.95
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	2.54	0.078	-0.29	5.37	-3.63	0.004	-6.09	-1.17
3	2.29	0.072	-0.21	4.79	-3.28	0.004	-5.52	-1.05
4	2.16	0.074	-0.21	4.52	-2.94	0.004	-4.94	-0.94
5	1.84	0.084	-0.25	3.93	-2.66	0.004	-4.47	-0.85
6	1.71	0.089	-0.26	3.67	-2.57	0.004	-4.31	-0.83
7	1.50	0.095	-0.26	3.27	-2.46	0.004	-4.13	-0.79
8	1.52	0.092	-0.25	3.30	-2.44	0.004	-4.09	-0.78
9	1.51	0.09	-0.24	3.26	-2.43	0.004	-4.08	-0.78
10	1.53	0.088	-0.23	3.28	-2.38	0.004	-3.99	-0.76
11	1.53	0.085	-0.21	3.27	-2.53	0.004	-4.25	-0.81
12	1.60	0.086	-0.22	3.43	-2.64	0.004	-4.44	-0.84
13	1.79	0.084	-0.24	3.82	-2.72	0.004	-4.58	-0.86
14	1.91	0.08	-0.23	4.05	-2.49	0.004	-4.20	-0.77

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
15	2.57	0.073	-0.24	5.39	-2.10	0.011	-3.71	-0.48
Obesity								
Age (years)								
2	13.70	0	11.12	16.28	16.38	0	14.09	18.68
3	12.05	0	9.77	14.33	14.58	0	12.50	16.66
4	11.43	0	9.28	13.59	13.48	0	11.61	15.34
5	10.13	0	8.23	12.04	12.27	0	10.58	13.96
6	9.52	0	7.73	11.31	11.71	0	10.09	13.34
7	8.52	0	6.92	10.13	11.27	0	9.72	12.82
8	8.58	0	6.97	10.19	11.11	0	9.58	12.64
9	8.47	0	6.88	10.05	11.08	0	9.55	12.60
10	8.48	0	6.89	10.06	10.89	0	9.40	12.38
11	8.44	0	6.86	10.02	11.49	0	9.90	13.08
12	8.85	0	7.15	10.56	11.92	0	10.18	13.66
13	9.81	0	7.76	11.85	12.27	0	10.35	14.19
14	10.30	0	7.98	12.61	11.23	0	9.20	13.26
15	13.14	0	9.35	16.92	9.50	0	5.84	13.17
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Ethnicity								
Other/Uknown	-4.75	0	-7.14	-2.35	17.05	0	14.27	19.83
Bangladeshi	-6.26	0.004	-10.51	-2.01	24.14	0	19.84	28.45
Black	-5.43	0.001	-8.71	-2.14	19.95	0	16.57	23.34
Chinese/Other Asian	-6.17	0.002	-10.00	-2.35	22.28	0	18.50	26.07
Indian	-6.20	0.002	-10.19	-2.21	22.89	0	19.02	26.76
Pakistani	-6.04	0.003	-10.09	-1.99	23.03	0	19.04	27.02
White	-4.92	0.002	-7.98	-1.85	18.01	0	15.11	20.91
Mixed	-5.38	0.002	-8.71	-2.06	19.81	0	16.51	23.10
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	1.22	0.136	-0.38	2.82	-2.49	0.004	-4.18	-0.80
Bangladeshi	2.59	0.072	-0.23	5.40	-3.85	0.004	-6.50	-1.20
Black	1.92	0.083	-0.25	4.10	-3.04	0.004	-5.12	-0.97
Chinese/Other Asian	2.26	0.081	-0.28	4.80	-3.40	0.004	-5.71	-1.09
Indian	2.39	0.076	-0.25	5.03	-3.50	0.004	-5.88	-1.12
Pakistani	2.46	0.073	-0.23	5.14	-3.60	0.004	-6.06	-1.14
White	1.82	0.079	-0.21	3.85	-2.57	0.004	-4.32	-0.82
Mixed	1.97	0.081	-0.24	4.17	-2.94	0.004	-4.93	-0.94
Obesity								
Ethnicity								
Other/Uknown	7.52	0	6.06	8.99	11.32	0	9.76	12.89
Bangladeshi	13.55	0	10.97	16.13	16.92	0	14.44	19.39
Black	10.54	0	8.57	12.52	13.61	0	11.70	15.52

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Chinese/Other Asian	12.27	0	9.95	14.60	15.19	0	13.03	17.35
Indian	12.77	0	10.35	15.19	15.63	0	13.40	17.85
Pakistani	12.93	0	10.49	15.38	15.94	0	13.65	18.23
White	9.84	0	8.00	11.68	11.80	0	10.18	13.42
Mixed	10.68	0	8.67	12.69	13.28	0	11.42	15.14
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
IMD								
Highest quintile	-4.91	0.001	-7.90	-1.92	18.25	0	15.32	21.18
Fourth quintile	-4.89	0.001	-7.91	-1.88	18.20	0	15.26	21.15
Third quintile	-5.02	0.001	-8.11	-1.94	18.54	0	15.52	21.56
Second quintile	-5.27	0.001	-8.43	-2.11	19.03	0	15.90	22.16
Lowest quintile	-5.17	0.001	-8.28	-2.07	18.81	0	15.72	21.90
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	1.76	0.083	-0.23	3.74	-2.59	0.004	-4.35	-0.83
Fourth quintile	1.78	0.081	-0.22	3.78	-2.62	0.004	-4.40	-0.84
Third quintile	1.82	0.082	-0.23	3.86	-2.70	0.004	-4.53	-0.87
Second quintile	1.85	0.085	-0.25	3.94	-2.81	0.004	-4.72	-0.90
Lowest quintile	1.82	0.084	-0.25	3.88	-2.78	0.004	-4.66	-0.89
Obesity								
IMD								
Highest quintile	9.62	0	7.81	11.43	11.92	0	10.27	13.56
Fourth quintile	9.69	0	7.87	11.51	11.98	0	10.32	13.63
Third quintile	9.91	0	8.05	11.77	12.29	0	10.59	13.98
Second quintile	10.17	0	8.26	12.07	12.73	0	10.97	14.49
Lowest quintile	10.00	0	8.13	11.86	12.58	0	10.84	14.32
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Region								
North East	-4.96	0.001	-7.95	-1.96	16.43	0	13.78	19.08
North West	-4.76	0.002	-7.83	-1.69	17.06	0	14.29	19.84
Yorkshire and The Humber	-5.18	0.001	-8.16	-2.19	17.47	0	14.68	20.25
East Midlands	-4.55	0.004	-7.62	-1.49	18.13	0	14.98	21.28
West Midlands	-4.95	0.001	-7.84	-2.05	17.15	0	14.30	19.99
East of England	-5.60	0.001	-8.84	-2.35	21.14	0	17.79	24.49
London	-5.77	0.001	-9.14	-2.40	21.13	0	17.57	24.69
South East	-4.74	0.001	-7.65	-1.83	18.16	0	15.24	21.07
South West	-4.73	0.002	-7.75	-1.71	18.83	0	15.82	21.84
Missing	-4.68	0.003	-7.78	-1.59	16.00	0	13.33	18.67
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
North East	1.75	0.084	-0.23	3.74	-2.32	0.004	-3.90	-0.74
North West	1.85	0.076	-0.19	3.88	-2.47	0.004	-4.15	-0.79
Yorkshire and The Humber	1.71	0.092	-0.28	3.69	-2.38	0.004	-4.01	-0.74
East Midlands	1.86	0.072	-0.17	3.89	-2.80	0.004	-4.72	-0.89
West Midlands	1.67	0.089	-0.25	3.59	-2.56	0.004	-4.30	-0.82
East of England	1.86	0.091	-0.30	4.02	-2.83	0.005	-4.78	-0.87
London	1.94	0.089	-0.30	4.18	-3.22	0.004	-5.41	-1.03
South East	1.72	0.081	-0.21	3.65	-2.58	0.004	-4.33	-0.82
South West	1.81	0.077	-0.19	3.81	-2.65	0.004	-4.46	-0.84
Missing	1.87	0.074	-0.18	3.92	-2.32	0.004	-3.90	-0.74
Obesity								
Region								
North East	9.62	0	7.81	11.43	10.69	0	9.21	12.17
North West	9.85	0	8.00	11.70	11.28	0	9.73	12.83
Yorkshire and The Humber	9.59	0	7.78	11.40	11.13	0	9.59	12.67
East Midlands	9.79	0	7.92	11.65	12.46	0	10.66	14.26
West Midlands	9.30	0	7.56	11.05	11.54	0	9.94	13.15
East of England	10.42	0	8.45	12.40	13.32	0	11.48	15.17
London	10.84	0	8.81	12.87	14.41	0	12.39	16.42
South East	9.37	0	7.61	11.12	11.85	0	10.22	13.48
South West	9.69	0	7.87	11.52	12.24	0	10.55	13.92
Missing	9.89	0	8.00	11.78	10.59	0	9.08	12.10

Prescriptions – results

Table E 9 Regression coefficients (marginal effects) for the two parts of the model- Prescription resource use

Total_Consultations	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	Year before (ZIMB)				Year after (ZIP)			
UK90_bmi								
Underweight	-0.087	0.000	-0.125	-0.050	-0.044	0.017	-0.079	-0.008
Overweight	0.086	0.000	0.064	0.109	0.059	0.000	0.038	0.080
Obesity	0.077	0.000	0.058	0.095	0.058	0.000	0.040	0.076
Sex								
Female	-0.070	0.000	-0.084	-0.056	-0.071	0.000	-0.085	-0.058
age_whole								
3	-0.160	0.000	-0.192	-0.128	-0.042	0.013	-0.075	-0.009
4	-0.142	0.000	-0.173	-0.110	-0.003	0.843	-0.036	0.029

Total_Consultations Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
5	-0.196	0.000	-0.228	-0.165	-0.023	0.161	-0.055	0.009
6	-0.140	0.000	-0.173	-0.107	0.036	0.026	0.004	0.068
7	-0.156	0.000	-0.190	-0.122	0.062	0.000	0.030	0.093
8	-0.125	0.000	-0.159	-0.092	0.091	0.000	0.060	0.123
9	-0.024	0.155	-0.058	0.009	0.173	0.000	0.142	0.205
10	0.054	0.002	0.019	0.089	0.233	0.000	0.200	0.266
11	0.142	0.000	0.102	0.182	0.314	0.000	0.277	0.351
12	0.130	0.003	0.046	0.215	0.289	0.000	0.213	0.364
13	0.134	0.042	0.005	0.264	0.180	0.001	0.069	0.291
14	0.106	0.193	-0.053	0.265	-0.040	0.601	-0.190	0.110
15	0.055	0.807	-0.385	0.494	-0.488	0.023	-0.910	-0.066
Ethnicity								
Other/Uknown	-0.352	0.000	-0.381	-0.323	-0.368	0.000	-0.389	-0.346
Bangladeshi	0.446	0.000	0.404	0.489	0.268	0.000	0.227	0.309
Black	0.292	0.000	0.261	0.324	0.182	0.000	0.153	0.210
Chinese/Other Asian	0.192	0.000	0.153	0.231	0.085	0.000	0.048	0.122
Indian	0.269	0.000	0.232	0.306	0.133	0.000	0.097	0.170
Pakistani	0.366	0.000	0.332	0.400	0.226	0.000	0.195	0.258
Mixed	0.111	0.000	0.076	0.146	0.080	0.000	0.048	0.112
IMD								
Fourth quintile	0.002	0.890	-0.023	0.026	0.011	0.342	-0.012	0.034
Third quintile	0.035	0.005	0.010	0.059	0.041	0.001	0.018	0.064
Second quintile	0.060	0.000	0.036	0.084	0.056	0.000	0.033	0.079
Lowest quintile	0.076	0.000	0.052	0.100	0.074	0.000	0.052	0.097
Region								
North East	0.164	0.000	0.121	0.206	0.109	0.000	0.070	0.149
North West	0.253	0.000	0.229	0.278	0.204	0.000	0.181	0.226
Yorkshire and The Humber	0.229	0.000	0.186	0.272	0.180	0.000	0.141	0.219
East Midlands	0.183	0.000	0.131	0.235	0.139	0.000	0.091	0.187
West Midlands	0.205	0.000	0.180	0.230	0.162	0.000	0.139	0.185
East of England	-0.001	0.963	-0.041	0.039	0.023	0.229	-0.014	0.059
South East	0.151	0.000	0.125	0.176	0.126	0.000	0.104	0.149
South West	-0.012	0.372	-0.039	0.015	0.013	0.287	-0.011	0.038
Missing	0.196	0.000	0.134	0.258	-0.003	0.917	-0.060	0.054
_cons	1.882	0.000	1.847	1.918	1.994	0.000	1.960	2.029
inflate								
UK90_bmi								
Underweight	0.283	0.001	0.118	0.447	0.012	0.613	-0.033	0.056
Overweight	0.018	0.769	-0.099	0.134	-0.064	0.000	-0.092	-0.036
Obesity	-0.014	0.805	-0.122	0.094	-0.122	0.000	-0.146	-0.097

Total_Consultations	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	Year before (ZIMB)				Year after (ZIP)			
Sex								
Female	0.083	0.028	0.009	0.157	0.025	0.006	0.007	0.042
age_whole								
3	-0.049	0.674	-0.276	0.178	0.168	0.000	0.126	0.211
4	0.153	0.166	-0.064	0.369	0.163	0.000	0.120	0.205
5	0.367	0.003	0.125	0.609	0.303	0.000	0.262	0.344
6	0.671	0.000	0.428	0.915	0.205	0.000	0.163	0.247
7	0.742	0.000	0.480	1.005	0.232	0.000	0.191	0.274
8	0.691	0.000	0.426	0.956	0.152	0.000	0.110	0.194
9	0.633	0.000	0.374	0.893	0.073	0.001	0.030	0.117
10	0.296	0.036	0.019	0.573	0.078	0.001	0.032	0.123
11	0.451	0.002	0.166	0.736	-0.009	0.747	-0.062	0.045
12	1.031	0.000	0.580	1.483	0.244	0.000	0.144	0.344
13	1.298	0.000	0.724	1.871	0.386	0.000	0.246	0.525
14	1.064	0.006	0.312	1.815	0.289	0.006	0.083	0.494
15	-0.089	0.935	-2.229	2.050	0.786	0.010	0.190	1.382
Ethnicity								
Other/Uknown	3.355	0.000	2.698	4.012	0.534	0.000	0.509	0.558
Bangladeshi	-23.610	0.000	-24.270	-22.950	-0.888	0.000	-0.977	-0.800
Black	0.838	0.005	0.246	1.429	-0.330	0.000	-0.372	-0.289
Chinese/Other Asian	-24.881	0.000	-25.897	-23.866	-0.397	0.000	-0.455	-0.339
Indian	-22.921	0.000	-23.560	-22.282	-0.528	0.000	-0.589	-0.467
Pakistani	-23.166	0.000	-23.795	-22.538	-0.652	0.000	-0.706	-0.598
Mixed	-0.223	0.686	-1.305	0.859	-0.147	0.000	-0.194	-0.101
IMD								
Fourth quintile	0.281	0.002	0.104	0.458	0.053	0.001	0.022	0.084
Third quintile	0.317	0.000	0.149	0.485	0.063	0.000	0.032	0.094
Second quintile	0.544	0.000	0.385	0.702	0.023	0.129	-0.007	0.054
Lowest quintile	0.470	0.000	0.302	0.638	0.027	0.079	-0.003	0.056
Region								
North East	0.300	0.018	0.052	0.548	-0.010	0.706	-0.060	0.041
North West	-0.093	0.141	-0.216	0.031	-0.135	0.000	-0.165	-0.105
Yorkshire and The Humber	0.090	0.391	-0.115	0.295	-0.035	0.172	-0.085	0.015
East Midlands	-0.259	0.046	-0.513	-0.005	-0.315	0.000	-0.384	-0.246
West Midlands	0.233	0.000	0.123	0.343	-0.120	0.000	-0.150	-0.090
East of England	-0.544	0.001	-0.867	-0.222	0.077	0.001	0.033	0.122
South East	-0.314	0.000	-0.457	-0.170	-0.139	0.000	-0.170	-0.109
South West	-0.448	0.000	-0.635	-0.262	0.028	0.090	-0.004	0.060
Missing	-1.217	0.002	-2.000	-0.434	-0.187	0.000	-0.271	-0.103
_cons	-5.181	0.000	-5.724	-4.638	-1.154	0.000	-1.201	-1.108

Total_Consultations Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
/lnalpha	0.671	0.000	0.656	0.686				
alpha	1.956		1.927	1.987				

Table E 10 Regression coefficients (marginal effects) for the two parts of the model- Prescription Costs

Total_costs	Coefficient Year before (two-part GLM)	P>z	[95% conf.	interval]	Coefficient Year after (two-part GLM)	P>z	[95% conf.	interval]
logit								
UK90_bmi								
Underweight	-0.106	0.000	-0.146	-0.065	-0.002	0.926	-0.045	0.041
Overweight	0.032	0.013	0.007	0.058	0.056	0.000	0.029	0.083
Obesity	0.080	0.000	0.058	0.102	0.118	0.000	0.095	0.141
Sex								
Female	-0.085	0.000	-0.101	-0.069	-0.038	0.000	-0.055	-0.022
age_whole								
3	0.107	0.000	0.068	0.145	0.000	0.985	-0.040	0.040
4	-0.038	0.050	-0.076	0.000	-0.110	0.000	-0.150	-0.070
5	-0.159	0.000	-0.196	-0.123	-0.214	0.000	-0.252	-0.176
6	-0.096	0.000	-0.133	-0.059	-0.056	0.005	-0.095	-0.017
7	-0.177	0.000	-0.214	-0.140	-0.109	0.000	-0.148	-0.071
8	-0.067	0.000	-0.105	-0.030	0.030	0.135	-0.009	0.069
9	0.024	0.228	-0.015	0.062	0.122	0.000	0.081	0.163
10	0.128	0.000	0.087	0.169	0.116	0.000	0.073	0.160
11	0.232	0.000	0.184	0.281	0.242	0.000	0.191	0.293
12	-0.006	0.892	-0.100	0.087	0.025	0.622	-0.074	0.123
13	-0.093	0.173	-0.227	0.041	-0.121	0.087	-0.259	0.017
14	0.008	0.939	-0.191	0.207	-0.003	0.974	-0.208	0.201
15	0.896	0.013	0.190	1.602	-0.549	0.071	-1.144	0.047
Ethnicity								
Other/Uknown	-0.901	0.000	-0.925	-0.878	-0.455	0.000	-0.479	-0.431
Bangladeshi	0.634	0.000	0.566	0.703	0.962	0.000	0.877	1.046
Black	0.204	0.000	0.168	0.240	0.395	0.000	0.355	0.435
Chinese/Other Asian	0.191	0.000	0.141	0.240	0.447	0.000	0.392	0.503
Indian	0.334	0.000	0.284	0.385	0.505	0.000	0.449	0.562
Pakistani	0.523	0.000	0.478	0.568	0.733	0.000	0.681	0.785
Mixed	0.097	0.000	0.056	0.138	0.186	0.000	0.142	0.230
IMD								
Fourth quintile	0.002	0.896	-0.027	0.031	-0.020	0.191	-0.050	0.010
Third quintile	0.015	0.306	-0.014	0.043	-0.018	0.218	-0.048	0.011

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Second quintile	-0.059	0.000	-0.087	-0.032	-0.006	0.707	-0.034	0.023
Lowest quintile	-0.103	0.000	-0.130	-0.076	-0.010	0.507	-0.038	0.019
Region								
North East	0.315	0.000	0.268	0.363	0.120	0.000	0.070	0.170
North West	0.365	0.000	0.337	0.392	0.148	0.000	0.119	0.177
Yorkshire and The Humber	0.099	0.000	0.053	0.145	-0.100	0.000	-0.147	-0.053
East Midlands	0.442	0.000	0.381	0.504	0.372	0.000	0.305	0.439
West Midlands	0.210	0.000	0.183	0.237	0.180	0.000	0.151	0.209
East of England	-0.204	0.000	-0.246	-0.163	-0.357	0.000	-0.399	-0.315
South East	0.117	0.000	0.089	0.145	-0.017	0.243	-0.046	0.012
South West	0.272	0.000	0.242	0.302	0.014	0.392	-0.018	0.045
Missing	0.615	0.000	0.534	0.696	0.337	0.000	0.254	0.421
_cons	0.500	0.000	0.459	0.541	0.808	0.000	0.765	0.851
glm								
UK90_bmi								
Underweight	0.226	0.015	0.043	0.409	0.262	0.000	0.115	0.409
Overweight	0.082	0.268	-0.063	0.226	-0.014	0.698	-0.083	0.055
Obesity	-0.043	0.267	-0.118	0.033	0.154	0.037	0.009	0.298
Sex								
Female	-0.076	0.007	-0.132	-0.021	-0.085	0.009	-0.149	-0.021
age_whole								
3	-0.445	0.000	-0.567	-0.324	-0.169	0.014	-0.302	-0.035
4	-0.462	0.000	-0.582	-0.341	-0.161	0.007	-0.278	-0.044
5	-0.439	0.000	-0.599	-0.279	-0.132	0.123	-0.299	0.036
6	-0.426	0.000	-0.551	-0.301	-0.080	0.224	-0.209	0.049
7	-0.324	0.000	-0.446	-0.202	-0.076	0.149	-0.179	0.027
8	-0.329	0.000	-0.451	-0.207	0.012	0.873	-0.134	0.158
9	-0.088	0.349	-0.272	0.096	0.098	0.061	-0.004	0.201
10	-0.061	0.331	-0.183	0.062	0.246	0.000	0.135	0.358
11	0.095	0.188	-0.046	0.236	0.323	0.000	0.199	0.447
12	0.235	0.058	-0.008	0.477	0.435	0.000	0.209	0.662
13	0.180	0.201	-0.096	0.456	0.233	0.175	-0.104	0.570
14	-0.042	0.789	-0.352	0.267	0.009	0.976	-0.587	0.606
15	-0.433	0.283	-1.223	0.357	-0.407	0.401	-1.357	0.543
Ethnicity								
Other/Uknown	-0.591	0.000	-0.693	-0.488	-0.775	0.000	-0.862	-0.688
Bangladeshi	0.030	0.765	-0.165	0.224	0.152	0.480	-0.270	0.574
Black	0.095	0.410	-0.131	0.321	-0.084	0.077	-0.177	0.009
Chinese/Other Asian	-0.069	0.286	-0.196	0.058	0.366	0.322	-0.359	1.091

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Indian	-0.104	0.128	-0.238	0.030	-0.179	0.006	-0.305	-0.052
Pakistani	0.436	0.012	0.097	0.775	0.175	0.004	0.054	0.296
Mixed	-0.042	0.495	-0.162	0.078	-0.081	0.175	-0.197	0.036
IMD								
Fourth quintile	0.023	0.597	-0.063	0.110	-0.118	0.102	-0.260	0.023
Third quintile	0.099	0.020	0.016	0.182	-0.080	0.261	-0.220	0.060
Second quintile	0.037	0.353	-0.042	0.116	-0.109	0.192	-0.272	0.055
Lowest quintile	0.114	0.007	0.031	0.198	-0.089	0.206	-0.228	0.049
Region								
North East	0.075	0.273	-0.059	0.209	0.079	0.368	-0.093	0.252
North West	0.032	0.497	-0.060	0.123	0.068	0.289	-0.057	0.192
Yorkshire and The Humber	0.082	0.247	-0.057	0.220	0.188	0.203	-0.101	0.477
East Midlands	-0.046	0.608	-0.224	0.131	-0.169	0.053	-0.340	0.003
West Midlands	0.199	0.007	0.054	0.344	0.100	0.073	-0.010	0.210
East of England	0.151	0.033	0.012	0.290	0.056	0.498	-0.106	0.219
South East	0.107	0.037	0.006	0.208	0.055	0.336	-0.057	0.166
South West	-0.347	0.000	-0.437	-0.257	-0.275	0.000	-0.377	-0.173
Missing	-0.243	0.004	-0.407	-0.079	-0.298	0.017	-0.542	-0.053
_cons	5.512	0.000	5.365	5.659	5.387	0.000	5.203	5.571

Table E 11 The relationship between prescription costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	27.07313	0.064	-1.599276	55.74553	40.45	0.00	14.70	66.19
Female	23.505	0.067	-1.617	48.628	35.92	0.00	13.09	58.75
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	12.627	0.236	-8.278	33.532	0.23	0.96	-9.22	9.67
Female	11.198	0.228	-6.993	29.390	0.27	0.95	-8.13	8.66
Obesity								
Sex								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Male	-2.078	0.677	-11.849	7.693	27.62	0.02	3.79	51.46
Female	-1.637	0.709	-10.233	6.959	24.70	0.02	3.34	46.06
Underweight								
Age (years)								
2	34.034	0.065	-2.053	70.122	39.59	0.00	14.43	64.75
3	22.977	0.062	-1.150	47.104	33.37	0.00	12.02	54.72
4	20.803	0.066	-1.352	42.958	32.21	0.00	10.83	53.59
5	19.614	0.077	-2.136	41.363	31.50	0.00	11.06	51.93
6	20.895	0.068	-1.565	43.354	35.42	0.00	12.90	57.95
7	22.088	0.071	-1.897	46.073	34.85	0.00	12.69	57.01
8	23.179	0.068	-1.700	48.058	39.50	0.00	13.75	65.25
9	30.936	0.064	-1.851	63.724	44.22	0.00	16.17	72.27
10	33.233	0.061	-1.594	68.060	51.16	0.00	18.61	83.72
11	40.695	0.059	-1.503	82.893	56.93	0.00	20.60	93.25
12	41.203	0.069	-3.227	85.632	57.94	0.00	19.58	96.30
13	36.026	0.076	-3.725	75.777	43.25	0.01	12.54	73.95
14	29.838	0.072	-2.620	62.296	34.96	0.02	5.11	64.80
15	32.828	0.117	-8.275	73.930	22.54	0.09	-3.51	48.58
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	15.972	0.230	-10.115	42.059	0.25	0.96	-9.00	9.50
3	10.561	0.232	-6.749	27.870	0.21	0.96	-7.59	8.00
4	9.823	0.229	-6.170	25.816	0.32	0.93	-7.21	7.86
5	9.524	0.220	-5.696	24.744	0.45	0.90	-6.93	7.84
6	10.000	0.227	-6.228	26.227	0.28	0.95	-8.00	8.56
7	10.774	0.225	-6.630	28.177	0.34	0.93	-7.81	8.50
8	11.039	0.228	-6.903	28.980	0.20	0.97	-9.03	9.42
9	14.443	0.266	-11.023	39.908	0.08	0.99	-10.23	10.39
10	15.194	0.233	-9.796	40.185	0.12	0.99	-11.81	12.05
11	18.198	0.237	-11.953	48.349	-0.12	0.99	-13.36	13.13
12	19.297	0.234	-12.480	51.074	0.33	0.96	-13.20	13.86
13	17.146	0.234	-11.081	45.373	0.49	0.93	-9.64	10.62
14	13.86118	0.238	-9.165038	36.8874	0.23	0.96	-7.93	8.40
15	12.8924	0.311	-12.025	37.8098	0.38	0.89	-4.93	5.68
Obesity								
Age (years)								
2	-2.544484	0.684	-14.8153	9.72633	27.10	0.02	3.92	50.29
3	-1.874017	0.654	-10.05642	6.308383	22.84	0.03	2.87	42.82
4	-1.512446	0.695	-9.068424	6.043531	22.36	0.02	3.41	41.32
5	-1.23891	0.74	-8.547841	6.070021	22.22	0.03	1.92	42.52
6	-1.424093	0.716	-9.095299	6.247113	24.39	0.02	3.68	45.10

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
7	-1.360421	0.746	-9.581502	6.86066	24.18	0.02	3.93	44.43
8	-1.61801	0.708	-10.0983	6.862281	26.91	0.03	2.29	51.54
9	-2.364729	0.679	-13.57338	8.843916	29.77	0.02	4.29	55.24
10	-2.765903	0.647	-14.59155	9.059746	34.52	0.02	4.84	64.20
11	-3.671736	0.614	-17.93885	10.59537	37.78	0.02	5.14	70.42
12	-3.104729	0.684	-18.05016	11.8407	39.59	0.02	6.07	73.11
13	-2.519925	0.709	-15.75695	10.71711	30.16	0.02	3.94	56.38
14	-2.326419	0.672	-13.10778	8.454937	23.98	0.06	-0.57	48.52
15	-4.177228	0.463	-15.32785	6.973395	16.03	0.12	-4.39	36.46
Underweight								
Ethnicity								
Other/Uknown	8.214	0.108	-1.799	18.227	15.95	0.00	5.78	26.11
Bangladeshi	35.301	0.053	-0.454	71.057	57.94	0.01	15.53	100.35
Black	30.273	0.062	-1.461	62.008	40.13	0.00	14.57	65.69
Chinese/Other Asian	26.162	0.063	-1.427	53.751	64.79	0.04	3.42	126.17
Indian	27.856	0.056	-0.712	56.424	38.65	0.00	14.19	63.11
Pakistani	54.728	0.059	-2.050	111.506	58.93	0.00	21.69	96.17
White	26.815	0.067	-1.911	55.541	40.56	0.00	14.57	66.54
Mixed	25.982	0.067	-1.808	53.772	38.51	0.00	13.82	63.19
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	4.899	0.197	-2.535	12.333	0.46	0.81	-3.31	4.23
Bangladeshi	14.975	0.249	-10.505	40.456	-1.13	0.87	-14.57	12.30
Black	14.099	0.222	-8.521	36.719	-0.14	0.98	-9.47	9.19
Chinese/Other Asian	12.086	0.232	-7.741	31.913	-0.33	0.97	-15.40	14.74
Indian	12.399	0.240	-8.273	33.072	-0.29	0.95	-9.26	8.68
Pakistani	23.341	0.322	-22.810	69.492	-0.89	0.90	-14.52	12.74
White	12.629	0.226	-7.833	33.091	0.40	0.94	-9.09	9.89
Mixed	12.172	0.228	-7.635	31.979	0.14	0.98	-8.84	9.12
Obesity								
Ethnicity								
Other/Uknown	0.150	0.934	-3.409	3.709	11.84	0.01	2.62	21.06
Bangladeshi	-3.750	0.539	-15.703	8.203	35.90	0.05	0.39	71.40
Black	-2.345	0.678	-13.399	8.709	26.49	0.02	3.97	49.01
Chinese/Other Asian	-2.095	0.660	-11.445	7.254	42.50	0.17	-18.40	103.39
Indian	-2.559	0.605	-12.256	7.138	25.11	0.03	3.01	47.21
Pakistani	-5.730	0.550	-24.516	13.057	37.16	0.03	3.85	70.48
White	-1.976941	0.69	-11.69207	7.738185	28.13	0.02	4.49	51.77
Mixed	-1.961794	0.683	-11.36602	7.442427	26.10	0.02	4.18	48.03
Underweight								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
IMD								
Highest quintile	24.16	0.07	-1.67	49.99	41.51	0.00	14.88	68.14
Fourth quintile	24.61	0.07	-2.21	51.44	36.71	0.00	13.25	60.17
Third quintile	26.34	0.07	-1.59	54.28	37.69	0.00	13.79	61.59
Second quintile	23.80	0.07	-1.57	49.17	36.89	0.00	13.37	60.41
Lowest quintile	27.54	0.06	-1.39	56.47	39.44	0.00	14.19	64.69
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	11.42	0.23	-7.09	29.94	0.40	0.94	-9.32	10.11
Fourth quintile	11.56	0.23	-7.26	30.38	0.33	0.94	-8.26	8.92
Third quintile	12.34	0.23	-7.80	32.48	0.29	0.95	-8.52	9.10
Second quintile	11.27	0.23	-7.11	29.65	0.19	0.97	-8.43	8.80
Lowest quintile	12.92	0.24	-8.76	34.59	0.13	0.98	-9.07	9.33
Obesity								
IMD								
Highest quintile	-1.75	0.70	-10.53	7.03	28.77	0.03	2.88	54.66
Fourth quintile	-1.84	0.69	-10.73	7.06	25.38	0.02	3.65	47.10
Third quintile	-1.98	0.68	-11.50	7.53	25.95	0.02	4.01	47.88
Second quintile	-1.70	0.70	-10.38	6.97	25.15	0.03	3.05	47.24
Lowest quintile	-2.06	0.69	-12.07	7.95	26.70	0.02	3.96	49.44
Underweight								
Region								
North East	28.79	0.06	-1.72	59.31	42.26	0.00	14.69	69.83
North West	28.92	0.06	-1.17	59.01	42.66	0.00	15.24	70.08
Yorkshire and The Humber	26.48	0.07	-2.31	55.27	44.58	0.01	13.49	75.68
East Midlands	27.17	0.06	-1.09	55.42	35.05	0.00	12.27	57.83
West Midlands	32.01	0.06	-1.39	65.42	43.84	0.00	16.14	71.55
East of England	23.65	0.08	-2.87	50.16	35.91	0.00	12.60	59.23
London	21.22	0.07	-1.70	44.14	35.18	0.00	12.78	57.58
South East	26.42	0.07	-2.60	55.45	40.08	0.00	14.60	65.56
South West	18.04	0.06	-1.07	37.15	28.29	0.00	9.54	47.03
Missing	25.53	0.06	-0.64	51.69	32.97	0.00	10.83	55.10
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	13.30	0.23	-8.46	35.07	0.28	0.96	-9.60	10.15
North West	13.10	0.24	-8.61	34.80	0.14	0.98	-9.81	10.10
Yorkshire and The Humber	12.77	0.23	-7.95	33.49	0.64	0.91	-9.82	11.10
East Midlands	12.08	0.25	-8.35	32.51	-0.16	0.97	-8.30	7.98

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
West Midlands	14.86	0.25	-10.51	40.23	0.03	1.00	-10.18	10.25
East of England	12.09	0.22	-7.03	31.20	0.88	0.84	-7.59	9.36
London	10.35	0.22	-6.31	27.01	0.18	0.97	-8.04	8.39
South East	12.59	0.23	-7.83	33.00	0.42	0.93	-8.97	9.80
South West	8.37	0.23	-5.26	22.01	0.30	0.93	-6.32	6.92
Missing	11.04	0.24	-7.32	29.40	-0.04	0.99	-7.71	7.64
Obesity								
Region								
North East	-2.31	0.66	-12.61	8.00	28.96	0.02	4.62	53.30
North West	-2.50	0.63	-12.68	7.69	28.89	0.03	3.23	54.56
Yorkshire and The Humber	-1.74	0.73	-11.51	8.03	31.44	0.04	2.05	60.83
East Midlands	-2.50	0.61	-11.97	6.97	23.04	0.03	2.87	43.20
West Midlands	-2.51	0.67	-14.08	9.07	29.40	0.02	4.38	54.42
East of England	-1.06	0.82	-10.17	8.04	26.27	0.02	4.85	47.69
London	-1.31	0.75	-9.20	6.59	23.97	0.03	2.24	45.71
South East	-1.84	0.71	-11.50	7.81	27.86	0.02	4.56	51.16
South West	-1.42	0.67	-7.89	5.05	19.68	0.02	3.25	36.11
Missing	-2.57	0.56	-11.28	6.14	21.95	0.03	2.53	41.37

Tests – results

Table E 12 Regression coefficients (marginal effects) for the two parts of the model- Test resource use

Total_Tests	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	Year before (ZIP)				Year after (ZIP)			
Total_Tests								
UK90_bmi								
Underweight	0.088	0.000	0.043	0.133	0.296	0.000	0.260	0.331
Overweight	-0.119	0.000	-0.151	-0.088	-0.150	0.000	-0.176	-0.124
Obesity	-0.123	0.000	-0.150	-0.095	-0.075	0.000	-0.097	-0.053
Sex								
Female	0.109	0.000	0.090	0.129	0.136	0.000	0.120	0.153
age_whole								
3	0.085	0.001	0.035	0.134	0.040	0.071	-0.003	0.084
4	0.162	0.000	0.114	0.210	0.098	0.000	0.055	0.140
5	0.204	0.000	0.157	0.251	0.090	0.000	0.049	0.131
6	0.231	0.000	0.185	0.278	0.100	0.000	0.059	0.141
7	0.227	0.000	0.180	0.273	0.113	0.000	0.072	0.153
8	0.262	0.000	0.215	0.309	0.140	0.000	0.099	0.181

Total_Tests Covariate	Coefficient Year before (ZIP)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
9	0.290	0.000	0.242	0.338	0.167	0.000	0.126	0.208
10	0.318	0.000	0.268	0.367	0.215	0.000	0.171	0.259
11	0.387	0.000	0.329	0.444	0.338	0.000	0.288	0.387
12	0.551	0.000	0.452	0.650	0.480	0.000	0.396	0.563
13	0.853	0.000	0.667	1.040	0.542	0.000	0.417	0.667
14	0.755	0.000	0.560	0.951	0.450	0.000	0.267	0.633
15	0.621	0.002	0.235	1.008	0.306	0.202	-0.165	0.778
Ethnicity								
Other/Uknown	0.081	0.000	0.050	0.113	0.054	0.000	0.029	0.079
Bangladeshi	0.276	0.000	0.219	0.334	0.298	0.000	0.247	0.349
Black	0.011	0.631	-0.033	0.054	0.006	0.728	-0.029	0.042
Chinese/Other Asian	0.208	0.000	0.156	0.261	0.183	0.000	0.139	0.227
Indian	0.283	0.000	0.237	0.330	0.264	0.000	0.221	0.306
Pakistani	0.370	0.000	0.331	0.409	0.367	0.000	0.333	0.401
Mixed	-0.001	0.964	-0.049	0.047	-0.006	0.776	-0.047	0.035
IMD								
Fourth quintile	-0.003	0.859	-0.039	0.033	0.000	0.996	-0.031	0.031
Third quintile	-0.011	0.509	-0.046	0.023	0.019	0.218	-0.011	0.048
Second quintile	0.036	0.032	0.003	0.068	0.029	0.050	0.000	0.058
Lowest quintile	0.050	0.003	0.017	0.083	0.077	0.000	0.048	0.105
Region								
North East	-0.635	0.000	-0.704	-0.566	-0.611	0.000	-0.663	-0.558
North West	-0.453	0.000	-0.486	-0.421	-0.385	0.000	-0.412	-0.357
Yorkshire and The Humber	-0.321	0.000	-0.381	-0.260	-0.291	0.000	-0.340	-0.243
East Midlands	-0.332	0.000	-0.399	-0.266	-0.253	0.000	-0.319	-0.188
West Midlands	-0.311	0.000	-0.342	-0.279	-0.304	0.000	-0.330	-0.278
East of England	-0.278	0.000	-0.330	-0.226	-0.244	0.000	-0.288	-0.199
South East	-0.325	0.000	-0.357	-0.292	-0.222	0.000	-0.250	-0.194
South West	-0.441	0.000	-0.477	-0.405	-0.316	0.000	-0.346	-0.286
Missing	-0.482	0.000	-0.568	-0.396	-0.470	0.000	-0.555	-0.385
_cons	2.265	0.000	2.214	2.316	2.162	0.000	2.117	2.207
inflate								
UK90_bmi								
Underweight	0.092	0.000	0.051	0.132	0.040	0.052	0.000	0.079
Overweight	-0.040	0.002	-0.065	-0.015	-0.049	0.000	-0.073	-0.024
Obesity	-0.087	0.000	-0.109	-0.066	-0.034	0.002	-0.055	-0.012
Sex								
Female	-0.150	0.000	-0.166	-0.135	-0.095	0.000	-0.110	-0.079
age_whole								

Total_Tests Covariate	Coefficient Year before (ZIP)	P>z	[95% conf.	interval]	Coefficient Year after (ZIP)	P>z	[95% conf.	interval]
3	-0.035	0.065	-0.073	0.002	-0.030	0.107	-0.067	0.007
4	-0.107	0.000	-0.144	-0.070	-0.256	0.000	-0.292	-0.219
5	-0.048	0.009	-0.084	-0.012	-0.312	0.000	-0.347	-0.277
6	-0.071	0.000	-0.107	-0.034	-0.496	0.000	-0.532	-0.460
7	0.005	0.801	-0.032	0.041	-0.536	0.000	-0.571	-0.500
8	-0.061	0.001	-0.098	-0.024	-0.683	0.000	-0.720	-0.647
9	-0.140	0.000	-0.178	-0.102	-0.793	0.000	-0.831	-0.756
10	-0.216	0.000	-0.255	-0.176	-0.808	0.000	-0.847	-0.768
11	-0.262	0.000	-0.308	-0.216	-0.942	0.000	-0.989	-0.896
12	-0.273	0.000	-0.363	-0.183	-1.038	0.000	-1.132	-0.944
13	-0.177	0.008	-0.308	-0.045	-0.826	0.000	-0.958	-0.693
14	-0.432	0.000	-0.618	-0.246	-0.830	0.000	-1.022	-0.638
15	-1.165	0.000	-1.742	-0.588	-1.058	0.000	-1.651	-0.466
Ethnicity								
Other/Uknown	0.659	0.000	0.634	0.684	0.330	0.000	0.307	0.353
Bangladeshi	-0.299	0.000	-0.360	-0.239	-0.420	0.000	-0.483	-0.358
Black	0.127	0.000	0.092	0.163	0.004	0.809	-0.030	0.039
Chinese/Other Asian	-0.089	0.000	-0.136	-0.042	-0.134	0.000	-0.182	-0.087
Indian	-0.219	0.000	-0.265	-0.172	-0.255	0.000	-0.303	-0.207
Pakistani	-0.243	0.000	-0.283	-0.204	-0.391	0.000	-0.433	-0.350
Mixed	0.041	0.044	0.001	0.081	-0.084	0.000	-0.124	-0.044
IMD								
Fourth quintile	-0.007	0.649	-0.034	0.021	0.047	0.001	0.019	0.074
Third quintile	-0.008	0.574	-0.036	0.020	0.083	0.000	0.056	0.111
Second quintile	0.026	0.059	-0.001	0.053	0.095	0.000	0.068	0.121
Lowest quintile	0.047	0.000	0.021	0.074	0.134	0.000	0.107	0.160
Region								
North East	-0.215	0.000	-0.261	-0.169	0.150	0.000	0.104	0.196
North West	-0.292	0.000	-0.319	-0.265	-0.082	0.000	-0.109	-0.056
Yorkshire and The Humber	-0.171	0.000	-0.216	-0.125	-0.073	0.002	-0.119	-0.028
East Midlands	-0.274	0.000	-0.332	-0.216	-0.205	0.000	-0.264	-0.146
West Midlands	-0.124	0.000	-0.151	-0.097	-0.094	0.000	-0.121	-0.068
East of England	-0.088	0.000	-0.130	-0.047	-0.043	0.040	-0.084	-0.002
South East	-0.212	0.000	-0.239	-0.184	-0.079	0.000	-0.106	-0.052
South West	-0.159	0.000	-0.189	-0.130	0.006	0.683	-0.023	0.035
Missing	-0.183	0.000	-0.256	-0.110	0.162	0.000	0.090	0.235
_cons	0.636	0.000	0.595	0.677	0.242	0.000	0.203	0.282

Table E 13 Regression coefficients (marginal effects) for the two parts of the model- Test costs

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
logit								
UK90_bmi								
Underweight	-0.092	0.000	-0.132	-0.051	-0.039	0.055	-0.079	0.001
Overweight	0.040	0.002	0.015	0.065	0.047	0.000	0.022	0.071
Obesity	0.087	0.000	0.065	0.108	0.033	0.002	0.012	0.054
Sex								
Female	0.151	0.000	0.135	0.167	0.095	0.000	0.080	0.111
age_whole								
3	0.036	0.059	-0.001	0.073	0.031	0.102	-0.006	0.067
4	0.108	0.000	0.071	0.145	0.256	0.000	0.220	0.293
5	0.049	0.007	0.013	0.086	0.312	0.000	0.277	0.348
6	0.072	0.000	0.035	0.109	0.497	0.000	0.461	0.533
7	-0.003	0.853	-0.040	0.033	0.536	0.000	0.501	0.572
8	0.063	0.001	0.026	0.099	0.684	0.000	0.648	0.720
9	0.141	0.000	0.104	0.179	0.794	0.000	0.757	0.832
10	0.217	0.000	0.177	0.257	0.809	0.000	0.769	0.849
11	0.264	0.000	0.218	0.310	0.944	0.000	0.897	0.991
12	0.275	0.000	0.185	0.364	1.040	0.000	0.946	1.135
13	0.178	0.008	0.047	0.309	0.828	0.000	0.695	0.960
14	0.434	0.000	0.248	0.620	0.832	0.000	0.640	1.024
15	1.167	0.000	0.589	1.744	1.060	0.000	0.468	1.653
Ethnicity								
Other/Uknown	-0.658	0.000	-0.683	-0.633	-0.330	0.000	-0.353	-0.307
Bangladeshi	0.300	0.000	0.239	0.360	0.421	0.000	0.358	0.484
Black	-0.127	0.000	-0.162	-0.092	-0.004	0.818	-0.039	0.030
Chinese/Other Asian	0.089	0.000	0.042	0.136	0.135	0.000	0.088	0.182
Indian	0.219	0.000	0.172	0.266	0.256	0.000	0.208	0.304
Pakistani	0.244	0.000	0.204	0.283	0.392	0.000	0.351	0.434
Mixed	-0.041	0.044	-0.081	-0.001	0.084	0.000	0.044	0.124
IMD								
Fourth quintile	0.007	0.649	-0.021	0.034	-0.047	0.001	-0.074	-0.019
Third quintile	0.008	0.575	-0.020	0.036	-0.083	0.000	-0.110	-0.056
Second quintile	-0.026	0.060	-0.053	0.001	-0.094	0.000	-0.121	-0.067
Lowest quintile	-0.047	0.001	-0.074	-0.021	-0.133	0.000	-0.159	-0.107
Region								
North East	0.212	0.000	0.167	0.258	-0.157	0.000	-0.202	-0.111
North West	0.291	0.000	0.265	0.318	0.081	0.000	0.054	0.107
Yorkshire and The	0.171	0.000	0.125	0.216	0.073	0.002	0.027	0.118

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Humber								
East Midlands	0.274	0.000	0.215	0.332	0.205	0.000	0.146	0.264
West Midlands	0.124	0.000	0.097	0.150	0.093	0.000	0.067	0.120
East of England	0.088	0.000	0.047	0.130	0.042	0.042	0.002	0.083
South East	0.211	0.000	0.184	0.239	0.079	0.000	0.052	0.106
South West	0.159	0.000	0.129	0.189	-0.007	0.634	-0.036	0.022
Missing	0.182	0.000	0.109	0.255	-0.165	0.000	-0.238	-0.092
_cons	-0.637	0.000	-0.678	-0.597	-0.244	0.000	-0.284	-0.204
glm								
UK90_bmi								
Underweight	-0.108	0.000	-0.158	-0.057	-0.150	0.000	-0.187	-0.113
Overweight	0.060	0.000	0.028	0.092	0.061	0.000	0.039	0.084
Obesity	0.014	0.309	-0.013	0.041	0.023	0.020	0.004	0.042
Sex								
Female	-0.041	0.000	-0.061	-0.021	-0.063	0.000	-0.077	-0.048
age_whole								
3	-0.036	0.232	-0.096	0.023	0.062	0.012	0.013	0.111
4	0.065	0.023	0.009	0.120	0.410	0.000	0.365	0.455
5	0.254	0.000	0.200	0.308	0.646	0.000	0.602	0.690
6	0.399	0.000	0.346	0.452	0.826	0.000	0.782	0.869
7	0.509	0.000	0.456	0.563	0.953	0.000	0.910	0.997
8	0.665	0.000	0.612	0.718	1.111	0.000	1.068	1.155
9	0.788	0.000	0.734	0.842	1.197	0.000	1.153	1.240
10	0.852	0.000	0.797	0.907	1.265	0.000	1.220	1.309
11	0.929	0.000	0.869	0.989	1.364	0.000	1.317	1.411
12	0.965	0.000	0.861	1.069	1.328	0.000	1.250	1.406
13	0.938	0.000	0.808	1.068	1.233	0.000	1.119	1.347
14	0.984	0.000	0.799	1.168	1.079	0.000	0.954	1.205
15	0.949	0.000	0.578	1.320	1.223	0.000	1.027	1.420
Ethnicity								
Other/Uknown	-0.122	0.000	-0.156	-0.088	-0.264	0.000	-0.287	-0.241
Bangladeshi	0.067	0.023	0.009	0.125	0.158	0.000	0.115	0.202
Black	-0.041	0.055	-0.083	0.001	-0.004	0.792	-0.034	0.026
Chinese/Other Asian	0.062	0.030	0.006	0.119	-0.008	0.718	-0.049	0.034
Indian	-0.003	0.911	-0.054	0.049	-0.035	0.070	-0.073	0.003
Pakistani	0.071	0.001	0.029	0.113	0.025	0.104	-0.005	0.056
Mixed	-0.034	0.186	-0.084	0.016	0.039	0.023	0.005	0.073
IMD								
Fourth quintile	-0.028	0.120	-0.063	0.007	-0.034	0.006	-0.059	-0.010
Third quintile	-0.014	0.414	-0.048	0.020	-0.037	0.003	-0.061	-0.013

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Second quintile	-0.012	0.488	-0.046	0.022	-0.081	0.000	-0.105	-0.058
Lowest quintile	-0.028	0.106	-0.061	0.006	-0.120	0.000	-0.143	-0.096
Region								
North East	-0.151	0.000	-0.214	-0.089	0.040	0.115	-0.010	0.089
North West	-0.061	0.000	-0.095	-0.028	0.166	0.000	0.142	0.190
Yorkshire and The Humber	0.045	0.147	-0.016	0.105	0.143	0.000	0.097	0.189
East Midlands	-0.146	0.000	-0.221	-0.071	0.052	0.038	0.003	0.102
West Midlands	-0.044	0.009	-0.077	-0.011	0.057	0.000	0.034	0.080
East of England	0.028	0.346	-0.031	0.087	0.143	0.000	0.102	0.183
South East	-0.100	0.000	-0.133	-0.066	0.028	0.020	0.004	0.052
South West	-0.113	0.000	-0.151	-0.076	0.068	0.000	0.041	0.096
Missing	-0.018	0.682	-0.107	0.070	0.017	0.569	-0.041	0.075
_cons	4.543	0.000	4.486	4.600	4.487	0.000	4.442	4.533

Table E 14 The relationship between test costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
Underweight										
Sex										
Male	-8.10	1.34	0	-10.72	-5.48	-17.99	2.07	0	-22.05	-13.93
Female	-8.18	1.36	0	-10.85	-5.52	-17.10	1.96	0	-20.95	-13.26
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Sex										
Male	4.67	1.03	0	2.64	6.70	9.83	1.57	0	6.76	12.90
Female	4.72	1.05	0	2.66	6.78	9.28	1.48	0	6.37	12.19
Obesity										
Sex										
Male	3.63	0.86	0	1.94	5.32	4.33	1.29	0.001	1.80	6.86
Female	3.57	0.87	0	1.85	5.28	4.06	1.22	0.001	1.66	6.46
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
Age (years)										
2	-4.90	0.81	0	-6.50	-3.31	-5.92	0.71	0	-7.31	-4.53
3	-4.80	0.79	0	-6.36	-3.24	-6.36	0.76	0	-7.85	-4.87
4	-5.48	0.91	0	-7.27	-3.69	-10.04	1.18	0	-12.35	-7.73
5	-6.40	1.06	0	-8.48	-4.32	-12.94	1.51	0	-15.90	-9.97
6	-7.47	1.24	0	-9.89	-5.05	-16.62	1.92	0	-20.40	-12.85
7	-8.01	1.32	0	-10.59	-5.43	-19.12	2.20	0	-23.44	-14.80

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
8	-9.65	1.59	0	-12.77	-6.52	-23.60	2.71	0	-28.91	-18.29
9	-11.33	1.88	0	-15.01	-7.64	-26.69	3.05	0	-32.68	-20.71
10	-12.52	2.09	0	-16.63	-8.41	-28.79	3.30	0	-35.25	-22.33
11	-13.80	2.33	0	-18.36	-9.24	-33.13	3.80	0	-40.57	-25.69
12	-14.44	2.51	0	-19.37	-9.51	-32.47	3.87	0	-40.06	-24.89
13	-13.43	2.42	0	-18.17	-8.70	-27.24	3.49	0	-34.08	-20.39
14	-15.76	3.08	0	-21.79	-9.73	-23.22	3.10	0	-29.29	-17.15
15	-18.68	5.00	0	-28.47	-8.88	-28.99	4.86	0	-38.52	-19.46
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Age (years)										
2	2.82	0.63	0	1.59	4.06	3.40	0.54	0	2.35	4.46
3	2.77	0.61	0	1.56	3.97	3.65	0.58	0	2.51	4.78
4	3.16	0.70	0	1.78	4.54	5.64	0.89	0	3.89	7.40
5	3.69	0.82	0	2.08	5.30	7.24	1.15	0	4.99	9.49
6	4.31	0.96	0	2.43	6.18	9.14	1.46	0	6.28	12.00
7	4.62	1.02	0	2.61	6.63	10.48	1.67	0	7.20	13.76
8	5.56	1.23	0	3.14	7.98	12.76	2.05	0	8.75	16.77
9	6.53	1.46	0	3.68	9.38	14.29	2.30	0	9.77	18.80
10	7.22	1.61	0	4.07	10.38	15.39	2.48	0	10.53	20.25
11	7.96	1.78	0	4.47	11.46	17.50	2.84	0	11.93	23.07
12	8.33	1.90	0	4.61	12.05	17.04	2.82	0	11.51	22.57
13	7.75	1.80	0	4.22	11.27	14.60	2.49	0	9.72	19.47
14	9.10	2.24	0	4.71	13.50	12.46	2.15	0	8.24	16.67
15	10.87	3.35	0.001	4.30	17.44	15.10	2.97	0	9.27	20.92
Obesity										
Age (years)										
2	2.21	0.52	0	1.18	3.24	1.56	0.44	0	0.69	2.43
3	2.15	0.51	0	1.14	3.16	1.67	0.48	0	0.74	2.60
4	2.42	0.59	0	1.27	3.57	2.54	0.74	0.001	1.10	3.99
5	2.86	0.68	0	1.52	4.21	3.25	0.95	0.001	1.40	5.10
6	3.33	0.80	0	1.76	4.89	4.05	1.20	0.001	1.69	6.40
7	3.63	0.85	0	1.96	5.30	4.62	1.38	0.001	1.92	7.32
8	4.31	1.03	0	2.30	6.32	5.56	1.68	0.001	2.26	8.87
9	4.98	1.21	0	2.61	7.35	6.18	1.89	0.001	2.47	9.89
10	5.41	1.33	0	2.80	8.03	6.65	2.04	0.001	2.65	10.64
11	5.90	1.47	0	3.01	8.79	7.48	2.33	0.001	2.90	12.05
12	6.16	1.56	0	3.10	9.23	7.24	2.29	0.002	2.75	11.72
13	5.86	1.47	0	2.98	8.75	6.32	1.96	0.001	2.48	10.16
14	6.46	1.80	0	2.93	10.00	5.40	1.68	0.001	2.10	8.70
15	6.20	2.43	0.011	1.45	10.96	6.37	2.13	0.003	2.20	10.54
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.	P>z	[95% conf.	interval]
Underweight										
Ethnicity										
Other/Uknown	-5.41	0.87	0	-7.11	-3.70	-12.49	1.46	0	-15.36	-9.62

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
Bangladeshi	-10.36	1.79	0	-13.87	-6.86	-23.22	2.70	0	-28.51	-17.92
Black	-7.56	1.25	0	-10.00	-5.12	-16.70	1.93	0	-20.49	-12.90
Chinese/Other Asian	-9.24	1.56	0	-12.31	-6.18	-17.79	2.09	0	-21.88	-13.70
Indian	-9.16	1.57	0	-12.24	-6.09	-18.30	2.13	0	-22.48	-14.13
Pakistani	-10.12	1.73	0	-13.50	-6.74	-20.66	2.38	0	-25.33	-15.99
White	-8.59	1.42	0	-11.37	-5.80	-18.46	2.12	0	-22.61	-14.31
Mixed	-7.83	1.31	0	-10.39	-5.27	-18.37	2.12	0	-22.54	-14.21
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Ethnicity										
Other/Uknown	3.12	0.68	0	1.78	4.45	7.01	1.11	0	4.83	9.19
Bangladeshi	5.98	1.35	0	3.33	8.64	12.23	2.00	0	8.30	16.16
Black	4.36	0.96	0	2.47	6.24	9.14	1.46	0	6.28	12.01
Chinese/Other Asian	5.33	1.20	0	2.99	7.67	9.61	1.55	0	6.56	12.65
Indian	5.29	1.19	0	2.95	7.63	9.76	1.59	0	6.65	12.87
Pakistani	5.84	1.32	0	3.25	8.43	10.88	1.78	0	7.39	14.36
White	4.95	1.10	0	2.79	7.11	10.06	1.61	0	6.91	13.20
Mixed	4.51	1.00	0	2.54	6.48	9.96	1.60	0	6.82	13.11
Obesity										
Ethnicity										
Other/Uknown	2.68	0.57	0	1.57	3.80	3.15	0.91	0.001	1.36	4.94
Bangladeshi	4.32	1.12	0	2.13	6.51	5.21	1.64	0.001	2.00	8.42
Black	3.48	0.80	0	1.91	5.05	4.03	1.20	0.001	1.68	6.38
Chinese/Other Asian	4.04	0.99	0	2.09	5.99	4.19	1.27	0.001	1.70	6.68
Indian	3.87	0.99	0	1.92	5.81	4.21	1.30	0.001	1.66	6.75
Pakistani	4.21	1.09	0	2.07	6.35	4.63	1.46	0.001	1.78	7.49
White	3.75	0.92	0	1.95	5.55	4.41	1.32	0.001	1.82	7.01
Mixed	3.50	0.83	0	1.86	5.13	4.36	1.31	0.001	1.78	6.93
	dy/dx	std.	P>z	[95% conf.	interval]	z		[95% conf.	interval]	
Underweight										
IMD										
Highest quintile	-8.56	1.42	0	-11.34	-5.77	-19.79	2.27		-24.24	-15.34
Fourth quintile	-8.26	1.37	0	-10.95	-5.58	-18.58	2.14		-22.76	-14.39
Third quintile	-8.19	1.36	0	-10.85	-5.53	-17.69	2.04		-21.69	-13.70
Second quintile	-7.96	1.32	0	-10.54	-5.38	-16.62	1.91		-20.37	-12.87
Lowest quintile	-7.95	1.32	0	-10.53	-5.37	-16.56	1.91		-20.30	-12.82
Healthy weight	(base outcome)					(base outcome)				
Overweight										
IMD										
Highest quintile	4.93	1.10	0	2.78	7.09	10.70	1.72		7.33	14.07
Fourth quintile	4.77	1.06	0	2.68	6.85	10.09	1.62		6.92	13.26
Third quintile	4.72	1.05	0	2.66	6.78	9.65	1.54		6.63	12.68
Second quintile	4.59	1.02	0	2.60	6.59	9.08	1.45		6.24	11.92
Lowest quintile	4.59	1.02	0	2.59	6.58	9.05	1.44		6.22	11.88
Obesity										
IMD										

	Year before					Year after				
	dy/dx	std. error	P>z	[95% conf.	interval]	dy/dx	std. error	P>z	[95% conf.	interval]
Highest quintile	3.75	0.92	0	1.96	5.55	4.67	1.41		1.89	7.44
Fourth quintile	3.63	0.88	0	1.90	5.36	4.42	1.33		1.81	7.03
Third quintile	3.61	0.87	0	1.90	5.33	4.24	1.27		1.76	6.73
Second quintile	3.56	0.85	0	1.90	5.22	4.00	1.19		1.66	6.33
Lowest quintile	3.53	0.84	0	1.88	5.19	3.98	1.19		1.66	6.31
	dy/dx	std.	P>z	[95% conf.	interval]	dy/dx	std.		[95% conf.	interval]
Underweight										
Region										
North East	-7.63	1.28	0	-10.14	-5.11	-15.33	1.82		-18.90	-11.77
North West	-8.77	1.47	0	-11.65	-5.90	-19.79	2.28		-24.26	-15.33
Yorkshire and The Humber	-9.52	1.60	0	-12.65	-6.38	-20.05	2.34		-24.64	-15.46
East Midlands	-7.93	1.35	0	-10.59	-5.28	-18.63	2.18		-22.90	-14.36
West Midlands	-8.30	1.37	0	-10.99	-5.60	-17.99	2.07		-22.05	-13.94
East of England	-8.53	1.43	0	-11.32	-5.73	-18.75	2.18		-23.03	-14.47
London	-7.43	1.22	0	-9.82	-5.05	-15.20	1.76		-18.65	-11.76
South East	-8.20	1.36	0	-10.88	-5.53	-17.99	2.06		-22.03	-13.95
South West	-7.76	1.29	0	-10.28	-5.23	-17.41	2.01		-21.34	-13.48
Missing	-10.23	1.76	0	-13.68	-6.78	-18.54	2.21		-22.87	-14.21
Healthy weight	(base outcome)					(base outcome)				
Overweight										
Region										
North East	4.40	0.99	0	2.46	6.33	8.54	1.37		5.85	11.22
North West	5.06	1.13	0	2.85	7.28	10.75	1.72		7.38	14.12
Yorkshire and The Humber	5.49	1.23	0	3.08	7.90	10.88	1.75		7.45	14.32
East Midlands	4.58	1.04	0	2.55	6.61	9.99	1.63		6.80	13.18
West Midlands	4.78	1.06	0	2.70	6.87	9.74	1.56		6.68	12.80
East of England	4.92	1.10	0	2.77	7.07	10.21	1.64		7.00	13.42
London	4.28	0.94	0	2.43	6.13	8.34	1.33		5.73	10.95
South East	4.73	1.05	0	2.67	6.80	9.75	1.57		6.68	12.82
South West	4.47	1.00	0	2.52	6.43	9.55	1.52		6.56	12.53
Missing	5.90	1.34	0	3.27	8.54	10.20	1.65		6.98	13.43
Obesity										
Region										
North East	3.33	0.82	0	1.72	4.94	3.82	1.12		1.63	6.00
North West	3.76	0.94	0	1.92	5.60	4.71	1.42		1.93	7.48
Yorkshire and The Humber	4.18	1.02	0	2.19	6.18	4.76	1.44		1.95	7.58
East Midlands	3.42	0.86	0	1.74	5.10	4.33	1.33		1.72	6.93
West Midlands	3.68	0.88	0	1.95	5.42	4.25	1.28		1.74	6.77
East of England	3.80	0.91	0	2.02	5.59	4.48	1.35		1.84	7.12
London	3.43	0.79	0	1.89	4.97	3.68	1.09		1.54	5.82
South East	3.58	0.88	0	1.86	5.30	4.26	1.29		1.74	6.78
South West	3.42	0.83	0	1.80	5.05	4.21	1.25		1.76	6.67
Missing	4.43	1.11	0	2.26	6.61	4.52	1.34		1.88	7.15

Appendix F

Complete list of HES variables (Admitted patient care, Outpatient care and Accident and emergency care) for deriving HRG codes

Table F 1 Complete list of HES variables for deriving HRG codes

Grouper field name/variable	Description/source	Further description	Data source in hospital episode statistics (HES) or CPRD if included	Mandation
		Admitted patient care		
PROCODET	PROCODET	Provider code of treatment		Mandatory
PROVSPNO	spno	Spell number uniquely identifying a hospitalisation	hes_episodes	Mandatory
EPIORDER	eorder	Order of episode within spell	hes_episodes	Mandatory
STARTAGE	Whole years rounded down: START DATE (EPISODE (epistart)) – PERSON BIRTH DATE	epistart is Date of start of episode	hes_episodes - age(Defined cohort_ages 2 and above_v6.dta)	Mandatory
SEX	CPRD		1=male(Defined cohort_ages 2 and above_v6.dta)	Mandatory
CLASSPAT	classpat	Patient classification: (Actual Management) 1=Ordinary admission; 2=Day case admission; 3=Regular day attendee; 4=Regular night attendee; 5=Mothers and babies using only delivery facilities; 8=Not applicable (other maternity event)	hes_episodes	Mandatory
ADMISORC	admisorc	Source of admission	hes_episodes	Mandatory
ADMIMETH	admimeth	Method of admission	hes_episodes	Mandatory
DISDEST	disdest	Destination on discharge	hes_episodes	Mandatory
DISMETH	dismeth	Method of discharge	hes_episodes	Mandatory
EPIDUR	epidur	Duration of episode in days	hes_episodes	Mandatory
MAINSPEF	mainspef	Speciality under which consultant is contracted	hes_episodes	Mandatory
NEOCARE	leave blank		blank/zero	Optional
TRETSPEF	tretspef	Speciality under which consultant is working in period of care	hes_episodes	Mandatory

DIAG_01	ICD	d_order=1 is the primary ICD	hes_diagnosis_epi	Mandatory
DIAG_02 - DIAG_99	ICD	d_order >=2 are the DIAG_02 to DIAG_99	hes_diagnosis_epi	Optional
OPER_01	OPCS	p_order = 1 is the primary procedure	hes_procedures_epi	Optional
OPER_02 - OPER_99	OPCS	p_order >=2 are the OPER_02 to OPER_99	hes_procedures_epi	Optional
CRITICALCAREDAYS			ccdisdate - ccstartdate (hes_ccare)	Optional
REHABILITATIONDAYS			blank/zero	Optional
SPCDAYS			blank/zero	Optional
Outpatient care				
STARTAGE	APPOINTMENT DATE – PERSON BIRTH DATE	apptdate-age (Whole years rounded down)	hesop_appointment_YYYY.txt - age(Defined cohort_ages 2 and above_v6.dta)	Mandatory
SEX	CPRD		1=male(Defined cohort_ages 2 and above_v6.dta)	Mandatory
MAINSPEF	mainspef	Main speciality	hesop_clinical_YYYY.txt	Mandatory
TRETSPEF	tretspef	Treatment speciality	hesop_clinical_YYYY.txt	Mandatory
FIRSTATT	firstatt	First attendance	hesop_appointment_YYYY.txt	Mandatory
OPER_01	opertn_01	Main (i.e. most resource intensive) operation	hesop_clinical_YYYY.txt	Optional
OPER_2 -OPER_99		Secondary operation/procedure	hesop_clinical_YYYY.txt	Optional
Accident and emergency care				
AGE	Whole years rounded down: ARRIVAL DATE – PERSON BIRTH DATE	arrivaldate - age	Whole years rounded down:	Mandatory
AEPATIENTGROUP	aepatgroup	Patient group	hesae_attendance_21_000719_DM.txt	Optional
INV_01	invest	Main investigation	hesae_investigation.txt	Optional
INV_02 - INV_99	invest2	Secondary investigation	hesae_investigation.txt	Optional
TREAT_01	treat	Main treatment	hesae_treatment.txt	Optional
TREAT_02 - TREAT_99	treat2	Secondary treatment	hesae_treatment.txt	Optional

Algorithm for deriving department codes

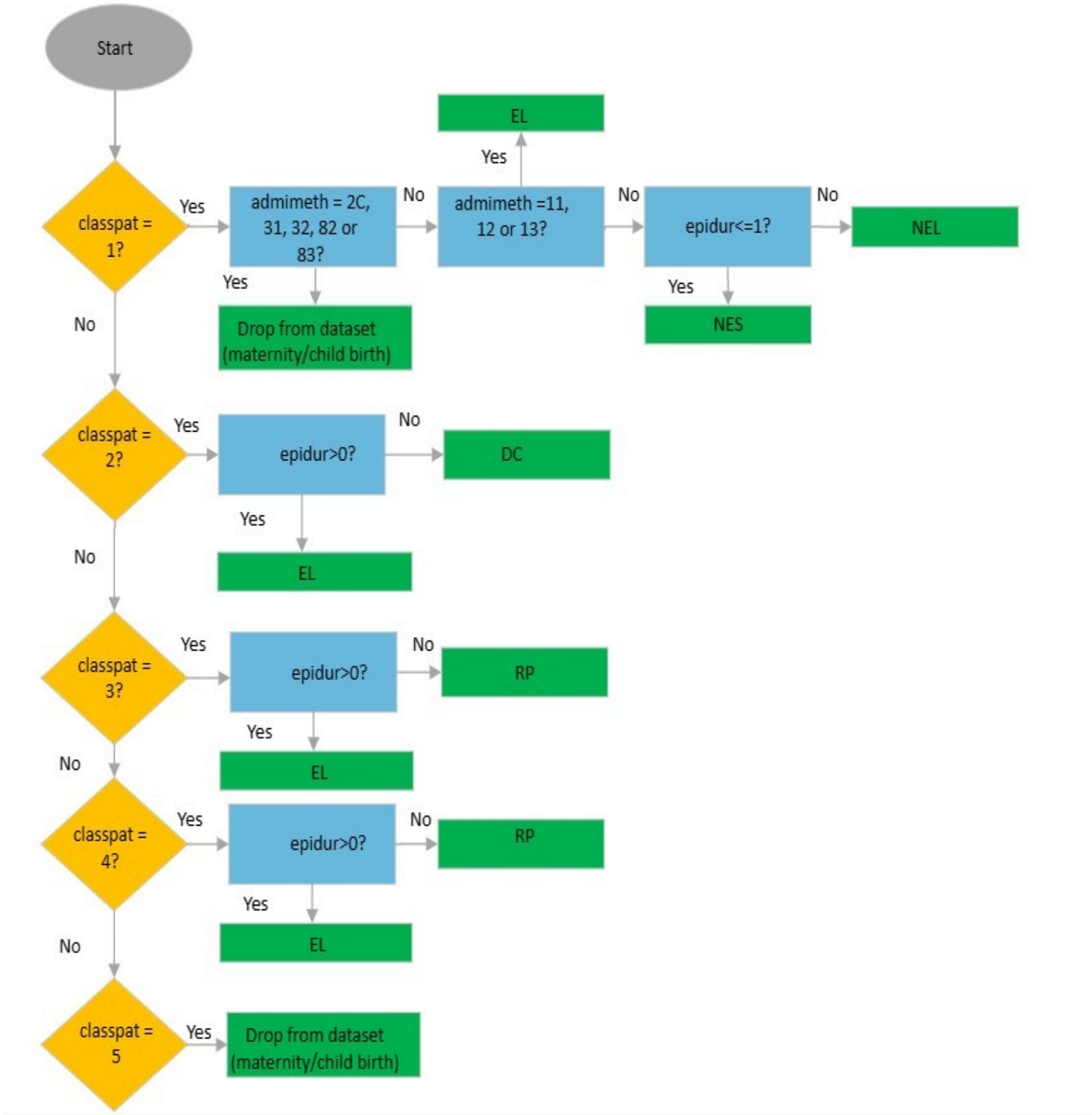

Figure F 1 Algorithm for deriving department codes

The yellow and blue boxes are described in the table above; EL: Elective Inpatient, NEL: Non Elective Long Stay (two days or more), NES: Non Elective Short Stay (Less than two days), DC: Day Case, RP: Regular Day or Night Admission

HRGs with LA97B had no associated cost and were equated to a zero. In one instance, negative (error) cost was reported in the 21/22 NHS National Cost Collection Data. I therefore used the 20/21 National Cost Collection Data and inflated to 21/22 costs (Unit Costs of Health and Social Care 2022, page 104). In a few cases, there were missing unit cost (NAUC) values in the 21/22 NHS National Cost Collection Data (probably due to the effect of

COVID restrictions on data collection). In such cases, I estimated the weighted average unit costs (NAUC) of department codes associated with a HRG.

Categorisation of resource use and costs into the year before or after a BMI measurement

Admitted patient care- categorisation of resource use and costs into the year before or after a BMI measurement

Figure 19 illustrates the algorithm used to allocate resource utilisation and associated costs to either the year preceding or the year following the index BMI measurement. It was chosen to avoid double counting costs in the year before and after the index BMI measurement while including relevant cost data. Costs one year before the index BMI measurement were included if the date of the start of an episode ('epistart') was later than or equal to the date of the calendar year before the index BMI measurement and the date of the end of the episode ('epiend') was before the date of the index BMI measurement. Costs one year after the index BMI measurement were included if the date of the start of an episode ('epistart') was later than or equal to the date of the index measurement and the date of the end of the episode ('epiend') was before or equal to the date of the calendar year after the index measurement.

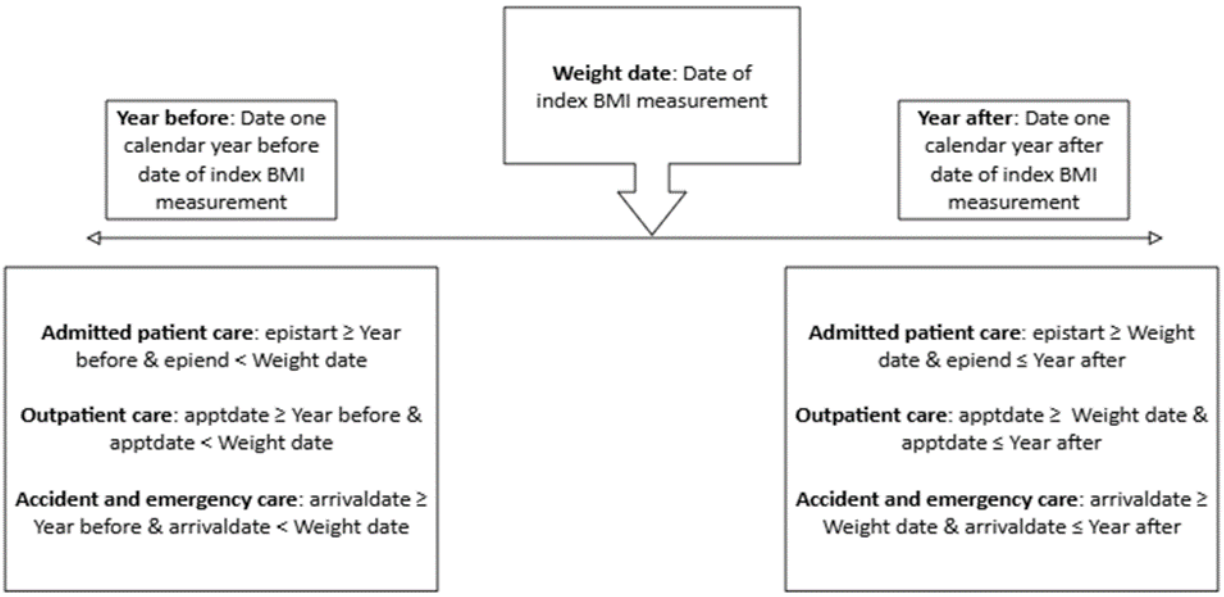

Figure F 2 Categorisation of resource use and costs (admitted patient care, outpatient care, accident and emergency care) one year before and after the index BMI measurement

Outpatient care - categorisation of resource use and costs into the year before or after a BMI measurement

I used a similar formula as admitted patient care to categorise outpatient care resource use and costs (see Figure 19). Costs one year before the index BMI measurement were included if the appointment date ('apptdate') was later than or equal to the date of the calendar year before the index measurement and before the date of the index measurement. Costs one year after the index BMI measurement were included if the appointment date('apptdate') later than or equal to the date of the index measurement and before or equal to the date of the calendar year after the index measurement.

Accident and emergency care - categorisation of resource use and costs into the year before or after a BMI measurement

I used a similar formula as admitted patient care to categorise accident and emergency care resource use and costs (see Figure 19). Costs one year before the index BMI measurement were included if the arrival date of a patient in the accident and emergency department ('arrivaldate') was later than or equal to the date of the calendar year before the index measurement and before the date of the index measurement. Costs one year after the index BMI measurement were included if the arrival date of a patient in the accident and emergency department ('arrivaldate') was later than or equal to the date of the index measurement and before or equal to the date of the calendar year after the index measurement.

Diagnostic tests

AIC and BIC test in Stata - Comparison of AIC and BIC outputs for ZINB and ZIP models

* Choose the model with the lowest outputs for AIC and BIC

Table F 2 Akaike's information criterion and Bayesian information criterion for ZINB and ZIP regression models - Admitted patient care episodes one year before and after BMI measurement

Year before						
Model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
ZINB	268,231	-150226.7	-149694.3	77	299542.6	300351.1
ZIP	268,231	-174274.7	-173589	76	347330	348128
Year after						
Model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
ZINB	268,231	-130957	-130625.4	77	261404.7	262213.2
ZIP	268,231	-151247.8	-150688.7	76	301529.3	302327.3

Table F 3 Akaike's information criterion and Bayesian information criterion for ZINB and ZIP regression models - Outpatient care attendances one year before and after BMI measurement

Year before						
Model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
ZINB	268,231	-445294.7	-444223.7	77	888601.4	889409.9

ZIP	268,231	-602636.7	-598580.4	76	1197313	1198111
Year after						
Model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
ZINB	268,231	-490114.8	-488967.9	77	978089.8	978898.3
ZIP	268,231	-653292.1	-649471.1	76	1299094	1299892

Table F 4 Akaike's information criterion and Bayesian information criterion for ZINB and ZIP regression models - Accident and emergency attendances one year before BMI measurement

Model	**N**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
ZINB	268,231	-257255.6	-255352.5	77	510858.9	511667.4
ZIP	268,231	-264697.4	-262718.4	76	525588.8	526386.8

Results

Admitted patient care – results

Table F 5 Regression coefficients (marginal effects) for the two parts of the model- Resource use

Total_episodes			**[95%**				**[95%**	
Covariate	**Coefficient**	**P>z**	**conf.**	**interval]**	**Coefficient**	**P>z**	**conf.**	**interval]**
	Year before (ZIMB)				**Year after (ZIMB)**			
UK90_bmi								
Underweight	-0.190	0.002	-0.311	-0.068	-0.054	0.350	-0.167	0.059
Overweight	0.168	0.002	0.060	0.275	0.158	0.004	0.051	0.266
Obesity	0.166	0.001	0.067	0.266	0.137	0.022	0.019	0.255
Sex								
Female	0.004	0.902	-0.064	0.072	-0.021	0.568	-0.093	0.051
age_whole								
3	-0.285	0.000	-0.384	-0.186	-0.231	0.000	-0.351	-0.110
4	-0.408	0.000	-0.503	-0.312	-0.331	0.000	-0.445	-0.218
5	-0.577	0.000	-0.695	-0.459	-0.459	0.000	-0.605	-0.313
6	-0.574	0.000	-0.706	-0.441	-0.398	0.000	-0.551	-0.244
7	-0.668	0.000	-0.817	-0.518	-0.539	0.000	-0.694	-0.384
8	-0.736	0.000	-0.873	-0.599	-0.531	0.000	-0.697	-0.364
9	-0.670	0.000	-0.834	-0.506	-0.293	0.011	-0.520	-0.066
10	-0.687	0.000	-0.865	-0.509	-0.458	0.000	-0.642	-0.274
11	-0.322	0.017	-0.585	-0.058	-0.207	0.074	-0.433	0.020
12	-0.581	0.027	-1.097	-0.065	-0.446	0.004	-0.751	-0.141
13	-0.343	0.302	-0.996	0.309	0.101	0.736	-0.487	0.689

Total_episodes Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIMB)	P>z	[95% conf.	interval]
14	-0.816	0.001	-1.295	-0.338	-0.516	0.017	-0.939	-0.092
15	-1.148	0.002	-1.867	-0.429	-0.726	0.118	-1.635	0.183
Ethnicity								
Other/Uknown	-0.094	0.593	-0.437	0.250	0.093	0.534	-0.199	0.385
Bangladeshi	0.264	0.199	-0.139	0.668	0.285	0.075	-0.029	0.600
Black	0.021	0.758	-0.111	0.152	0.227	0.001	0.091	0.363
Chinese/Other Asian	0.231	0.035	0.016	0.447	0.414	0.014	0.084	0.745
Indian	0.022	0.805	-0.153	0.198	0.071	0.439	-0.110	0.253
Pakistani	0.393	0.001	0.171	0.614	0.387	0.002	0.141	0.633
Mixed	0.129	0.187	-0.063	0.321	0.133	0.230	-0.084	0.350
IMD								
Fourth quintile	0.000	0.994	-0.122	0.121	-0.010	0.883	-0.149	0.128
Third quintile	-0.050	0.397	-0.167	0.066	-0.073	0.268	-0.203	0.056
Second quintile	-0.021	0.707	-0.131	0.089	-0.059	0.351	-0.181	0.064
Lowest quintile	-0.019	0.738	-0.128	0.091	-0.065	0.302	-0.188	0.058
Region								
North East	0.058	0.591	-0.153	0.269	0.194	0.048	0.002	0.386
North West	0.161	0.002	0.057	0.266	0.223	0.000	0.116	0.330
Yorkshire and The Humber	-0.197	0.011	-0.349	-0.046	0.038	0.728	-0.178	0.254
East Midlands	-0.162	0.124	-0.368	0.044	0.016	0.916	-0.282	0.314
West Midlands	0.078	0.190	-0.039	0.194	0.103	0.081	-0.013	0.218
East of England	-0.069	0.473	-0.258	0.120	-0.126	0.166	-0.305	0.052
South East	0.049	0.432	-0.073	0.170	0.208	0.002	0.075	0.342
South West	-0.077	0.257	-0.209	0.056	-0.024	0.713	-0.151	0.103
Missing	0.215	0.604	-0.597	1.027	-0.128	0.232	-0.339	0.082
_cons	-0.608	0.000	-0.754	-0.461	-1.001	0.000	-1.152	-0.849
inflate								
UK90_bmi								
Underweight	-0.165	0.310	-0.483	0.153	-0.336	0.028	-0.635	-0.037
Overweight	0.135	0.234	-0.088	0.358	0.212	0.064	-0.012	0.437
Obesity	0.095	0.350	-0.105	0.295	-0.039	0.749	-0.277	0.199
Sex								
Female	0.246	0.002	0.094	0.399	0.139	0.095	-0.024	0.302
age_whole								
3	0.503	0.001	0.201	0.806	0.310	0.090	-0.048	0.669
4	0.544	0.000	0.241	0.846	0.430	0.014	0.088	0.773
5	0.896	0.000	0.528	1.264	0.921	0.000	0.522	1.321
6	1.104	0.000	0.754	1.454	1.296	0.000	0.903	1.688
7	1.622	0.000	1.275	1.969	1.494	0.000	1.121	1.867

Total_episodes Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIMB)	P>z	[95% conf.	interval]
8	1.634	0.000	1.284	1.983	1.574	0.000	1.172	1.975
9	1.889	0.000	1.516	2.261	2.050	0.000	1.622	2.478
10	1.905	0.000	1.495	2.315	1.814	0.000	1.401	2.227
11	2.206	0.000	1.754	2.657	1.896	0.000	1.434	2.359
12	1.738	0.001	0.740	2.736	1.521	0.000	0.824	2.217
13	2.483	0.000	1.585	3.381	1.970	0.000	1.017	2.922
14	0.715	0.247	-0.496	1.926	1.507	0.005	0.449	2.566
15	1.045	0.143	-0.352	2.442	-6.015	0.970	-320.828	308.799
Ethnicity								
Other/Uknown	2.710	0.000	2.362	3.058	2.698	0.000	2.372	3.024
Bangladeshi	1.304	0.000	0.722	1.886	1.113	0.000	0.547	1.680
Black	0.147	0.450	-0.235	0.530	0.551	0.002	0.206	0.896
Chinese/Other Asian	0.463	0.059	-0.018	0.945	0.815	0.006	0.236	1.395
Indian	0.289	0.225	-0.178	0.757	0.287	0.276	-0.229	0.803
Pakistani	0.654	0.002	0.232	1.076	0.446	0.098	-0.083	0.975
Mixed	0.121	0.647	-0.399	0.641	0.185	0.518	-0.377	0.747
IMD								
Fourth quintile	-0.161	0.226	-0.421	0.099	-0.250	0.079	-0.529	0.029
Third quintile	-0.334	0.011	-0.593	-0.075	-0.525	0.000	-0.792	-0.258
Second quintile	-0.325	0.008	-0.564	-0.086	-0.545	0.000	-0.808	-0.282
Lowest quintile	-0.439	0.000	-0.674	-0.205	-0.610	0.000	-0.869	-0.351
Region								
North East	-0.303	0.276	-0.848	0.242	-0.338	0.232	-0.893	0.217
North West	-0.377	0.003	-0.628	-0.127	0.004	0.977	-0.268	0.276
Yorkshire and The Humber	-0.534	0.032	-1.023	-0.045	-0.054	0.851	-0.618	0.509
East Midlands	-0.003	0.992	-0.543	0.538	0.508	0.098	-0.094	1.109
West Midlands	0.243	0.055	-0.005	0.490	0.470	0.000	0.215	0.725
East of England	0.345	0.117	-0.086	0.776	0.415	0.055	-0.010	0.840
South East	0.160	0.227	-0.100	0.421	0.558	0.000	0.278	0.839
South West	0.262	0.101	-0.051	0.575	0.358	0.023	0.049	0.666
Missing	0.601	0.364	-0.696	1.897	0.143	0.639	-0.455	0.741
_cons	-2.674	0.000	-3.070	-2.278	-2.650	0.000	-3.088	-2.212
/lnalpha	1.573	0.000	1.521	1.625	1.727	0.000	1.660	1.793
alpha	4.822		4.577	5.080	5.622		5.261	6.008

Table F 6 Regression coefficients (marginal effects) for the two parts of the model- Costs

Total_costs	Coefficient Year before (two-part GLM)	P>z	[95% conf.	interval]	Coefficient Year after (two-part GLM)	P>z	[95% conf.	interval]
logit								
UK90_bmi								
Underweight	-0.077	0.011	-0.136	-0.018	0.082	0.007	0.023	0.142

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Overweight	0.064	0.000	0.029	0.099	0.030	0.119	-0.008	0.068
Obesity	0.078	0.000	0.047	0.109	0.080	0.000	0.048	0.113
Sex								
Female	-0.103	0.000	-0.126	-0.081	-0.084	0.000	-0.108	-0.059
age_whole								
3	-0.311	0.000	-0.355	-0.266	-0.209	0.000	-0.258	-0.161
4	-0.412	0.000	-0.457	-0.367	-0.289	0.000	-0.337	-0.240
5	-0.632	0.000	-0.677	-0.587	-0.519	0.000	-0.569	-0.470
6	-0.688	0.000	-0.735	-0.642	-0.609	0.000	-0.660	-0.558
7	-0.901	0.000	-0.949	-0.853	-0.755	0.000	-0.807	-0.703
8	-0.962	0.000	-1.011	-0.912	-0.791	0.000	-0.844	-0.738
9	-1.022	0.000	-1.074	-0.969	-0.821	0.000	-0.877	-0.765
10	-1.050	0.000	-1.106	-0.993	-0.828	0.000	-0.888	-0.768
11	-0.938	0.000	-1.004	-0.872	-0.704	0.000	-0.774	-0.635
12	-0.902	0.000	-1.040	-0.763	-0.697	0.000	-0.842	-0.552
13	-1.083	0.000	-1.304	-0.862	-0.526	0.000	-0.728	-0.324
14	-0.662	0.000	-0.939	-0.384	-0.714	0.000	-1.033	-0.395
15	-0.785	0.071	-1.637	0.067	-0.302	0.470	-1.123	0.518
Ethnicity								
Other/Uknown	-1.319	0.000	-1.369	-1.269	-1.146	0.000	-1.196	-1.095
Bangladeshi	-0.227	0.000	-0.317	-0.137	-0.137	0.004	-0.232	-0.043
Black	-0.023	0.355	-0.072	0.026	0.002	0.934	-0.050	0.054
Chinese/Other Asian	0.028	0.402	-0.037	0.092	0.058	0.099	-0.011	0.126
Indian	-0.074	0.031	-0.141	-0.007	-0.049	0.181	-0.120	0.023
Pakistani	0.041	0.140	-0.013	0.095	0.117	0.000	0.060	0.174
Mixed	0.026	0.345	-0.028	0.081	0.036	0.219	-0.022	0.095
IMD								
Fourth quintile	0.057	0.006	0.016	0.098	0.076	0.001	0.032	0.120
Third quintile	0.051	0.012	0.011	0.092	0.112	0.000	0.069	0.155
Second quintile	0.083	0.000	0.044	0.123	0.122	0.000	0.080	0.164
Lowest quintile	0.109	0.000	0.071	0.147	0.126	0.000	0.085	0.167
Region								
North East	0.219	0.000	0.157	0.281	0.312	0.000	0.248	0.376
North West	0.329	0.000	0.292	0.367	0.219	0.000	0.179	0.260
Yorkshire and The Humber	0.034	0.310	-0.032	0.101	0.107	0.002	0.039	0.175
East Midlands	-0.041	0.368	-0.129	0.048	-0.102	0.037	-0.197	-0.006
West Midlands	0.057	0.004	0.018	0.096	-0.008	0.709	-0.049	0.034
East of England	-0.151	0.000	-0.213	-0.089	-0.211	0.000	-0.278	-0.143
South East	0.057	0.006	0.017	0.097	0.023	0.283	-0.019	0.066
South West	-0.051	0.021	-0.095	-0.008	-0.057	0.016	-0.103	-0.010
Missing	0.019	0.723	-0.088	0.127	-0.008	0.895	-0.122	0.107

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
_cons	-1.162	0.000	-1.215	-1.109	-1.509	0.000	-1.566	-1.451
glm								
UK90_bmi								
Underweight	0.041	0.493	-0.077	0.160	0.151	0.017	0.027	0.276
Overweight	0.063	0.115	-0.015	0.140	0.010	0.815	-0.074	0.094
Obesity	0.059	0.102	-0.012	0.131	0.057	0.221	-0.034	0.147
Sex								
Female	0.031	0.208	-0.017	0.079	0.000	0.993	-0.058	0.059
age_whole								
3	-0.184	0.000	-0.281	-0.087	-0.176	0.002	-0.287	-0.064
4	-0.178	0.000	-0.275	-0.082	-0.148	0.009	-0.259	-0.036
5	-0.280	0.000	-0.375	-0.185	-0.171	0.008	-0.297	-0.044
6	-0.235	0.000	-0.329	-0.142	-0.057	0.341	-0.175	0.061
7	-0.189	0.001	-0.301	-0.076	-0.099	0.157	-0.236	0.038
8	-0.201	0.000	-0.312	-0.090	-0.161	0.007	-0.278	-0.043
9	-0.209	0.000	-0.315	-0.103	-0.040	0.556	-0.172	0.092
10	-0.107	0.073	-0.224	0.010	-0.052	0.423	-0.180	0.076
11	0.045	0.524	-0.094	0.185	0.065	0.355	-0.073	0.204
12	-0.033	0.827	-0.330	0.264	0.048	0.749	-0.244	0.340
13	0.006	0.982	-0.469	0.480	-0.064	0.736	-0.438	0.309
14	0.042	0.901	-0.624	0.709	-0.434	0.004	-0.728	-0.139
15	-1.165	0.000	-1.618	-0.711	-0.691	0.052	-1.386	0.005
Ethnicity								
Other/Uknown	-0.043	0.584	-0.199	0.112	-0.043	0.619	-0.214	0.127
Bangladeshi	0.005	0.970	-0.255	0.265	-0.061	0.541	-0.257	0.135
Black	-0.021	0.700	-0.129	0.086	0.062	0.356	-0.070	0.194
Chinese/Other Asian	0.008	0.903	-0.122	0.139	-0.001	0.994	-0.176	0.175
Indian	-0.053	0.465	-0.195	0.089	-0.096	0.249	-0.259	0.067
Pakistani	0.100	0.059	-0.004	0.203	0.045	0.419	-0.064	0.154
Mixed	-0.072	0.179	-0.177	0.033	-0.036	0.683	-0.210	0.138
IMD								
Fourth quintile	-0.002	0.963	-0.091	0.087	0.057	0.301	-0.051	0.164
Third quintile	-0.015	0.745	-0.103	0.074	-0.017	0.753	-0.122	0.089
Second quintile	-0.006	0.886	-0.091	0.079	0.023	0.646	-0.077	0.123
Lowest quintile	0.022	0.604	-0.061	0.105	0.072	0.192	-0.036	0.179
Region								
North East	-0.174	0.030	-0.331	-0.016	-0.104	0.280	-0.294	0.085
North West	-0.139	0.001	-0.219	-0.059	-0.095	0.046	-0.189	-0.002
Yorkshire and The Humber	-0.079	0.224	-0.207	0.048	0.003	0.978	-0.220	0.226

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
East Midlands	-0.043	0.638	-0.221	0.136	0.167	0.189	-0.082	0.416
West Midlands	-0.090	0.035	-0.173	-0.006	-0.051	0.310	-0.150	0.048
East of England	0.083	0.316	-0.080	0.247	0.029	0.753	-0.152	0.211
South East	-0.070	0.102	-0.154	0.014	-0.005	0.916	-0.108	0.097
South West	-0.098	0.045	-0.194	-0.002	-0.069	0.252	-0.187	0.049
Missing	-0.058	0.688	-0.338	0.223	-0.058	0.622	-0.289	0.173
_cons	8.330	0.000	8.211	8.449	8.231	0.000	8.095	8.366

Table F 7 The relationship between admitted patient care costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	-10.64	0.72	-68.90	47.62	100.06	0.00	33.50	166.63
Female	-10.38	0.71	-64.96	44.21	92.44	0.00	30.68	154.20
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	56.71	0.01	13.95	99.46	14.70	0.44	-22.50	51.90
Female	53.48	0.01	13.51	93.44	13.64	0.44	-20.75	48.02
Obesity								
Sex								
Male	61.21	0.00	22.27	100.15	53.89	0.01	11.59	96.20
Female	57.79	0.00	21.03	94.54	49.91	0.01	10.35	89.47
Underweight								
Age (years)								
2	-15.43	0.79	-129.64	98.79	165.33	0.00	53.32	277.34
3	-12.45	0.74	-87.29	62.39	117.46	0.00	38.62	196.30
4	-12.05	0.73	-81.06	56.96	113.28	0.00	36.69	189.87
5	-9.89	0.71	-61.21	41.43	90.78	0.00	29.95	151.60
6	-10.04	0.70	-61.26	41.17	94.34	0.00	31.20	157.48
7	-9.32	0.68	-53.75	35.12	79.39	0.00	26.09	132.69
8	-8.84	0.68	-50.35	32.66	72.18	0.00	23.81	120.55
9	-8.45	0.67	-47.52	30.61	79.38	0.00	26.42	132.34
10	-9.20	0.67	-51.42	33.03	77.86	0.00	25.32	130.40
11	-11.49	0.68	-65.78	42.81	97.46	0.00	31.80	163.11
12	-10.75	0.68	-61.72	40.22	95.15	0.01	25.70	164.60

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
13	-9.70	0.67	-53.55	34.15	95.41	0.01	22.13	168.70
14	-12.90	0.70	-77.42	51.62	54.85	0.01	12.86	96.85
15	-3.54	0.69	-20.76	13.68	59.53	0.09	-9.32	128.39
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	106.56	0.01	23.45	189.67	23.65	0.46	-38.78	86.09
3	71.77	0.01	17.04	126.51	17.05	0.45	-26.93	61.04
4	66.67	0.01	16.23	117.12	16.52	0.45	-25.95	58.98
5	50.39	0.01	12.37	88.41	13.40	0.44	-20.35	47.15
6	50.42	0.01	12.79	88.04	13.98	0.43	-21.00	48.96
7	44.26	0.01	11.32	77.19	11.83	0.43	-17.50	41.17
8	41.46	0.01	10.27	72.65	10.77	0.43	-15.83	37.38
9	39.14	0.01	10.28	68.01	11.86	0.43	-17.41	41.13
10	42.34	0.01	10.97	73.71	11.64	0.43	-17.07	40.34
11	54.12	0.01	13.96	94.29	14.50	0.43	-21.53	50.53
12	50.71	0.01	10.22	91.20	14.16	0.43	-21.23	49.55
13	43.87	0.03	5.27	82.47	14.12	0.44	-21.65	49.89
14	63.59	0.05	-1.05	128.23	8.18	0.43	-12.27	28.64
15	16.94	0.07	-1.66	35.54	8.72	0.47	-14.73	32.17
Obesity								
Age (years)								
2	114.14	0.00	37.25	191.03	87.58	0.02	15.93	159.23
3	77.27	0.00	26.64	127.89	62.78	0.02	12.38	113.19
4	71.87	0.00	25.61	118.13	60.72	0.02	11.47	109.96
5	54.47	0.00	19.88	89.06	49.03	0.02	9.69	88.38
6	54.53	0.00	20.05	89.01	51.08	0.01	11.02	91.15
7	47.97	0.00	17.27	78.66	43.15	0.02	8.52	77.78
8	44.96	0.00	17.10	72.82	39.27	0.01	9.10	69.44
9	42.47	0.00	16.13	68.80	43.21	0.01	10.21	76.22
10	45.95	0.00	17.54	74.35	42.39	0.01	10.07	74.71
11	58.68	0.00	22.15	95.21	52.91	0.01	11.96	93.86
12	54.98	0.00	17.28	92.68	51.67	0.02	9.42	93.92
13	47.64	0.01	10.21	85.07	51.61	0.02	7.22	96.01
14	68.82	0.03	5.60	132.05	29.83	0.02	4.39	55.27
15	18.36	0.06	-0.36	37.08	32.00	0.11	-6.92	70.92
Underweight								
Ethnicity								
Other/Uknown	-4.51	0.63	-22.71	13.68	36.21	0.00	12.00	60.41
Bangladeshi	-10.79	0.70	-65.06	43.47	91.63	0.00	28.49	154.76
Black	-11.66	0.71	-73.67	50.36	115.63	0.00	37.59	193.67
Chinese/Other Asian	-12.17	0.72	-79.08	54.74	113.32	0.00	35.56	191.08

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Indian	-10.79	0.71	-67.85	46.27	92.24	0.00	29.56	154.92
Pakistani	-13.20	0.73	-87.96	61.56	125.68	0.00	41.24	210.13
White	-11.54	0.72	-74.93	51.85	106.27	0.00	35.21	177.33
Mixed	-11.10	0.72	-72.43	50.23	106.90	0.00	34.05	179.74
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	18.71	0.01	4.68	32.73	5.52	0.41	-7.72	18.76
Bangladeshi	53.33	0.02	8.64	98.03	13.56	0.44	-20.65	47.76
Black	60.61	0.01	15.11	106.11	17.01	0.44	-25.89	59.91
Chinese/Other Asian	65.03	0.01	15.06	114.99	16.61	0.44	-25.77	58.98
Indian	55.74	0.01	13.19	98.29	13.60	0.44	-20.72	47.91
Pakistani	72.29	0.01	17.09	127.50	18.34	0.45	-28.70	65.38
White	61.68	0.01	15.37	107.98	15.61	0.44	-23.96	55.18
Mixed	59.64	0.01	14.37	104.91	15.68	0.44	-24.09	55.45
Obesity								
Ethnicity								
Other/Uknown	20.39	0.00	7.29	33.50	19.96	0.01	4.11	35.82
Bangladeshi	57.72	0.00	18.86	96.57	49.56	0.02	9.44	89.69
Black	65.47	0.00	23.95	107.00	62.32	0.01	13.21	111.44
Chinese/Other Asian	70.18	0.00	24.55	115.82	60.93	0.02	11.95	109.91
Indian	60.23	0.00	21.37	99.09	49.78	0.01	10.04	89.52
Pakistani	77.96	0.00	27.73	128.19	67.40	0.01	13.56	121.24
White	66.56	0.00	24.10	109.03	57.23	0.01	12.00	102.45
Mixed	64.35	0.00	22.91	105.80	57.51	0.01	11.66	103.36
Underweight								
IMD								
Highest quintile	-10.37	0.71	-64.13	43.39	86.61	0.00	28.59	144.63
Fourth quintile	-10.57	0.71	-67.04	45.89	97.84	0.00	32.35	163.33
Third quintile	-10.33	0.71	-65.07	44.41	92.52	0.00	30.41	154.62
Second quintile	-10.39	0.72	-66.20	45.42	96.53	0.00	32.00	161.05
Lowest quintile	-10.81	0.73	-70.97	49.35	104.25	0.00	34.82	173.68
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	52.80	0.01	13.34	92.26	12.82	0.44	-19.42	45.07
Fourth quintile	55.18	0.01	13.76	96.60	14.42	0.44	-21.90	50.75
Third quintile	53.56	0.01	13.29	93.83	13.62	0.44	-20.80	48.04
Second quintile	54.48	0.01	13.39	95.57	14.20	0.44	-21.72	50.11
Lowest quintile	58.40	0.01	14.33	102.48	15.29	0.44	-23.47	54.06

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Obesity								
IMD								
Highest quintile	57.08	0.00	20.77	93.39	46.88	0.01	9.92	83.83
Fourth quintile	59.60	0.00	21.56	97.64	52.81	0.01	11.22	94.39
Third quintile	57.86	0.00	20.91	94.82	49.89	0.01	10.57	89.21
Second quintile	58.84	0.00	21.42	96.25	52.02	0.01	11.11	92.92
Lowest quintile	63.01	0.00	22.76	103.27	56.10	0.01	11.45	100.74
Underweight								
Region								
North East	-10.81	0.74	-74.38	52.76	122.18	0.01	37.83	206.53
North West	-11.24	0.75	-79.63	57.15	110.34	0.00	36.11	184.58
Yorkshire and The Humber	-10.59	0.71	-66.20	45.03	108.75	0.01	33.35	184.14
East Midlands	-10.22	0.70	-62.65	42.22	103.40	0.01	29.72	177.07
West Midlands	-10.35	0.71	-65.15	44.45	91.81	0.00	30.34	153.27
East of England	-11.70	0.70	-70.71	47.30	86.57	0.00	26.94	146.19
London	-10.11	0.70	-62.25	42.02	90.68	0.00	30.35	151.00
South East	-10.53	0.71	-66.09	45.02	96.38	0.00	32.05	160.71
South West	-9.99	0.70	-60.95	40.97	88.45	0.00	28.95	147.94
Missing	-10.81	0.70	-66.06	44.44	90.34	0.01	26.65	154.04
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	61.18	0.01	14.25	108.12	17.68	0.45	-28.27	63.63
North West	65.51	0.01	15.42	115.59	16.08	0.45	-25.21	57.37
Yorkshire and The Humber	54.65	0.01	13.42	95.88	15.96	0.44	-24.33	56.26
East Midlands	51.56	0.01	12.16	90.96	15.33	0.44	-23.40	54.05
West Midlands	53.62	0.01	13.38	93.85	13.55	0.44	-20.58	47.69
East of England	58.20	0.01	13.95	102.45	12.86	0.43	-19.20	44.93
London	51.22	0.01	12.80	89.64	13.39	0.44	-20.25	47.03
South East	54.39	0.01	13.61	95.16	14.22	0.44	-21.62	50.06
South West	50.18	0.01	12.59	87.78	13.08	0.43	-19.70	45.86
Missing	54.36	0.01	11.26	97.46	13.36	0.44	-20.24	46.96
Obesity								
Region								
North East	65.91	0.00	20.59	111.22	65.17	0.02	9.49	120.85
North West	70.50	0.00	24.83	116.18	59.13	0.01	12.06	106.19
Yorkshire and The Humber	59.05	0.00	21.20	96.90	58.54	0.01	12.01	105.06
East Midlands	55.76	0.00	19.36	92.15	56.00	0.02	9.72	102.28
West Midlands	57.93	0.00	20.95	94.90	49.59	0.01	10.51	88.68
East of England	62.97	0.00	22.02	103.92	46.96	0.02	9.22	84.69
London	55.38	0.00	20.54	90.23	48.99	0.01	10.70	87.28

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
South East	58.77	0.00	21.50	96.04	52.04	0.01	10.93	93.16
South West	54.28	0.00	19.91	88.65	47.84	0.01	9.89	85.79
Missing	58.79	0.01	17.22	100.35	48.85	0.02	9.26	88.45

Outpatient care – results

Table F 8 Regression coefficients (marginal effects) for the two parts of the model- Resource use

Total_OPC_attendance	**Coefficient**	**P>z**	**[95% conf.**	**interval]**	**Coefficient**	**P>z**	**[95% conf.**	**interval]**
Covariate	**Year before (ZIMB)**				**Year after (ZIMB)**			
UK90_bmi					0.0490515	0.048	0.0003732	0.0977298
Underweight	0.055	0.110	-0.012	0.122	0.076	0.000	0.045	0.107
Overweight	0.070	0.000	0.035	0.105	0.110	0.000	0.074	0.146
Obesity	0.104	0.000	0.068	0.140				
Sex					-0.029	0.009	-0.050	-0.007
Female	-0.037	0.002	-0.062	-0.013				
age_whole					-0.105	0.000	-0.149	-0.061
3	-0.140	0.000	-0.193	-0.087	-0.089	0.000	-0.130	-0.049
4	-0.152	0.000	-0.202	-0.101	-0.167	0.000	-0.209	-0.124
5	-0.214	0.000	-0.266	-0.162	-0.152	0.000	-0.195	-0.108
6	-0.188	0.000	-0.238	-0.138	-0.193	0.000	-0.247	-0.140
7	-0.202	0.000	-0.260	-0.145	-0.235	0.000	-0.280	-0.191
8	-0.267	0.000	-0.321	-0.212	-0.198	0.000	-0.244	-0.152
9	-0.228	0.000	-0.282	-0.174	-0.103	0.000	-0.152	-0.053
10	-0.154	0.000	-0.216	-0.092	-0.006	0.827	-0.063	0.050
11	-0.040	0.268	-0.110	0.031	0.020	0.708	-0.083	0.122
12	-0.161	0.007	-0.276	-0.045	0.282	0.003	0.098	0.465
13	-0.022	0.802	-0.196	0.152	0.217	0.061	-0.010	0.444
14	0.305	0.073	-0.028	0.638	0.088	0.794	-0.571	0.746
15	-0.375	0.084	-0.801	0.051				
Ethnicity					-0.396	0.000	-0.474	-0.317
Other/Uknown	-0.412	0.000	-0.490	-0.333	-0.232	0.000	-0.323	-0.141
Bangladeshi	-0.211	0.000	-0.318	-0.104	-0.010	0.692	-0.058	0.038
Black	-0.029	0.352	-0.089	0.032	0.028	0.464	-0.047	0.104
Chinese/Other Asian	-0.003	0.957	-0.095	0.089	-0.037	0.243	-0.099	0.025
Indian	-0.051	0.184	-0.126	0.024	0.045	0.115	-0.011	0.100
Pakistani	0.043	0.213	-0.025	0.110	-0.011	0.690	-0.065	0.043
Mixed	0.009	0.798	-0.060	0.078				
IMD					0.047	0.007	0.013	0.082

Total_OPC_attendance	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	**Year before (ZIMB)**				**Year after (ZIMB)**			
Fourth quintile	0.053	0.010	0.012	0.093	0.045	0.011	0.010	0.079
Third quintile	0.027	0.161	-0.011	0.066	0.061	0.000	0.027	0.095
Second quintile	0.046	0.022	0.007	0.086	0.116	0.000	0.083	0.148
Lowest quintile	0.101	0.000	0.064	0.138				
Region					0.287	0.000	0.157	0.416
North East	0.451	0.000	0.342	0.561	-0.042	0.039	-0.082	-0.002
North West	-0.010	0.667	-0.054	0.034	0.012	0.673	-0.044	0.068
Yorkshire and The Humber	0.021	0.492	-0.038	0.080	-0.097	0.006	-0.167	-0.027
East Midlands	-0.126	0.001	-0.202	-0.050	0.075	0.001	0.032	0.118
West Midlands	0.128	0.000	0.075	0.180	-0.096	0.000	-0.149	-0.042
East of England	-0.047	0.148	-0.111	0.017	0.083	0.000	0.043	0.124
South East	0.114	0.000	0.069	0.158	-0.075	0.000	-0.117	-0.033
South West	-0.074	0.001	-0.119	-0.028	-0.210	0.000	-0.289	-0.130
Missing	-0.143	0.001	-0.224	-0.062				
					1.005	0.000	0.946	1.065
_cons	0.932	0.000	0.868	0.996				
inflate								
UK90_bmi					-0.060	0.403	-0.199	0.080
Underweight	0.291	0.000	0.161	0.421	0.082	0.058	-0.003	0.167
Overweight	0.022	0.612	-0.063	0.107	0.038	0.347	-0.041	0.117
Obesity	-0.024	0.546	-0.101	0.053				
Sex					0.195	0.000	0.136	0.254
Female	0.279	0.000	0.221	0.336				
age_whole					0.856	0.000	0.670	1.042
3	0.766	0.000	0.616	0.916	0.590	0.000	0.401	0.780
4	0.596	0.000	0.445	0.747	1.047	0.000	0.861	1.233
5	0.608	0.000	0.455	0.760	1.053	0.000	0.871	1.235
6	0.595	0.000	0.446	0.745	1.241	0.000	1.059	1.424
7	0.936	0.000	0.788	1.083	1.232	0.000	1.047	1.417
8	0.985	0.000	0.837	1.134	1.157	0.000	0.967	1.346
9	0.943	0.000	0.791	1.094	1.400	0.000	1.213	1.587
10	0.970	0.000	0.808	1.132	1.319	0.000	1.115	1.523
11	0.907	0.000	0.728	1.085	1.551	0.000	1.269	1.833
12	1.031	0.000	0.728	1.334	1.569	0.000	1.175	1.963
13	1.116	0.000	0.718	1.514	1.580	0.000	1.011	2.149
14	1.645	0.000	1.175	2.115	2.157	0.000	0.972	3.342
15	0.433	0.570	-1.062	1.929				
Ethnicity					1.685	0.000	1.524	1.846
Other/Uknown	1.953	0.000	1.815	2.092	0.530	0.000	0.290	0.769
Bangladeshi	0.464	0.000	0.214	0.714	0.759	0.000	0.621	0.896

Total_OPC_attendance	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	Year before (ZIMB)				Year after (ZIMB)			
Black	0.740	0.000	0.605	0.876	0.507	0.000	0.318	0.696
Chinese/Other Asian	0.389	0.000	0.185	0.592	0.445	0.000	0.262	0.628
Indian	0.365	0.000	0.180	0.550	0.473	0.000	0.316	0.631
Pakistani	0.262	0.003	0.086	0.437	0.233	0.010	0.055	0.411
Mixed	0.256	0.005	0.077	0.434				
IMD					-0.006	0.921	-0.122	0.110
Fourth quintile	0.049	0.383	-0.061	0.159	-0.030	0.596	-0.143	0.082
Third quintile	-0.060	0.268	-0.166	0.046	0.034	0.528	-0.071	0.139
Second quintile	-0.041	0.425	-0.143	0.060	0.108	0.038	0.006	0.210
Lowest quintile	-0.015	0.764	-0.113	0.083				
Region					-2.733	0.000	-4.010	-1.456
North East	-1.320	0.000	-1.635	-1.006	-1.347	0.000	-1.520	-1.175
North West	-0.998	0.000	-1.125	-0.871	-0.530	0.000	-0.711	-0.349
Yorkshire and The Humber	-0.625	0.000	-0.817	-0.433	-0.613	0.000	-0.837	-0.388
East Midlands	-0.615	0.000	-0.854	-0.377	-0.205	0.000	-0.300	-0.110
West Midlands	-0.077	0.126	-0.175	0.021	-0.145	0.082	-0.308	0.018
East of England	0.109	0.150	-0.039	0.258	-0.600	0.000	-0.711	-0.489
South East	-0.437	0.000	-0.537	-0.337	-0.335	0.000	-0.455	-0.215
South West	-0.221	0.000	-0.335	-0.107	-0.928	0.000	-1.342	-0.514
Missing	-0.773	0.000	-1.094	-0.452	-2.906	0.000	-3.151	-2.662
_cons	-2.484	0.000	-2.697	-2.271	0.653	0.000	0.626	0.681
/lnalpha	0.858	0.000	0.828	0.888	1.922	1.975		
alpha	2.358	2.430						

Table F 9 Regression coefficients (marginal effects) for the two parts of the model- Costs

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
logit								
Underweight	-0.1053539	0	-0.145963	-0.0647449	0.0102559	0.615	-0.0296794	0.0501912
Overweight	0.046	0.000	0.021	0.071	0.017	0.166	-0.007	0.042
Obesity	0.077	0.000	0.056	0.099	0.049	0.000	0.028	0.071
Sex								
Female	-0.136	0.000	-0.152	-0.120	-0.096	0.000	-0.112	-0.081
age_whole								
3	-0.343	0.000	-0.380	-0.306	-0.354	0.000	-0.391	-0.317
4	-0.306	0.000	-0.343	-0.269	-0.276	0.000	-0.313	-0.239
5	-0.344	0.000	-0.380	-0.309	-0.489	0.000	-0.525	-0.453
6	-0.332	0.000	-0.368	-0.296	-0.484	0.000	-0.520	-0.447

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
7	-0.472	0.000	-0.508	-0.436	-0.592	0.000	-0.628	-0.555
8	-0.541	0.000	-0.577	-0.504	-0.628	0.000	-0.665	-0.592
9	-0.513	0.000	-0.551	-0.475	-0.597	0.000	-0.634	-0.559
10	-0.498	0.000	-0.537	-0.458	-0.625	0.000	-0.665	-0.585
11	-0.405	0.000	-0.451	-0.358	-0.551	0.000	-0.597	-0.504
12	-0.536	0.000	-0.628	-0.444	-0.608	0.000	-0.698	-0.519
13	-0.486	0.000	-0.619	-0.354	-0.556	0.000	-0.687	-0.425
14	-0.558	0.000	-0.750	-0.367	-0.589	0.000	-0.779	-0.399
15	-0.385	0.172	-0.937	0.167	-0.993	0.001	-1.579	-0.407
Ethnicity								
Other/Uknown	-1.129	0.000	-1.155	-1.103	-0.942	0.000	-0.966	-0.918
Bangladeshi	-0.279	0.000	-0.341	-0.217	-0.306	0.000	-0.367	-0.245
Black	-0.273	0.000	-0.308	-0.238	-0.272	0.000	-0.306	-0.237
Chinese/Other	-0.114	0.000	-0.161	-0.067	-0.133	0.000	-0.179	-0.086
Indian	-0.138	0.000	-0.185	-0.091	-0.147	0.000	-0.193	-0.100
Pakistani	-0.090	0.000	-0.130	-0.050	-0.135	0.000	-0.174	-0.095
Mixed	-0.074	0.000	-0.114	-0.034	-0.078	0.000	-0.118	-0.039
IMD								
Fourth	0.022	0.128	-0.006	0.050	0.045	0.002	0.017	0.073
Third	0.046	0.001	0.019	0.074	0.046	0.001	0.019	0.074
Second	0.052	0.000	0.025	0.079	0.046	0.001	0.020	0.073
Lowest	0.101	0.000	0.074	0.128	0.062	0.000	0.036	0.088
Region								
North	0.699	0.000	0.653	0.746	0.820	0.000	0.772	0.868
North	0.388	0.000	0.361	0.415	0.456	0.000	0.429	0.482
Yorkshire	0.240	0.000	0.195	0.286	0.240	0.000	0.195	0.285
East	0.163	0.000	0.104	0.223	0.214	0.000	0.156	0.272
West	0.143	0.000	0.116	0.170	0.177	0.000	0.151	0.203
East	-0.059	0.006	-0.101	-0.017	-0.023	0.268	-0.065	0.018
South	0.274	0.000	0.246	0.301	0.325	0.000	0.298	0.352
South	0.071	0.000	0.042	0.101	0.111	0.000	0.082	0.140
Missing	0.256	0.000	0.184	0.329	0.241	0.000	0.168	0.314
_cons	0.136	0.000	0.095	0.176	0.450	0.000	0.410	0.491
glm								
UK90_bmi								
Underweight	-0.009	0.674	-0.053	0.035	0.017	0.397	-0.022	0.055
Overweight	0.048	0.001	0.020	0.076	0.059	0.000	0.034	0.083
Obesity	0.046	0.001	0.019	0.073	0.056	0.000	0.031	0.082
Sex								
Female	-0.026	0.007	-0.044	-0.007	-0.031	0.000	-0.048	-0.015

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
age_whole								
3	-0.074	0.000	-0.116	-0.033	-0.051	0.003	-0.085	-0.017
4	-0.088	0.000	-0.127	-0.050	-0.059	0.000	-0.092	-0.026
5	-0.169	0.000	-0.209	-0.129	-0.108	0.000	-0.140	-0.075
6	-0.137	0.000	-0.177	-0.097	-0.052	0.004	-0.087	-0.017
7	-0.103	0.000	-0.147	-0.059	-0.045	0.027	-0.085	-0.005
8	-0.122	0.000	-0.163	-0.082	-0.061	0.000	-0.095	-0.028
9	-0.070	0.000	-0.110	-0.031	-0.017	0.324	-0.051	0.017
10	0.019	0.436	-0.029	0.066	0.067	0.001	0.029	0.106
11	0.092	0.001	0.037	0.146	0.143	0.000	0.097	0.189
12	0.010	0.826	-0.078	0.097	0.133	0.002	0.050	0.216
13	0.094	0.170	-0.040	0.229	0.314	0.000	0.170	0.457
14	0.287	0.016	0.053	0.520	0.259	0.001	0.100	0.418
15	-0.262	0.197	-0.660	0.136	0.107	0.666	-0.377	0.591
Ethnicity								
Other/Uknown	-0.275	0.000	-0.321	-0.230	-0.272	0.000	-0.314	-0.230
Bangladeshi	-0.185	0.000	-0.257	-0.112	-0.200	0.000	-0.269	-0.130
Black	-0.021	0.317	-0.063	0.020	-0.006	0.731	-0.041	0.029
Chinese/Other	-0.009	0.804	-0.082	0.064	0.009	0.761	-0.050	0.068
Indian	-0.044	0.113	-0.098	0.010	-0.047	0.046	-0.092	-0.001
Pakistani	0.036	0.160	-0.014	0.086	0.035	0.104	-0.007	0.078
Mixed	0.029	0.291	-0.025	0.084	0.010	0.642	-0.031	0.050
IMD								
Fourth	0.024	0.134	-0.007	0.055	0.013	0.346	-0.014	0.041
Third	0.010	0.522	-0.020	0.040	0.020	0.140	-0.007	0.047
Second	0.021	0.184	-0.010	0.052	0.027	0.053	0.000	0.054
Lowest	0.055	0.000	0.026	0.084	0.066	0.000	0.040	0.091
Region								
North	0.183	0.000	0.115	0.252	0.077	0.037	0.004	0.149
North	-0.038	0.011	-0.067	-0.009	-0.050	0.000	-0.075	-0.025
Yorkshire	0.017	0.423	-0.025	0.060	0.033	0.120	-0.009	0.075
East	-0.055	0.055	-0.110	0.001	-0.031	0.227	-0.081	0.019
West	0.054	0.005	0.016	0.092	0.017	0.266	-0.013	0.047
East	0.029	0.240	-0.020	0.078	0.032	0.131	-0.009	0.073
South	0.088	0.000	0.055	0.122	0.076	0.000	0.047	0.105
South	-0.136	0.000	-0.169	-0.103	-0.117	0.000	-0.145	-0.088
Missing	-0.116	0.000	-0.177	-0.054	-0.136	0.000	-0.194	-0.078
_cons	6.972	0.000	6.926	7.019	6.947	0.000	6.906	6.988

Table F 10 The relationship between outpatient costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	-28.61	0.01	-49.57	-7.66	11.27	0.33	-11.44	33.99
Female	-26.86	0.01	-45.73	-8.00	10.43	0.33	-10.55	31.40
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	33.56	0.00	18.64	48.49	36.13	0.00	21.01	51.26
Female	30.62	0.00	17.11	44.12	33.24	0.00	19.27	47.20
Obesity								
Sex								
Male	40.29	0.00	26.33	54.25	42.86	0.00	27.71	58.01
Female	37.09	0.00	24.37	49.82	39.79	0.00	25.67	53.91
Underweight								
Age (years)								
2	-31.86	0.02	-57.87	-5.85	13.14	0.34	-13.64	39.92
3	-28.70	0.01	-49.53	-7.86	11.24	0.33	-11.44	33.92
4	-28.14	0.01	-48.80	-7.47	11.36	0.33	-11.61	34.32
5	-25.58	0.01	-44.11	-7.05	9.98	0.33	-10.10	30.06
6	-26.56	0.01	-45.91	-7.21	10.60	0.33	-10.72	31.92
7	-26.66	0.01	-45.28	-8.04	10.20	0.33	-10.30	30.71
8	-25.70	0.00	-43.32	-8.08	9.88	0.33	-9.98	29.75
9	-27.29	0.01	-46.14	-8.44	10.48	0.33	-10.59	31.54
10	-29.96	0.01	-50.83	-9.10	11.30	0.33	-11.40	34.00
11	-32.84	0.01	-56.27	-9.41	12.54	0.33	-12.67	37.75
12	-29.10	0.01	-49.20	-9.00	11.97	0.33	-12.09	36.03
13	-31.30	0.01	-53.34	-9.25	14.26	0.33	-14.56	43.08
14	-36.85	0.01	-63.15	-10.55	13.13	0.33	-13.38	39.65
15	-22.21	0.02	-40.15	-4.27	9.17	0.35	-9.97	28.32
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	40.34	0.00	21.87	58.82	43.04	0.00	25.15	60.93

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
3	33.42	0.00	18.57	48.27	36.14	0.00	21.04	51.25
4	33.07	0.00	18.33	47.82	36.66	0.00	21.33	51.99
5	29.76	0.00	16.48	43.03	31.85	0.00	18.45	45.24
6	31.01	0.00	17.23	44.79	33.85	0.00	19.58	48.11
7	30.24	0.00	16.86	43.63	32.39	0.00	18.72	46.06
8	28.80	0.00	16.17	41.43	31.33	0.00	18.11	44.56
9	30.74	0.00	17.23	44.24	33.27	0.00	19.25	47.30
10	33.87	0.00	18.98	48.75	35.83	0.00	20.70	50.97
11	37.81	0.00	21.07	54.55	39.92	0.00	23.13	56.70
12	32.60	0.00	18.03	47.16	37.95	0.00	21.66	54.24
13	35.27	0.00	19.10	51.44	45.29	0.00	25.15	65.43
14	40.97	0.00	20.49	61.45	41.64	0.00	22.66	60.62
15	25.11	0.00	9.27	40.96	28.41	0.01	7.81	49.01
Obesity								
Age (years)								
2	47.33	0.00	29.93	64.73	49.11	0.00	30.97	67.24
3	40.20	0.00	26.25	54.15	42.64	0.00	27.41	57.88
4	39.67	0.00	25.80	53.54	42.93	0.00	27.47	58.38
5	35.81	0.00	23.34	48.28	38.05	0.00	24.57	51.54
6	37.28	0.00	24.37	50.19	40.41	0.00	26.17	54.64
7	36.70	0.00	23.86	49.53	39.06	0.00	24.88	53.24
8	35.09	0.00	23.30	46.87	37.89	0.00	24.73	51.06
9	37.38	0.00	24.79	49.98	40.12	0.00	26.14	54.10
10	41.14	0.00	27.34	54.95	43.30	0.00	28.29	58.31
11	45.65	0.00	29.93	61.38	47.91	0.00	31.19	64.64
12	39.72	0.00	26.04	53.39	45.86	0.00	29.55	62.18
13	42.89	0.00	27.38	58.40	54.57	0.00	34.07	75.07
14	50.05	0.00	29.37	70.73	50.34	0.00	31.03	69.64
15	30.50	0.00	13.66	47.34	35.78	0.00	12.42	59.13
Underweight								
Ethnicity								
Other/Uknown	-14.98	0.00	-23.55	-6.41	5.79	0.33	-5.87	17.44
Bangladeshi	-23.88	0.00	-39.97	-7.78	8.62	0.33	-8.66	25.90
Black	-27.63	0.00	-45.90	-9.36	10.34	0.33	-10.41	31.09
Chinese/Other Asian	-2.77	0.01	-50.13	-8.60	11.32	0.33	-11.42	34.05
Indian	-28.31	0.01	-48.18	-8.44	10.66	0.33	-10.74	32.06
Pakistani	-31.71	0.01	-54.72	-8.70	12.06	0.33	-12.17	36.29
White	-30.50	0.01	-53.23	-7.76	12.10	0.33	-12.33	36.53
Mixed	-30.84	0.01	-52.95	-8.72	11.66	0.33	-11.81	35.13
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Other/Uknown	14.84	0.00	8.52	21.16	17.73	0.00	9.97	25.49
Bangladeshi	26.36	0.00	14.65	38.07	27.16	0.00	15.48	38.83
Black	30.22	0.00	17.07	43.37	32.54	0.00	18.74	46.33
Chinese/Other Asian	4.37	0.00	18.38	48.34	35.98	0.00	20.46	51.49
Indian	32.04	0.00	17.83	46.26	33.89	0.00	19.53	48.26
Pakistani	36.74	0.00	20.31	53.17	38.49	0.00	22.23	54.75
White	36.22	0.00	20.05	52.39	38.96	0.00	22.70	55.22
Mixed	35.54	0.00	19.68	51.40	37.26	0.00	21.62	52.89
Obesity								
Ethnicity								
Other/Uknown	18.94	0.00	12.81	25.07	22.77	0.00	14.77	30.76
Bangladeshi	32.27	0.00	21.27	43.28	33.19	0.00	21.51	44.86
Black	37.12	0.00	24.83	49.41	39.86	0.00	26.12	53.59
Chinese/Other Asian	5.67	0.00	26.47	54.42	43.28	0.00	27.93	58.62
Indian	38.89	0.00	25.50	52.29	40.78	0.00	26.32	55.23
Pakistani	44.26	0.00	28.91	59.60	45.98	0.00	29.71	62.26
White	43.29	0.00	28.13	58.45	45.82	0.00	29.47	62.16
Mixed	42.88	0.00	28.11	57.65	44.43	0.00	28.74	60.13
Underweight								
IMD								
Highest quintile	-28.08	0.01	-48.13	-8.03	10.95	0.33	-11.09	32.99
Fourth quintile	-28.29	0.01	-48.60	-7.99	11.02	0.33	-11.20	33.24
Third quintile	-27.34	0.01	-46.86	-7.82	10.76	0.33	-10.90	32.41
Second quintile	-26.86	0.01	-45.93	-7.79	10.45	0.33	-10.57	31.48
Lowest quintile	-28.55	0.01	-49.52	-7.58	11.24	0.33	-11.41	33.89
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	32.36	0.00	17.98	46.74	35.00	0.00	20.25	49.75
Fourth quintile	32.72	0.00	18.22	47.22	35.30	0.00	20.51	50.09
Third quintile	31.50	0.00	17.59	45.42	34.37	0.00	19.96	48.77
Second quintile	30.82	0.00	17.20	44.45	33.34	0.00	19.33	47.35
Lowest quintile	33.56	0.00	18.62	48.50	36.03	0.00	20.96	51.10
Obesity								
IMD								
Highest quintile	39.06	0.00	25.59	52.52	41.70	0.00	26.94	56.46
Fourth quintile	39.45	0.00	25.79	53.11	41.92	0.00	27.04	56.80
Third quintile	38.03	0.00	24.98	51.08	40.99	0.00	26.56	55.42
Second quintile	37.27	0.00	24.56	49.97	39.89	0.00	25.89	53.89
Lowest quintile	40.26	0.00	26.17	54.36	42.76	0.00	27.44	58.07

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Region								
North East	-36.16	0.03	-68.11	-4.21	14.91	0.34	-15.73	45.54
North West	-28.49	0.01	-50.48	-6.49	11.71	0.33	-12.00	35.42
Yorkshire and The Humber	-29.62	0.01	-51.35	-7.89	11.90	0.33	-12.09	35.89
East Midlands	-26.08	0.01	-44.51	-7.64	10.54	0.33	-10.67	31.75
West Midlands	-29.39	0.01	-50.15	-8.64	11.06	0.33	-11.19	33.31
East of England	-27.96	0.00	-46.83	-9.09	10.66	0.33	-10.76	32.07
London	-24.48	0.00	-40.67	-8.28	9.19	0.33	-9.25	27.62
South East	-31.09	0.01	-53.93	-8.24	12.35	0.33	-12.56	37.26
South West	-24.49	0.01	-41.57	-7.40	9.70	0.33	-9.81	29.21
Missing	-26.74	0.01	-46.30	-7.18	10.41	0.33	-10.57	31.38
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	48.36	0.00	25.76	70.95	49.34	0.00	28.66	70.02
North West	34.67	0.00	19.04	50.30	37.95	0.00	22.14	53.75
Yorkshire and The Humber	34.79	0.00	19.26	50.32	38.12	0.00	22.12	54.12
East Midlands	29.88	0.00	16.59	43.17	33.63	0.00	19.38	47.88
West Midlands	33.57	0.00	18.78	48.36	35.23	0.00	20.42	50.04
East of England	30.97	0.00	17.32	44.63	33.73	0.00	19.44	48.01
London	26.75	0.00	15.09	38.40	28.88	0.00	16.59	41.16
South East	36.53	0.00	20.23	52.83	39.70	0.00	23.09	56.31
South West	27.77	0.00	15.54	40.01	30.88	0.00	17.90	43.86
Missing	31.29	0.00	17.28	45.30	33.31	0.00	19.23	47.38
Obesity								
Region								
North East	55.87	0.00	33.33	78.42	55.27	0.00	32.55	77.99
North West	41.13	0.00	26.50	55.77	44.14	0.00	28.24	60.03
Yorkshire and The Humber	41.73	0.00	27.18	56.28	45.26	0.00	29.21	61.32
East Midlands	36.13	0.00	23.65	48.61	40.17	0.00	25.91	54.44
West Midlands	40.63	0.00	26.81	54.46	42.23	0.00	27.39	57.06
East of England	37.87	0.00	25.07	50.67	40.90	0.00	26.62	55.17
London	32.87	0.00	22.01	43.73	35.46	0.00	23.26	47.65
South East	43.81	0.00	28.52	59.10	46.85	0.00	30.16	63.55
South West	33.69	0.00	22.22	45.16	37.06	0.00	24.06	50.07
Missing	37.57	0.00	24.38	50.77	39.61	0.00	25.46	53.75

Accident and Emergency Care – results

Table F 11 Regression coefficients (marginal effects) for the two parts of the model- Resource use

Total_AE_attendance	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	**Year before (ZIMB)**				**Year after (ZIMB)**			
UK90_bmi								
Underweight	-0.070	0.015	-0.127	-0.014	0.006	0.850	-0.057	0.069
Overweight	0.047	0.019	0.008	0.086	0.028	0.140	-0.009	0.065
Obesity	0.093	0.000	0.054	0.132	0.132	0.000	0.091	0.172
Sex								
Female	-0.055	0.000	-0.080	-0.030	0.015	0.263	-0.011	0.041
age_whole								
3	-0.259	0.000	-0.299	-0.220	-0.150	0.000	-0.197	-0.103
4	-0.370	0.000	-0.416	-0.324	-0.218	0.000	-0.266	-0.170
5	-0.560	0.000	-0.613	-0.507	-0.318	0.000	-0.367	-0.270
6	-0.643	0.000	-0.716	-0.570	-0.310	0.000	-0.361	-0.259
7	-0.759	0.000	-0.824	-0.694	-0.290	0.000	-0.363	-0.216
8	-0.710	0.000	-0.795	-0.625	-0.292	0.000	-0.343	-0.241
9	-0.662	0.000	-0.750	-0.574	-0.207	0.000	-0.260	-0.153
10	-0.574	0.000	-0.674	-0.473	-0.144	0.000	-0.198	-0.089
11	-0.452	0.000	-0.563	-0.341	-0.052	0.101	-0.114	0.010
12	-0.419	0.000	-0.570	-0.268	-0.011	0.866	-0.145	0.122
13	-0.359	0.015	-0.649	-0.070	0.089	0.375	-0.108	0.286
14	-0.459	0.001	-0.741	-0.177	0.033	0.829	-0.271	0.337
15	-0.089	0.759	-0.656	0.479	-0.404	0.517	-1.625	0.817
Ethnicity								
Other/Uknown	-0.263	0.000	-0.373	-0.153	-0.156	0.000	-0.228	-0.083
Bangladeshi	0.013	0.768	-0.072	0.097	-0.046	0.295	-0.131	0.040
Black	-0.052	0.045	-0.104	-0.001	-0.050	0.053	-0.100	0.001
Chinese/Other	0.193	0.000	0.125	0.261	0.069	0.042	0.002	0.135
Indian	0.013	0.726	-0.060	0.086	0.042	0.216	-0.024	0.108
Pakistani	0.001	0.963	-0.060	0.063	-0.030	0.339	-0.091	0.031
Mixed	0.094	0.002	0.033	0.155	0.042	0.160	-0.017	0.101
IMD								
Fourth	0.084	0.000	0.043	0.125	0.038	0.117	-0.009	0.085
Third	0.146	0.000	0.106	0.186	0.119	0.000	0.073	0.166
Second	0.217	0.000	0.177	0.256	0.160	0.000	0.115	0.204
Lowest	0.298	0.000	0.259	0.337	0.221	0.000	0.178	0.265
Region								
North	0.315	0.000	0.230	0.401	0.082	0.122	-0.022	0.187
North	-0.075	0.000	-0.113	-0.036	-0.123	0.000	-0.163	-0.083
Yorkshire	-0.221	0.000	-0.293	-0.149	-0.261	0.000	-0.340	-0.183
East	-0.265	0.000	-0.345	-0.184	-0.249	0.000	-0.347	-0.151

Total_AE_attendance	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
Covariate	Year before (ZIMB)				Year after (ZIMB)			
West	-0.253	0.000	-0.292	-0.213	-0.207	0.000	-0.249	-0.165
East	-0.371	0.000	-0.431	-0.311	-0.389	0.000	-0.461	-0.317
South	-0.200	0.000	-0.240	-0.161	-0.119	0.000	-0.163	-0.075
South	-0.196	0.000	-0.241	-0.152	-0.114	0.000	-0.162	-0.067
Missing	-0.381	0.000	-0.505	-0.257	-0.376	0.000	-0.533	-0.218
_cons	-0.036	0.223	-0.093	0.022	0.283	0.000	0.218	0.347
inflate								
UK90_bmi								
Underweight	0.043	0.768	-0.244	0.330	0.050	0.213	-0.029	0.128
Overweight	-0.148	0.237	-0.393	0.097	-0.064	0.009	-0.113	-0.016
Obesity	-0.101	0.344	-0.311	0.109	-0.005	0.837	-0.049	0.040
Sex								
Female	0.194	0.031	0.018	0.370	0.135	0.000	0.104	0.167
age_whole								
3	0.297	0.162	-0.119	0.712	0.147	0.000	0.081	0.213
4	0.726	0.002	0.277	1.175	0.260	0.000	0.193	0.327
5	0.689	0.013	0.147	1.231	0.365	0.000	0.298	0.432
6	1.149	0.000	0.563	1.736	0.510	0.000	0.442	0.577
7	1.119	0.000	0.574	1.664	0.606	0.000	0.525	0.687
8	1.260	0.000	0.622	1.898	0.518	0.000	0.451	0.586
9	1.335	0.000	0.702	1.968	0.562	0.000	0.494	0.631
10	1.444	0.000	0.782	2.105	0.547	0.000	0.477	0.617
11	1.572	0.000	0.914	2.231	0.532	0.000	0.453	0.610
12	1.345	0.002	0.512	2.177	0.541	0.000	0.385	0.697
13	1.689	0.001	0.671	2.707	0.648	0.000	0.431	0.864
14	1.156	0.111	-0.265	2.577	0.564	0.001	0.229	0.898
15	0.074	0.973	-4.218	4.365	0.231	0.778	-1.376	1.839
Ethnicity								
Other/Uknown	1.916	0.000	1.251	2.581	0.406	0.000	0.335	0.478
Bangladeshi	0.887	0.001	0.343	1.430	0.042	0.465	-0.070	0.153
Black	0.239	0.283	-0.198	0.677	0.078	0.016	0.014	0.142
Chinese/Other	0.675	0.009	0.170	1.180	0.039	0.356	-0.044	0.122
Indian	0.055	0.868	-0.597	0.708	0.067	0.128	-0.019	0.152
Pakistani	0.337	0.171	-0.146	0.819	0.028	0.479	-0.050	0.107
Mixed	0.374	0.132	-0.113	0.861	0.104	0.005	0.031	0.177
IMD								
Fourth	-0.034	0.799	-0.298	0.229	-0.088	0.005	-0.149	-0.027
Third	0.027	0.832	-0.225	0.280	-0.078	0.010	-0.137	-0.019
Second	0.013	0.921	-0.243	0.269	-0.121	0.000	-0.178	-0.064
Lowest	-0.026	0.838	-0.273	0.221	-0.168	0.000	-0.224	-0.113

Total_AE_attendance Covariate	Coefficient Year before (ZIMB)	P>z	[95% conf.	interval]	Coefficient Year after (ZIMB)	P>z	[95% conf.	interval]
Region								
North	-0.151	0.572	-0.677	0.374	-0.304	0.000	-0.414	-0.193
North	0.070	0.570	-0.173	0.313	-0.015	0.554	-0.066	0.036
Yorkshire	0.400	0.024	0.052	0.748	-0.012	0.818	-0.112	0.089
East	-0.482	0.116	-1.084	0.120	-0.040	0.546	-0.168	0.089
West	0.269	0.028	0.029	0.509	0.059	0.030	0.006	0.111
East	-0.037	0.866	-0.466	0.392	-0.057	0.261	-0.157	0.042
South	0.221	0.073	-0.020	0.462	0.109	0.000	0.055	0.164
South	0.086	0.550	-0.197	0.370	0.101	0.001	0.043	0.159
Missing	0.381	0.283	-0.315	1.077	0.191	0.047	0.003	0.379
_cons	-3.568	0.000	-4.068	-3.068				
/lnalpha	0.354	0.000	0.288	0.420	-0.038	0.362	-0.119	0.043
alpha	1.424	1.521						

Table F 12 Regression coefficients (marginal effects) for the two parts of the model- Costs

Total_costs	Coefficient Year before (two-part GLM)	P>z	[95% conf.	interval]	Coefficient Year after (two-part GLM)	P>z	[95% conf.	interval]
logit								
UK90_bmi								
Underweight	-0.072	0.001	-0.116	-0.029	-0.035	0.129	-0.079	0.010
Overweight	0.083	0.000	0.056	0.109	0.072	0.000	0.045	0.100
Obesity	0.102	0.000	0.079	0.125	0.098	0.000	0.074	0.121
Sex								
Female	-0.103	0.000	-0.120	-0.086	-0.102	0.000	-0.119	-0.084
age_whole								
3	-0.301	0.000	-0.338	-0.264	-0.232	0.000	-0.270	-0.194
4	-0.462	0.000	-0.499	-0.425	-0.374	0.000	-0.412	-0.335
5	-0.651	0.000	-0.687	-0.614	-0.536	0.000	-0.573	-0.498
6	-0.811	0.000	-0.848	-0.773	-0.645	0.000	-0.684	-0.607
7	-0.905	0.000	-0.943	-0.867	-0.711	0.000	-0.750	-0.672
8	-0.901	0.000	-0.939	-0.863	-0.638	0.000	-0.677	-0.599
9	-0.870	0.000	-0.909	-0.830	-0.612	0.000	-0.652	-0.572
10	-0.826	0.000	-0.867	-0.784	-0.554	0.000	-0.597	-0.512
11	-0.756	0.000	-0.805	-0.707	-0.478	0.000	-0.528	-0.429
12	-0.661	0.000	-0.758	-0.564	-0.458	0.000	-0.557	-0.358
13	-0.714	0.000	-0.859	-0.570	-0.487	0.000	-0.636	-0.339
14	-0.659	0.000	-0.868	-0.451	-0.441	0.000	-0.655	-0.228
15	-0.113	0.691	-0.671	0.445	-0.516	0.110	-1.148	0.117

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Ethnicity								
Other/Uknown	-0.756	0.000	-0.785	-0.728	-0.451	0.000	-0.479	-0.424
Bangladeshi	-0.120	0.000	-0.185	-0.056	-0.064	0.060	-0.130	0.003
Black	-0.073	0.000	-0.110	-0.037	-0.099	0.000	-0.137	-0.061
Chinese/Other	0.077	0.002	0.028	0.126	0.023	0.384	-0.028	0.074
Indian	0.006	0.806	-0.044	0.057	-0.020	0.464	-0.072	0.033
Pakistani	-0.048	0.029	-0.090	-0.005	-0.042	0.067	-0.086	0.003
Mixed	0.015	0.485	-0.027	0.057	-0.054	0.016	-0.099	-0.010
IMD								
Fourth	0.081	0.000	0.050	0.112	0.102	0.000	0.069	0.134
Third	0.123	0.000	0.092	0.153	0.155	0.000	0.123	0.187
Second	0.200	0.000	0.170	0.229	0.220	0.000	0.190	0.251
Lowest	0.286	0.000	0.257	0.315	0.306	0.000	0.276	0.336
Region								
North	0.361	0.000	0.315	0.407	0.310	0.000	0.262	0.357
North	-0.048	0.001	-0.076	-0.019	-0.077	0.000	-0.106	-0.048
Yorkshire	-0.283	0.000	-0.333	-0.233	-0.187	0.000	-0.238	-0.137
East	-0.150	0.000	-0.214	-0.086	-0.155	0.000	-0.221	-0.089
West	-0.258	0.000	-0.287	-0.230	-0.202	0.000	-0.231	-0.173
East	-0.339	0.000	-0.385	-0.293	-0.265	0.000	-0.312	-0.218
South	-0.204	0.000	-0.234	-0.175	-0.176	0.000	-0.207	-0.146
South	-0.199	0.000	-0.231	-0.167	-0.168	0.000	-0.201	-0.135
Missing	-0.388	0.000	-0.471	-0.304	-0.440	0.000	-0.529	-0.352
_cons	-0.096	0.000	-0.138	-0.054	-0.517	0.000	-0.560	-0.474
glm								
UK90_bmi								
Underweight	-0.042	0.013	-0.076	-0.009	0.006	0.725	-0.028	0.040
Overweight	0.006	0.512	-0.013	0.026	0.017	0.095	-0.003	0.038
Obesity	0.032	0.002	0.012	0.052	0.069	0.000	0.044	0.093
Sex								
Female	-0.019	0.005	-0.032	-0.006	0.006	0.447	-0.009	0.020
age_whole								
3	-0.117	0.000	-0.144	-0.090	-0.092	0.000	-0.121	-0.063
4	-0.169	0.000	-0.196	-0.142	-0.142	0.000	-0.171	-0.113
5	-0.246	0.000	-0.272	-0.219	-0.198	0.000	-0.226	-0.170
6	-0.258	0.000	-0.285	-0.231	-0.167	0.000	-0.196	-0.138
7	-0.297	0.000	-0.330	-0.265	-0.143	0.000	-0.184	-0.102
8	-0.270	0.000	-0.298	-0.243	-0.128	0.000	-0.157	-0.099
9	-0.235	0.000	-0.263	-0.206	-0.070	0.000	-0.101	-0.038

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
10	-0.189	0.000	-0.220	-0.158	-0.022	0.196	-0.054	0.011
11	-0.131	0.000	-0.167	-0.094	0.031	0.100	-0.006	0.068
12	-0.100	0.008	-0.173	-0.026	0.037	0.324	-0.037	0.111
13	-0.040	0.631	-0.203	0.123	0.195	0.003	0.064	0.326
14	-0.115	0.123	-0.261	0.031	0.095	0.258	-0.070	0.261
15	-0.023	0.912	-0.440	0.393	-0.165	0.186	-0.410	0.080
Ethnicity								
Other/Uknown	-0.111	0.000	-0.144	-0.079	-0.111	0.000	-0.147	-0.074
Bangladeshi	0.058	0.010	0.014	0.101	0.023	0.354	-0.025	0.071
Black	0.045	0.001	0.018	0.072	0.058	0.000	0.028	0.088
Chinese/Other	0.092	0.000	0.054	0.129	0.064	0.002	0.024	0.104
Indian	-0.015	0.411	-0.050	0.020	0.007	0.724	-0.031	0.044
Pakistani	0.066	0.000	0.035	0.098	0.032	0.053	0.000	0.065
Mixed	0.092	0.000	0.062	0.123	0.070	0.000	0.036	0.104
IMD								
Fourth	0.020	0.079	-0.002	0.042	0.010	0.400	-0.013	0.033
Third	0.031	0.006	0.009	0.052	0.035	0.004	0.011	0.059
Second	0.052	0.000	0.031	0.073	0.047	0.000	0.025	0.070
Lowest	0.087	0.000	0.067	0.108	0.091	0.000	0.069	0.114
Region								
North	0.086	0.002	0.033	0.140	0.020	0.608	-0.055	0.095
North	-0.077	0.000	-0.098	-0.057	-0.070	0.000	-0.091	-0.048
Yorkshire	-0.074	0.000	-0.112	-0.036	-0.099	0.000	-0.138	-0.060
East	-0.121	0.000	-0.167	-0.075	-0.121	0.000	-0.170	-0.073
West	-0.056	0.000	-0.077	-0.035	-0.036	0.002	-0.058	-0.013
East	-0.125	0.000	-0.158	-0.092	-0.172	0.000	-0.205	-0.139
South	-0.050	0.000	-0.072	-0.029	-0.031	0.012	-0.055	-0.007
South	-0.065	0.000	-0.090	-0.041	-0.052	0.000	-0.078	-0.026
Missing	-0.153	0.000	-0.216	-0.091	-0.176	0.000	-0.247	-0.106
_cons	6.011	0.000	5.979	6.043	5.866	0.000	5.830	5.902

Table F 13 The relationship between accident and emergency costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Sex								
Male	-9.13	0.00	-13.43	-4.83	-1.60	0.43	-5.60	2.39
Female	-8.46	0.00	-12.43	-4.49	-1.54	0.42	-5.30	2.22
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	6.56	0.00	3.70	9.42	6.11	0.00	3.55	8.68
Female	6.16	0.00	3.51	8.81	5.81	0.00	3.39	8.22
Obesity								
Sex								
Male	10.82	0.00	8.00	13.65	12.74	0.00	9.87	15.61
Female	10.10	0.00	7.47	12.73	12.02	0.00	9.28	14.77
Underweight								
Age (years)								
2	-14.45	3.58	-21.47	-7.44	-2.02	0.49	-7.74	3.69
3	-11.44	2.78	-16.89	-5.98	-1.77	0.45	-6.38	2.85
4	-10.07	2.43	-14.84	-5.30	-1.61	0.44	-5.65	2.44
5	-8.42	2.02	-12.37	-4.47	-1.42	0.42	-4.87	2.02
6	-7.64	1.82	-11.21	-4.07	-1.40	0.41	-4.73	1.92
7	-6.90	1.64	-10.11	-3.68	-1.39	0.40	-4.64	1.86
8	-7.07	1.68	-10.36	-3.78	-1.45	0.41	-4.89	1.99
9	-7.45	1.77	-10.92	-3.98	-1.56	0.41	-5.26	2.14
10	-7.95	1.89	-11.67	-4.24	-1.67	0.42	-5.67	2.34
11	-8.74	2.09	-12.83	-4.64	-1.80	0.42	-6.21	2.60
12	-9.15	2.22	-13.50	-4.80	-1.77	0.42	-6.08	2.54
13	-9.07	2.32	-13.62	-4.52	-1.99	0.42	-6.77	2.80
14	-8.40	2.15	-12.62	-4.18	-1.78	0.42	-6.08	2.52
15	-12.61	4.33	-21.10	-4.11	-1.42	0.42	-4.86	2.02
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	9.42	2.32	4.86	13.98	8.31	0.00	4.69	11.93
3	7.91	1.83	4.32	11.50	6.92	0.00	3.97	9.87
4	7.15	1.61	3.99	10.31	6.16	0.00	3.57	8.75
5	6.15	1.35	3.51	8.79	5.34	0.00	3.12	7.56
6	5.69	1.23	3.29	8.10	5.20	0.00	3.04	7.35
7	5.20	1.11	3.03	7.38	5.10	0.00	2.99	7.21
8	5.33	1.13	3.11	7.55	5.38	0.00	3.15	7.60
9	5.60	1.19	3.26	7.94	5.77	0.00	3.38	8.16
10	5.95	1.27	3.46	8.45	6.22	0.00	3.64	8.80

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
11	6.49	1.40	3.74	9.23	6.79	0.00	3.95	9.63
12	6.75	1.49	3.84	9.66	6.66	0.00	3.83	9.48
13	6.77	1.56	3.72	9.81	7.42	0.00	4.16	10.67
14	6.25	1.45	3.41	9.09	6.65	0.00	3.59	9.70
15	8.63	2.79	3.17	14.09	5.29	0.00	2.15	8.43
Obesity								
Age (years)								
2	16.32	2.34	11.73	20.91	17.91	0.00	13.73	22.09
3	13.29	1.83	9.71	16.87	14.61	0.00	11.26	17.97
4	11.86	1.60	8.72	15.01	12.87	0.00	9.94	15.79
5	10.07	1.33	7.45	12.68	11.03	0.00	8.53	13.52
6	9.23	1.21	6.87	11.60	10.68	0.00	8.27	13.08
7	8.39	1.12	6.19	10.59	10.44	0.00	7.91	12.96
8	8.60	1.11	6.43	10.77	11.04	0.00	8.58	13.50
9	9.04	1.17	6.76	11.33	11.87	0.00	9.23	14.52
10	9.63	1.24	7.19	12.07	12.83	0.00	9.96	15.69
11	10.53	1.37	7.85	13.22	14.07	0.00	10.91	17.24
12	10.99	1.49	8.07	13.92	13.78	0.00	10.48	17.07
13	10.96	1.70	7.63	14.30	15.30	0.00	11.16	19.43
14	10.14	1.60	7.01	13.28	13.72	0.00	9.55	17.90
15	14.58	3.91	6.91	22.25	10.89	0.00	5.41	16.37
Underweight								
Ethnicity								
Other/Uknown	-5.36	0.00	-7.84	-2.88	-1.22	0.39	-4.01	1.57
Bangladeshi	-10.16	0.00	-14.99	-5.33	-1.76	0.44	-6.19	2.67
Black	-10.41	0.00	-15.34	-5.49	-1.82	0.43	-6.36	2.73
Chinese/Other Asian	-11.21	0.00	-16.56	-5.86	-1.82	0.44	-6.46	2.82
Indian	-9.32	0.00	-13.75	-4.88	-1.64	0.43	-5.74	2.45
Pakistani	-9.96	0.00	-14.69	-5.24	-1.71	0.43	-5.96	2.54
White	-9.15	0.00	-13.46	-4.84	-1.60	0.43	-5.58	2.38
Mixed	-10.59	0.00	-15.60	-5.57	-1.75	0.43	-6.08	2.59
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	4.19	0.00	2.49	5.89	4.43	0.00	2.61	6.25
Bangladeshi	7.31	0.00	4.11	10.52	6.74	0.00	3.88	9.60
Black	7.43	0.00	4.17	10.69	6.94	0.00	4.03	9.86
Chinese/Other Asian	7.86	0.00	4.33	11.40	7.04	0.00	4.05	10.02
Indian	6.67	0.00	3.73	9.60	6.26	0.00	3.62	8.90
Pakistani	7.17	0.00	4.04	10.30	6.51	0.00	3.77	9.24
White	6.57	0.00	3.70	9.44	6.09	0.00	3.54	8.64
Mixed	7.53	0.00	4.22	10.85	6.64	0.00	3.85	9.42

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Obesity								
Ethnicity								
Other/Uknown	6.65	0.00	4.94	8.37	9.01	0.00	6.87	11.14
Bangladeshi	12.06	0.00	8.87	15.25	14.08	0.00	10.81	17.35
Black	12.30	0.00	9.07	15.53	14.48	0.00	11.20	17.75
Chinese/Other Asian	13.13	0.00	9.59	16.66	14.75	0.00	11.34	18.16
Indian	11.02	0.00	8.10	13.94	13.03	0.00	10.03	16.03
Pakistani	11.82	0.00	8.72	14.92	13.55	0.00	10.46	16.64
White	10.84	0.00	8.01	13.67	12.69	0.00	9.83	15.55
Mixed	12.49	0.00	9.20	15.78	13.81	0.00	10.68	16.95
Underweight								
IMD								
Highest quintile	-7.45	0.00	-10.92	-3.97	-1.36	0.41	-4.57	1.84
Fourth quintile	-8.15	0.00	-11.98	-4.33	-1.47	0.42	-5.01	2.07
Third quintile	-8.50	0.00	-12.50	-4.51	-1.55	0.42	-5.32	2.23
Second quintile	-9.25	0.00	-13.61	-4.89	-1.63	0.43	-5.70	2.43
Lowest quintile	-9.84	0.00	-14.49	-5.19	-1.73	0.44	-6.13	2.66
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	5.54	0.00	3.20	7.88	5.03	0.00	2.95	7.10
Fourth quintile	5.98	0.00	3.42	8.54	5.49	0.00	3.21	7.77
Third quintile	6.19	0.00	3.52	8.86	5.83	0.00	3.39	8.26
Second quintile	6.64	0.00	3.74	9.54	6.22	0.00	3.61	8.82
Lowest quintile	6.98	0.00	3.90	10.07	6.67	0.00	3.86	9.48
Obesity								
IMD								
Highest quintile	8.99	0.00	6.68	11.30	10.31	0.00	7.99	12.63
Fourth quintile	9.77	0.00	7.24	12.30	11.34	0.00	8.79	13.90
Third quintile	10.15	0.00	7.52	12.79	12.07	0.00	9.34	14.80
Second quintile	10.96	0.00	8.10	13.82	12.96	0.00	10.04	15.87
Lowest quintile	11.59	0.00	8.52	14.67	13.98	0.00	10.75	17.20
Underweight								
Region								
North East	-13.34	0.00	-19.83	-6.85	-1.95	0.49	-7.52	3.61
North West	-9.26	0.00	-13.63	-4.88	-1.61	0.43	-5.63	2.41
Yorkshire and The Humber	-8.05	0.00	-11.80	-4.31	-1.49	0.42	-5.09	2.12
East Midlands	-7.92	0.00	-11.66	-4.18	-1.42	0.42	-4.85	2.02
West Midlands	-8.21	0.00	-12.06	-4.37	-1.56	0.42	-5.31	2.20
East of England	-7.35	0.00	-10.79	-3.91	-1.28	0.41	-4.33	1.77

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
London	-9.59	0.00	-14.12	-5.06	-1.69	0.43	-5.94	2.55
South East	-8.09	0.00	-11.87	-4.30	-1.50	0.41	-5.09	2.10
South West	-8.37	0.00	-12.29	-4.44	-1.53	0.42	-5.22	2.17
Missing	-6.86	0.00	-10.10	-3.63	-1.23	0.39	-4.06	1.60
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	8.77	0.00	4.55	13.00	8.07	0.00	4.51	11.63
North West	6.59	0.00	3.69	9.49	6.14	0.00	3.56	8.71
Yorkshire and The Humber	5.94	0.00	3.41	8.48	5.58	0.00	3.25	7.91
East Midlands	5.78	0.00	3.28	8.27	5.31	0.00	3.08	7.54
West Midlands	6.06	0.00	3.48	8.63	5.82	0.00	3.40	8.23
East of England	5.46	0.00	3.15	7.77	4.76	0.00	2.78	6.73
London	6.86	0.00	3.86	9.87	6.47	0.00	3.75	9.19
South East	5.96	0.00	3.42	8.50	5.59	0.00	3.27	7.91
South West	6.13	0.00	3.50	8.76	5.72	0.00	3.34	8.10
Missing	5.16	0.00	2.98	7.35	4.47	0.00	2.61	6.34
Obesity								
Region								
North East	15.13	0.00	10.60	19.66	17.42	0.00	12.66	22.18
North West	10.92	0.00	8.05	13.80	12.80	0.00	9.91	15.70
Yorkshire and The Humber	9.68	0.00	7.17	12.19	11.54	0.00	8.91	14.17
East Midlands	9.46	0.00	6.97	11.95	10.98	0.00	8.43	13.52
West Midlands	9.87	0.00	7.34	12.41	12.02	0.00	9.32	14.71
East of England	8.87	0.00	6.58	11.16	9.78	0.00	7.56	12.00
London	11.35	0.00	8.38	14.32	13.51	0.00	10.47	16.55
South East	9.72	0.00	7.22	12.22	11.52	0.00	8.92	14.12
South West	10.02	0.00	7.43	12.61	11.83	0.00	9.16	14.49
Missing	8.34	0.00	6.15	10.53	9.11	0.00	6.95	11.28

Appendix G

Aggregated primary care costs – results

Table G 1 Regression coefficients (marginal effects) for the two parts of the model

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
logit								
UK90_bmi								
Underweight	-0.125	0.000	-0.174	-0.077	0.179	0.000	0.093	0.264
Overweight	0.001	0.927	-0.030	0.033	-0.081	0.001	-0.127	-0.035
Obesity	0.041	0.003	0.014	0.069	0.054	0.013	0.011	0.096
Sex								
Female	-0.085	0.000	-0.105	-0.065	0.037	0.017	0.007	0.067
age_whole								
3	0.248	0.000	0.198	0.297	0.513	0.000	0.434	0.593
4	0.154	0.000	0.105	0.203	-0.114	0.001	-0.183	-0.044
5	-0.118	0.000	-0.164	-0.072	-0.342	0.000	-0.406	-0.277
6	-0.189	0.000	-0.234	-0.143	-0.025	0.480	-0.094	0.044
7	-0.294	0.000	-0.339	-0.249	-0.131	0.000	-0.199	-0.063
8	-0.199	0.000	-0.245	-0.153	0.069	0.054	-0.001	0.140
9	-0.107	0.000	-0.155	-0.060	0.117	0.002	0.043	0.190
10	-0.040	0.122	-0.091	0.011	-0.025	0.515	-0.100	0.050
11	0.056	0.068	-0.004	0.116	0.222	0.000	0.129	0.315
12	-0.004	0.950	-0.119	0.112	0.410	0.000	0.213	0.607
13	-0.020	0.815	-0.187	0.147	0.356	0.012	0.080	0.632
14	0.295	0.027	0.033	0.556	0.430	0.039	0.022	0.837
15	0.662	0.130	-0.194	1.517	0.601	0.407	-0.820	2.022
Ethnicity								
Other/Uknown	-1.123	0.000	-1.148	-1.097	-0.213	0.000	-0.256	-0.171
Bangladeshi	0.470	0.000	0.379	0.560	1.300	0.000	1.077	1.523
Black	-0.010	0.666	-0.054	0.034	0.528	0.000	0.442	0.615
Chinese/Other	0.002	0.952	-0.060	0.063	0.472	0.000	0.356	0.587
Indian	0.227	0.000	0.162	0.293	0.653	0.000	0.529	0.776
Pakistani	0.372	0.000	0.313	0.431	1.124	0.000	0.996	1.252
Mixed	0.024	0.370	-0.029	0.077	0.304	0.000	0.217	0.390
IMD								
Fourth	0.026	0.158	-0.010	0.063	-0.026	0.328	-0.077	0.026
Third	0.015	0.408	-0.021	0.051	-0.061	0.018	-0.112	-0.011
Second	-0.077	0.000	-0.111	-0.043	0.004	0.876	-0.047	0.055

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Lowest	-0.121	0.000	-0.155	-0.088	0.021	0.405	-0.029	0.071
Region								
North	0.192	0.000	0.134	0.251	-0.484	0.000	-0.571	-0.397
North	0.403	0.000	0.369	0.437	-0.453	0.000	-0.509	-0.398
Yorkshire	-0.024	0.384	-0.079	0.030	-0.856	0.000	-0.933	-0.780
East	0.536	0.000	0.456	0.616	0.252	0.001	0.104	0.400
West	0.013	0.430	-0.019	0.045	-0.200	0.000	-0.258	-0.141
East	-0.063	0.015	-0.113	-0.012	-0.858	0.000	-0.930	-0.786
South	0.255	0.000	0.220	0.289	-0.517	0.000	-0.573	-0.461
South	0.360	0.000	0.322	0.398	-0.720	0.000	-0.776	-0.664
Missing	0.456	0.000	0.353	0.559	-0.423	0.000	-0.564	-0.283
_cons	1.611	0.000	1.560	1.663	2.919	0.000	2.840	2.998
glm								
UK90_bmi								
Underweight	-0.305	0.000	-0.432	-0.179	-0.135	0.133	-0.310	0.041
Overweight	0.045	0.298	-0.040	0.131	0.130	0.001	0.055	0.205
Obesity	0.184	0.000	0.086	0.282	0.211	0.000	0.117	0.305
Sex								
Female	-0.187	0.000	-0.250	-0.124	-0.201	0.000	-0.259	-0.143
age_whole								
3	0.155	0.091	-0.025	0.334	0.121	0.159	-0.047	0.289
4	0.263	0.001	0.108	0.418	0.356	0.000	0.229	0.484
5	0.544	0.000	0.368	0.720	0.509	0.000	0.375	0.644
6	0.612	0.000	0.455	0.770	0.596	0.000	0.470	0.722
7	0.575	0.000	0.427	0.723	0.721	0.000	0.563	0.880
8	0.736	0.000	0.576	0.896	0.719	0.000	0.601	0.837
9	0.805	0.000	0.654	0.955	0.820	0.000	0.706	0.935
10	0.884	0.000	0.731	1.037	0.987	0.000	0.844	1.129
11	0.929	0.000	0.761	1.097	1.054	0.000	0.921	1.187
12	0.922	0.000	0.667	1.178	0.945	0.000	0.762	1.129
13	1.198	0.000	0.614	1.782	0.822	0.000	0.623	1.021
14	0.767	0.000	0.519	1.015	0.406	0.001	0.166	0.645
15	1.054	0.000	0.505	1.602	0.727	0.042	0.025	1.429
Ethnicity								
Other/Uknown	-0.350	0.000	-0.488	-0.211	-0.499	0.000	-0.644	-0.353
Bangladeshi	0.422	0.020	0.065	0.779	0.367	0.002	0.134	0.599
Black	0.141	0.071	-0.012	0.293	0.089	0.138	-0.029	0.207
Chinese/Other	0.020	0.813	-0.147	0.188	0.107	0.219	-0.064	0.278
Indian	0.167	0.112	-0.039	0.374	0.120	0.147	-0.042	0.282
Pakistani	0.274	0.000	0.132	0.416	0.301	0.000	0.171	0.430

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Mixed	0.155	0.033	0.012	0.298	0.208	0.000	0.094	0.323
IMD								
Fourth	-0.077	0.160	-0.185	0.030	-0.156	0.014	-0.280	-0.032
Third	-0.027	0.629	-0.138	0.083	-0.120	0.068	-0.248	0.009
Second	-0.013	0.798	-0.116	0.089	-0.182	0.008	-0.316	-0.048
Lowest	0.053	0.345	-0.057	0.164	-0.174	0.016	-0.315	-0.032
Region								
North	-0.030	0.686	-0.175	0.115	0.033	0.657	-0.112	0.178
North	0.249	0.000	0.135	0.364	0.354	0.000	0.212	0.496
Yorkshire	0.325	0.001	0.130	0.521	0.331	0.000	0.168	0.495
East	0.418	0.046	0.007	0.829	0.306	0.034	0.023	0.588
West	0.288	0.000	0.171	0.405	0.222	0.000	0.119	0.326
East	-0.007	0.944	-0.203	0.189	-0.041	0.600	-0.196	0.113
South	0.255	0.000	0.132	0.377	0.242	0.000	0.133	0.350
South	0.065	0.270	-0.050	0.180	0.198	0.000	0.097	0.299
Missing	0.281	0.006	0.081	0.482	0.108	0.166	-0.045	0.262
_cons	7.020	0.000	6.852	7.187	7.065	0.000	6.912	7.219

Table G 2 The relationship between aggregate primary care costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	-543.90	0.00	-729.51	-358.29	-243.57	0.15	-571.22	84.08
Female	-437.53	0.00	-587.06	-288.00	-196.15	0.15	-460.45	68.15
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	90.73	0.30	-82.05	263.51	277.73	0.00	101.88	453.57
Female	72.66	0.30	-65.42	210.74	223.42	0.00	82.68	364.17
Obesity								
Sex								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Male	409.16	0.00	184.18	634.13	503.18	0.00	262.06	744.31
Female	328.67	0.00	150.13	507.21	404.04	0.00	217.81	590.27
Underweight								
Age (years)								
2	-282.28	0.00	-385.11	-179.44	-120.91	0.15	-284.50	42.69
3	-336.81	0.00	-464.71	-208.92	-143.76	0.13	-331.32	43.81
4	-373.93	0.00	-505.07	-242.79	-170.26	0.15	-403.47	62.95
5	-475.64	0.00	-646.48	-304.81	-187.96	0.16	-448.11	72.20
6	-506.26	0.00	-682.92	-329.60	-218.38	0.15	-512.77	76.00
7	-478.00	0.00	-642.33	-313.67	-242.64	0.15	-576.07	90.79
8	-570.30	0.00	-772.18	-368.41	-249.25	0.14	-583.02	84.53
9	-621.85	0.00	-837.27	-406.43	-278.86	0.14	-650.56	92.84
10	-676.96	0.00	-911.76	-442.16	-321.81	0.14	-753.87	110.25
11	-721.38	0.00	-972.47	-470.30	-357.19	0.14	-831.41	117.02
12	-718.44	0.00	-1007.61	-429.28	-320.37	0.14	-743.35	102.61
13	-932.24	0.00	-1568.28	-296.19	-272.34	0.14	-634.18	89.50
14	-620.99	0.00	-870.69	-371.28	-175.00	0.14	-409.19	59.19
15	-954.11	0.00	-1559.59	-348.63	-274.43	0.18	-676.42	127.57
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	47.19	0.31	-43.01	137.40	137.74	0.00	47.94	227.54
3	56.81	0.30	-50.76	164.37	161.51	0.00	60.06	262.97
4	62.90	0.30	-57.05	182.85	194.82	0.00	71.26	318.38
5	79.15	0.31	-72.03	230.32	217.44	0.00	75.78	359.09
6	83.94	0.30	-76.08	243.95	248.87	0.00	89.83	407.92
7	78.85	0.31	-71.71	229.42	277.56	0.00	104.25	450.86
8	94.47	0.30	-84.90	273.84	283.28	0.00	104.68	461.88
9	103.42	0.30	-93.48	300.32	316.52	0.00	117.36	515.68
10	112.90	0.30	-102.31	328.12	367.23	0.00	124.73	609.73
11	120.80	0.30	-109.15	350.74	404.52	0.00	150.06	658.97
12	120.01	0.31	-109.83	349.86	361.50	0.00	129.94	593.07
13	155.54	0.32	-151.99	463.07	308.04	0.00	107.87	508.20
14	104.81	0.31	-95.89	305.51	197.72	0.00	66.59	328.84
15	162.68	0.32	-158.48	483.84	307.21	0.04	18.87	595.56
Obesity								
Age (years)								
2	212.50	0.00	91.78	333.21	249.18	0.00	127.97	370.39
3	254.30	0.00	113.16	395.44	284.64	0.00	125.53	443.76
4	282.07	0.00	120.12	444.02	355.24	0.00	187.83	522.66
5	357.51	0.00	150.15	564.87	404.08	0.00	211.40	596.75
6	380.08	0.00	171.72	588.44	450.52	0.00	229.84	671.20

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
7	358.29	0.00	163.86	552.72	505.83	0.00	268.25	743.41
8	428.04	0.00	195.79	660.29	510.26	0.00	271.67	748.85
9	467.34	0.00	213.52	721.15	568.79	0.00	304.18	833.40
10	509.22	0.00	231.42	787.02	666.39	0.00	353.41	979.37
11	543.35	0.00	235.17	851.54	723.85	0.00	383.08	1064.61
12	540.71	0.00	225.21	856.21	642.47	0.00	332.54	952.40
13	701.34	0.01	152.29	1250.40	549.90	0.00	282.62	817.18
14	468.99	0.00	194.33	743.65	352.23	0.00	169.67	534.79
15	723.11	0.01	169.04	1277.18	537.50	0.02	81.32	993.68
Underweight								
Ethnicity								
Other/Uknown	-278.25	0.00	-376.77	-179.73	-129.39	0.16	-309.17	50.40
Bangladeshi	-782.31	0.00	-1184.95	-379.67	-337.53	0.13	-772.21	97.15
Black	-528.13	0.00	-719.61	-336.66	-232.11	0.13	-532.66	68.43
Chinese/Other Asian	-478.81	0.00	-662.15	-295.48	-245.18	0.14	-568.18	77.82
Indian	-588.55	0.00	-830.93	-346.17	-260.73	0.14	-602.44	80.98
Pakistani	-729.97	0.00	-977.90	-482.04	-338.67	0.13	-772.09	94.75
White	-514.69	0.00	-690.39	-339.00	-227.06	0.15	-536.48	82.36
Mixed	-566.73	0.00	-773.72	-359.75	-272.07	0.14	-630.83	86.69
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	43.66	0.30	-39.39	126.70	148.67	0.00	51.06	246.27
Bangladeshi	132.45	0.31	-120.74	385.65	374.99	0.00	132.29	617.68
Black	87.66	0.31	-80.67	256.00	260.23	0.00	98.60	421.87
Chinese/Other Asian	79.77	0.30	-72.48	232.02	275.63	0.00	98.50	452.75
Indian	98.97	0.31	-90.61	288.55	292.26	0.00	107.45	477.07
Pakistani	123.43	0.31	-112.50	359.36	377.20	0.00	141.70	612.70
White	86.13	0.30	-77.68	249.95	260.31	0.00	94.80	425.82
Mixed	94.64	0.31	-87.31	276.58	307.74	0.00	112.78	502.71
Obesity								
Ethnicity								
Other/Uknown	205.51	0.00	90.73	320.29	273.12	0.00	130.81	415.43
Bangladeshi	591.39	0.00	221.55	961.23	646.04	0.00	314.56	977.52
Black	396.59	0.00	179.63	613.55	456.73	0.00	243.17	670.30
Chinese/Other Asian	359.98	0.00	157.43	562.54	486.33	0.00	242.46	730.20
Indian	443.88	0.00	186.81	700.95	512.75	0.00	259.43	766.07
Pakistani	551.58	0.00	241.97	861.18	653.27	0.00	334.26	972.27
White	387.55	0.00	174.27	600.82	476.36	0.00	253.51	699.22
Mixed	426.42	0.00	187.53	665.31	549.45	0.00	285.05	813.85
Underweight								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
IMD								
Highest quintile	-514.34	0.00	-694.50	-334.18	-253.53	0.15	-598.55	91.48
Fourth quintile	-468.51	0.00	-631.06	-305.95	-215.77	0.15	-508.42	76.88
Third quintile	-477.72	0.00	-642.89	-312.56	-217.54	0.15	-512.93	77.85
Second quintile	-468.26	0.00	-629.72	-306.80	-206.28	0.14	-480.87	68.31
Lowest quintile	-537.50	0.00	-722.73	-352.26	-225.34	0.14	-527.13	76.44
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	85.91	0.30	-77.86	249.68	290.29	0.00	108.07	472.51
Fourth quintile	78.31	0.30	-71.08	227.70	246.88	0.00	89.85	403.91
Third quintile	79.70	0.30	-71.84	231.25	248.59	0.00	86.07	411.11
Second quintile	77.75	0.30	-69.96	225.47	234.23	0.00	87.10	381.36
Lowest quintile	89.28	0.30	-80.71	259.26	255.88	0.00	94.78	416.98
Obesity								
IMD								
Highest quintile	387.07	0.00	172.12	602.02	529.98	0.00	279.93	780.02
Fourth quintile	352.66	0.00	156.82	548.51	450.14	0.00	238.26	662.02
Third quintile	359.39	0.00	161.20	557.59	452.19	0.00	236.83	667.56
Second quintile	351.73	0.00	158.93	544.54	421.13	0.00	227.12	615.13
Lowest quintile	403.78	0.00	183.51	624.06	460.08	0.00	234.72	685.43
Underweight								
Region								
North East	-405.22	0.00	-549.24	-261.21	-180.03	0.15	-422.42	62.37
North West	-564.46	0.00	-761.73	-367.19	-262.28	0.15	-619.28	94.71
Yorkshire and The Humber	-576.61	0.00	-787.40	-365.83	-237.40	0.17	-577.42	102.62
East Midlands	-663.25	0.00	-1026.34	-300.17	-274.07	0.14	-639.04	90.89
West Midlands	-563.77	0.00	-751.70	-375.84	-242.38	0.14	-561.95	77.20
East of England	-386.26	0.00	-533.09	-239.43	-162.81	0.17	-395.22	69.61
London	-395.14	0.00	-534.10	-256.18	-187.08	0.13	-430.11	55.96
South East	-540.60	0.00	-730.28	-350.92	-238.68	0.15	-561.49	84.13
South West	-456.23	0.00	-614.60	-297.85	-210.08	0.16	-505.78	85.62
Missing	-622.41	0.00	-871.83	-372.99	-219.00	0.15	-515.97	77.97
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	67.54	0.30	-61.03	196.11	206.20	0.00	72.37	340.04
North West	94.88	0.30	-86.14	275.90	299.36	0.00	112.87	485.86
Yorkshire and The Humber	95.15	0.31	-87.03	277.33	276.67	0.00	93.50	459.83
East Midlands	111.84	0.31	-102.06	325.74	307.16	0.00	101.13	513.18

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
West Midlands	93.25	0.31	-85.20	271.70	273.95	0.00	101.07	446.83
East of England	63.88	0.30	-57.20	184.95	189.52	0.00	61.37	317.67
London	65.04	0.30	-58.45	188.53	210.21	0.00	80.11	340.31
South East	90.42	0.30	-81.56	262.40	273.44	0.00	95.46	451.41
South West	76.60	0.30	-69.23	222.44	243.42	0.00	85.52	401.33
Missing	104.98	0.31	-95.60	305.57	249.78	0.00	88.66	410.89
Obesity								
Region								
North East	304.73	0.00	137.41	472.05	376.79	0.00	198.06	555.53
North West	425.68	0.00	191.62	659.75	543.49	0.00	290.66	796.32
Yorkshire and The Humber	432.22	0.00	176.54	687.90	520.71	0.00	274.80	766.63
East Midlands	500.75	0.00	166.68	834.82	538.69	0.00	246.66	830.73
West Midlands	422.94	0.00	193.50	652.38	488.40	0.00	253.51	723.29
East of England	289.73	0.00	125.82	453.63	355.99	0.00	185.37	526.61
London	296.00	0.00	131.99	460.01	370.55	0.00	185.75	555.35
South East	407.01	0.00	181.25	632.76	499.77	0.00	265.16	734.39
South West	343.93	0.00	153.83	534.03	453.79	0.00	241.31	666.27
Missing	469.93	0.00	196.77	743.09	452.91	0.00	236.40	669.43

Aggregated secondary care costs – results

Table G 3 Regression coefficients (marginal effects) for the two parts of the model

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
logit								
UK90_bmi								
Underweight	-0.084	0.000	-0.124	-0.044	0.001	0.947	-0.039	0.042
Overweight	0.058	0.000	0.033	0.083	0.038	0.003	0.013	0.063
Obesity	0.086	0.000	0.064	0.107	0.060	0.000	0.038	0.082
Sex								
Female	-0.150	0.000	-0.166	-0.135	-0.120	0.000	-0.136	-0.104
age_whole								
3	-0.384	0.000	-0.423	-0.345	-0.385	0.000	-0.425	-0.345
4	-0.439	0.000	-0.478	-0.400	-0.385	0.000	-0.425	-0.345
5	-0.560	0.000	-0.598	-0.522	-0.599	0.000	-0.637	-0.560
6	-0.615	0.000	-0.653	-0.577	-0.658	0.000	-0.697	-0.619
7	-0.749	0.000	-0.787	-0.711	-0.758	0.000	-0.796	-0.719
8	-0.811	0.000	-0.849	-0.772	-0.776	0.000	-0.815	-0.737
9	-0.787	0.000	-0.826	-0.747	-0.739	0.000	-0.780	-0.699

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
10	-0.779	0.000	-0.821	-0.738	-0.764	0.000	-0.806	-0.722
11	-0.682	0.000	-0.730	-0.635	-0.694	0.000	-0.742	-0.646
12	-0.748	0.000	-0.839	-0.656	-0.729	0.000	-0.820	-0.638
13	-0.710	0.000	-0.842	-0.579	-0.718	0.000	-0.850	-0.586
14	-0.681	0.000	-0.870	-0.491	-0.752	0.000	-0.942	-0.562
15	-0.314	0.263	-0.864	0.236	-0.890	0.002	-1.462	-0.319
Ethnicity								
Other/Uknown	-1.169	0.000	-1.193	-1.144	-0.898	0.000	-0.921	-0.874
Bangladeshi	-0.280	0.000	-0.341	-0.219	-0.280	0.000	-0.341	-0.219
Black	-0.260	0.000	-0.295	-0.225	-0.272	0.000	-0.307	-0.237
Chinese/Other	-0.063	0.010	-0.110	-0.015	-0.093	0.000	-0.141	-0.045
Indian	-0.118	0.000	-0.166	-0.071	-0.154	0.000	-0.202	-0.106
Pakistani	-0.109	0.000	-0.150	-0.069	-0.121	0.000	-0.163	-0.080
Mixed	-0.080	0.000	-0.120	-0.039	-0.097	0.000	-0.138	-0.056
IMD								
Fourth	0.062	0.000	0.033	0.090	0.078	0.000	0.050	0.106
Third	0.089	0.000	0.061	0.117	0.093	0.000	0.065	0.121
Second	0.127	0.000	0.099	0.154	0.115	0.000	0.088	0.142
Lowest	0.189	0.000	0.162	0.216	0.159	0.000	0.132	0.186
Region								
North	0.640	0.000	0.590	0.690	0.772	0.000	0.720	0.824
North	0.298	0.000	0.271	0.326	0.371	0.000	0.344	0.399
Yorkshire	0.066	0.005	0.020	0.112	0.110	0.000	0.064	0.156
East	0.059	0.051	0.000	0.119	0.099	0.001	0.040	0.158
West	-0.005	0.718	-0.031	0.022	0.072	0.000	0.045	0.098
East	-0.185	0.000	-0.226	-0.143	-0.095	0.000	-0.137	-0.054
South	0.111	0.000	0.083	0.138	0.212	0.000	0.185	0.240
South	-0.044	0.003	-0.074	-0.015	0.031	0.044	0.001	0.060
Missing	0.047	0.213	-0.027	0.121	0.129	0.001	0.054	0.203
_cons	0.953	0.000	0.911	0.995	1.011	0.000	0.968	1.053
glm								
UK90_bmi								
Underweight	-0.021	0.548	-0.092	0.049	0.108	0.003	0.038	0.178
Overweight	0.074	0.004	0.024	0.124	0.042	0.061	-0.002	0.086
Obesity	0.071	0.002	0.026	0.116	0.083	0.001	0.032	0.133
Sex								
Female	-0.016	0.300	-0.046	0.014	-0.027	0.092	-0.058	0.004
age_whole								
3	-0.222	0.000	-0.286	-0.158	-0.160	0.000	-0.222	-0.097

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
4	-0.255	0.000	-0.317	-0.192	-0.177	0.000	-0.240	-0.115
5	-0.408	0.000	-0.468	-0.347	-0.278	0.000	-0.345	-0.212
6	-0.377	0.000	-0.438	-0.316	-0.213	0.000	-0.278	-0.148
7	-0.405	0.000	-0.480	-0.330	-0.262	0.000	-0.340	-0.185
8	-0.429	0.000	-0.498	-0.360	-0.308	0.000	-0.370	-0.246
9	-0.432	0.000	-0.496	-0.369	-0.245	0.000	-0.316	-0.173
10	-0.349	0.000	-0.418	-0.280	-0.197	0.000	-0.263	-0.130
11	-0.221	0.000	-0.303	-0.140	-0.074	0.050	-0.148	0.000
12	-0.284	0.000	-0.430	-0.138	-0.090	0.205	-0.228	0.049
13	-0.288	0.018	-0.526	-0.050	0.056	0.558	-0.130	0.241
14	-0.082	0.675	-0.464	0.301	-0.134	0.168	-0.324	0.057
15	-0.782	0.000	-1.167	-0.396	-0.212	0.492	-0.815	0.392
Ethnicity								
Other/Uknown	-0.462	0.000	-0.543	-0.381	-0.465	0.000	-0.544	-0.387
Bangladeshi	-0.140	0.050	-0.279	0.000	-0.158	0.004	-0.266	-0.050
Black	0.002	0.949	-0.062	0.066	0.058	0.107	-0.013	0.129
Chinese/Other	0.012	0.783	-0.076	0.101	0.026	0.601	-0.073	0.125
Indian	-0.066	0.132	-0.151	0.020	-0.064	0.122	-0.146	0.017
Pakistani	0.105	0.004	0.034	0.176	0.087	0.009	0.021	0.152
Mixed	0.018	0.596	-0.049	0.085	0.022	0.603	-0.060	0.104
IMD								
Fourth	0.014	0.605	-0.038	0.066	0.043	0.108	-0.009	0.095
Third	0.004	0.874	-0.047	0.056	0.031	0.227	-0.019	0.081
Second	0.023	0.380	-0.028	0.073	0.055	0.026	0.006	0.103
Lowest	0.052	0.035	0.004	0.100	0.095	0.000	0.042	0.147
Region								
North	0.073	0.242	-0.049	0.196	0.075	0.311	-0.070	0.220
North	-0.011	0.642	-0.060	0.037	-0.035	0.152	-0.083	0.013
Yorkshire	-0.023	0.556	-0.099	0.053	0.042	0.432	-0.063	0.147
East	-0.082	0.120	-0.185	0.021	0.007	0.917	-0.119	0.132
West	-0.008	0.754	-0.060	0.043	-0.029	0.269	-0.079	0.022
East	0.012	0.795	-0.081	0.105	-0.039	0.376	-0.125	0.047
South	0.012	0.650	-0.038	0.062	0.020	0.438	-0.030	0.070
South	-0.129	0.000	-0.185	-0.073	-0.110	0.001	-0.172	-0.048
Missing	-0.096	0.219	-0.249	0.057	-0.141	0.023	-0.263	-0.020
_cons	7.799	0.000	7.723	7.875	7.596	0.000	7.522	7.671

Table G 4 The relationship between aggregate secondary care costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	-53.62	0.13	-123.38	16.14	115.80	0.01	35.81	195.79
Female	-51.70	0.11	-115.76	12.36	106.67	0.01	32.56	180.79
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	102.32	0.00	45.79	158.85	57.79	0.02	10.13	105.45
Female	95.81	0.00	44.02	147.60	54.24	0.02	9.99	98.48
Obesity								
Sex								
Male	110.07	0.00	59.43	160.70	110.60	0.00	54.68	166.51
Female	103.89	0.00	56.71	151.08	103.54	0.00	50.87	156.21
Underweight								
Age (years)								
2	-73.78	0.20	-187.40	39.83	166.24	0.00	51.86	280.62
3	-59.93	0.15	-140.66	20.80	126.25	0.01	39.11	213.39
4	-57.40	0.14	-133.43	18.62	123.49	0.01	37.99	208.98
5	-48.57	0.12	-110.06	12.91	102.58	0.01	31.46	173.70
6	-49.99	0.12	-112.34	12.35	107.24	0.01	32.76	181.71
7	-47.74	0.10	-104.78	9.31	97.53	0.01	29.48	165.58
8	-46.11	0.09	-100.14	7.92	92.32	0.01	27.87	156.77
9	-46.12	0.10	-100.53	8.29	99.90	0.01	30.42	169.38
10	-50.17	0.10	-109.60	9.25	103.79	0.01	31.20	176.37
11	-57.59	0.11	-127.95	12.77	120.64	0.01	36.63	204.64
12	-53.07	0.10	-116.41	10.28	115.00	0.01	33.65	196.35
13	-51.81	0.11	-114.68	11.06	129.54	0.01	36.46	222.62
14	-63.22	0.11	-140.58	14.14	103.56	0.01	28.30	178.81
15	-32.27	0.15	-76.60	12.07	88.80	0.04	3.70	173.91
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	156.47	0.00	65.44	247.49	77.04	0.03	9.29	144.78
3	116.67	0.00	51.57	181.78	61.86	0.02	10.02	113.69
4	110.63	0.00	49.39	171.87	60.46	0.02	9.48	111.44

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
5	91.17	0.00	41.08	141.26	51.93	0.02	9.39	94.48
6	92.95	0.00	42.40	143.51	54.75	0.02	10.17	99.32
7	86.51	0.00	40.09	132.92	50.59	0.02	9.97	91.20
8	82.67	0.00	37.76	127.58	48.01	0.01	9.65	86.36
9	83.04	0.00	38.81	127.28	51.66	0.02	10.21	93.11
10	90.49	0.00	42.11	138.86	53.84	0.01	10.70	96.99
11	105.69	0.00	48.68	162.70	61.91	0.02	11.89	111.94
12	95.78	0.00	42.96	148.59	59.54	0.02	11.29	107.80
13	93.67	0.00	39.59	147.75	67.19	0.02	12.16	122.21
14	114.58	0.00	39.51	189.64	54.06	0.02	9.83	98.29
15	62.06	0.00	19.99	104.12	47.83	0.05	0.21	95.45
Obesity								
Age (years)								
2	163.96	0.00	81.35	246.57	148.98	0.00	68.72	229.23
3	124.82	0.00	65.81	183.84	118.68	0.00	57.40	179.95
4	118.67	0.00	63.24	174.10	116.01	0.00	55.59	176.42
5	98.49	0.00	53.44	143.53	99.20	0.00	48.56	149.83
6	100.68	0.00	55.06	146.30	104.46	0.00	52.08	156.84
7	94.38	0.00	50.74	138.02	96.33	0.00	45.95	146.70
8	90.47	0.00	51.12	129.82	91.38	0.00	46.59	136.18
9	90.76	0.00	51.01	130.52	98.40	0.00	50.35	146.45
10	98.86	0.00	55.71	142.00	102.52	0.00	52.46	152.58
11	114.89	0.00	63.82	165.95	118.05	0.00	59.72	176.38
12	104.61	0.00	57.15	152.07	113.40	0.00	56.49	170.30
13	102.26	0.00	52.05	152.46	127.93	0.00	61.44	194.42
14	125.00	0.00	53.29	196.71	102.84	0.00	49.42	156.26
15	66.61	0.00	26.62	106.60	90.65	0.01	19.35	161.94
Underweight								
Ethnicity								
Other/Uknown	-27.54	0.04	-53.57	-1.51	50.48	0.01	14.57	86.39
Bangladeshi	-49.74	0.11	-110.19	10.70	95.98	0.01	28.78	163.19
Black	-57.28	0.10	-125.86	11.30	117.50	0.01	35.40	199.60
Chinese/Other Asian	-58.70	0.13	-134.23	16.83	122.65	0.01	37.33	207.98
Indian	-53.66	0.12	-121.11	13.79	107.73	0.01	32.76	182.70
Pakistani	-64.29	0.13	-146.94	18.36	131.89	0.01	40.70	223.09
White	-56.99	0.14	-132.34	18.35	123.93	0.01	38.23	209.63
Mixed	-58.58	0.13	-133.36	16.19	121.97	0.01	37.15	206.79
Healthy weight	(base outcome)				(base			
Overweight								
Ethnicity								
Other/Uknown	43.81	0.00	21.59	66.03	28.92	0.01	7.27	50.57
Bangladeshi	90.51	0.00	38.52	142.50	49.89	0.02	9.41	90.37

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Black	103.87	0.00	48.29	159.45	61.44	0.01	12.65	110.24
Chinese/Other Asian	110.90	0.00	49.18	172.63	62.04	0.02	10.82	113.26
Indian	99.88	0.00	44.96	154.79	55.07	0.02	10.25	99.90
Pakistani	121.36	0.00	54.24	188.48	66.41	0.02	11.75	121.08
White	109.82	0.00	49.10	170.55	61.16	0.02	10.16	112.16
Mixed	110.51	0.00	49.72	171.31	61.51	0.02	11.22	111.80
Obesity								
Ethnicity								
Other/Uknown	49.85	0.00	29.07	70.63	54.41	0.00	27.77	81.04
Bangladeshi	98.61	0.00	53.13	144.10	94.97	0.00	46.95	142.98
Black	113.28	0.00	63.20	163.35	116.87	0.00	59.39	174.35
Chinese/Other Asian	119.57	0.00	63.99	175.16	118.51	0.00	58.16	178.86
Indian	108.13	0.00	58.53	157.72	105.06	0.00	52.04	158.08
Pakistani	130.88	0.00	70.80	190.97	126.95	0.00	62.65	191.24
White	117.80	0.00	63.02	172.58	117.22	0.00	57.10	177.33
Mixed	119.21	0.00	64.36	174.05	117.55	0.00	58.26	176.84
Underweight								
IMD								
Highest quintile	-52.18	0.11	-116.55	12.20	104.94	0.01	31.99	177.89
Fourth quintile	-52.76	0.12	-119.31	13.78	111.73	0.01	34.18	189.28
Third quintile	-51.78	0.12	-117.00	13.44	108.47	0.01	33.14	183.81
Second quintile	-52.10	0.12	-118.21	14.00	109.77	0.01	33.66	185.88
Lowest quintile	-54.25	0.14	-125.63	17.14	119.13	0.01	36.92	201.34
Healthy weight	(base outcome)				outcome)			
Overweight								
IMD								
Highest quintile	96.46	0.00	44.28	148.65	53.38	0.02	9.65	97.12
Fourth quintile	98.82	0.00	44.91	152.73	56.19	0.02	10.07	102.32
Third quintile	96.88	0.00	44.05	149.70	54.77	0.02	9.89	99.66
Second quintile	97.89	0.00	44.06	151.72	55.48	0.02	10.09	100.88
Lowest quintile	104.25	0.00	46.63	161.88	59.26	0.02	10.33	108.20
Obesity								
IMD								
Highest quintile	104.65	0.00	57.33	151.98	101.90	0.00	50.60	153.21
Fourth quintile	106.83	0.00	58.08	155.59	107.43	0.00	53.00	161.86
Third quintile	104.76	0.00	57.18	152.35	104.66	0.00	51.94	157.37
Second quintile	105.76	0.00	57.73	153.78	106.00	0.00	52.78	159.22
Lowest quintile	111.95	0.00	59.57	164.33	113.47	0.00	54.85	172.09
Underweight								
Region								

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
North East	-60.37	0.22	-156.67	35.94	159.65	0.01	48.67	270.63
North West	-55.38	0.16	-132.22	21.46	124.53	0.01	38.54	210.53
Yorkshire and The Humber	-53.97	0.12	-122.44	14.50	121.93	0.01	36.72	207.14
East Midlands	-49.32	0.12	-111.33	12.69	111.50	0.01	32.90	190.11
West Midlands	-53.41	0.11	-119.38	12.55	108.59	0.01	33.21	183.97
East of England	-55.44	0.10	-121.27	10.39	103.30	0.01	30.79	175.80
London	-50.04	0.10	-110.23	10.14	99.40	0.01	30.21	168.58
South East	-54.74	0.13	-124.61	15.12	118.21	0.01	36.44	199.99
South West	-48.03	0.11	-107.09	11.03	100.89	0.01	30.64	171.13
Missing	-50.58	0.12	-114.18	13.02	102.54	0.01	30.54	174.54
Healthy weight	(base outcome)				outcome)			
Overweight								
Region								
North East	130.74	0.00	53.03	208.46	72.60	0.03	7.03	138.17
North West	109.92	0.00	47.95	171.89	60.22	0.02	9.11	111.33
Yorkshire and The Humber	101.85	0.00	45.93	157.77	61.42	0.02	11.22	111.62
East Midlands	92.10	0.00	41.47	142.72	56.66	0.02	9.40	103.93
West Midlands	98.74	0.00	45.28	152.20	55.35	0.02	10.30	100.39
East of England	100.04	0.00	46.05	154.02	53.54	0.02	10.50	96.58
London	91.04	0.00	41.86	140.21	51.93	0.01	10.52	93.35
South East	103.21	0.00	46.75	159.66	58.99	0.02	10.20	107.79
South West	88.59	0.00	40.62	136.55	51.46	0.02	9.77	93.15
Missing	94.28	0.00	41.39	147.16	51.81	0.02	9.16	94.45
Obesity								
Region								
North East	136.34	0.00	59.43	213.25	140.79	0.00	53.38	228.20
North West	117.03	0.00	61.42	172.63	115.75	0.00	55.66	175.84
Yorkshire and The Humber	109.87	0.00	59.49	160.25	117.40	0.00	58.17	176.63
East Midlands	99.65	0.00	53.78	145.51	108.18	0.00	52.05	164.31
West Midlands	107.13	0.00	58.94	155.31	105.62	0.00	52.64	158.60
East of England	109.27	0.00	60.07	158.48	101.95	0.00	50.84	153.07
London	99.24	0.00	55.50	142.97	98.80	0.00	50.44	147.16
South East	111.36	0.00	60.48	162.25	112.90	0.00	55.43	170.37
South West	96.15	0.00	52.92	139.39	98.20	0.00	49.10	147.29
Missing	102.03	0.00	52.47	151.60	98.98	0.00	48.35	149.61

Total direct healthcare costs – results

Table G 5 Regression coefficients (marginal effects) for the two parts of the model

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
logit								
UK90_bmi								
Underweight	-0.149	0.000	-0.205	-0.092	0.124	0.045	0.003	0.245
Overweight	0.039	0.042	0.001	0.077	-0.069	0.050	-0.137	0.000
Obesity	0.052	0.001	0.020	0.084	-0.002	0.947	-0.064	0.060
Sex								
Female	-0.141	0.000	-0.164	-0.117	-0.051	0.024	-0.095	-0.007
age_whole								
3	0.102	0.001	0.041	0.164	0.560	0.000	0.437	0.683
4	-0.020	0.514	-0.081	0.040	-0.093	0.081	-0.198	0.012
5	-0.243	0.000	-0.300	-0.186	-0.464	0.000	-0.559	-0.369
6	-0.341	0.000	-0.398	-0.284	0.032	0.557	-0.074	0.137
7	-0.486	0.000	-0.541	-0.430	-0.183	0.000	-0.283	-0.082
8	-0.415	0.000	-0.472	-0.359	0.140	0.011	0.032	0.247
9	-0.308	0.000	-0.367	-0.249	0.169	0.003	0.057	0.281
10	-0.285	0.000	-0.347	-0.223	-0.171	0.002	-0.280	-0.061
11	-0.176	0.000	-0.248	-0.103	0.123	0.076	-0.013	0.259
12	-0.270	0.000	-0.404	-0.136	0.504	0.001	0.198	0.810
13	-0.229	0.021	-0.424	-0.034	0.480	0.029	0.048	0.912
14	0.090	0.568	-0.218	0.397	1.439	0.004	0.448	2.431
15	0.072	0.872	-0.802	0.946	0.535	0.602	-1.472	2.541
Ethnicity								
Other/Uknown	-1.497	0.000	-1.526	-1.469	-0.782	0.000	-0.837	-0.727
Bangladeshi	0.307	0.000	0.197	0.417	1.202	0.000	0.852	1.552
Black	-0.169	0.000	-0.222	-0.117	0.307	0.000	0.184	0.430
Chinese/Other	-0.100	0.008	-0.175	-0.026	0.344	0.000	0.172	0.516
Indian	0.072	0.072	-0.006	0.151	0.529	0.000	0.343	0.715
Pakistani	0.166	0.000	0.095	0.236	1.075	0.000	0.862	1.288
Mixed	-0.065	0.048	-0.129	0.000	0.300	0.000	0.165	0.436
IMD								
Fourth	0.071	0.002	0.027	0.114	0.052	0.164	-0.021	0.124
Third	0.033	0.133	-0.010	0.075	0.080	0.032	0.007	0.152
Second	-0.026	0.214	-0.067	0.015	0.161	0.000	0.087	0.234
Lowest	-0.021	0.298	-0.061	0.019	0.243	0.000	0.171	0.316
Region								
North	0.339	0.000	0.265	0.413	0.261	0.002	0.096	0.427
North	0.467	0.000	0.426	0.508	0.026	0.551	-0.060	0.112
Yorkshire	0.006	0.847	-0.059	0.072	-0.848	0.000	-0.953	-0.742

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
East	0.450	0.000	0.357	0.542	1.335	0.000	1.002	1.668
West	0.003	0.893	-0.034	0.039	0.079	0.073	-0.007	0.166
East	-0.101	0.001	-0.160	-0.041	-0.877	0.000	-0.973	-0.781
South	0.281	0.000	0.240	0.321	-0.276	0.000	-0.356	-0.196
South	0.323	0.000	0.278	0.368	-0.774	0.000	-0.849	-0.699
Missing	0.378	0.000	0.256	0.500	-0.045	0.703	-0.276	0.186
_cons	2.375	0.000	2.312	2.438	3.697	0.000	3.582	3.812
glm								
UK90_bmi								
Underweight	-0.205	0.000	-0.293	-0.118	-0.048	0.412	-0.161	0.066
Overweight	0.062	0.038	0.003	0.121	0.101	0.000	0.046	0.156
Obesity	0.150	0.000	0.083	0.217	0.172	0.000	0.108	0.235
Sex								
Female	-0.149	0.000	-0.192	-0.106	-0.156	0.000	-0.197	-0.114
age_whole								
3	-0.118	0.014	-0.211	-0.024	-0.089	0.062	-0.183	0.005
4	-0.088	0.028	-0.167	-0.009	0.027	0.470	-0.046	0.099
5	0.008	0.883	-0.098	0.114	0.060	0.161	-0.024	0.143
6	0.053	0.231	-0.034	0.140	0.133	0.001	0.056	0.210
7	0.009	0.827	-0.074	0.092	0.198	0.001	0.085	0.311
8	0.104	0.026	0.013	0.196	0.173	0.000	0.103	0.243
9	0.156	0.000	0.072	0.241	0.276	0.000	0.207	0.345
10	0.242	0.000	0.156	0.327	0.412	0.000	0.318	0.506
11	0.332	0.000	0.224	0.440	0.503	0.000	0.419	0.587
12	0.298	0.001	0.124	0.473	0.410	0.000	0.279	0.540
13	0.508	0.032	0.043	0.972	0.372	0.000	0.228	0.515
14	0.244	0.020	0.038	0.450	0.019	0.830	-0.152	0.189
15	0.369	0.098	-0.068	0.807	0.234	0.397	-0.307	0.775
Ethnicity								
Other/Uknown	-0.491	0.000	-0.589	-0.392	-0.599	0.000	-0.709	-0.488
Bangladeshi	0.234	0.107	-0.050	0.518	0.212	0.025	0.026	0.397
Black	0.088	0.096	-0.016	0.192	0.064	0.119	-0.016	0.145
Chinese/Other	0.049	0.389	-0.062	0.160	0.084	0.149	-0.030	0.198
Indian	0.112	0.154	-0.042	0.266	0.061	0.307	-0.056	0.179
Pakistani	0.240	0.000	0.138	0.342	0.246	0.000	0.149	0.343
Mixed	0.101	0.029	0.010	0.191	0.136	0.001	0.058	0.213
IMD								
Fourth	-0.051	0.177	-0.125	0.023	-0.088	0.073	-0.183	0.008
Third	-0.014	0.721	-0.090	0.062	-0.070	0.169	-0.169	0.029
Second	0.005	0.896	-0.066	0.076	-0.105	0.044	-0.206	-0.003

Total_costs	Coefficient	P>z	[95% conf.	interval]	Coefficient	P>z	[95% conf.	interval]
	Year before (two-part GLM)				Year after (two-part GLM)			
Lowest	0.068	0.081	-0.008	0.145	-0.082	0.143	-0.191	0.028
Region								
North	0.117	0.028	0.013	0.221	0.147	0.008	0.039	0.254
North	0.189	0.000	0.113	0.265	0.255	0.000	0.151	0.359
Yorkshire	0.201	0.001	0.082	0.321	0.251	0.000	0.133	0.368
East	0.275	0.079	-0.032	0.581	0.210	0.047	0.003	0.417
West	0.185	0.000	0.107	0.263	0.140	0.000	0.070	0.211
East	-0.026	0.656	-0.138	0.087	-0.057	0.264	-0.158	0.043
South	0.191	0.000	0.108	0.275	0.182	0.000	0.108	0.256
South	0.003	0.941	-0.075	0.081	0.100	0.005	0.031	0.169
Missing	0.182	0.021	0.027	0.337	0.025	0.664	-0.087	0.137
_cons	7.952	0.000	7.852	8.053	7.890	0.000	7.789	7.991

Table G 6 The relationship between total direct healthcare costs and BMI category (with healthy weight as comparator) by covariates one year before (left half) and after (right half) the index BMI measurement

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Underweight								
Sex								
Male	-593.74	0.00	-809.32	-378.16	-135.75	0.44	-476.36	204.85
Female	-499.30	0.00	-679.19	-319.42	-113.42	0.44	-400.09	173.25
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Sex								
Male	203.94	0.03	18.73	389.15	325.35	0.00	139.40	511.30
Female	171.44	0.03	17.27	325.61	272.76	0.00	116.95	428.56
Obesity								
Sex								
Male	501.99	0.00	272.94	731.03	585.71	0.00	352.91	818.52
Female	420.38	0.00	231.36	609.40	491.71	0.00	301.90	681.52
Underweight								
Age (years)								
2	-530.04	0.00	-725.87	-334.21	-108.61	0.44	-381.10	163.89
3	-470.82	0.00	-650.04	-291.60	-102.55	0.42	-352.43	147.33

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
4	-483.35	0.00	-660.87	-305.84	-110.25	0.44	-389.46	168.97
5	-521.41	0.00	-716.36	-326.46	-107.19	0.45	-387.86	173.48
6	-544.91	0.00	-743.28	-346.55	-123.35	0.43	-431.91	185.22
7	-514.16	0.00	-698.85	-329.46	-128.35	0.44	-456.19	199.50
8	-568.06	0.00	-776.18	-359.95	-128.90	0.43	-449.51	191.71
9	-604.29	0.00	-823.95	-384.62	-143.69	0.43	-500.46	213.08
10	-657.67	0.00	-896.81	-418.53	-158.93	0.44	-562.93	245.07
11	-727.13	0.00	-992.87	-461.39	-179.63	0.43	-627.80	268.55
12	-699.54	0.00	-974.44	-424.64	-164.52	0.43	-568.33	239.28
13	-848.79	0.00	-1358.99	-338.60	-152.94	0.43	-530.06	224.18
14	-654.50	0.00	-925.69	-383.31	-108.95	0.41	-370.06	152.16
15	-798.89	0.00	-1248.71	-349.06	-139.74	0.43	-489.00	209.53
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Age (years)								
2	182.14	0.03	14.46	349.82	259.97	0.00	109.80	410.14
3	161.83	0.03	13.75	309.92	240.56	0.00	103.51	377.61
4	166.10	0.03	13.73	318.46	265.45	0.00	113.52	417.38
5	179.07	0.03	16.49	341.65	265.12	0.00	110.77	419.47
6	187.09	0.03	17.91	356.27	294.81	0.00	125.02	464.59
7	176.47	0.03	17.75	335.19	310.10	0.00	136.73	483.48
8	195.00	0.03	20.56	369.45	306.87	0.00	131.89	481.84
9	207.50	0.03	20.12	394.87	341.71	0.00	147.16	536.26
10	225.84	0.03	21.14	430.53	384.69	0.00	154.03	615.35
11	249.76	0.03	22.68	476.84	428.48	0.00	183.56	673.41
12	240.22	0.03	19.97	460.47	388.00	0.00	163.34	612.66
13	291.50	0.05	-1.56	584.55	361.69	0.00	150.41	572.97
14	224.94	0.04	14.69	435.19	252.35	0.00	104.46	400.23
15	274.51	0.05	-2.37	551.38	328.16	0.01	70.35	585.97
Obesity								
Age (years)								
2	450.20	0.00	241.66	658.73	467.80	0.00	281.47	654.13
3	400.64	0.00	216.79	584.48	429.27	0.00	242.79	615.75
4	410.39	0.00	218.91	601.86	478.78	0.00	290.59	666.98
5	440.30	0.00	230.96	649.63	483.23	0.00	291.13	675.34
6	458.80	0.00	251.26	666.34	530.15	0.00	314.57	745.73
7	431.09	0.00	237.25	624.92	560.10	0.00	342.39	777.80
8	477.18	0.00	263.12	691.24	550.95	0.00	336.46	765.44
9	509.09	0.00	280.81	737.37	613.24	0.00	375.82	850.67
10	554.45	0.00	304.36	804.53	695.31	0.00	422.46	968.16
11	614.73	0.00	323.38	906.09	769.93	0.00	466.95	1072.91
12	589.87	0.00	307.65	872.09	693.92	0.00	414.13	973.71
13	715.98	0.00	259.41	1172.55	647.62	0.00	386.00	909.24

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
14	556.02	0.00	283.14	828.89	447.89	0.00	259.51	636.28
15	677.47	0.00	252.90	1102.05	585.86	0.00	193.70	978.02
Underweight								
Ethnicity								
Other/Uknown	-293.93	0.00	-393.41	-194.45	-63.66	0.47	-237.02	109.70
Bangladeshi	-723.62	0.00	-1077.49	-369.74	-165.32	0.41	-561.76	231.13
Black	-588.25	0.00	-805.25	-371.24	-132.17	0.42	-456.14	191.81
Chinese/Other Asian	-574.75	0.00	-793.49	-356.00	-139.11	0.43	-481.29	203.07
Indian	-627.34	0.00	-882.14	-372.54	-139.90	0.42	-482.20	202.40
Pakistani	-768.55	0.00	-1044.26	-492.84	-180.32	0.41	-612.30	251.65
White	-582.07	0.00	-794.69	-369.45	-132.71	0.44	-467.76	202.34
Mixed	-618.18	0.00	-848.05	-388.30	-148.10	0.43	-512.93	216.73
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Ethnicity								
Other/Uknown	100.80	0.02	17.78	183.83	160.76	0.00	65.58	255.93
Bangladeshi	248.69	0.04	15.45	481.94	382.28	0.00	158.02	606.54
Black	201.85	0.03	17.36	386.35	311.36	0.00	134.22	488.51
Chinese/Other Asian	197.30	0.03	17.74	376.86	327.94	0.00	137.82	518.05
Indian	215.47	0.03	16.05	414.89	328.26	0.00	139.35	517.16
Pakistani	264.07	0.03	19.49	508.65	417.73	0.00	179.74	655.73
White	199.94	0.03	17.37	382.52	319.44	0.00	136.81	502.08
Mixed	212.26	0.03	18.19	406.33	350.69	0.00	149.71	551.68
Obesity								
Ethnicity								
Other/Uknown	235.96	0.00	127.28	344.64	295.31	0.00	171.96	418.65
Bangladeshi	616.20	0.00	301.92	930.48	678.04	0.00	391.63	964.45
Black	494.51	0.00	270.94	718.08	556.62	0.00	340.18	773.07
Chinese/Other Asian	484.98	0.00	261.42	708.54	586.42	0.00	344.30	828.54
Indian	531.70	0.00	281.02	782.38	585.84	0.00	349.16	822.52
Pakistani	653.31	0.00	350.45	956.17	741.49	0.00	441.97	1041.01
White	493.79	0.00	268.72	718.85	576.10	0.00	350.44	801.77
Mixed	522.60	0.00	281.31	763.88	628.26	0.00	379.49	877.04
Underweight								
IMD								
Highest quintile	-557.85	0.00	-763.11	-352.59	-0.76	0.45	-477.09	209.57
Fourth quintile	-524.46	0.00	-716.24	-332.68	-0.77	0.44	-436.15	190.02
Third quintile	-530.31	0.00	-722.82	-337.81	-0.77	0.44	-433.43	188.09
Second quintile	-528.95	0.00	-720.23	-337.68	-0.79	0.43	-415.39	177.67
Lowest quintile	-595.74	0.00	-812.05	-379.44	-0.79	0.43	-454.55	193.37

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Healthy weight	(base outcome)				(base outcome)			
Overweight								
IMD								
Highest quintile	191.59	0.03	17.67	365.51	3.48	0.00	142.21	508.43
Fourth quintile	180.15	0.03	15.98	344.33	3.41	0.00	126.80	468.43
Third quintile	182.13	0.03	17.27	346.99	3.33	0.00	121.82	469.53
Second quintile	181.63	0.03	18.28	344.98	3.44	0.00	121.88	445.76
Lowest quintile	204.59	0.03	19.33	389.86	3.44	0.00	133.34	486.90
Obesity								
IMD								
Highest quintile	471.44	0.00	256.13	686.75	5.03	0.00	359.47	818.77
Fourth quintile	443.86	0.00	241.18	646.54	5.00	0.00	326.98	748.49
Third quintile	447.78	0.00	242.89	652.66	4.91	0.00	320.50	746.52
Second quintile	445.46	0.00	244.16	646.75	5.07	0.00	312.82	707.57
Lowest quintile	502.52	0.00	274.04	731.01	4.87	0.00	332.32	780.13
Underweight								
Region								
North East	-570.21	0.00	-782.55	-357.87	-133.10	0.42	-457.64	191.45
North West	-619.37	0.00	-849.51	-389.23	-148.76	0.43	-517.43	219.90
Yorkshire and The Humber	-609.79	0.00	-832.56	-387.02	-132.65	0.47	-489.78	224.47
East Midlands	-654.29	0.00	-975.10	-333.48	-148.63	0.41	-504.46	207.19
West Midlands	-598.54	0.00	-809.65	-387.42	-132.77	0.43	-459.33	193.78
East of England	-465.02	0.00	-636.74	-293.31	-95.98	0.47	-356.55	164.59
London	-463.70	0.00	-631.09	-296.32	-107.06	0.43	-372.07	157.95
South East	-591.93	0.00	-810.37	-373.48	-134.28	0.44	-473.87	205.30
South West	-498.26	0.00	-681.41	-315.12	-113.53	0.46	-417.56	190.50
Missing	-631.33	0.00	-884.41	-378.25	-122.01	0.43	-425.06	181.04
Healthy weight	(base outcome)				(base outcome)			
Overweight								
Region								
North East	195.91	0.03	16.16	375.67	313.17	0.00	132.94	493.41
North West	212.87	0.03	16.76	408.98	352.55	0.00	156.01	549.09
Yorkshire and The Humber	209.31	0.03	19.97	398.66	333.05	0.00	136.77	529.34
East Midlands	224.84	0.04	14.33	435.34	343.23	0.00	140.62	545.84
West Midlands	205.46	0.03	19.53	391.38	313.77	0.00	134.38	493.17
East of England	159.60	0.03	16.25	302.95	242.35	0.00	98.80	385.91
London	159.15	0.03	18.02	300.28	254.10	0.00	109.49	398.70
South East	203.33	0.03	18.33	388.34	324.12	0.00	133.90	514.34
South West	171.18	0.03	14.86	327.51	284.16	0.00	118.33	449.98
Missing	216.94	0.03	16.33	417.55	290.08	0.00	122.78	457.37

	Year before				Year after			
	dy/dx	P>z	[95% conf.	interval]	dy/dx	P>z	[95% conf.	interval]
Obesity								
Region								
North East	484.05	0.00	259.90	708.20	559.58	0.00	331.63	787.53
North West	526.84	0.00	287.03	766.65	631.81	0.00	388.63	874.99
Yorkshire and The Humber	512.65	0.00	270.69	754.61	610.55	0.00	367.28	853.82
East Midlands	555.23	0.00	258.43	852.03	608.41	0.00	342.80	874.02
West Midlands	502.85	0.00	277.04	728.67	561.66	0.00	336.87	786.46
East of England	390.58	0.00	211.18	569.97	445.22	0.00	267.13	623.32
London	387.84	0.00	210.40	565.28	455.64	0.00	270.75	640.53
South East	501.24	0.00	270.69	731.79	585.19	0.00	355.92	814.46
South West	422.61	0.00	229.85	615.37	520.31	0.00	315.66	724.96
Missing	536.24	0.00	280.55	791.93	520.53	0.00	312.93	728.13