Assessing the differential impact of health-related food taxes and subsidies in the UK by household income

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Abstract

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This thesis assesses the differential impact of health-related food taxes and subsidies (HRFTS) in the UK by household income. In the UK, dietary risk factors account for nearly a fifth of deaths and a tenth of disability adjusted life years (DALYs). The high prevalence of poor diet in the UK suggests that population approaches are required to encourage healthier diets. Health-related food taxes and subsidies are interventions that aim to improve the healthiness of diets by raising the price of unhealthy foods and/or lowering the price of healthy foods. At present, there is limited evidence of the differential impacts of HRFTS on low income groups. This thesis helps to fill this gap using a combination of experimental and modelling methods.

This thesis includes reviews of both the experimental and modelling studies that have examined the differential impact of HRFTS. Both reviews find few UK studies that examine the possible impacts of such policies on households of different income groups. In addition, the reviews identify areas where better methodological approaches could help to establish the extent to which HRFTS may have different impacts on different population groups.

I develop a UK Virtual Supermarket (UKVS) – a 3D computer simulation of a small supermarket - that can be used as an experimental environment in which to test the impact of HRFTS. Following the development of the UKVS, I conduct a feasibility study to assess recruitment, retention, purchasing variability, and participant responses to the UKVS. The feasibility study provides valuable information for conducting future randomised controlled trials using the UKVS.

I also model the health impact of selected HRFTS by household income in the UK. I combine multiple years of data from the Living Costs and Food Survey (LCFS) to estimate income tertile specific changes in purchases under HRFTS. I use the Preventable Risk Integrated ModEl (PRIME), a comparative risk assessment model, to assess the health impact of the purchasing changes estimated to result from the HRFTS scenarios.

The thesis concludes by recommending that experimental and modelling methods should be used in combination to better assess the likely impact of HRFTS on different population groups.

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List of abbreviations

BMI	Body Mass Index
CI	Confidence Interval
DALY	Disability adjusted life year
DDA	Deaths delayed or averted
EU	European Union
HED	High Energy Density
HRFTS	Health-related food taxes and subsidies
LCFS	Living Costs and Food Survey
LED	Low Energy Density
OECD	Organisation for Economic Cooperation and Development
NDNS	National Diet and Nutrition Survey
NHS	National Health Service
NZVS	New Zealand Virtual Supermarket
ONS	Office for National Statistics
PRIME	Preventable Risk Integrated ModEl
QUAIDS	Quadratic Almost Ideal Demand System
SD	Standard Deviation
SE	Standard Error
SSB	Sugar-sweetened beverage
UKVS	UK Virtual Supermarket
VAT	Value Added Tax
WHO	World Health Organisation

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Chapter 1: Introduction

This chapter provides the rationale for the thesis. I begin by providing a summary of the impact of unhealthy diets and argue that population interventions are best placed to address the current burden of diet-related diseases in the UK. I move on to identify health-related food taxes and subsidies (HRFTS) as the population intervention that I focus on in this thesis. I highlight the different methodological approaches that can be used to assess the impact of HRFTS and outline the need for research that examines the differential impact of HRFTS. I move on to outline the research questions that this thesis will address. The chapter concludes with a summary of the contents of each chapter of the thesis.

The impact of unhealthy diets

Unhealthy diets pose a substantial threat to public health. Globally, dietary risk factors account for 11.3 million deaths and 241.4 disability adjusted life years (DALYs) [1]. In the UK, dietary risk factors account for nearly a fifth of deaths and a tenth of DALYs [2]. This means that suboptimal diet alone has a similar health burden to tobacco use, and to alcohol use and inadequate physical activity combined. Unhealthy diets also contribute to high blood pressure, high body mass index (BMI), and high cholesterol; these three metabolic risks are also ranked in the top ten leading risk factors for deaths and DALYs in the UK [2].

Poor diet related ill health was estimated to cost the National Health Service (NHS) £5.8 billion (21.6% of total NHS costs) in 2005/6 when the latest estimates were produced [3]. Diet also has influences beyond the healthcare system. For example, diets have an impact on workplace productivity [4], cognitive development in children [5], and healthier diets may also have lower greenhouse gas emissions [6].

Diets in the UK are unhealthy on a number of counts. Only 30% of adults aged 19-64 years and under 10% of 11-18 year olds meet the "5-a-day" guideline for fruit and vegetable intake [7]. Mean intakes of fibre are 13.7-13.9g/day [7], well below the recently revised recommendation of 30g/day [8]. Mean saturated fat, salt, and non-milk extrinsic sugar intakes also exceed recommendations [7]. In addition, over two-thirds of adults are overweight or obese [7]. There are also differences in diets by socioeconomic factors. Individuals with lower incomes consume less fruits and vegetables, and more non-milk extrinsic sugars and red and processed meats than those with higher incomes [9]. Similar patterns are present by occupation and education level [9]. Data from the National Diet and Nutrition Survey suggests that where there are differences by income, it tends to be those with lower incomes that have worse diets [7]. Given the high burden of poor diet, considerable improvements in population health in the UK could be achieved if diets were improved.

Population level interventions

The high prevalence of poor diets suggests that population approaches are required. The population approach refers to lowering the mean level of risk, to shift the whole distribution of exposure in a favourable direction [10]. The notion of population approaches to addressing diseases was coined by Geoffrey Rose who first noted that "a large number of people at a small risk may give rise to more cases of disease than the small number who are at a high risk" in 1985. Geoffrey Rose continued to argue that under these circumstances, population level interventions would be expected to bring about the greatest health benefits.

Unhealthy diets in the UK provide the case in point: there are a large number of people who are exposed to more than just a small risk, and they give rise to more cases of disease than those at high risk. For example, two thirds of coronary heart disease, stroke, and colorectal cancer deaths occur in individuals whose fibre consumption is moderate (10-20g/day). Under one fifth of total deaths from these three diseases occur in individuals with low fibre consumption (<10g/day)[a].

[a] Based on own calculations using the Preventable Risk Integrated ModEl [194]. Calculations assume a lognormal relative risk relationship between fibre intake and disease [237–239] and normally distributed fibre intakes taken from the National Diet and Nutrition Survey [7]

Population approaches to improve diet include restricting the advertising of unhealthy foods, reformulation of processed foods, legislation to remove industrial trans-fatty acids, mass media campaigns, restriction of fast food outlets, and taxes and subsidies on foods [11,12]. Analyses have repeatedly shown that population approaches can be effective and cost-effective but evidence is often poor and/or limited to specific contexts [12,13]. Health-related food taxes and subsidies (HRFTS) are one of several population interventions recommended by the World Health Organisation (WHO) Global Status Report on Non-Communicable Diseases [14].

Health-related food taxes and subsidies

HRFTS are interventions that aim to improve the healthiness of diets by raising the price of unhealthy foods and/or lowering the price of healthy foods. HRFTS target a key determinant of food choice: price. In the UK, 36% of shoppers consider price to be the most important and 90% of shoppers list price in the top five most important influences on food purchases [15].

Several HRFTS have been implemented. Various types of sugar-sweetened beverage (SSB) taxes have been introduced in Mexico, France, and Chile [16–18] and recently announced in the UK [19]. Dominica applies an excise tax to foods and drinks with high sugar content, Hungary has a “public health tax” that is applied to selected foods, including those with high salt or sugar content, and Finland levies taxes on confectionery and ice-cream [18]. In

addition, various HRFTS have been suggested in the academic literature including subsidies on healthy foods and taxes based on nutrient profiling models [20].

Figure 1 illustrates the path by which HRFTS are expected to lead to health impacts. HRFTS are designed to lead to changes in consumer prices, price changes lead to changes in purchases, these in turn lead to changes in the foods and nutrients consumed, and dietary changes result in health impacts. The magnitude and direction of the HRFTS impact will depend on factors at each stage. The food industry may absorb some of the tax or increase prices beyond the magnitude of the HRFTS. Changes in purchases will depend on how price sensitive consumers are, and the substitutions they make. Own-price elasticity is the extent to which purchases of a product change when the price of a product changes, cross-price elasticity is the extent to which purchases of other products change. Both own- and cross-price elasticities differ for different types of food and in different contexts [21].

Figure 1: Pathway of HRFTS health impacts



Natural experiments, experimental studies in controlled environments and modelling studies are used to gather evidence on the impact of HRFTS. Natural experiments include the evaluation of HRFTS post-implementation and observations of purchasing changes under circumstances resembling HRFTS. Experimental studies in controlled environments implement HRFTS scenarios in artificial environments; participant responses in the artificial

environment can be used to estimate what the wider impact of HRFTS would be. Modelling studies use existing data on changes in behaviour under price fluctuations to estimate the impact of HRFTS scenarios. Thow et al systematically reviewed the literature across these study designs and conclude that HRFTS can be effective in promoting desired dietary changes [20]. Other reviews that focus on particular study designs or types of intervention similarly concluded that HRFTS have the potential to improve diets [22–25].

Compiling evidence from multiple study designs is advantageous as they all have their strengths and limitations. Natural experiments provide evidence on what actually happens under the implementation of a HRFTS. They can provide information on a broad range of outcomes, including the actual changes in consumer price changes that result from HRFTS. However, natural experiments are limited to examining implemented interventions and cannot be used to assess the possible impacts of multiple HRFTS in the same population. In addition, it is difficult to ascertain whether observed changes in natural experiments are due to the intervention or other factors due to the lack of control group. Experimental studies can be used to assess multiple HRFTS scenarios. Randomised controlled trials in particular allow us to establish the impact of a HRFTS independently of concurrent changes that may confound the observed relationship in natural experiments. However, the validity of the findings of experimental studies is limited by the extent to which they mimic the actual environmental and purchasing changes that would result from the implementation of HRFTS. In addition, it is impractical to use experimental studies to assess health impacts that may take many years to manifest. Modelling studies can be used to assess longer term

impacts of HRFTS and can also assess the impact of multiple HRFTS simultaneously. However, modelling studies are limited by the quality of data inputs and the extent to which assumptions made in the modelling process reflect reality. Crucially, the strengths and weaknesses of different study designs are complementary and therefore weaknesses can be overcome by the use of evidence from multiple designs.

Differential impacts

Many argue food prices contribute to socioeconomic differences in diets and health outcomes based on evidence suggesting that healthy foods are more expensive than less healthy foods and that cost is a barrier to healthy purchasing [26–31]. Multiple reviews have suggested that upstream and structural interventions (e.g. HRFTS) may be more likely to reduce inequalities than downstream and agent-centred interventions (e.g. dietary counselling) [32–34]. Whilst HRFTS are classified within categories of interventions that are expected to reduce inequalities, the lack of specific evidence on the differential impacts of HRFTS on population sub-groups is a frequently identified research gap [20–22,25].

From an economic perspective, tax interventions are commonly criticised for being regressive as low income households spend a greater proportion of their total income on food [35–37]. The regressive impact is observed because lower income households need to devote a greater proportion of their overall household budget to continue purchasing the same foods in the event of food price increases. There are also criticisms that subsidies

may disproportionately benefit well-off households by reducing the absolute cost of (healthy) foods that well-off households already purchase in greater quantities [20]. The extent to which regressive economic impacts are observed depends on a variety of factors, not least the choice of foods that are subject to price changes and current purchasing differences between different income groups. Some argue that HRFTS policies need not be regressive, and that certain HRFTS may even be progressive [38,39].

From a public health perspective, it is unclear whether HRFTS would increase or decrease health inequalities. Some studies find that HRFTS result in greater health improvements in low income, or otherwise disadvantaged, population groups [40,41]. Reviews in this area suggest that even if HRFTS are economically regressive, these may be outweighed by positive health impacts [20,22]. These findings should be interpreted with caution as in both cases, the authors also conclude that further research into the differential impacts of HRFTS is warranted.

The mixed findings surrounding the likely differential impacts of HRFTS suggest there may be opportunities to design HRFTS that ameliorate or reduce inequalities as well as improving population diet as a whole. Examining the differential impact of HRFTS in the UK alongside estimates of the overall health impact of HRFTS is important because reducing inequalities has and continues to be stated as a government priority [42–45].

Thesis summary

HRFTS are a promising population level intervention to improve diets. There is limited evidence of the possible impacts of HRFTS in the UK, especially with respect to differential impacts of HRFTS across population sub-groups. This thesis aims to fill this gap using a combination of experimental and modelling methods.

The overall objectives of this thesis are:

- to identify HRFTS with the potential to improve population diets in the UK
- to develop and assess the suitability of a UK Virtual Supermarket as an experimental tool for assessing the differential impact of HRFTS in the UK
- to model the health impacts of selected HRFTS scenarios in the UK

This thesis comprises eight chapters, including this Introduction. Chapter 2 discusses the different types of HRFTS with the aim of identifying possible HRFTS that could be implemented in the UK context. The thesis then splits into two parts. Part A (Chapters 3-5) is based on experimental methods for assessing differential impacts of HRFTS. Chapter 3 presents a systematic review of experimental studies that examined the differential impacts. Chapter 4 outlines the development of a UK Virtual Supermarket (UKVS): a 3D computer simulation of a supermarket that can be used to examine purchasing behaviour. The feasibility of the use of the UKVS to examine purchasing behaviour across different income groups, and the implications for conducting trials of HRFTS are presented in

Chapter 5. Part B (Chapters 6 and 7) is concerned with modelling differential impacts of HRFTS. Chapter 6 contains a review of modelling methods that have been used to examine the differential impacts of HRFTS. Chapter 7 presents the modelling that I conducted to examine the impact of selected HRFTS scenarios. I conclude with a discussion of the overall findings of the thesis in Chapter 8.

Clarification of terminology

For brevity, I use the term 'food' to cover both foods and beverages throughout the thesis. For consistency, I use HRFTS to refer to the pricing interventions discussed. It should be noted that alternative terminology is used to refer to the same sorts of interventions in some of the literature (e.g. "fiscal measures to improve diet"). I consider HRFTS to be most appropriate term due to the focus on interventions that directly change the price of foods based on judgements of healthiness. Fiscal interventions to improve diet is a broader term that may also be applied to agricultural subsidies and food voucher programs that are beyond the scope of this thesis. Taxes on alcoholic drinks are not included in my definition of HRFTS. This is in line with other literature on HRFTS which implicitly excludes taxes on alcohol by treating them as part of the precedent for introducing HRFTS (e.g. [46]).

Chapter 2: Which health-related food taxes and subsidies might improve health in the UK?

This chapter provides a summary of the types of health-related food taxes and subsidies (HRFTS) that could lead to health improvements in the UK. I discuss the dietary changes that would be beneficial to health in the UK and the types of health-related food taxes and subsidies that could result in the desired dietary changes. I conclude that HRFTS in the UK that cover a broad range of foods are more likely to improve diets, and this conclusion has implications for the methods used to examine HRFTS in later chapters in the thesis.

Background

The public health impetus for implementing health HRFTS is to increase consumption of some foods and decrease consumption of others. In March 2016, the UK Government announced that it would be implementing a sugar-sweetened beverage (SSB) tax in the UK from 2018 [19]. This announcement follows a number of UK based modelling studies that found that SSB taxation is expected to lead to positive health impacts and long-term advocacy for an SSB tax from a broad range of organisations including the British Medical Association and Public Health England [47–49]. The announcement of the SSB tax demonstrates the willingness of the UK Government to engage with HRFTS, at least under certain conditions.

There is a broad range of possible HRFTS that have been implemented globally or suggested in the academic literature. Within a country, some HRFTS are more likely to improve population diets than others. For example, a SSB tax would not improve diets in a country where no SSBs were consumed. There are too many HRFTS options to assess all the health impacts for every country; we need a way to narrow down the possibilities and choose the options that are most likely to improve population diets. By narrowing down the possibilities for HRFTS, we can also identify the methodological approaches that are most suited to estimating the potential impacts of specific HRFTS.

Narrowing down the possibilities for HRFTS needs to begin by identifying the foods whose consumption should be increased and foods whose consumption should be decreased. The choice of target foods can be assisted by evidence from: the distribution of diet-related diseases, current dietary patterns, and the health impact of changes in diets. Once desired dietary changes are identified, we can proceed to weigh the HRFTS options that might lead to the desired changes. This chapter applies the above principles to the UK context to address the following research questions:

- What changes in population diets should be encouraged in the UK?
- What types of HRFTS could result in the desired dietary changes?

Population diet in the UK

UK households spend 11.4% of total spending on food and beverage purchases, rising to 16.5% for low income households [50]. In the last decade, there has been an overall rise in food prices [50] though the magnitude has varied considerably across different goods [51]. 43% of food consumed in the UK originates from outside the UK [50]. Over a quarter of UK food (28%) originates from the European Union (EU) [50].

Ideally, HRFTS should be set in accordance with the diet-related disease burden in the population, in order to maximise the potential health benefits of the policy. The Global Burden of Disease Project estimates that dietary components accounted for nearly one tenth of global DALYs in 2013 [1]. The impact of dietary risk factors varies considerably, from 3% of deaths in Chad to 43% of deaths in Georgia [2]. The additional burden of high blood pressure, high body mass index, and other metabolic risk factors that are related to dietary intakes suggests that the overall burden is even higher. Given the differences in disease burden linked to diets, we would expect HRFTS to be more successful in countries and regions with a high burden of disease from dietary risk factors.

Adherence to dietary recommendations in the UK

Current adherence to dietary guidelines provides an indicator of which aspects of dietary behaviour are unhealthy and can therefore be used to inform targets for HRFTS. UK dietary recommendations state that individuals should consume plenty of starchy foods, at least 5 portions of fruit and vegetables a day, some protein rich foods, some milk and dairy, and

just a little saturated fat, salt and sugar [52]. These guidelines are displayed pictorially as the Eatwell Guide [53].

The current diets of the majority of the UK population do not meet dietary recommendations [7]. Mean saturated fat, non-milk extrinsic sugar[b], and salt intakes are above the recommended level while mean fruit and vegetable, fibre, and fish and oily fish intakes are below recommendations [7]. The high prevalence of overweight and obesity in the UK indicates that there is also an excess consumption of calories relative to energy expenditure. Low fruit intake, low vegetable intake, and high processed meat intake are the top three dietary risks when burden is measured in deaths or DALYs [2]. The proportion of disease burden due to dietary risks is similar across levels of deprivation in England [2].

Contributions to nutrient intakes from different food categories

Examining the contributions of food categories to nutrient intake may provide an indication of specific foods to target with HRFTS. If one food was to blame for inadequate nutrient intake, the choice of food to target with a HRFTS intervention would be obvious. This is not the case in the UK. Table 1 displays the average contribution of various food groups to macronutrient and salt intake in UK adults (18-64yrs). Non-milk extrinsic sugars, saturated fat, and salt are nutrients whose consumption should be reduced, while fibre consumption

[b] In 2015, the Scientific Advisory Committee on Nutrition recommended that the definition of 'free sugars' be used in place of 'non-milk extrinsic sugars' [240]. Where the older term is used, it is for consistency with terminology in referenced literature.

should be increased [7]. The majority of food categories contribute to intakes of multiple nutrients, both nutrients that should be increased and nutrients that should be decreased given current population intakes. Cereals and cereal products contribute a substantial proportion of average daily intakes for all “big 8” nutrients (energy, protein, carbohydrate, sugars, fat, saturated fat, sodium and dietary fibre). Even though meat and meat products are the biggest contributors to saturated fat, and sodium intake (nutrients that should be reduced based on current dietary guidelines), they are also the biggest contributor to protein intake. Even when the data are further sub-categorised, the majority of foods account for intakes of both positive and negative nutrients. Beverages are the exception; they account for 10% of total energy intake, but provide 35% of non-milk extrinsic sugars and negligible contributions to other nutrient intakes.

There are differences in food purchasing and dietary intakes between different demographic and socioeconomic groups [7,54,55]. Differential impacts of HRFTS could arise simply due to different levels of consumption in different population sub-groups. For example, soft drinks account for 5% of energy intake in 11-18 year olds but only 1% for those aged 65+. All else being equal, a SSB tax could reduce SSB consumption with effects on obesity in younger age groups but is less likely to influence obesity prevalence in older adults; similar results are observed in modelling studies [47,56].

There is limited potential to improve diet in the UK by changing the consumption of individual foods or nutrients. Low fruit and vegetable consumption are two of the biggest contributors to disease burden in the UK, but still account for less than half of the disease

burden that results from dietary risk factors [2]. Ideally, a HRFTS should change consumption across a broad range of foods and nutrients – including increasing fruit and vegetable consumption – to have maximal health impact.

Targets of health-related food taxes and subsidies

Previous studies reveal a variety of types of HRFTS that could be applied to improve health in the UK. The first step is to decide which foods will be subjected to price changes. HRFTS interventions either classify the foods targeted based on constituents of foods (single nutrients, nutrient profile models) or on food categories, though there are a few exceptions. Multiple methods may be used within a single HRFTS policy.

Single nutrient-based

Single nutrient-based HRFTS classify foods based on the amount of a particular nutrient that products contain. This method assumes that changing the price of foods based on the content of a particular nutrient will result in healthier purchases overall. The Danish saturated fat tax was an example of a nutrient based tax; a 16DKK tax per kilo of saturated fat was levied on products with a saturated fat content greater than 2.3g/100g [57]. The Danish saturated fat tax is the only tax of this kind that has been implemented, but taxes based on energy density, sugar and salt content and a fibre subsidy have been suggested [40,58–60].

Table 1: The percentage contribution of food groups to the nutrient intake of UK adults

Table adapted from additional data provided in the National Diet and Nutrition Survey Results (2008/2009-2011/2012) release [7]	Energy	Protein	Carbohydrate	Added sugars	Fibre	Fat	Saturated fat	Sodium
Cereals and cereal products	31	23	45	21	39	19	20	31
Milk and milk products	9	13	5	6	1	13	22	9
Eggs and egg dishes	2	3	0	0	0	4	3	2
Fat spreads	3	-	-	-	-	-	-	-
Meat and meat products	17	38	6	2	11	24	24	27
Fish and fish dishes	3	8	1	0	1	5	3	5
Vegetables and potatoes	11	8	14	2	31	10	6	8
Salad and other raw vegetables	1	1	1	-	4	1	-	1
Vegetables (not raw) including vegetable dishes	4	4	4	2	16	3	2	6
Other potatoes, potato salads and dishes	2	1	4	-	5	1	1	1
Savoury snacks	2	1	-	-	-	-	-	-
Nuts and seeds	1	1	0	0	1	2	1	0
Fruit	3	1	6	1	9	1	0	1
Sugar, preserves and confectionery	5	1	7	26	1	3	5	1
Sugars inc. table sugar, preserves and sweet spreads	2	-	5	17	-	0	0	-
Non-alcoholic beverages	4	1	8	25	0	0	1	1
Alcoholic beverages	6	1	3	10	0	0	0	1
Miscellaneous	3	2	3	5	3	5	3	9
Dry weight beverages	0	0	0	1	0	0	0	0
Soup, manufactured/retail and homemade	1	1	1	1	2	1	1	3
Savoury sauces, pickles, gravies, condiments	2	1	1	2	1	4	2	6
Values represent the average percentage of nutrient intake that is obtained from each food group. Red indicates nutrients to discourage, green indicates nutrients to encourage based on current consumption levels, - indicates a contribution <0.5%)								

Single nutrient taxes include those that apply price changes incrementally, such as the Danish saturated fat tax. Alternatively, single nutrient based interventions could change prices at nutrient levels above or below a specific cut-off value. Incremental price changes ensure that the price changes are proportional to the nutrient content of a product, but are administratively more complex.

The objective measurement of the nutritional content of foods is an advantageous feature of single nutrient based measures. The alternative is subjective classification of foods which is problematic as the health impacts of specific foods can rarely be established. In the EU, nutrition labelling is mandatory on pre-packaged foods; manufacturers are instructed to provide energy, fat, saturated fat, carbohydrate, sugars, protein, and salt information [61]. The use of nutrient based HRFTS may be less appropriate in settings where this level of nutritional information is not already available.

The Danish saturated fat tax provides evidence that single nutrient approaches can have positive health impacts [62]. Other modelling studies also show positive health impacts from single nutrient based interventions [40,63]. However, single nutrient based measures are criticised for not adequately accounting for the complexity of diets. Modelling studies demonstrate that single-nutrient taxes may result in poor health outcomes if consumption changes lead to less healthy diets overall, such as increased salt consumption in response to a saturated fat tax [64]. Multiple single nutrient taxes may be used in combination to try to avoid unintended consequences. For example, the 3.57DKK/kg tax on added sugar that was due to be introduced in Denmark in parallel to the saturated fat tax [65].

Nutrient profile based

An alternative to single nutrient based interventions is to classify foods based on several nutrients simultaneously. Nutrient profiling is the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health [66]. Nutrient profile models generally attempt to reconcile the positive and negative characteristics of foods into a single score or classification.

Different nutrient profile models include different nutrients, and the relative weighting that is assigned to different components of a nutrient profile model can vary considerably. The availability of existing nutrient profile models may ease the development of a nutrient profile based HRFTS. Nutrient profile models have been used for a range of health promotion interventions. For example, the Ofcom model is used to determine what foods can be advertised to children in the UK and the Choices nutrient profile model is used to identify foods that can carry a front of pack health symbol in the Netherlands [67,68].

Nutrient profile models have been suggested as a method of classifying foods for HRFTS. A randomised controlled trial in New Zealand discounted products that met the criteria for the Heart Foundation Tick program [69] and UK based modelling studies have used the Ofcom model and similar nutrient profile models to determine which products should be subject to a tax [37,64]. As with single nutrient based HRFTS, nutrient profile based measures have the advantage that nutrient content can be objectively measured.

The application of nutrient profile based HRFTS is not without its problems. The choice of nutrient profile model is difficult as there is no gold standard against which to measure their adequacy, though comparisons of some nutrient profile models with nutritionists' assessments show good agreement [70]. This is particularly problematic considering that different nutrient profile models can vary substantially in the proportion of foods classified as being healthy [71,72]. For example, depending on which nutrient profile model was used, the proportion of food advertisements allowed to be shown to children in the UK ranged from 2.1% (0.4%, 3.7%) to 47.4% (42.1%, 52.6%) [71]. Where nutrient profile models have been used for (other) regulatory purposes, it may be easier to select a nutrient profile model for HRFTS.

Category based

In contrast to classifying foods based on their constituents, foods can also be classified by grouping similar products. Category based HRFTS classify foods and apply price changes according to food category rather than nutritional composition. Category based HRFTS assume that foods in the same category have similar health impacts. Where nutritional information is not readily available, category-based classification of products may be the only way to implement HRFTS. Category based HRFTS are also suited to instances where the health effects of entire categories has been studied, such as the positive health impacts of fruit and vegetable consumption [73,74] or the negative health impact of SSBs [75–79].

Category based allocation could be based on similar nutritional content or existing categorisation systems used for trade or other purposes (e.g. World Trade Organisation Harmonised Commodity Coding System, Codex Alimentarius [80]). However, existing categorisation systems may be incomplete for HRFTS or inadequate at differentiating between healthier and less healthy products in categories of interest.

SSB taxes are arguably the category-based HRFTS that has received the most attention. SSB taxes have gained popularity in HRFTS discourse due to the ease of defining target products, the growing evidence base indicating the association of SSB consumption with a multitude of negative outcomes [75–79] and the availability of healthier substitutes. SSB taxes have been implemented in a number of countries including Mexico [81], Hungary and Finland [82]. A SSB tax is due to be introduced in the UK in 2018. Many studies highlight the potential positive health impacts of SSB taxes [47,56,83–85], and evaluation of the recently implemented Mexican SSB tax has shown reductions in purchases of SSBs [17].

Fruit and vegetable subsidies are another category-based HRFTS intervention that has received attention in the academic literature [86]. Fruit and vegetable subsidies are effectively an extension of voucher schemes that provide free or reduced price fruits and vegetables for certain groups of people, these schemes are in place in several countries including the UK [86,87]. Recent reviews suggest that fruit and vegetable subsidies may be effective in increasing consumption but noted that the possible impact on overall calorie intake is unclear [20,24]. However, evidence from other interventions suggests that increases in fruit and vegetable intake are unlikely to lead to weight gain [88].

Choice of method of application of HRFTS

In addition to choosing the foods that will be targeted by a HRFTS, a decision also needs to be made with respect to how price changes will be applied. HRFTS may be implemented through a variety of different mechanisms. The magnitude of the price changes may be high or low; and the implementation can be based on incremental reforms of an existing pricing structure or completely novel implementation. The WHO Regional Office for Europe identifies three types of tax mechanism for the implementation of HRFTS policy:

- excise taxes that charge a set amount on a given quantity of product (e.g. £ per kg);
- ad-valorem taxes that are levied on the sale of goods and determined based on the gross value or costs (i.e. % increase in price);
- value-added taxes that tax each stage of production that adds value to a product with reimbursement of taxes paid to previous suppliers in the chain [38].

In addition to the mechanisms identified by the WHO Regional Office for Europe, HRFTS could also be applied through less traditional approaches including minimum unit pricing and industry levies. Unit pricing approaches set a minimum or maximum unit price for which a particular good can be sold. Minimum unit pricing is advocated as a method to reduce alcohol consumption as it has the greatest influence on excessive drinkers [89], but the approach has yet to be applied to foods. Industry levies require manufacturers to pay a set amount to produce particular products, typically based on the total amount of a particular good that is produced. The UK SSB tax is set to be applied as an industry levy

[19]. There has been less discussion about the method of applying subsidy interventions, though some have suggested that mechanisms similar to those of value-added taxation could be used to introduce negative rates of tax [90]. Other subsidy interventions have focused on the removal of existing taxes rather than novel subsidies per se [69].

Different methods of implementation have different advantages and disadvantages. There may be different impacts based on the application of a HRFTS due to incentives for reformulation, ease of substitution to different (but nutritionally similar) goods, and the extent to which the HRFTS leads to changes in consumer prices. For example, the application of a UK SSB tax as an industry levy means that manufacturers and importers are free to choose if and how the cost of the levy changes the (consumer) cost of SSBs compared to other products in the manufacturer's portfolio.

Advantages and disadvantages may also stem from considerations beyond public health such as the ease of administration of HRFTS and cost of implementation. For example, the requirement for production efficiency is a key reason for the use of value-added taxes rather than taxes that burden intermediate transactions [91] and the administrative burden is likely to be greater if taxes are levied on ingredients [82]. In addition, some methods of implementation may be less stable over time. For example, excise duties have to be regularly adjusted for inflation otherwise their real value will erode over time [92].

The differential impact of HRFTS can also be influenced by the mechanism by which the HRFTS is applied. Ad valorem taxes result in greater price increases on the products that

are already more expensive as they are based on the monetary value of foods. This leads to greater price increases for households that purchase more expensive versions of similar products than for households purchasing cheaper versions of the product. In contrast, excise taxes apply a fixed price increase regardless of product value and therefore lead to proportionally greater price increases of cheaper versions of targeted foods. Therefore, excise taxes are more likely to be regressive than ad valorem taxes.

Existing mechanisms for implementing food price changes in the UK

Value added tax (VAT) and excise duties are two mechanisms that are currently used to change the price of goods, and that could be used to implement HRFTS.

Value added tax

VAT is applied to the majority of goods in the UK, including many food items. Internationally, VATs are a common intervention to generate government revenue but there is diversity in both the rates of tax and the items on which it is applied internationally [93]. VAT was introduced in the UK in the 1970s [94]. The products that VAT is applied to was nominally based on the distinction between necessities and luxury goods, but some of the distinctions made in the original implementation of VAT are now outdated. For example, VAT is levied on chocolate covered biscuits but not on cakes [95].

In the UK, VAT accounts for a fifth of all revenue generated through taxation [93]. VAT rates for different goods are set at a national level, although there is also EU legislation that

governs the application of VAT across member states [96]. Food products can be judged to be standard rated (20% VAT applied) or zero rated (0% VAT applied) and the tax rate is determined based on a product category description. Zero-rating is disallowed at the EU level, but some member states negotiated exemptions when VAT was initially implemented with few changes since. Most foods are zero-rated under the current VAT scheme. This includes healthy foods such as fruits and vegetables, and foods which are mostly unhealthy such as cakes and dairy desserts. The cost of zero-rating of food items was estimated at £16,800 million for the 2014/15 tax year and is projected to increase [97]. Current category definitions for VAT were largely set at the implementation of VAT in the 1970s with minor amendments since, primarily to account for new food products. A selection of foods and their current VAT status, based on the UK VAT notice [95], is provided in Table 2 for illustrative purposes.

Table 2: Value added tax classifications of selected foods

Standard rated (i.e. 20% VAT applied)	Zero-rated (i.e. no VAT applied)
Ice-cream Juice and juice concentrates Cereal bars Chocolate covered biscuits Carbonated beverages	Fresh fruits Fresh vegetables Raw meat and fish Bread Cakes Chocolate chip biscuits Tea and coffee Sweeteners Ready meals

Excise duties

Excise duties are applied to a range of goods in the UK. Of relevance to health, excise duties are levied on tobacco products and alcoholic drinks [98,99]. The combined revenue from duties on tobacco and alcohol is approximately £19.8 billion per annum [99]. In general, higher excise duties are paid on alcoholic drinks with higher levels of alcohol, though the type of drink also matters - there are different rates for beer, cider, wine, and spirits [98].

Excise duties are not currently applied to any foods or non-alcoholic drinks in the UK. Internationally, HRFTS have been applied as excise duties – the Mexican and French SSB taxes, the Hungarian public health tax, and the (repealed) Danish saturated fat tax are all examples of excise based HRFTS [100].

HRFTS beyond health

Whilst this thesis primarily focuses on the public health impacts of HRFTS, below I discuss some of the factors that may influence the implementation and effectiveness of HRFTS beyond health. Often, evidence on political acceptability, government revenue, wider economic impacts, and environmental impact is lacking. However, I have tried to consider evidence on these other aspects where possible in this thesis.

Political acceptability

Whilst the public health impetus for implementing HRFTS is to improve diets, they need to be implemented to have a health impact. In a Delphi study, more frequent promotions of

healthy food items, lower VAT rates for healthy food items, offering the healthier option of comparable products for a lower price, and price cuts on healthy food options were ranked as the top monetary incentives to stimulate healthy eating [101]. The study included experts from a range of sectors, including government and the food industry. It demonstrates that interventions that reduce prices are likely to be more popular than those that increase prices. It is also important to examine the public health impacts of (currently) unpopular interventions. Interventions with the potential to have large positive impacts may be missed if only popular interventions are examined. Growing evidence on the positive health impacts could eventually sway public opinion. For example, four US cities voted in favour of SSB tax measures in the most recent election [102]. In addition, there may be methods to influence public opinion without changing the proposed intervention. For example, ring-fencing revenue for health-related expenditure may increase public support for HRFTS [103].

Government revenue

HRFTS have impacts on government revenue. The generation of revenue, whether for health promotion or other activities, has been an explicit aim of a number of HRFTS that have been implemented to date [104]. Examining revenue impacts of HRFTS may be especially important in the current climate where government health care expenditure has experienced a decline [105]. Even small taxes on widely consumed foods may raise substantial revenues which could then be used for health promotion (even if they are unlikely to change food consumption) [104] and have greater impact on improving health

than a HRFTS alone. On the other hand, subsidy interventions require considerable financial resources to implement and may or may not be a cost-effective way to use tax money.

Revenue effects are important as HRFTS that have unexpected revenue burdens may not be economically sustainable in the long term. For example, the Danish saturated fat tax was repealed partly due to administration costs and claimed losses from cross-border trade despite overall increases in revenue [65]. On the other hand, HRFTS that result in decreases in government revenue may still be viable if they are cost-effective and popular enough to counteract industry pressure. The administrative cost of commodity taxes are generally low – they rarely exceed 1% of the revenue yield [92].

Wider economic impacts

HRFTS not only have impacts on the money raised by government, but also on the wider economy. For example, a key counterargument to HRFTS raised by the food industry is that HRFTS would result in job losses. One report estimates that the sugar sweetened beverage levy due to be introduced in the UK could result in more than 4,000 job losses in the SSB industry [106]. However, this report has been criticised for failing to account for potential increases in jobs in related sectors such as the milk industry [107]. Other studies have found that the implementation of HRFTS (specifically a SSB tax) may result in increases in jobs [108]. There is limited evidence of job losses from European countries that have actually

implemented HRFTS [82]. Job losses are not only an economic concern as unemployment is associated with poorer mental and physical health and wellbeing [109].

Environmental impact

The rationale for implementing HRFTS also has much in common with arguments over using fiscal interventions to reduce environmental impacts: both can be justified by arguing that the policy internalises negative externalities and corrects traditional market failures. Evidence from modelling studies indicates that carbon taxes on foods may simultaneously improve both health and environmental outcomes [110,111]. Changes in the food system that result from HRFTS that consider environmental impact may have wider health benefits beyond immediate nutritional impacts.

HRFTS options for the UK

So far, I have discussed general evidence on targets and methods of application of HRFTS, and UK data on dietary disease burden, population diets, and food prices. As demonstrated in earlier sections, UK diets are unhealthy across a broad range of food categories and nutrients. Currently, the UK does not implement taxes based on the healthiness of foods, though this is set to change with the introduction of the SSB levy in 2018. This section brings together these elements to argue that reforming VAT to reflect the healthiness of foods and fruit and vegetable subsidies are HRFTS that are likely to have the maximum public

health impact, and that could be implemented within the current pricing structures in the UK.

VAT reform

VAT reform is a possible option for HRFTS policy in the UK as the current VAT system does not align with health promotion objectives [112]. Zero-rating of unhealthy foods exerts a double cost on government revenue, first through the direct loss of revenue from zero-rating and then through the excess expenditure on healthcare system resulting from the overconsumption of (unhealthy) zero-rated food and beverages.

VAT could be applied based on the healthiness of foods, rather than the seemingly haphazard method of distinguishing products that is currently adopted. This would require a method to distinguish between healthy and less healthy foods. The use of the OfCom nutrient profiling model to regulate the advertising of foods to children provides a precedent for using the OfCom model to distinguish between healthy and less healthy foods for a HRFTS. So far, modelling evidence on the likely impact of such reforms appears broadly positive [37,64].

Fruit and vegetable subsidies

Fruit and vegetable subsidies could be beneficial in the UK as low fruit and vegetable intakes are the dietary risk factors with the greatest impact on mortality and disease burden [2]. Fruit and vegetable subsidies may have the potential to reduce some health inequalities; purchases are socially patterned and this has been argued to be partly due to

cost differences [28,54,113]. Fruit and vegetable subsidies would cost money but could be combined with revenue raising measures. The price lowering nature of fruit and vegetable subsidies may make them more politically acceptable than taxes on commonly consumed foods, and combined tax/subsidy interventions may be more popular than tax interventions alone. The only UK based study to examine the health impacts of fruit and vegetable subsidies (all in combination with a revenue raising measure) concludes that they would have a positive health impact [37].

Excise duties

I have argued that HRFTS that target a broad range of foods are likely to have better health impacts than interventions that focus on single foods or nutrients. Excise duties are well suited to applying price changes to specific foods, but are unlikely to be appropriate for changing prices across a broad range of foods. Excise duties require more frequent reassessment to adjust for inflation to ensure their real value is maintained and are more likely to have regressive impacts than value added tax approaches.

Current evidence for the impact of HRFTS in the UK

Two UK based studies modelled the health impact of HRFTS that cover a broad range of foods, including taxes on dietary sources of saturated fats, a tax on less healthy foods as defined by nutrient profile models, and taxes on less healthy foods combined with subsidies on fruits and vegetables [37,64]. Both studies find mixed impacts – some

scenarios have positive health impacts and others have negative health impacts. With respect to the differential impact of HRFTS, Nnoaham et al found that all the scenarios they examined were economically regressive [37]. No other assessments of the differential impacts of HRFTS that target a broad range of foods are currently available for the UK. This is problematic in the context of the magnitude of existing health inequalities in the UK, government commitments to reducing inequalities, and the general lack of evidence on the differential impacts of HRFTS. Another limitation of the existing evidence is that the results of both studies were based on data gathered between 1988 and 2000; updates to the evidence base are needed given that food prices, and food consumption, have experienced changes since [26,51,114].

Conclusion

The public health imperative for introducing HRFTS is to improve population diets by increasing consumption of some foods and reducing the consumption of others. The choice of foods to target with an intervention should be based on data on the dietary needs of the population in question. The choice of HRFTS that is implemented to meet these objectives should consider existing evidence on different types of HRFTS intervention, current influences on prices, and a variety of external factors such as the likely acceptability of a HRFTS. UK diets are unhealthy across a range of foods and nutrients and this influences the HRFTS that may be effective. I argue that HRFTS that reform VAT to better reflect the

healthiness of foods and fruit and vegetable subsidies merit consideration in the UK. Comparative assessments of the likely impacts of such policies are needed to establish the magnitude of health impacts, especially with respect to the differential impact of interventions.

Part A – Experimental

So far in this thesis, I have introduced the rationale for HRFTS and argued that more evidence is needed to establish the impacts of HRFTS in the UK, particularly with respect to the differential impacts of HRFTS. As outlined in the introduction, we can estimate the possible impact of HRFTS using natural experiments, experimental studies, and modelling studies. This part of the thesis focuses on the experimental approach. The following chapter (Chapter 3) systematically reviews existing literature on the differential impacts of HRFTS by personal characteristics. Using the findings from the systematic review, I then go on to develop a UK Virtual Supermarket (Chapter 4) and examine the feasibility of using this software for testing the differential impact of HRFTS in the UK (Chapter 5).

Chapter 3: Differential impacts of HRFTS by personal characteristics – a systematic review of experimental studies

This chapter presents a systematic review of experimental studies that examine the differential impact of food price changes by personal characteristics and has been published as a standalone article [115]. The systematic review finds evidence of HRFTS having a differential impact depending on the personal characteristics of study participants, however the extent and nature of these differences remains unclear. The limited evidence base suggests ample opportunity to extend experimental work in this area.

Introduction

The possibility for HRFTS to have differential impacts has been noted in multiple studies, but numeric estimates of differential impacts differ, especially with respect to the regressiveness of different interventions [20]. The uncertainty around the differential impact of HRFTS is apparent across multiple study designs, and this is reflected in the conclusions of reviews of modelling studies [22], experimental studies [25] and natural experiments [116]. More needs to be understood about these potential differential health impacts in order to balance concerns with respect to the regressive economic nature of fiscal measures to improve population diets [23,116].

Experimental studies in this field involve subjecting groups of participants to a proposed HRFTS in a controlled setting and measuring the difference in real or hypothetical purchases between groups that are exposed and not exposed to the HRFTS. A merit of experimental studies compared to other study designs is that the controlled nature of experimental settings can help to disentangle the effect of the pricing intervention from confounders. For example, price elasticities for food groups observed naturally (using panel data on natural price fluctuations over time) are subject to non-measured influences on consumption patterns over time, such as upwards trends in meat consumption associated with increases in gross domestic product (GDP) [117]. Price changes in natural experiments may be a result of the market reacting to changes in demand, rather than the influence on demand that is the assumed relationship. In addition, experimental studies avoid the problems of extrapolation (typically of responses under small irregular fluctuations to a larger permanent price change) inherent in modelling studies.

Experimental studies can also inform the policy making process by providing much needed evidence with respect to the potential benefits (e.g. expected revenue gains) and harms (e.g. unintended purchasing shifts) of a suggested pricing intervention without the need for existing price elasticity data. This means that experimental studies may be especially informative when the proposed scope of the HRFTS is outside traditional food groups for which price elasticity data are collected; for example, in the case of nutrient profile based HRFTS often considered by public health researchers.

Finally, experimental studies have the potential to determine differential effects of food price changes if they collect individual level data and can therefore compare the responses of different groups, and examine the interactions between multiple personal characteristics.

Whilst experimental studies have their strengths, their limitations mean they cannot be used in isolation to determine the effects of pricing interventions. For example, the population recruited for an experimental study may not be representative of the population in which a possible pricing intervention is planned, the setting may not reflect the usual setting in which purchasing decisions are made, and therefore the purchase changes observed may not be those that would be observed in a real-life context. Experimental studies are typically of limited duration and therefore may not be able to provide evidence of the long-term purchasing shifts a price change could induce. Finally, experimental studies are often based on non-real purchases where participants do not consume the foods they buy in the experimental environment, so even estimates of short-term changes in purchases may be biased. Despite these and other limitations, their strengths offer the opportunity to use the evidence gathered in experimental research to complement that from other sources. To date there has been no systematic review of experimental studies published in the literature that specifically addresses how the effects of HRFTS vary by subgroups defined by personal characteristics (e.g. income; BMI). Although Epstein and colleagues [25] conducted a targeted review of the experimental literature examining the extent to which price changes influenced purchases, the focus of

the review was not on potential moderators of price sensitivity, and therefore numeric estimates of the effects of moderators were not presented.

This review set out to examine how personal characteristics moderate purchases in response to price changes, utilising price elasticity measures. Price elasticity is defined as change in demand for a unit change in price and is a common metric that can be used to examine differential effects across a heterogeneous selection of included studies. Recent systematic reviews of other study designs have addressed the issue of differential effects of food price changes and limited consistency in the results has lead review authors to conclude that the patterns based on personal characteristics are not consistent [20,22,116]. For example, Green et al note that there are differences in price elasticities by income which vary by food category [116] and Eyles et al find differences across studies with respect to the degree to which pricing policies are regressive [22]. I focus exclusively on experimental studies and add a synthesised, numeric interpretation of the available experimental evidence base to the conclusions drawn by existing reviews of other study designs.

Research questions

The primary research question I address is:

- How do personal characteristics (such as sex, socioeconomic status, income, and impulsivity) moderate changes in purchases of targeted foods in response to food/beverage price changes in experimental settings?

In this context, I have defined personal characteristics as modifiable and un-modifiable participant features that may influence the response of individuals to a change in food and beverage prices. This includes factors such as age, sex, personality measurements (e.g. impulsivity as measured by the stop-signal reaction task), socio-economic status, income and education. I focus on personal characteristics rather than individual characteristics due to the expectation that included studies may look at households' rather than individuals' purchases. This means that studies which determined socio-economic status at the household level, rather than at the individual level, would not have been excluded from our analysis; i.e. I could include studies where the participant's socio-economic status was defined on the basis of the occupation of their partner. HRFTS may also incorporate non-pricing elements such as coupons, but here I have excluded coupon-based interventions as these may operate on other decision making mechanisms and behavioural frameworks besides those involving price [118,119].

In addition to the primary research question, I also aimed to address the following secondary research questions:

- How do personal characteristics (see definition above) moderate changes in purchases of *non-targeted* foods in response to food/beverage price changes in experimental settings?
- How do the following factors influence differential responses to food/beverage pricing intervention by personal characteristic:

- Magnitude of the experimental price change (i.e. do larger price changes have an effect that is different to smaller price changes?)
- Scope of pricing target (i.e. do interventions that target a broad range of products have a different effect than interventions targeting a narrow range of products?)
- Direction of price change (i.e. do individuals react to price increases and decreases in an equivalent fashion or does the direction of the price change have an independent effect?)
- Information about price change (i.e. does the method by which individuals are informed about the price change result in different responses?)

- How will changes in food price affect the total price of the diet for different groups defined by socioeconomic or other personal characteristics?

Methods

Identification of relevant studies

I systematically reviewed the experimental literature according to a pre-defined protocol which was registered with the PROSPERO International Prospective Register of Systematic Reviews (registration no. CRD42014009705). The protocol is available on the PROSPERO

website at http://www.crd.york.ac.uk/PROSPEROFILES/9705_PROTOCOL_20140414.pdf (accessed September 2014) and is attached in Appendix (i).

PubMed, EMBASE, Web of Science, PsychInfo, and EconLit were searched to identify potentially relevant studies using equivalent search strategies (see Table 3). A broad selection of food related search terms was chosen and the search strategy itself did not include any mention of personal characteristics as I wanted the search to pick up any experimental literature that could help answer the research question. The searches and title/abstract screening were initially conducted in March 2014 and then updated in August 2014 as I was aware that at least one relevant study had been published since the initial searches were carried out.

Table 3: PubMed search strategy

The same search terms were used in all databases, with variations in notation made to ensure searches were equivalent.	
1	food OR foods OR snack OR snacks OR beverage* OR "soft drink" OR soda OR "carbonated drink"
2	fruit* OR vegetable* OR cereal* OR candy OR sweets OR confectionary OR chocolate* OR meat OR dairy
3	sugar OR sugars OR sugary OR "energy dense" OR "energy density" OR fat OR fats OR saturates OR "saturated fat" OR salt OR sodium OR fibre OR fiber
4	1 OR 2 OR 3
5	tax OR taxation OR taxes OR taxed OR subsidy OR subsidies OR price OR prices OR discount OR discounts
6	experiment OR experimental OR trial OR test OR supermarket* OR shop OR shops OR store OR stores OR controlled OR participant* OR intervention OR interventions OR random OR randomised OR randomized
7	4 AND 5 AND 6

All search hits were imported into an EndNote X7 library and titles and abstracts were screened for relevance. A 10% sample of the search hits was cross-checked for relevance by a second researcher. Full text articles were retrieved where the title and abstract indicated that the article was potentially relevant. In addition, the reference lists of included studies and three relevant recent reviews [23–25] were hand searched to identify additional articles of relevance.

An article was included if it was a controlled experimental study that reported results stratified by socioeconomic status or other personal characteristics of study participants, examined the effect of price change(s) on food or beverage purchases, collected individual level data to determine the effect (i.e. excluding single site studies such as vending or cafeteria studies where the outcome was total sales of targeted food), and that had either the price elasticity or changes in purchases or consumption of targeted or non-targeted foods as an outcome measure.

An article was excluded if it examined price changes of alcoholic drinks in isolation, was a review or commentary article where no original data were presented, did not test pricing interventions in isolation from other interventions (e.g. pricing inventions combined with tailored nutrition education), examined exclusively children's (<18 years of age) purchases, was published prior to January 1980, or was not available in English.

Data extraction and analysis

For numeric data, data reported in the included studies were converted to own price elasticity values for the target food. Accompanied 95% confidence intervals were obtained using either the reported confidence intervals for change in purchases or by conducting a Monte Carlo analysis using reported standard errors around the purchasing estimates. To conduct the Monte Carlo analysis, I set up an Excel sheet to randomly select values from within the distribution of baseline and intervention purchases; this enabled the creation of 10,000 possible price elasticities assuming independence between the baseline and intervention purchases (a conservative assumption). The mean and 95th percentiles of these price elasticities gave the study price elasticity estimate and associated 95% confidence intervals, respectively. Alternatively, where changes in purchases of the target food were reported as number of calories from the target foods, price elasticity for a kilocalorie of the target food was calculated instead. In situations where an effect by a personal characteristic was reported but complete data were not given, study authors were contacted and asked to provide these data. I assumed that purchases in the control and intervention groups were normally distributed and independent of each other. This method means that the confidence intervals represent a conservative estimate and may be wider than the confidence intervals that would actually be observed. A meta-analysis was not undertaken as it was deemed inappropriate to combine price elasticities from differently defined personal characteristic groupings, countries, experimental settings, purchasing tasks and/or food groups. Studies were grouped according to the type of

personal characteristics that were analysed: non-modifiable (age, sex), individual (personality (e.g. impulsivity, dietary restraint), BMI) and societal (income, socio-economic status, education). Where applicable, the results of fully adjusted models are the results reported in the data extraction table. Where relevant data were reported, cross-price elasticities for non-target foods were derived in the same way as own-price elasticities. A narrative summary of the available evidence on the secondary research questions is presented in the results section.

Quality of included studies

The quality of included studies in relation to the primary research question was assessed according to the Cochrane Risk of Bias tool [120] and is tabulated in the results section. Nine questions across five domains of bias were used to assess study quality. Information from included studies was supplemented by information from study authors where answers were unclear from the manuscript; all study authors were contacted and additional information was obtained for six of the studies.

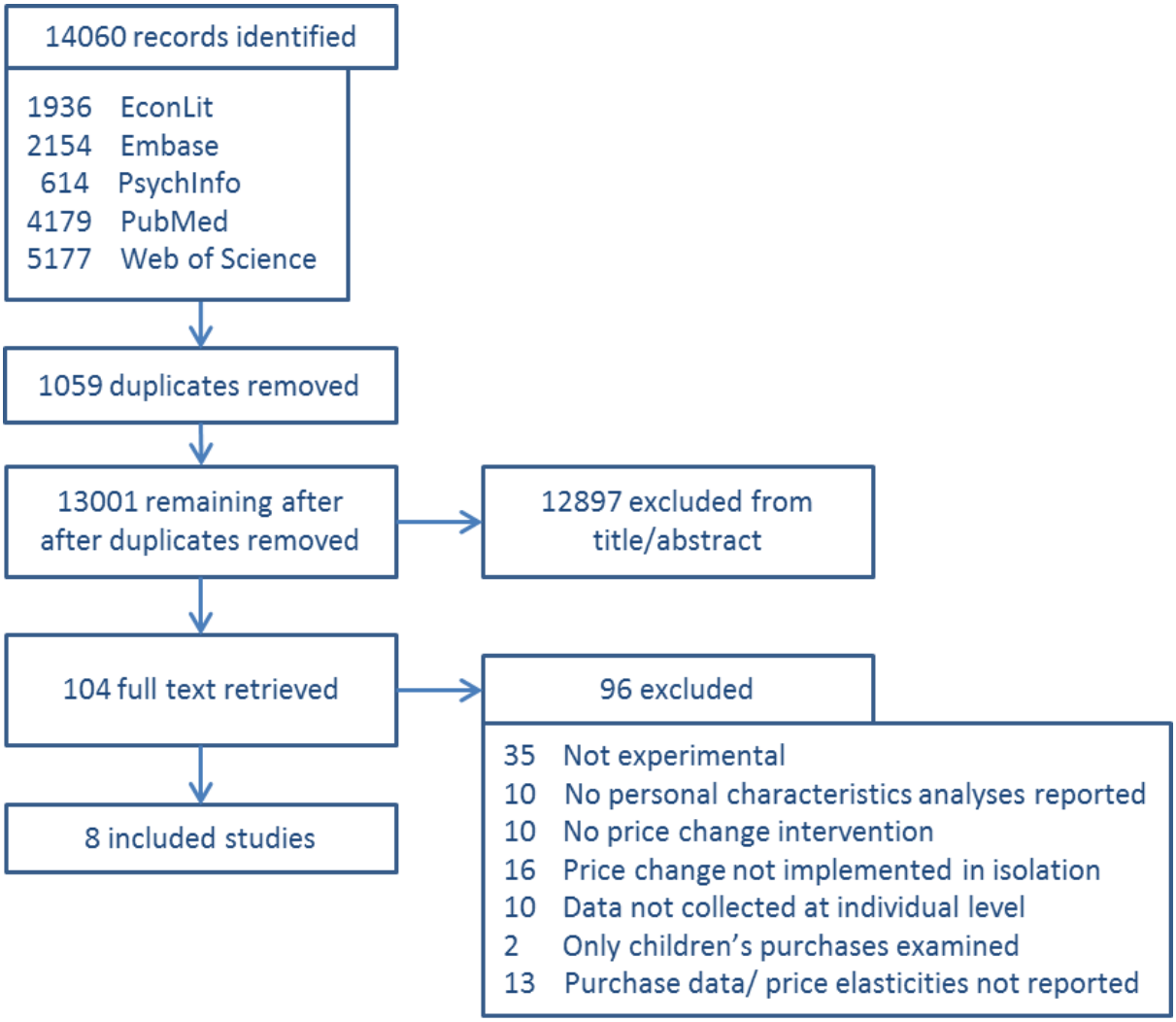
Results

Description of included studies

In total, 13,001 unique references were identified through the search strategy. From these, a total of eight articles were deemed eligible for inclusion in the present review. A PRISMA

2009 flow diagram is presented in Figure 2 with reasons for exclusion detailed. No additional studies were identified through hand searches of the reference lists of included articles or relevant reviews.

Figure 2: PRISMA flow diagram of included studies



A summary of the included studies is given in Table 4. Six studies examined income [35,59,121–124], three examined BMI [59,122,124], two examined ethnicity/minority status [121,123]. Education [121], sleep deprivation [125], age [124], hunger [124],

impulsivity [126], sex [123], price perception [123] and habit strength [123] were each examined in one of the included studies.

In one of the included studies, participants made purchases in a real-life supermarket [121], three studies utilised an experimental (laboratory) store [122,124,125], and four studies utilised computer based stores (three used an analogue online shop [35,59,126] and one used a virtual supermarket [123]). Three studies were based in the Netherlands [59,123,126], two in the USA [122,124], and one in New Zealand [121], France [35] and Sweden [125].

A price change was defined based on foods' energy content in five of the studies [59,122,124–126], a nutrient profile model in two studies [35,121] and fruits and vegetable subsidies were tested in two studies [35,123]. One of these studies [35] looked at both a fruit and vegetable subsidy and a nutrient profiling model based tax. Of the studies that had an energy based price change, four changed prices based on the number of calories per gram [59,122,125,126] and one changed prices based on the calorie for nutrient index [124]. The magnitude of the price changes examined ranged from 12.5% [121] to 50% [59,126]. The baseline/ control prices in all eight studies were based on actual prices of products in a comparable real world setting. Five studies examined a combination of price increases and decreases [35,122,124–126], two examined price decreases only [121,123], and one examined price increases only [59].

Although all included studies had an experimental design, there was considerable variation in study procedures, the primary outcome measure recorded by the researchers, and the analytic method used to present the results. Broadly, six studies included one experimental session/task [35,59,122–124,126] (often with multiple tasks in the single session [35,122,124,126]), one study required participants to visit the experimental laboratory on two occasions [125], and the final study tracked actual participant purchases over 50 weeks (12 baseline, 24 intervention, 24 follow-up) [121]. Sample size ranged from 16 [125] to 1104 [121]; four of the studies had sample sizes less than 100.

Primary outcome: price elasticities for target foods

For six studies, it was possible to convert reported results to point price elasticities for the target food, by personal characteristics. Overall, it was possible to calculate 18 sets of own-price elasticity estimates (i.e. calculations of price elasticity by personal characteristic); these are displayed in Table 5.

Only two studies [125,126] provided enough data to calculate price elasticities for all the personal characteristics examined. Four studies provided partial data and the authors were contacted for further details [35,59,121,122]. Two studies [123,124] only reported that there were no significant interactions with modifiers/interaction terms. The confidence intervals for price elasticity estimates in two studies [35,121] could be obtained using the confidence intervals for the change in purchases between the baseline and intervention

phases. For the remaining studies, I conducted a Monte Carlo analysis to obtain confidence intervals around the price elasticity estimates.

The own-price elasticities calculated span six personal characteristics: impulsivity, ethnicity, obesity, sleep deprivation, income, and education. Apart from for income and obesity, the price elasticities calculated for a personal characteristic relate to the findings from a single study. A difference of greater than 0.2 in the mean point price elasticity estimate between groups was chosen as representing a noteworthy difference between groups. A value of 0.2 represents a difference in price elasticities that is greater than differences between population subgroups that have been observed under natural price fluctuations, as reported in a recent systematic review [116]. Eleven out of 18 own price elasticity estimates differed by more than 0.2 between personal characteristic groupings. The greatest difference in own price elasticities between groups was observed between ethnic groups in the SHOP study (a difference in price elasticity of 2.43 between Maori and Pacific participants) [121].

I found a consistent indication of differences in own price elasticity estimates across all four studies which examined the effect of income [35,59,121,122]. However, there was no consistent pattern with respect to whether high income or low income groups were more price sensitive. Within studies that examined price changes across different foods, differences in price elasticity estimates by personal characteristic were often not concordant (i.e. large differences in price elasticity by personal characteristic for one set of

target foods did not necessarily mean that there were large differences in the price elasticities in other target foods examined).

There were two sets of price elasticity estimates derived to represent the response to a price change in high energy dense foods by obesity status. Despite the scope of the tax being comparable across the two studies [59,122] the studies had contrasting findings; there was not a large difference in the Nederkoorn study [59] but there was in the Epstein (2007) [122] study. This may suggest that the impact of a particular personal characteristic may be context, or culturally specific.

For the personal characteristics where price elasticity estimates were derived from a single study, there was mixed evidence of an effect of personal characteristics. While there were differences of greater than 0.2 in the price elasticity for healthy foods based on ethnicity in the SHOP study [121], there was a considerable degree of overlap in the confidence intervals. In the same study, no considerable difference was observed by education group. For impulsivity and sleep deprivation, it appears as though there may be differential effects under some conditions but not others. In the impulsivity study [126], there was a difference of greater than 0.2 for low energy density foods but not for high energy density foods. In the sleep deprivation study [125], there was a difference of greater than 0.2 for a price increase but not for a price decrease in the target foods. In summary this indicates that the effect of personal characteristics in responses to price changes may be complex, even within a single personal characteristic.

Secondary research questions

How do personal characteristics affect changes in purchases of non-targeted foods in response to food/beverage price changes in experimental settings?

The differential effects of the applied price change on purchases of products other than the targeted product was discussed in five of the included studies [35,122–126], with sufficient numeric data provided to estimate cross price elasticities by personal characteristic in four [35,122,125,126]. It was possible to obtain a total of 15 cross-price elasticity sets across four personal characteristics (impulsivity, income, sleep deprivation, and obesity); these are shown in Table 6.

Six of the 15 cross price elasticity estimate sets had a difference of greater than 0.2 between groups. The greatest difference in cross-price elasticity was observed in the Giesen [126] study where there was a 0.57 difference in the cross-price elasticity of calories from high energy dense foods when the price of low energy dense foods was changed. Overall, there was no clear pattern of the effects of any personal characteristics on cross price elasticities. Income was the only personal characteristic for which there was data from more than one study. None of the income related cross-price elasticity differences represented a difference of more than 0.2. For impulsivity and obesity, some cross price elasticities showed a difference of greater than 0.2 while others did not. There were differences greater than 0.2 in the cross price elasticities by sleep deprivation status.

Impact of magnitude, target, direction, and information on differential responses to food/beverage pricing interventions by personal characteristic

Two studies examined multiple price conditions for the target product(s) and three personal characteristics were considered in these studies (BMI, study income, and sleep deprivation) [122,125]. From this limited evidence base, it is not possible to draw conclusions with respect to how the direction of a price change might differentially impact different groups. There was no data from the included studies as to how the magnitude of price changes may impact differential effects (i.e. whether a price increase of 10% and 20% induce proportional purchasing changes) and the heterogeneity of studies even further prohibited such conclusions.

Four of the included studies [35,122,124,126] tested price changes on more than one set of target products. Three of these studies provided data that enabled the calculation of own price elasticities for the different target foods [35,122,126]. Within studies, price elasticity differences between personal characteristic groups did appear to differ based on the target of the price change. For example, there was not a considerable difference in the price elasticity estimates between low and high study income for low energy density foods but there was a difference in the price elasticity of high energy density foods in the Epstein (2007) study [122].

There was no evidence available from the included studies to enable us to examine the impact of information provision on differential impacts of price changes by personal characteristic. Although three studies [121,122,124] informed participants of the price

changes that were implemented, none had an uninformed or differently informed comparison group.

How do changes in food price affect the total price of the diet for different groups defined by socioeconomic or other personal characteristics?

There was only one study that explicitly examined the impact of price changes on the total price of the diet [35]. The study tested two interventions (fruit and vegetable subsidy, and nutrient profile based changes); both price changes tested resulted in a reduction in daily expenditure. For the fruit and vegetable subsidy, low income participants reduced expenditure by a greater absolute amount than the median income participants. For the nutrient profile condition, the same absolute reduction in expenditure was observed for both groups. The authors also reported the redistributive effects of the intervention and found that they were more favourable for the median income group than the low income group. Nederkoorn et al [59] discussed changes in total price of the diet but no differential effects by personal characteristic were noted.

Study quality

Table 7 shows the judgements made in relation to the quality of included studies. No study was judged to be at low risk of bias across all domains, and there was considerable variance in the risk of bias across the five domains. There were no studies where the researchers were blinded to the allocation of participants, but there was often no or little contact between participants and researchers post-randomisation and therefore the impact on results is likely to be minimal. Only two studies required participants to make purchases

using their own money and therefore there is considerable risk of performance bias across the included studies.

Table 4: Summary of included studies

Author (Year)	Country	Setting	Design of study	Duration of study	Target of pricing intervention	Intervention conditions[a]	Personal characteristic(s) examined	Analysis type
Blakely (2011)	New Zealand	Leading supermarket chain	2x2 factorial randomised controlled trial	12wk baseline, 24wk intervention, 24wk follow-up	'Healthier' foods as assessed by a modified version of the New Zealand Heart Foundation Tick nutrient profile model	a) Control; b) Tailored nutrition education; c) 12% discount on 'healthier foods'; d) Both tailored nutrition education and 12% discount on healthier foods	Ethnicity, Education, Household income	ANCOVA

Author (Year)	Country	Setting	Design of study	Duration of study	Target of pricing intervention	Intervention conditions[a]	Personal characteristic(s) examined	Analysis type
Chapman (2013)	Sweden	Controlled laboratory setting	Three repeat purchasing tasks following a (randomised) night of either sleep or total sleep deprivation	Two laboratory visits (sleep and total sleep deprivation)	HED foods	Randomised to: i) Total sleep deprivation; ii) Sleep. Purchasing tasks were: 1) Control; 2i) 25% price increase on HED[b] foods; 2ii) 25% price decrease on HED[b] foods	Sleep deprivation	ANOVA
Darmon (2014)	France	Computer shopping task conducted in the laboratory	Four repeat purchasing tasks	One laboratory visit	Fruit and vegetables and 'other healthy products' as defined by a nutrient profiling model (SAIN/LIM)	1) Software test; 2) Control; 3) 30% fruit and vegetable subsidy; 4) 30% price increase on unhealthy foods and 30% price decrease on healthy foods (including fruit and vegetables)	Income	General linear model

Author (Year)	Country	Setting	Design of study	Duration of study	Target of pricing intervention	Intervention conditions[a]	Personal characteristic(s) examined	Analysis type
Epstein (2007)	USA	Controlled laboratory setting	Six repeat purchasing tasks following randomisation to price change target	Single laboratory visit lasting approximately two hours	Either HED or LED foods (randomly assigned)	Randomised to either: a) HED[b] price changes; or b) LED[c] price changes. This was followed by the following tasks (presented in random order): i) $15 budget, target price 75%; ii) $15 budget, no price change; iii) $15 budget, target price 125%; iv) $30 budget, target price 75%; v) $30 budget, no price change; vi) $30 budget, target price 125%	Study income, Obesity	Regression

Author (Year)	Country	Setting	Design of study	Duration of study	Target of pricing intervention	Intervention conditions[a]	Personal characteristic(s) examined	Analysis type
Epstein (2010)	USA	Controlled laboratory setting	Five repeat purchasing tasks presented in a randomised and counterbalanced order	Single laboratory visit lasting ~2hours	High and low CFN[d] foods	i) Control; ii) Low CFN[d] prices lowered 25%; iii) Low CFN[d] prices lowered 12.5%; iv) High CFN[d] prices raised 12.5%; v) High CFN[d] prices raised 25%	Age, Minority status, BMI, Family income, Hunger	Regression
Giesen (2012)	Netherlands	Computer shopping task conducted in the laboratory	Three repeat purchasing tasks	Single laboratory visit	HED and LED foods	1) Control followed by 2i) HED[b] price increase of 50%; and 2ii) LED[c] price decrease of 50% (counterbalanced order)	Impulsivity (as measured by the stop-signal reaction time test)	ANOVA

Author (Year)	Country	Setting	Design of study	Duration of study	Target of pricing intervention	Intervention conditions[a]	Personal characteristic(s) examined	Analysis type
Nederkoorn (2011)	Netherlands	Computer shopping task conducted remotely	Two condition randomised controlled trial	Single remote analogue purchasing task	HED foods	a) Control; or b) 50% tax on HED[b] products	Budget, Weight status	Regression
Waterlander (2012)	Netherlands	Virtual Supermarket	Two condition randomised controlled trial	Single remote analogue purchasing task	Fruits and vegetables	a) Control; or b) 25% discount on fruit and vegetables	Sex, Budget, Price perception score, Habit strength	ANCOVA

a Roman numerals (e.g. i, ii, iii) indicate participants were assigned to each condition in a randomised order. Alphabet characters indicate that participants were randomised to only one of the conditions presented. Numbers indicate where the order of conditions was pre-specified.

b HED: High energy density

c LED: Low energy density

d CFN: Calorie for Nutrient

Table 5: Own-price elasticities for target products by participant sub-groups

Personal characteristic		Measure	Author name (year)	Target food	Price change [a]	Personal characteristic categories (no. participants)	Price elasticity result (95% confidence intervals)	Difference between groups?[c]
Non-modifiable	Impulsivity	Stop signal reaction time (SSRT) test score	Giesen (2012)	High energy density foods	+25%	Low SSRT score (15)	0.41(-0.46, 2.08)	No
						High SSRT score (16)	0.49 (-0.68, 1.21)	
				Low energy density foods	-25%	Low SSRT score (20)	-1.45 (0.41, 3.18)	Yes
						High SSRT score (19)	0.00 (-1.06, 0.64)	
	Ethnicity	Self-report ethnicity response	Blakely (2011)	'Healthier foods' defined by a modified version of the New Zealand Heart Foundation Tick	-12.5%	Maori (207)	0.24 (1.75, -1.27)	Yes
						Pacific (85)	-2.19 (-0.11, -4.26)	
						European/other (736)	-0.99 (-0.58, -1.38)	
Modifiable	Obesity	BMI (binary)	Epstein (2007)	High energy density foods	+/-25%	Non-obese (30)	-1.05 (-1.24, -0.86)	Yes
						Obese (17)	-0.77 (-0.99, -0.55)	
				Low energy density foods	+/-25%	Non-obese (30)	-0.76 (-0.87, -0.64)	No
						Obese (17)	-0.83 (-0.99, -0.55)	
			Nederkoorn (2010)	High energy density foods (defined as >300kcal/100g)	+50%	Lean[d]	-0.43 (-1.33, 1.07)	No
						Overweight[d]	-0.34 (-1.01, 0.71)	

Personal characteristic		Measure	Author name (year)	Target food	Price change [a]	Personal characteristic categories (no. participants)	Price elasticity result (95% confidence intervals)	Difference between groups?[c]
	Sleep deprivation	Binary	Chapman (2013)	High calorie foods	-25%	Total sleep deprivation (14)	-0.94 (-2.14, -0.02)	No
						Sleep (14)	-0.77 (-1.93, 0.12)	
					+25%	Total sleep deprivation (14)	-0.98 (-1.81, 0.01)	Yes
						Sleep (14)	-1.19 (-1.73, -0.51)	
Societal	Income	Study income (per household member)	Epstein (2007)	High energy density foods	+25%	US $15 (47)	-1.80 (-2.02, -1.57)	Yes
						US $30 (47)	-1.17 (-1.44, -0.89)	
					-25%	US $15 (47)	-1.00 (-1.66, -0.37)	Yes
						US $30 (47)	-1.42 (-1.91, -0.96)	
				Low energy density foods	+25%	US $15 (47)	-0.82 (-0.90, -0.75)	No
						US $30 (47)	-0.80 (-0.91, -0.69)	
					-25%	US $15 (47)	-1.18 (-1.50, -0.85)	No
						US $30 (47)	-1.11 (-1.36, -0.86)	
		Daily household grocery budget	Nederkoorn (2010)	High energy density foods (defined as >300kcal/100g)	+50%	<10€ (83)	-0.44 (-1.33, 1.07)[b]	Yes
						10-20€ (162)	-0.46 (-0.87, 0.03)[b]	
						>20€ (61)	-0.26 (-0.71, 0.32)[b]	

Personal characteristic		Measure	Author name (year)	Target food	Price change [a]	Personal characteristic categories (no. participants)	Price elasticity result (95% confidence intervals)	Difference between groups?[c]
		Household income	Blakely (2011) **	'Healthier foods' defined by a modified version of the New Zealand Heart Foundation Tick	-12.5%	<NZ $60,000 (533)	-0.19 (0.22, -0.60)	Yes
						>NZ $60,000 (441)	-0.06 (0.23, -0.34)	
						Declined to answer (54)	-1.28 (0.63, -3.19)	
			Darmon (2014)	Fruit and vegetables	-30%	Low income (95)	-0.82 (-0.70, -0.94)	Yes
						Medium income (33)	-1.28 (-1.08, -1.47)	
				Healthy products (inc. fruit and vegetables)	-30%	Low income (95)	-0.40 (-0.39, -0.41)†	Yes
						Medium income (33)	-0.71 (-0.66, -0.76)†	
				Unhealthy products	+30%	Low income (95)	-0.75 (-1.28, -0.22)†	Yes
						Medium income (33)	-1.18 (-0.87, -0.48)†	
	Education	Highest qualification obtained	Blakely (2011) **	'Healthier foods' defined by a modified version of the New Zealand Heart Foundation Tick	-12.5%	Nil/Secondary (523)	-0.94 (-0.36, -1.51)	No
						Tertiary/trade/ other (503)	-0.78 (-0.22, -1.35)	

a Given for reference purposes price elasticities given are point price elasticities and the calculations are therefore partially dependent on the magnitude of the price change

b Value reported is the price elasticity for a calorie of the targeted food

Personal characteristic	Measure	Author name (year)	Target food	Price change [a]	Personal characteristic categories (no. participants)	Price elasticity result (95% confidence intervals)	Difference between groups?[c]
c 'Yes' values indicate that the difference between price elasticity values of the pairwise groups was greater than +/-0.2. d Number of participants not explicitly stated † These calculations ignore the impact of the price changes of the non-target food and are therefore likely to be an overestimation of the true own price elasticity as the price increase on unhealthy products and price decrease on healthy products was applied simultaneously ** Data not published in included manuscript, provided by Tony Blakely and Yannan Jiang (personal communication)							

Table 6: Cross-price elasticities for non-target products by personal characteristic groups

Personal characteristic	Measure	Author name (year)	Target food	Price change applied to target food(s)	Non-target product considered	Personal characteristic categories	Price elasticity result (95% confidence intervals)	Difference between groups?
Impulsivity	Stop signal reaction time	Giesen (2012)	High energy density foods	+25%	Kcal from medium energy density foods	Low SSRT score	0.15 (-0.53, 1.04)	No
						High SSRT score	0.07 (-0.74, 0.61)	
					Kcal from low energy density foods	Low SSRT score	-0.62 (-1.00, -0.07)	Yes
						High SSRT score	-0.05 (-1.01, 0.72)	
			Low energy density foods	-25%	Kcal from high energy density foods	Low SSRT score	-0.29 (-0.88, 0.57)	Yes
						High SSRT score	-0.82 (-1.81, -0.12)	
					Kcal from medium energy density foods	Low SSRT score	0.32 (-0.35, 1.19)	Yes
						High SSRT score	-0.32 (-1.17, 0.31)	
Income	Study income	Epstein (2007)	High energy density foods	+25%	Low energy density foods	US $15	0.29 (0.02, 0.58)	No
						US $30	0.17 (0.08, 0.43)	
				-25%	Low energy density foods	US $15	0.07 (-0.14, 0.28)	No
						US $30	0.04 (-0.14, 0.22)	
			Low energy density foods	+25%	High energy density foods	US $15	0.19 (-0.07, 0.48)	No
						US $30	0.16 (-0.02, 0.34)	
				-25%	High energy density foods	US $15	-0.57 (-1.01, -0.14)	No
						US $30	-0.40 (-0.66, -0.14)	

Personal characteristic	Measure	Author name (year)	Target food	Price change applied to target food(s)	Non-target product considered	Personal characteristic categories	Price elasticity result (95% confidence intervals)	Difference between groups?
	Household income	Darmon (2014)	Fruit and vegetables	-30%	Other healthy products	Low income	0.03 (0.07, -0.01)	No
						Medium income	-0.16 (-0.14, -0.18)	
					Neutral products	Low income	0.26 (0.19, 0.34)	No
						Medium income	0.27 (0.23, 0.31)	
					Unhealthy products	Low income	0.14 (-0.44, 0.72)	No
						Medium income	0.08 (-0.57, 0.73)	
Sleep deprivation	Binary	Chapman (2013)	High calorie food items	-25%	Low calorie food items	Total sleep deprivation	-0.07 (-1.70, 1.16)	Yes
						Sleep	-0.37 (-1.92, 0.78)	
				+25%	Low calorie food items	Total sleep deprivation	0.37 (-1.05, 2.23)	Yes
						Sleep	0.93 (-0.45, 2.76)	
Obesity	Binary	Epstein (2007)	High energy density foods	+/-25%	Low energy density foods	Non-obese	0.22 (0.09, 0.34)	Yes
						Obese	-0.02 (-0.19, 0.15)	
			Low energy density foods	+/-25%	High energy density foods	Non-obese	-0.07 (-0.25, 0.10)	No
						Obese	-0.12 (-0.32, 0.08)	

Table 7: Assessment of the quality of included studies

		Blakely (2011)	Chapman (2013)	Darmon (2014)	Epstein (2007)	Epstein (2010)	Giesen (2012)	Nederkoorn (2011)	Waterlander (2012)
Selection bias	Were participants randomised to the study [price] conditions?	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
	Were participant recruitment methods independent of personal characteristics?	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Performance bias	Were participants blinded to the aims of the research study (i.e. blinded to the fact that the study changed prices)?	No	No*	No	No	No	Yes*	Yes	Yes
	Did the study design require participants to make actual purchases using their own money?	Yes	No	Yes	No	No	No	No	No

		Blakely (2011)	Chapman (2013)	Darmon (2014)	Epstein (2007)	Epstein (2010)	Giesen (2012)	Nederkoorn (2011)	Waterlander (2012)
Detection bias	Were participants blinded to the outcome of interest (i.e. were participants aware of why prices changed)?	No*	Yes*	Yes	Unknown	Unknown	Yes*	Yes	Yes
	Were researchers blinded to the allocation of participants?	No*	No*	No	No	No	No*	No*	No
Attrition bias	Was complete outcome data obtained?	No	No	No	Yes	Yes	No	No	No
	Was attrition unrelated to the personal characteristics examined?	No	Yes	Unknown*	Yes	Yes	Yes*	Unknown*	Unknown*
Reporting bias	Did the study set out to look at differences by personal characteristics?	Yes	Yes	Yes	Unknown	Unknown	Yes	Yes	No
'Yes' responses represent low risk of bias; 'No' responses represent higher risk of bias. *Indicates where study authors provided additional information to help clarify response									

Discussion

This systematic review finds that price changes may have a differential effect amongst participants depending on purchasers' personal characteristics. From the experimental literature reviewed here, income related effects do appear to be present but the direction of these effects is unclear. In addition, this review observes that there may be other personal characteristics, such as ethnicity and obesity status, for which the differential effects may also be important to consider in order to avoid increasing health inequalities. However, the results included in this review were typically under-powered as evidenced by the wide confidence intervals around price elasticities. Therefore, it is possible that the patterns observed represent chance findings, especially in instances where a personal characteristic was only examined in a single study.

Differences in own price elasticities for different target products within studies suggest that the choice of target products may influence the extent to which responses vary by personal characteristic. This also appears to be the case in relation to cross price elasticities. However, owing to the limited data it is too early to draw conclusions with respect to either the personal characteristics or target foods for which this is relevant.

Observational studies suggest that there are differential effects by personal characteristics such as income [116] and adequately powered experimental studies are needed to test whether these effects are due to confounding. An examination of the influences of

personal characteristic on responses to food price changes is required to assess whether existing dietary inequalities might be affected with the introduction of HRFTS.

Limitations of included studies

This systematic review identified a number of weaknesses in experimental studies conducted to date that examine the differential effect of food price changes by personal characteristic. Primarily, included studies did not have large enough sample sizes to enable statistically significant differences by personal characteristics to be observed. I found that the confidence intervals around own price elasticity estimates were often very wide which suggests that the studies were not adequately powered to examine the differential effects of the price changes implemented.

In several cases, sample sizes were not even sufficient to determine conclusively whether a price change resulted in increases or decreases in the purchase of target products in a particular sub-group of participants [59,121,125,126]. This may be partly due to the difficulty of recruiting from particular population sub-groups (e.g. [127]).

Another weakness of included studies was that continuously distributed personal characteristics were dichotomised, and the range in the personal characteristic measure was generally not reported, thus making it difficult to establish the homogeneity of the study sample. Studies where there is little difference in the personal characteristic measure across dichotomised groups may fail to identify differential effects due to the two groups being too similar to establish an effect. The extent to which this false dichotomisation may

have influenced the power of studies to detect differential effects by personal characteristics is unclear.

Limitations of the systematic review

The broad search strategy adopted for this review meant I was able to identify studies spanning a wide range of personal characteristics. Despite this, only eight relevant studies were identified. These were highly heterogeneous in the targeted foods, range of products available, price intervention applied, study task and personal characteristic measures used. The small number of heterogeneous studies meant that there were too few studies on specific personal characteristics and pricing interventions for general conclusions to be drawn. The variation in the study setting, price change interventions, shopping tasks conducted, and other factors also meant that it is not appropriate to conduct a meta-analysis and therefore pooled estimates of the effects of particular personal characteristics are not available.

The conversion of the results reported in included studies to a common metric enabled transparent comparison of results across studies. In some cases, price elasticities were obtained for calories from the target product rather than price elasticities for the amount of the target products purchased. Although price elasticities for calories and amount of product are not directly equivalent and therefore cannot be compared directly, both give an indication of the magnitude of a purchasing shift under a given pricing condition. A weakness of the approach of converting reported study results to price elasticities was that

the confidence intervals were probably overestimates and this may partly account for the difficulty in exactly establishing differential effects by personal characteristic across the included studies.

Due to the lack of power of included studies to establish the statistical significance of differences between groups, I examined differences in the mean price elasticity estimates. A difference in price elasticities of greater than 0.2 was chosen to indicate that there were potentially differential effects according to personal characteristic, but this cut-off was somewhat arbitrary. In small studies with little power, price elasticity differences greater than 0.2 may occur simply by chance. In addition, very small differences in price elasticity across commonly consumed product categories may have a greater impact on diet than large differences in price elasticity for foods that are less commonly consumed. However, this is unlikely to have biased the findings of this review as all the included studies tested the effects of price changes across relatively broad food categories.

The secondary research questions that were included ensured that differential effects of a price change could be examined in the broadest sense possible. However, it was not possible to draw conclusions about differential effects of pricing interventions on substitution patterns, total price of the diet, and non-price elements of pricing interventions (e.g. information) due to the small number of studies.

Comparison with previous reviews

This review set out to assess differential effects of food price changes systematically and quantify these effects across included studies by using a common metric. This differs from Epstein and colleagues' [25] targeted review of experimental studies which provided a broader narrative description of the experimental evidence base. Overall, they conclude that additional focused research is needed to better inform policy and they state that there is a suggestion that some individual characteristics do moderate the effects of pricing interventions [25]. However, the authors do not quantify these effects as this was not the primary focus of their review. By adopting a systematic approach, I identified all the focused research that has been conducted and have ensured an unbiased representation of the totality of findings from the existing evidence base. The secondary research questions chosen in this review built partly upon Epstein and colleagues' [25] earlier observations as I was intrigued as to what a systematic synthesis would find, and whether the seemingly growing popularity of the subject would yield novel findings from more recent literature. There were fewer studies included in this review due to the more focused nature of the research question and stricter inclusion criteria. For example, no vending machine studies were deemed eligible for this review as these studies did not collect data at the individual level.

Overall, reviews of HRFTS to improve population diets note the importance of considering the differential effects of HRFTS to improve population diets, and the limited evidence base that is currently available to address this issue [22,25,128]. Where differential effects have

been observed, the focus has primarily been on differential effects for different socioeconomic groups, and the findings have tended to suggest that pricing strategies result in improved health benefits for lower socioeconomic groups, but that those same policies tend to be economically regressive [22].

Suggestions for future research

The findings of this systematic review indicate that future research should make a greater effort to test the differential effects of HRFTS-related price changes across population relevant sub-groups by recruiting sufficient sample sizes from the different subgroups for adequately powered statistical analyses. Explicit efforts should be made to establish the effects of pricing interventions on both own and cross price elasticity values and the overall diet by conducting experiments in realistic food purchasing settings with diverse food options such as supermarkets.

Conclusion

Insight into the differential effects of HRFTS to improve population diets is important in order to establish the ultimate effects on food purchasing patterns, public health outcomes, and health disparities. Experimental studies provide an opportunity to examine the differential effects of HRFTS in detail. I find that there is some evidence of HRFTS having a differential impact depending on the personal characteristics of study participants, however the extent and nature of these differences remains unclear.

The limited sample sizes and heterogeneity of studies mean it is not possible to draw coherent conclusions with respect to specific personal characteristics or with respect to the exact magnitude or direction of differences. I recommend that future experimental studies ensure that they are adequately powered to examine relevant differential effects for the HRFTS that is being trialled, as there is an insufficient evidence base to date to be able to draw generalizable conclusions about the impact of particular personal characteristics.

The limited evidence base on the differential impacts of HRFTS that has used experimental methods suggested considerable opportunity for UK based experimental research in this area. The lack of existing studies in the UK meant that the first step was to develop an appropriate experimental environment.

Chapter 4: The development of the UK Virtual Supermarket

Introduction

The systematic review (see previous chapter) revealed no UK based experimental studies of the effects of price interventions on food purchasing behaviour, stratified by personal characteristics. Therefore, I aimed to develop a method by which the effects of price changes on purchasing behaviour could be examined experimentally in the UK to complement the findings from other study designs.

This chapter outlines the development process for the creation of a UK Virtual Supermarket (UKVS). The Dutch Virtual Supermarket, developed for researchers at Vrije Universiteit by SARA Computing and Networking Services Amsterdam (SURFsara) [129], was used as a template. Models of UK products were placed within the existing layout and other changes were made to the software to align it with the purposes of this DPhil project. In this chapter, I will describe the key stages that were involved in the development of the UKVS: product selection, adaptation of the Dutch Virtual Supermarket to reflect UK supermarket settings, and software testing.

Rationale for a Virtual Supermarket

As outlined in Chapter 2, health-related food taxes and subsidies (HRFTS) in the UK are likely, all other things being equal, to have bigger effects if they cover a broad range of

different foods. Experimental studies that aim to examine the impacts of such interventions therefore need to have a large enough product selection to examine changes in purchases across a broad range of different food products. The majority of food in the UK is purchased in supermarket chains [130]. Supermarkets are therefore an ideal environment in which to assess the likely impact of HRFTS interventions. Testing the impacts of HRFTS in real supermarkets is problematic owing to resource, practical and ethical constraints, this is especially true for tax interventions that may lead to reduced profits for supermarkets. A UK Virtual Supermarket appeared a promising solution to this issue.

A virtual supermarket is a 3D graphical representation of a real supermarket in which participants can complete shopping tasks. Virtual supermarkets have been previously used to examine price interventions and have been validated against real supermarket purchases [131–133]. For example, the New Zealand Virtual Supermarket (NZVS), also developed by SURFsara, was validated by comparing participants' real life purchases with those made in the NZVS over a three-week period [133]. The validation study found that shopping patterns in the NZVS were comparable to those in real life: the four food groups with the highest relative expenditure were the same and there was no trend of overspending in the NZVS. However, no assessment could be made as to whether there were differences in purchases across different income groups. The large product selection, ability to collect data from large numbers of participants remotely, and immersive

participant experience are advantageous features of an experimental environment intended to collect data on HRFTS.

Development of the UK Virtual Supermarket

The use of an existing Dutch Virtual Supermarket as the template for a new UKVS was agreed with the researchers at Vrije Universiteit Amsterdam who had developed the Dutch Virtual Supermarket, with SURFsara contracted as the software developers. SURFsara are a not-for-profit software development company that had previously developed both the Dutch and New Zealand versions of the Virtual Supermarket. The resources available enabled the development of a UK version based on the existing Dutch Virtual Supermarket, and this was much cheaper than developing a UK Virtual Supermarket from scratch. The creation of the UKVS from the Dutch Virtual Supermarket consisted of: the replacement of Dutch products with UK products, changes to the software to make it fit within the UK context, and changes to the study procedure format (namely to enable multiple shopping tasks per participant). Screenshots from the completed UKVS are displayed in Figure 3.

As the purpose of the UKVS is to replicate the experiences of participants in a real life supermarket, the development process needed to ensure that features such as the layout of products and the selection available mirrored a real life experience.

Figure 3: Screenshots from the UK Virtual Supermarket



Shelf space allocation

The Dutch Virtual Supermarket used as the template for the UKVS contained four shelf types: fridge, freezer, shelf and special (e.g. bakery stand). The internal layout of the Dutch Virtual Supermarket was mapped out with the location of shelf types and spaces recorded. This gave the maximum number of products and distribution of shelf types.

Shelf spaces were allocated to food categories based on surveys of real (small) UK supermarkets. Three stores from different supermarket chains in the Oxford area were surveyed. Permission was sought from the duty manager to count the number of products available and generate a sketch map of the layout of categories. Due to the limited number

of possible shelf spaces in the UKVS, I decided against including non-food products and therefore I did not count non-food items in the store surveys. Products displayed at the checkout were also not counted as these shelf spaces are not present in the UKVS.

Food category groupings differed across the stores surveyed. Due to these differences, one store was used as the primary store upon which shelf space allocations were made in the Virtual Supermarket. The store chosen was the one that was closest to the existing Virtual Supermarket in terms of layout: it had the same number of aisles and was the most similar in shape to the Dutch Virtual Supermarket template.

Based on the percentage of shelf space allocated to categories in real stores, and the layout constraints inherent within the Virtual Supermarket, product categories were allocated to particular shelves. There were 578 spaces across 52 shelves (of different types) available in the existing layout. The real store had a total of 2635 products across 75 shelves (food products only). The shelf space allocated to each category in the real store was scaled to give the amount of shelf space that the category should occupy in the UKVS, based on shelf type (i.e. fridge, freezer, and shelf).

I allocated food categories to specific shelves in the UKVS, grouping categories together so that they appeared close to those similar to in real life. This was done whilst keeping the total shelf space allocated to a category as close to the allocated shelf space as possible without splitting up food categories. This set the number of product spaces that were available in each food category.

Next, I selected individual products for each category. I used the Living Costs and Food Survey (LCFS) 2012 data to ensure popular products were available in the UKVS. The 256 food categories in the LCFS database were ranked based on the percentage of the sample that purchased the category and the average expenditure on the food category. I then checked that the first 50 LCFS categories on each list were represented in the shelf space allocation. No changes needed to be made based on this step, as the popular product categories according to the LCFS were captured with the store survey methods.

Product selection

An online supermarket (*www.sainsburys.co.uk*) was used to review products available in each food category that was allocated space in the UKVS. The following information was recorded for each food category: corresponding online categories and sub-categories, number of products in online category, price range, sizes available, brands, top sellers, flavours/types of products included in the category, and any other information on the different products available that appeared relevant to the category.

Specific products in each category were chosen, usually based on the top seller(s). However, I also attempted to ensure that the diversity within categories was captured. For example, where several sizes of the same product dominated the top sellers list, I chose one size and then filled the remainder of the selection with products lower in the top sellers list. The exception to this method was the selection of sandwiches and similar products, classified in the “Meal Deal” category in the shelf space surveys of real stores, as these

were not available in the online store. For this category, product selections were made based on the actual products that were available in a real small store. Selected products were placed within the shelf spaces allocated to their category. Products were placed close to similar ones (e.g. branded sausages next to value sausages). A total of 530 products were selected.

Once the UK products had been selected, I created 3D computer models of the selected products based on images provided by Brandbank for each product. Brandbank (a Nielsen company) is one of the largest providers of digital product information [134]. The 3D models were created in Blender, open source product modelling software. The 3D models were then transferred to SURFsara who placed the products on the virtual shelves. Nutritional information was also provided by Brandbank. Where missing from the Brandbank dataset, nutritional data was supplemented by matching products with online equivalents or a UK Nutrient Databank equivalent. Generic names were used on shelf labels to shorten the length of labels. In addition, generic names meant that many products also represent a broader variety of products (e.g. Yeo Valley strawberry yogurt was listed as Yeo Valley fruit yogurt).

Price information was collected in January 2016 based on the cost of products on the online supermarket from which products were chosen. There were some products for which price information was not available online. For these, the price was based on either the in-store price (in the case of “Meal Deal” style products) or the price of the most similar product available (e.g. based on a different supermarket’s version of the product).

Automation of recruitment

Delays between participant contact/enrolment and study completion result in the attrition of participants, which increases with the length of the delay [135]. In order to minimise the potential for this delay, I automated the recruitment procedure such that participants are able to complete the study procedure without researcher contact.

A UKVS website (*www.virtualsupermarket.dph.ox.ac.uk*) was created as the starting point for participant engagement. On this site, potential participants were able to read the participant information sheet and register for taking part in a UKVS study. If interested in taking part, potential participants could complete an online consent form and fill in some basic demographic details. Upon submission of this contact form, the participant received an automated email with their unique participant identifier/password combination and a link to download the UKVS software. This automation was a novel feature of the UKVS; it considerably reduced delays compared to more researcher-intensive alternatives. In addition, the online nature of the consent procedure mimicked the online nature of the UKVS study procedure and increased the fluidity of the process, thus reducing the burden on study participants.

Software testing

The purpose of the software-testing phase was to ensure no residual issues remained within the software that might diminish participants' ability to complete the planned study

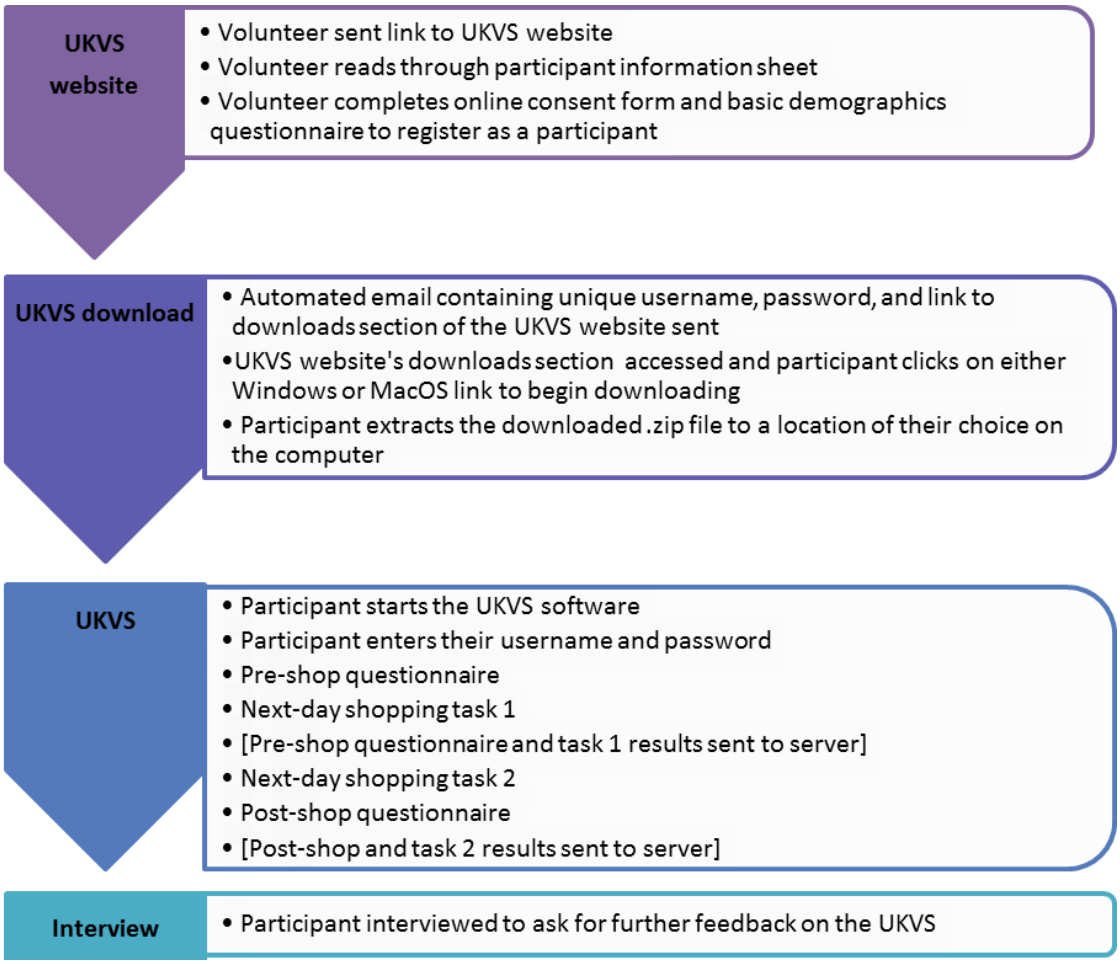
procedures. In addition, I aimed to obtain qualitative feedback to enable improvements to the materials provided to study participants. The protocol for software testing is attached as Appendix (ii). This section provides information on the findings from the software-testing phase.

Procedure

The software testing study procedure aimed to recruit a convenience sample of 20 adults. Participants completed two 'next-day' shopping tasks: participants were told to imagine that they had no food at home and that they needed to purchase foods and drinks for their household for at least the next day. Participants were told to imagine that the second shopping task took place a week after the first shopping task. This procedure was similar to the instructions provided in studies identified in the systematic review in Chapter 3 [35,59,126]. Participants also completed pre- and post- questionnaires embedded in the software that were designed to collect information on the sociodemographic characteristics of participants, details on typical shopping behaviour, and perceptions of the UKVS. Participants were interviewed over the phone or in person following their completion of the study procedure.

Figure 4 shows a flowchart of the procedure from the participant's perspective. The interviews were used to gauge why participants responded favourably or unfavourably to particular aspects of the study and this helped to determine the importance of particular software changes.

Figure 4: Flow chart of participant experience for the software testing study



Results

Recruitment

I recruited friends and family to be participants for the software testing study by email and word of mouth. Twenty-eight people registered to take part in the UKVS software testing study by completing the online consent process. The first twenty participants to complete the study procedure were interviewed to ask about their experiences and comprised the software-testing sample. Of the remaining eight volunteers, four were unable to complete

the study process and four were contacted to inform them that data collection had been completed. There was one participant who reported completing the UKVS procedure, but for whom results for the second shopping task and post-shop questionnaire did not upload to the server.

Details of non-completers

Four of the 28 volunteers were unable to complete the study procedure. Two of them were using MacOS computers. During the software testing phase, it was discovered that the UKVS runs slightly differently on MacOS computers and that there are additional steps in the download process. One of the software testing participants who was unable to complete the study was using an Ubuntu/Linux operating system. Whilst this participant has previously used software intended for Windows on this machine, they were unable to do so on this occasion. There was not the potential to provide support to Ubuntu/Linux users on how to run the UKVS. The reason that the final participant was unable to complete the study remained unknown, but appeared to be a localised issue as the software did work on very similar Windows machines.

Participant characteristics

Personal characteristics of the software-testing sample are displayed in Table 8. The software-testing sample all had an educational level at or above A levels or equivalent. Over half of the software testing samples lived in single person households. Participants reported using a range of different computer types and had a variety of typical grocery shopping routines.

Table 8: Characteristics of software testers

Mean age (in years)	29 (SD 8)
Gender (n)	
- Male	5
- Female	14
- Other	1
Ethnicity (n)	
- White	15
- Black/African/Caribbean/Black British	1
- Asian/Asian British	2
- Mixed/multiple	1
- Prefer not to say	1
Household size	
- One	11
- Two	5
- Three or more	4
Typical weekly food and drink expenditure (£)	50.50 (SD 19.99)
Current work status (n)	
- Unemployed	3
- Full-time employed	9
- Part-time employed	1
- Looking after children/family	1
- Other	6
Computer type (n)	
- Windows 8	4
- Windows 7	5
- Mac OS	6
- Other	4
- Don’t know	1
Usual supermarket (n)	
- Tesco	12
- Sainsbury’s	4
- Asda	0
- Morrisons	0
- Waitrose	4

- Lidl or Aldi	0
How often do you buy food and drink in a supermarket?	
- Every day	1
- Every other day	2
- 3-4 times per week	6
- Twice weekly	7
- Once weekly	4
- Every other week	0
- Monthly or less	0

Shopping behaviour

Software testing participants bought an average of 25.9 items (SD 11.8) and spent an average of £30.83 (SD 18.31) per shopping task in the UKVS. Table 9 displays the average nutritional composition of a shopping task across software testers

I used two-sample t tests to examine whether there was a difference between purchases (product count, amount spent, and nutritional information) across the first and second shopping task and observed no statistically significant differences. This provides an initial indication that shopping behaviour is similar across multiple shops in the UKVS, and that there is no order effect on purchasing in the UKVS.

Table 9: Nutritional composition of the shopping basket in the software testing sample

	Average content of shop		% Energy		Difference between the two shops*		
	Mean	SD	Mean	SD	Mean	SD	p value
Energy (kcal)	16,042	9,126	-	-	1,899	10,958	0.50
Protein (g)	793	638	18.9	7.0	3	817	0.99
Fat (g)	558	328	31.1	5.7	-32	423	0.75
Saturated fat (g)	213	121	12.0	4.4	-19	187	0.66
Carbohydrates (g)	1,951	1,172	49.1	7.1	426	1,427	0.21
Sugars (g)	688	463	18.0	5.9	150	727	0.38
Fibre (g)	234	145	3.0	0.8	26	138	0.43
Sodium (mg)	13,295	8,690	-	-	10,050	10,050	0.97
*First shop minus second shop							

UKVS questionnaire responses

Following the completion of the UKVS shopping tasks, participants completed a questionnaire embedded into the UKVS software asking about their experience of using the UKVS. Participants recorded their response to statements such as "The UKVS was easy to use" on a 5-point Likert scale. Participant responses are recorded in Table 10. The post-shop questionnaire also asked participants how often they end up doing a next-day shop like the ones in the study. There was considerable variety in the responses, as shown in Table 11.

Fourteen participants reported that there were products that they could not find in the UKVS. Several products listed by participants were available in the UKVS (e.g. crumpets, eggs). Other products that participants listed were ones that were similar to existing products (e.g. low-fat cheddar, "orange juice with bits"). Several participants did not

specify specific products that they could not find, but suggested greater diversity in categories as a whole (e.g. “more fruit and veg variety”).

Table 10: Participant responses to statements about their experience of using the UKVS

	Strongly agree or agree	Neither agree nor disagree	Disagree or strongly disagree
The VS was easy to understand	16	1	2
The products I purchased in the VS resemble my usual food purchases	14	2	3
I could find my way around the VS easily	14	3	2
The VS contained sufficient product variety	7	10	2
I felt I had sufficient product choice options in the VS	3	12	4
Stock in the Virtual Supermarket is representative of stock in an actual supermarket	13	4	4
I could find all the products that I wanted to find relatively easily	13	3	3
I could imagine doing my real-life shopping in the VS	13	3	3
Prices in the VS are similar to prices in an actual supermarket	15	3	1
In the next-day shopping tasks, I spent the same amount of money in the Virtual Supermarket as I would have in the same task in real life	12	6	1
In the next-day shopping tasks, I bought the same sorts of food and drink as I would have in the same task in real life	15	2	2
VS: Virtual Supermarket			

Table 11: Usual frequency of next day shops

	N
A few times per year	1
Every few months	1
Monthly	3
A few times a month	5
Weekly	5
A few times a week	4
Every day	0

Interview responses

Participants were positive about their experience of the UKVS when interviewed. The majority of participants (n= 15) referred to the realism of the UKVS as its best feature, either of the experience as a whole or of specific elements (e.g. layout). Other features participants listed as the best aspect of the UKVS were the ease, speed, or fun of using the UKVS. Two participants noted that they thought the best feature of the UKVS was that it was interesting, reflecting on their own shopping behaviour.

There was less agreement across the participants about the worst aspect of the UKVS. Eight participants said that the worst aspect was the limited product selection. Eight participants gave an answer in relation to navigating around the store (e.g. difficulties seeing products on the bottom shelf, trouble in finding items). Three participants said that the worst aspect was something about the information provided to them (e.g. that they were unclear about what was meant by a next-day shopping task).

I asked participants whether there was any advice that they would provide to future participants. I prompted participants that the purpose of this question was to elucidate whether there were any additions/changes required to the "Frequently Asked Questions" or participant information. From this, I established that many of the software testing participants had not read the PDF document containing detailed participant instructions that was available on the website. This suggested that the UKVS was generally straightforward to use without further instructions but that the web link to access detailed participant instructions was not obvious.

Following the discussion about the best and worst features of the UKVS, I presented some statements to the participants similar to those contained within the software and asked them to rank them on a 5-point Likert scale. The results are displayed in Table 12. Participants generally responded that the UKVS was easy to use, that they understood the instructions and questionnaires, that it was not confusing being a participant in the study, and that they could find their way around easily. Whilst several participants had noted the product selection as the worst feature of the UKVS, over half the sample agreed they were able to find everything that they wanted in the UKVS. When participants gave a neutral or negative response to a statement, I asked whether there were changes that would improve that aspect of the software.

Finally, I asked participants what they would change if they could change anything about the software. Participants generally responded with a solution to the aspect of the UKVS that they had regarded as the worst, e.g. by suggesting increased product choice if they'd

listed poor choice as the worst feature. The suggestions made by participants were added to a list of possible software modifications.

Table 12: Participant responses to interview statements

	Strongly agree or agree	Neither agree nor disagree	Disagree or strongly disagree
The VS was easy to use	19	1	0
I understood the instructions provided to me in the VS	17	2	1
I could find my way around the VS easily	18	2	0
I understood how to buy things in the VS	19	1	0
I understood the questionnaires in the VS	19	1	0
I could find everything I wanted in the VS	11	4	5
I found it confusing being a participant in this study	0	2	18
VS: Virtual Supermarket			

Post-testing modifications

Based on interviews with software testing participants, I compiled a list of possible changes to make to the UKVS that would improve the participant experience. Minor changes were made to the content and layout of participant information. In response to noting the additional steps in the download procedure for MacOS computers, additional download instructions were added to the MacOS instructions. I also expanded participant

information to say that the software is designed for Windows and Mac users but that those with other operating systems are welcome to complete the study if they are able to run the software on their machines. Other changes included adding information on navigating around the UKVS to the Downloads page of the website and adding to the Frequently Asked Questions section. Within the UKVS software, additional information was added to clarify the next-day shopping task procedure. Minor changes were made to the UKVS internal environment (e.g. changes to display of nutritional information to add product size details).

Strengths and limitations

The development of the UKVS used data from a variety of sources in order to attempt to create a virtual shopping experience reflecting a real life experience. This section describes the strengths and limitations of the development process and then the strengths and limitations of the software testing process.

Use of an existing Virtual Supermarket

The use of the existing Dutch VS as the basis for the UKVS meant that the resources required for development were considerably smaller than if the UKVS had been developed from scratch. The main limitation of this approach was that the layout and total number of products were restricted to the existing capabilities. The existing Dutch layout had features that were compatible with the three stores surveyed in Oxford which suggests the layout is similar to that of real small stores in the UK. For example, the presence of special fruit

and vegetable stalls and a bakery section in the Dutch layout is present in real small stores in the UK.

Product selection

There are over 500 products available for participants to choose from in the UKVS. Initial observations from face validity checks and the software testing study confirm that it is possible for participants to perform shopping tasks in this environment. The number of products in the UKVS is limited compared to a real store; the three real smaller stores contained between 2600 and 3300 food and beverage products. Previous experimental studies identified in the systematic review included between 60 [122] and 708 [59,136], when the study that took place in a real supermarket is excluded [121]. Including the impact of generic product names, the UKVS has a comparable product range to the existing studies with the largest selection.

The use of real small supermarket stores ensured that the categories available reflected those that would be available in smaller supermarkets. Small supermarkets were chosen as the basis of the UKVS as the existing layout reflected that of a smaller store. I chose not to survey large stores or online databases to determine the product range owing to inherent differences between these environments and that of the UKVS. In addition, the shelf space devoted to particular categories may not be equivalent between large and small supermarkets owing to differing constraints. For instance, certain categories available in large supermarkets are not found in smaller stores (e.g. fresh meat and fish

counters). The distribution of food categories in large and small stores may also differ owing to different resource constraints such as storage space and regularity of deliveries.

The use of an online supermarket platform to gauge the variety of products available was advantageous as it enabled remote data collection and remote product selection decision making. The online supermarket chosen was one of the UK market leaders and the same chain as the small supermarket chain that formed the primary basis for the shelf space allocation. This facilitated mapping online categories to the food categories represented in the shelf space allocation.

Top selling products within categories were generally the ones chosen to attempt to ensure that participants are able to purchase the products they normally would despite the smaller selection available. However, I relied on the supermarket website's classification of 'top sellers'. It is unclear over what timeframe a product would be classified as a 'top seller' and whether this was based on the total sales data, online sales data, or other measures (e.g. manufacturer payments to retailer). In addition, whilst sorting by top sellers showed the ranking of various products, the absolute differences in the popularity of products were unknown.

Next-day shopping task

The UKVS differed from previous versions of the Virtual Supermarket where participants were asked to conduct only one (weekly) shop, having been randomised to either the control or an intervention condition. In the systematic review, I had identified a number of

studies where participants conducted several shopping tasks within the same experimental session. It seemed advantageous to include this capability in the UKVS for several reasons.

The ability to conduct multiple shopping tasks within the same experimental session was added to reduce the "Waitrose Effect", namely a lack of response to price changes owing to an impression that the participant is shopping in a supermarket chain that is generally more expensive overall. At this stage, it is not clear whether the Waitrose Effect might make an impact (and if so, how) on participants. However, this seemed a relevant concern as this thesis had the explicit aim of capturing differential effects, and would therefore include participants whose usual supermarkets may vary considerably in their usual prices. As an example, the price of a 200g pack of mushrooms ranged from 49p in Aldi to £1.19 in Waitrose (for the cheapest variety) at time of writing.

Other advantages of moving to participants conducting multiple shopping tasks are that it enables within-subject variance of purchasing decisions to be measured. The main disadvantage of asking participants to conduct multiple shopping tasks is that the amount of time participants are required to spend increases as the number of tasks is increased. This was compensated for by changing the shopping task to a next-day shop (rather than a weekly shop format). Next-day shopping tasks were used in three of the eight studies included in the systematic review [35,59,126]. In addition, the selection of products is designed to be much more comparable with a small supermarket experience and therefore it made sense to adapt the task to be in line with consumers' use of smaller stores. Also,

UK data suggest that an increasing proportion of grocery spend is due to “top-up” shops compared to “main shopping trips” [137].

The main disadvantage of moving to a next-day shopping task was that the total amount of purchases, and purchases at each category level will be smaller than under a weekly shop task as less food is required. This has implications for the analysis of intervention trials as a greater percentage of non-consumers might be expected at the food category level. The extent of this problem is likely to depend upon the nature of the intervention being tested and is examined further in the following chapter.

Strengths and limitations of software testing

Software testing enabled me to collect feedback on the UKVS, and rectify problems prior to recruitment for the feasibility study. Strengths of the software testing procedure included that the procedure reflected the planned procedure for future UKVS studies, and the addition of interviews enabled me to tease out which changes to the software could make a meaningful difference to the participant experience. The main limitation of the software testing phase was that the convenience sample meant that participants represented only a fraction of the total demographic spread I hoped to recruit in the feasibility study. For example, there were no software testing participants who were over 50 years of age. In addition, the average household size of the sample was smaller than the UK average [138].

The positive responses of software testers suggested that the process of developing the UKVS was successful. Software testers responded favourably to the UKVS; the realism of the software was frequently mentioned as a positive feature and many of the participants gave examples of behaviours in the UKVS that were similar to their behaviours in real life. For example, one participant noted that they found it difficult to avoid adding discretionary items to their cart on their way around the store. Other participants explicitly stated that they felt that they were doing "what they would normally do" when completing the virtual shopping tasks. The positive feedback from software testing participants indicated that the UKVS is immersive and prompts participants to go about their shopping in a typical way.

Conclusion

This chapter has outlined how the UKVS was developed. The aim of the development process was to replicate a real life small supermarket experience as accurately as possible within the resource constraints. Software testing participants responded favourably to the UKVS, indicating that they found the software realistic and that they felt that their behaviour was reflective of their actual shopping experience. Feedback from software testing participants helped to improve the software by increasing the clarity of the instructions provided in relation to the shopping tasks and download procedure.

Chapter 5: The feasibility of using the UK Virtual Supermarket to assess food purchases in different income groups

This chapter describes a feasibility study that was designed to assess the effectiveness of online methods of participant recruitment, data completion rates, and shopping variability in the UK Virtual Supermarket (UKVS), by household income. This UKVS feasibility study revealed important limitations with recruitment and retention in the UKVS. However, the results suggest that the UKVS would be a feasible tool for examining purchasing behaviour in different income groups if these issues surrounding recruitment were resolved.

Background: the need for a feasibility study

There were two main reasons for conducting a feasibility study. Firstly, as no previous studies involving a virtual supermarket had been conducted in the UK, it was important to examine whether the methods that had been successfully employed in the Netherlands and New Zealand were appropriate for the UK context. Secondly, previous Virtual Supermarket studies had not been used to examine income group differences explicitly. Therefore, it was important to assess the feasibility of using the UKVS for this purpose and gather initial data to inform the sample sizes and methods for further studies. This chapter describes the feasibility study and how future UK studies can be informed by the findings.

Use of the UKVS in the UK context

Several elements of the UKVS were novel compared to previous studies conducted in virtual supermarkets. Firstly, the population targeted to take part in UKVS studies is different to that of experiments in the Netherlands and New Zealand. Countries differ in the availability of particular food groups [139], and populations differ in their dietary patterns [140,141], socioeconomic associations with dietary factors [142], and price elasticities [143]. Differences in diet related variables meant that a UK specific Virtual Supermarket study was necessary to enable the calculation of sample sizes that would be required for randomised controlled trials of pricing interventions.

The recruitment methods available in the UK also differ from those that have been used for previous Virtual Supermarket studies. The free online participant recruitment website available in the UK (*www.callforparticipants.com*) is different from websites used in previous Virtual Supermarket studies. In addition, for the UKVS feasibility study, I decided to recruit through Facebook due to its wide reach and previous use to recruit participants to research studies related to health behaviours [144,145]. Whilst the experiences from previous Virtual Supermarket studies could be used to generate an approximate timeline, the resources required to recruit a sufficiently large and diverse sample of UK based participants could not be guaranteed. This feasibility study was crucial in providing the first UK specific experience of recruitment for a Virtual Supermarket study.

The content of the UKVS differs from the Dutch and New Zealand Virtual Supermarkets in both the product selection available and in the task participants were assigned, as

described in Chapter 4. The software testing described in the previous chapter addressed this issue; it informed the adaptation of the information given to participants prior to taking part in the study and therefore helped to ensure that the UKVS was usable. The addition of multiple shopping tasks within the same experimental session was a novel feature of the UKVS. It was anticipated that this might have an impact on participant burden, and therefore on dropout rates. The average dropout rate observed across existing Virtual Supermarket studies is around 20% [123,131,132,146]. However, in a New Zealand based validation study that required participants to complete multiple shopping tasks over a 3-week period, only 60% of participants completed required elements of the study procedure to be included in the complete case analysis [133]. Prior to conducting this feasibility study, the effect of the change in study procedure specific to the UK setting and population on dropout rates was unclear.

Finally, the feasibility study was required to assess the sample sizes for randomised controlled trials in the UKVS. The effect of a fiscal intervention to improve diets can be assessed by several outcome measures including change in the quantity of foods purchased, nutrient content of the basket, and food expenditure. The choice of outcome measure will depend on the type of fiscal intervention implemented. For example, if the purpose of an intervention is to change consumption of a nutrient through price changes applied differentially to a range of foods, nutrient level measures will be more appropriate. However, if a fiscal intervention aims to reduce consumption of a particular food group (e.g. SSBs) then looking at the change in the quantity of this particular food purchased will

be most relevant. In Chapter 2, I argued that measures appropriate for the UK context are likely to target a broad range of different foods. Therefore, it is important that experimental studies are powered to look at a range of outcome measures to enable an assessment of unintended consequences.

Regardless of the outcome measure, an assessment of the baseline variability (both within subjects and across the sample as a whole) is required in order to inform sample size calculations. A larger sample size would be required to test an outcome with a high level of variability in the primary outcome measure than one with low variability, as this will increase standard errors around the primary outcome for both intervention and control arms. This feasibility study was needed in order to gauge variability across a range of possible outcome measures to inform the sample sizes that would be required for trials of different food pricing interventions. UKVS purchasing data from this study also helped to establish the kinds of interventions that were suitable for testing in the UKVS.

Accounting for income group differences in the UKVS

A feasibility study was also required to examine the suitability of the UKVS for examining differential responses to food price changes across income groups. Whilst income was the most studied personal characteristic identified in the systematic review [115], there were no experimental estimates from the UK. In addition, the systematic review suggested that income group differences in responses to food price are likely to be context specific and dependent on the products or food categories targeted by the pricing intervention.

Assessing income group differences in responses to food price changes in the UKVS may be problematic for a number of reasons not addressed in previous studies. Firstly, recruitment and retention rates can vary by participant group, possibly linked to differences in ease of participation. For example, the New Zealand SHOP study found that there were higher dropout rates in Māori and Pacific participants and it was argued that this was due to these participants being less familiar with the store card system by which data was collected [127]. The lack of familiarity in the SHOP study was partially due to the need to recruit Māori and Pacific participants into the store card system upon their recruitment into the study. This suggests that recruitment methods and the differences in the ease of participation across population sub-groups may result in differential dropout. This feasibility study was required to test whether the recruitment strategies led to equal recruitment across different income groups, and whether there were differences in the ease of participation by income that could bias the findings through differential dropout rates.

Secondly, the extent to which an experimental study accurately reflects reality may vary by participant group. In the context of the limited product selection in the UKVS, the distribution of products across value, own-brand, and branded products may or may not be an accurate reflection of that distribution in a participant's usual supermarket. For example, the total cost of a basket of foods in the UKVS might be higher than a participant would pay in real life if value versions of particular foods are not represented in the UKVS, or the reverse for participants who typically purchase speciality versions of particular

foods. In addition, the next-day shopping task assigned may be more or less realistic for different households, and this might be linked with household income. For example, those who shopped in low-cost supermarkets in the UK had a higher number of shops and visited more different store chains than those who shop in high-cost stores indicating that supermarket use may vary by income [147].

Research questions

This feasibility study aimed to collect data pertaining to uncertainties in recruitment rates and variations in purchases by income group. This data could then help to determine the feasibility of using the UKVS to examine income group differences in responses to a range of food price change scenarios. The feasibility study was framed around the following research questions:

- How effective are online methods, plus snowballing, for the recruitment of participants for a UK Virtual Supermarket study?
    - Do recruitment rates vary by income group?
- What are the dropout rates for a UK Virtual Supermarket study?
    - Do dropout rates vary by income group?
- How much variability is there in next-day shopping behaviour in the UK Virtual Supermarket?

    - Does variability in next day shopping behaviour vary by income group?

- How do participants report ease of participation and appreciation of the UK Virtual Supermarket?

    - Does ease of participation and appreciation vary by income group?

Methods

The full protocol for the feasibility study is included in Appendix (iii). Briefly, the feasibility study aimed to recruit 100 participants across three income tertiles to conduct two next-day shopping tasks in the UKVS. Participants were asked to complete questionnaires to establish demographic characteristics and their responses to the UKVS. I recorded participants' purchases at a food category and nutrient level to establish the variability in purchases; this was to inform sample size calculations for future studies. I compared participants' responses to the UKVS across income groups to establish if there were differences in acceptance by income group. I recorded when participants were enrolled in the study and the method by which they found out about the study to determine the effectiveness of different recruitment strategies.

Justification for methods of recruitment.

Two main recruitment strategies were trialled in this feasibility study. Firstly, an advert was placed on a free online participant recruitment website (*www.callforparticipants.com*). I

contacted researchers who previously used this website and whose advertisements appeared similar to the UKVS studies in terms of the incentive offered (prize draw, see below) and time to complete the study (45-60mins). No quantitative estimates of the recruitment rate using the site were found. However, this website is similar to one used for a New Zealand Virtual Supermarket study which succeeded in recruiting approximately 90 participants over a 6 week period (unpublished).

The second recruitment strategy was the use of Facebook adverts. Facebook ads are flexible and can be amended at any time. The population targeted can be adapted to the needs of the researcher. In this case, I allocated a total budget of £250. The population targeted was restricted to adults (18+) who live in the UK and use Facebook in English. Based on the findings of Lohse (2013) [148] and details provided by Facebook as part of the advertisement set up process, I expected a total of 107 participants to be recruited over the course of the 4 week timeframe for the advert at a cost of £250.

In addition, participants were encouraged to pass on the details of the study to their friends and family upon completion in an attempt to boost the numbers recruited (snowballing technique). Recruitment took place over 8 weeks starting in March 2016; because the effectiveness of the two main recruitment strategies was not known, additional recruitment strategies were planned if an insufficient number of participants had been recruited by a certain time point.

The aim was to recruit at least 20 participants in each income tertile, and up to 100 participants in total. Households were classified according to the modified OECD equivalised income scale used by the Office for National Statistics [149]. Equivalised household income was taken as the midpoint of the categorical ranges provided in the recruitment questionnaire, superseded by exact measures provided in the pre-shop questionnaire if available. Participants in the sample were assigned to income tertiles based on their equivalised household income relative to the UK population as a whole.

To be eligible to take part in the study, potential participants needed to be the primary household shopper (responsible for half or more of the household shopping), over 18 years old, with access to a computer with a working internet connection and have access to an email address. Potential participants also needed to be confident in using basic computer skills such as MS Word and the internet. Participants were excluded from taking part if another member of the household had signed up to take part as analysis was conducted at the household level. These criteria were the same as the criteria used in other Virtual Supermarket studies.

Participants completed online consent forms and were automatically sent the UKVS software and instructions through a dedicated website and email address. The automation of the process was intended to reduce dropout by reducing the delays between participants consenting to take part in the study and receiving the UKVS software. Participants were sent email reminders asking them to complete the study procedure one and two weeks after consent if they had not completed the study procedure. Email

reminders have previously been shown to increase response rates but it has been suggested that more than two reminders increases the number of people who view the email as spam [150].

Once participants had downloaded the UKVS software, participants were asked to conduct two next-day shopping tasks in the Virtual Supermarket imagining that they had no food at home. As in the software testing phase, participants were told to imagine that the second shopping task took place one week after the first shopping task. There were two questionnaires integrated into the UKVS software that participants were required to complete, one prior and one post the shopping tasks. The pre-shop questionnaire collected information about the characteristics of the household and typical family food shopping behaviours, including typical food budget and usual store. The post-shop questionnaire collected participants' experiences of using the UKVS and asked whether participants would be happy to be contacted to discuss their experience of using the UKVS. Whilst online surveys tend to result in more responses and longer responses to open-ended questionnaires than is typical of traditional mail or telephone surveys [150], I wanted to ensure that the flexibility of re-contacting participants was available in case responses to the UKVS were not positive. The full instructions provided to participants, including the embedded questionnaires, are also given in the Appendix (iii).

Participants' budgets were not capped in the feasibility study, but they were prompted to stay within their usual shopping budget. I chose not to cap the budget in the feasibility

study to enable comparisons of participants' self –reported usual spend with the amount spent in the UKVS.

The feasibility study received ethical approval from the University of Oxford Medical Sciences Inter-Divisional Research Ethics Committee (reference no. MSD-IDREC-C1-2013-149).

Outcome measures

Outcome measures were collected in relation to four domains: recruitment, participant characteristics, participant purchases, and participant feedback on the UKVS. For recruitment, the number of participants was recorded for each week of study recruitment in addition to participants' self-reported method of having found out about the study.

Participant characteristics that were recorded as part of this study included both individual and household level characteristics. Questions on socio-demographic variables were collected by asking participants the same questions as in large national surveys. In addition to socio-demographic characteristics, participants were asked about their shopping habits (including usual spend, usual supermarket, proportion of food purchased in supermarkets). Shopping habit related variables could be used to adapt eligibility criteria, exclude participants, or adapt the study procedures if, for instance, participant feedback is strongly related with shopping habits.

Participants' purchases were recorded in terms of the total amount spent, and the amount spent per food category. In addition, purchases were combined with nutritional

information to determine the total nutrient content of the basket for the 'big 8' nutrients (total energy; grams of protein, carbohydrates, sugars, fats, saturated fat, salt, and fibre). At the food category level, the percentage of the sample that purchased the food category and mean grams/litres purchased (by purchasers) were recorded for each food category. Purchasing values were used to produce estimates of the number of participants that would be required to detect selected changes in purchases of key food groups and nutrients.

Finally, participant feedback on the UKVS itself was collected. In previous Virtual Supermarket studies, participant feedback on the ease and understanding of the task was used to exclude participants from the analysis. In the feasibility study, I was interested in whether there were differences in feedback based on participant income, and what the feedback suggested about possible changes to make to the software for randomised controlled trials.

Changes to the planned protocol

Owing to the poor performance of the Facebook advertisements in recruiting participants in the first two weeks of the recruitment period, the adverts were suspended for one week in order to re-evaluate the study website. This included reducing the number of questions asked at registration and providing checkboxes rather than textboxes for some questionnaire variables, including household income. Small changes were made to the website to try to improve entry to the study. Recruitment through Facebook remained low

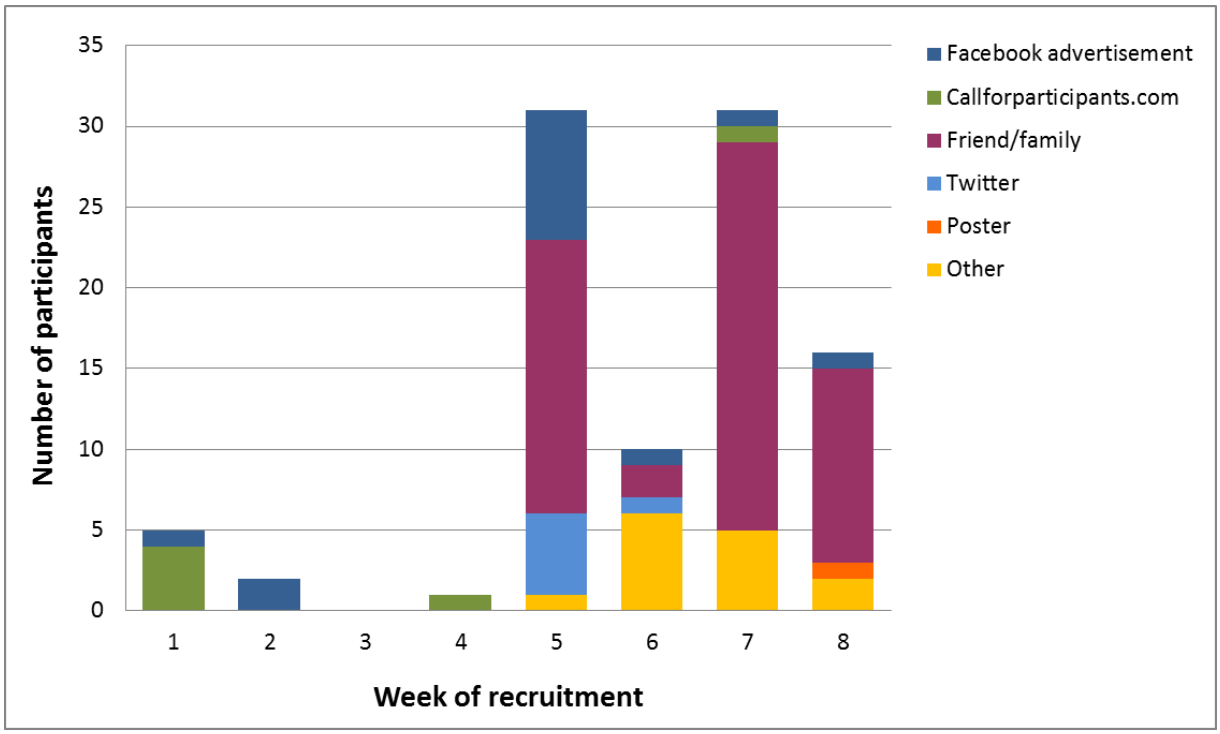
in week 4 and therefore I started recruiting through other methods. I put up posters in a variety of locations around Oxford, including in cafes, University departments, and shops. I emailed details of the study to leaders of clubs and community groups in Oxford and beyond. Finally, I also posted details of the UKVS study on my personal Facebook and Twitter pages and encouraged people to pass on details to anyone who they thought might be interested. The paid Facebook advertisements were shown for a total of 4 weeks.

Results

Recruitment

Ninety-six participants signed up to take part in the study between the 17th March and 23rd April 2016. Figure 5 shows the number of participants recruited in each week of the study, by self-reported recruitment method. No participants were recruited in week three as this was the week when the Facebook ads were suspended in order to review the study website. Those classified as being recruited through 'Friend/family' included some of my own friend/family members that found out about the study through personal Twitter and Facebook posts, but were mainly people who were not known to me personally and who had been recruited through information passed on to them by other participants.

Figure 5: Recruitment over time, by recruitment method



Differences in recruitment by equivalised income

29.6% of participants were classified as belonging to the lowest (national) income tertile, 16.3% in the middle income tertile, and 25.5% in the highest income tertile. 27.1% of the participants did not provide sufficient details for their equivalised household income to be calculated. Table 13 displays the methods by which participants were recruited by equivalised income tertile. Across all income groups, the majority of participants were recruited through friends/family.

Facebook advertisements

Facebook estimated that there were 5.4million users daily that met the advertisement target audience. In total, the Facebook advertisements were shown on 374,996 occasions

to 183,399 Facebook users. The advertisements generated 690 clicks through to the UKVS study website. Demographic characteristics for those that saw and clicked on the advertisements are shown in Table 14.

Completion

Of the 96 participants that signed up, 46 fully completed the study procedure, 2 partially completed the study procedure (only one shopping task completed), and 46 failed to complete the study procedure (non-completers). Demographic characteristics for completers and non-completers are shown in Table 15. There were significant differences in completion by household size, income, and equivalised income tertile.

Participants in the middle and high income tertiles were much more likely to complete the study than participants in the low income tertile and those whose income tertile was unknown.

Table 13: Recruitment methods by equivalised income tertile

	Equivalised income tertile			
	Lowest (n=29)	Middle (n=16)	Highest (n=25)	Unknown (n=26)
Call for participants	1 (3.4%)	1 (6.3%)	2 (8.0%)	2 (7.7%)
Facebook	5 (17.2%)	2 (12.5%)	1 (4.0%)	6 (23.1%)
Friend/family[c]	17 (58.6%)	10 (62.5%)	15 (60.0%)	13 (50.0%)
Other	6 (20.7%)	3 (18.8%)	7 (28%)	5 (19.2%)

[c] Friend/family refers to any participants who found out about the study from a friend/family. This includes some participants who I knew directly.

Table 14: Demographic characteristics of those reached through Facebook

	Number reached	Number that clicked through to study website
Gender		
- Male	106,182	503
- Female	68,751	163
- Unknown	8,467	24
Age (years)		
- 13-17[d]	32	0
- 18-24	19,479	29
- 25-34	12,763	34
- 35-44	12,095	22
- 45-54	29,506	69
- 55-64	48,826	207
- 65+	60,698	329
Region[e]		
- England	146,382	537
- Wales	11,395	46
- Scotland	20,944	79
- Northern Ireland	4,679	27

Table 15: Characteristics of completers and non-completers

	Completers	Non-completers	Total	p-value[a]
Age (years)				0.69
- Mean	38.5	37.3	37.9	
- SD	2.3	2.3	1.6	

[d] I specified that the advertisement was only to be shown to those aged 18 years or older so I'm not sure how/why a small number of those reached were <18 years

[e] There was one user who was reached while using Facebook in the UK, but then accessed the study website from Australia, and hence the total does not match the total number of clicks

	Completers	Non-completers	Total	p-value[a]
Household size				*0.03
- One	16 (33.3%)	12 (25.0%)	28 (29.2%)	
- Two	23 (47.9%)	17 (35.4%)	40 (41.7%)	
- Three	6 (12.5%)	5 (10.4%)	11 (11.5%)	
- Four or more	3 (6.3%)	14 (29.2%)	17 (17.6%)	
Responsibility for food shopping				0.27
- All	26 (54.2%)	28 (58.3%)	54 (56.3%)	
- Most	13 (27.1%)	7 (14.6%)	20 (20.8%)	
- Half[b]	8 (16.7%)	9 (18.8%)	17 (17.7%)	
- Little[b]	1 (2.1%)	3 (6.3%)	4 (4.2%)	
- None[b]	0 (0%)	1 (2.1%)	1 (1.0%)	
Computer type				0.50
- Windows 8[b]	8 (16.7%)	7 (14.6%)	15 (15.6%)	
- Windows 7[b]	17 (35.4%)	12 (25.0%)	29 (30.2%)	
- Windows Vista[b]	0 (0%)	2 (4.2%)	2 (2.1%)	
- Mac OS	13 (27.1%)	12 (25%)	25 (26.0%)	
- Other/unknown	11 (22.9%)	14 (29.2%)	25 (26.0%)	
Computer age				0.99
- < 1 year	7 (14.6%)	7 (14.6%)	14 (14.6%)	
- 1-5 years	33 (68.8%)	33 (68.8%)	66 (68.7%)	
- > 5 years	6 (12.5%)	7 (14.6%)	13 (13.5%)	
- Unknown	1 (2.1%)	1 (2.1%)	2 (2.1%)	
Recruitment method				0.11
- Call for participants[b]	3 (6.3%)	3 (6.3%)	6 (6.3%)	
- Facebook ad	4 (8.3%)	10 (20.8%)	14 (14.6%)	
- Friend/Family	32 (66.7%)	23 (47.9%)	55 (57.3%)	
- Other[b]	9 (18.8%)	12 (25.0%)	21 (21.9%)	
Income				*0.02
- £0 - £15,000	9 (18.8%)	11 (22.9%)	20 (20.8%)	
- £15,000 - £25,000	14 (29.2%)	4 (8.3%)	18 (18.8%)	
- £25,000 - £50,000	13 (27.1%)	9 (18.8%)	22 (22.9%)	
- £50,000 +	7 (14.6%)	9 (18.8%)	16 (16.7%)	
- Unknown	5 (10.4%)	15 (31.3%)	20 (20.8%)	

	Completers	Non-completers	Total	p-value[a]
Equivalised income tertile[f]				*<0.01
- Low	8 (16.7%)	21 (43.8%)	29 (30.2%)	
- Middle	16 (33.3%)	0 (0.0%)	16 (16.3%)	
- High	21 (43.8%)	4 (8.3%)	25 (25.5%)	
- Unknown	3 (6.3%)	23 (47.9%)	26 (26.5%)	

[a]Values represent p-values for chi^2 tests, apart from for age where a t-test was conducted to test for differences between completers and non-completers

[b]Grouped for chi2

*Statistically significant difference between completers and non-completers at P<.05

Participant characteristics

Further demographic details were collected within the UKVS for those that completed the study procedure (including partial completers); Table 16 displays these further demographic characteristics. The pre-shop questionnaire also asked questions regarding typical shopping behaviours, these results are presented in Table 17.

Table 16: Further demographic description of completers

Household income	
- Mean	£34,966
- SE	£4,018
Equivalised household income	
- Mean	£23,937
- SE	£2,380
Equivalised income tertile (based on LCFS tertiles)	
- Low income	8

[f] Calculated using midpoint of income group for non-completers

- Middle income	15
- High income	20
- Unknown	3
Gender	
- Male	14 (29.2%)
- Female	34 (70.8%)
Ethnicity	
- White	43 (89.6%)
- Mixed/multiple	2 (4.2%)
- Asian/Asian British	2 (4.2%)
- Other ethnic group	1 (2.1%)
Education	
- No qualifications	2 (4.2%)
- O levels/CSEs/GCSEs or equivalent	1 (2.1%)
- A levels or equivalent	3 (6.3%)
- Degree	40 (83.3%)
- Higher degree	1 (2.1%)
- Foreign qualifications	1 (2.1%)
Current work status	
- Unemployed	4 (8.3%)
- Full-time employed	18 (37.5%)
- Part-time employed	6 (12.5%)
- Self-employed	5 (10.4%)
- Looking after children/family	1 (2.1%)
- Other	14 (29.2%)
Current occupation	
- Higher managerial and professional	6 (12.5%)
- Lower managerial and professional	19 (39.6%)
- Intermediate	6 (12.5%)
- Routine	1 (2.1%)
- Never worked or long term unemployed	2 (4.2%)
- Other	13 (27.1%)
- Don't know/ Prefer not to say	1 (2.1%)

Table 17: Shopping behaviour of completers

Mean weekly household grocery budget (£) (SE)	65.10 (4.90)
Proportion of all food purchased in supermarkets	
- All	17 (35.4%)
- Most	26 (54.2%)
- Half	5 (10.4%)
- Little	0 (0.0%)
- None	0 (0.0%)
Supermarket frequency	
- Every day	2 (4.2%)
- Every other day	5 (10.4%)
- 3/4 times per week	11 (22.9%)
- Twice weekly	14 (29.2%)
- Once weekly	12 (25.0%)
- Every other week	4 (8.3%)
Usual grocery routine	
- Big shop	5 (10.4%)
- Big shop with top ups	22 (45.8%)
- Smaller shops	20 (41.7%)
- Daily purchases	1 (2.1%)
Dietary requirements	
- Yes	20 (41.7%)
- No	28 (58.3%)
Usual supermarket	
- Tesco	19 (39.6)
- Sainsbury's	14 (29.2)
- Asda	4 (8.3)
- Waitrose	4 (8.3)
- Lidl or Aldi	3 (6.3)
- Other	4 (8.3)

Participant feedback

Following the completion of the two shopping tasks, participants were asked for their feedback on the UKVS. Table 18 displays participant responses to statements relating to the ease of use, product choice, and similarity of UKVS purchases to real purchases.

Table 18: Participant perceptions of the UKVS

Statement	Strongly agree/ agree	Neither agree nor disagree	Disagree/ Strongly disagree
The Virtual Supermarket program was easy to understand	38 (82.6%)	6 (13.0%)	2 (4.3%)
The products I purchased in the VS resemble my usual food purchases	41 (89.1%)	5 (10.9%)	0 (0.0%)
I could find my way around the VS easily	42 (91.3%)	3 (6.5%)	1 (2.2%)
The VS contained sufficient product variety	17 (37.0%)	13 (28.3%)	16 (34.8%)
I felt I had sufficient product choice options in the VS	18 (39.1%)	10 (21.7%)	18 (39.1%)
Stock in the VS is representative of stock in an actual supermarket	31 (67.4%)	6 (13.0%)	9 (19.6%)
I could find the products I wanted to find in the VS relatively easily	36 (78.3%)	8 (17.4%)	2 (4.3%)
I could imagine doing my real-life shopping in the VS	21 (45.7%)	8 (17.4%)	17 (37.0%)
Prices in the VS are similar to prices in an actual supermarket	26 (56.5%)	14 (30.4%)	6 (13.0%)
In the shopping tasks, I think I spent around the same amount of money in the VS as I would have in the same task in real life	27 (58.7%)	12 (26.1%)	7 (15.2%)
In the shopping tasks, I bought the same sorts of food and drink as I would have in the same task in real life	41 (89.1%)	4 (8.7%)	1 (2.2%)

Items missing in the UKVS

36 participants (78.3%) reported that there were items that they could not find in the UKVS. Participants were prompted to list specific items that they couldn't find. Twelve participants (26.1%) listed a single missing item, 11 (23.9%) gave a list of items, 8 (17.4%) made general comments relating to variety (e.g. "meat", "some types of cereal, some types of vegetables"). The remaining 14 (30.4%) made no additional comments. Of the 46 specific products listed by participants, 9 (19.6%) were actually available in the UKVS.

Next-day shopping task

The majority of participants appeared to have adhered to the instructions for the shopping tasks. In the post-shop questionnaire, 14 (30.4%) participants reported that it would be one day until they next needed to go to the shops to buy food and drinks, 24 (52.2%) participants reported it would be 2-3 days, 3(6.5%) reported 4-6 days, and 5 (10.9%) reported it would be one week or more. Typical weekly budget correlated with the amount spent in shopping tasks (r=0.56).

The concept of a next-day shop appeared familiar to most participants. 23 (50%) participants reported that they do next-day shops monthly or more often, 10 (21.7%) reported doing next day shops at least a few times per year. However, 7 (15.2%) reported that they never did next-day shopping tasks.

Variability in purchases

Food categories

Details of food category level purchases in the UKVS are shown in Table 19. Foods were broadly grouped according to the Eatwell Guide [53]. Participants spent an average of £29.53 per shop (SD 19.55). On average, participants spent £5.80 (SD 13.90) less in the second shop compared to the first shop. Participants spent most on products in the `Beverages' category and least on 'Sugar products'. Nearly all participants made purchases in both the 'Bread and cereal products' and 'Fruits and vegetables' sub-categories. Only a third of participants made purchases in the 'Sugar products' category.

Nutrients

Table 20 displays mean calories, protein, fat, saturated fat, carbohydrate, sugar, and fibre purchased in the UKVS; the mean difference between the two shopping tasks is also given to give an indication of within-participant variability. There was considerable variation in the mean nutrients purchased in the UKVS, and this was apparent in all three income groups. The variability in the differences between the two shops was a little smaller, but remained high.

Table 19: Food category purchases in the UKVS

	% participants that were purchasers		Amount spent (£)		Grams purchased	
	Shop 1 (n = 48)	Shop 2 (n = 46)	Mean† (SD)	Mean difference (SD)*	Mean† (SD)	Mean difference (SD)*
Bread and cereal products	96	93	4.88 (3.31)	1.22 (3.30)	2056 (1190)	457 (1507)
Fruits and vegetables	96	96	5.24 (3.31)	0.72 (3.02)	2696 (1790)	217 (1626)
Meat and fish	75	83	5.28 (3.30)	-0.11 (4.58)	765 (485)	-47 (777)
Milk and dairy	90	83	4.71 (3.33)	1.12 (2.61)	2061 (1444)	390 (911)
Sugar products	33	37	1.54 (1.18)	-0.14 (0.92)	370 (432)	-67 (336)
Beverages	85	67	7.66 (13.61)	2.47 (9.56)	2418 (5217)	345 (1150)
Composite foods/ miscellaneous	83	76	3.83 (2.79)	0.51 (3.03)	746 (503)	129 (655)
Total			**29.53 (19.55)**	**5.80 (13.90)**	**10123 (6743)**	**1424 (4091)**

* First shop minus second shop

† Values represent means for the participants that made purchases in the category

Table 20: Nutrient quantities purchased in the UKVS (across all completers)

Mean amounts purchased* (SD)				
	All (n = 46)	Lowest income (n = 8)	Middle income (n = 15)	High income (n = 20)
Kcal	14,479 (8,742)	10,247 (5,489)	16,354 (8,859)	14,282 (9,878)
Protein (g)	836 (969)	1,087 (1,996)	941 (792)	632 (442)
Fat (g)	541 (353)	334 (240)	643 (335)	533 (403)
Saturated fat (g)	194 (125)	117 (91)	235 (130)	183 (129)
Carbohydrate (g)	1,706 (1140)	1,155 (547)	1,830 (1195)	1,764 (1275)
Sugar (g)	665 (549)	592 (714)	684 (491)	645 (545)
Fibre (g)	214 (153)	203 (208)	238 (174)	195 (128)
Sodium (mg)	13,750 (8,290)	9,634 (4,545)	15,452 (9,594)	13,829 (8,607)
Mean percentage energy from selected macronutrients* (SD)				
	All	Lowest income	Middle income	High income
Protein	22.4 (17.6)	32.5 (39.8)	20.5 (7.5)	19.6 (8.2)
Fat	33.0 (9.9)	29.2 (11.9)	36.8 (10.5)	31.6 (8.6)
Saturated fat	11.8 (4.3)	10.8 (5.61)	12.9 (4.7)	11.1 (3.6)
Carbohydrate	47.2 (9.4)	47.0 (14.1)	43.4 (7.8)	49.9 (8.1)
Sugar	18.7 (9.1)	22.0 (16.1)	15.7 (5.0)	19.7 (8.1)
Fibre	3.0 (1.1)	3.7 (2.02)	2.8 (0.9)	2.9 (0.5)
Mean difference between the two shops (SD)*				
	All	Lowest income	Middle income	High income
Kcal	1,825 (6,732)	-238 (2,728)	2,437 (6,927)	1,894 (7884)
Protein (g)	53 (855)	-497 (1,322)	220 (1,006)	141 (401)
Fat (g)	62 (279)	-51 (126)	36 (271)	86 (289)
Saturated fat (g)	15 (123)	-19 (44)	-10 (113)	25 (119)
Carbohydrate (g)	259 (1,192)	242 (569)	469 (1,434)	133 (1,286)
Sugar (g)	63 (409)	101 (272)	163 (421)	-26 (466)
Fibre (g)	27 (113)	-46 (144)	43 (126)	45 (89)
Sodium (mg)	2,314 (7,475)	-299 (3,742)	3,973 (10,185)	1,560 (5,712)

*First shop minus second shop

*Average of the average of two shops across participants

Sample size calculations for future studies

The purchasing data from this feasibility study provides details on the number of participants that would be required to test various pricing interventions in the UKVS. I estimated the total sample sizes that would be required to detect a 5%, 10%, and 20% change in nutrient purchases using ANCOVA methods in a full trial in the UKVS. I used the –power twomeans- command for estimating sample size in STATA 14 [151], assuming power = 0.8 and alpha = 0.05. These values were then adjusted to the sample size that would be required for ANCOVA using the Borm and colleagues method that incorporated estimates of the correlation between the two shops for the nutritional variables [152].

Table 21: Sample sizes required to detect nutrient changes in randomised controlled trials using the UK Virtual Supermarket

	Sample size required		
Outcome measure	5% change	10% change	20% change
Fruits and vegetables (g)	2,511	628	158
Energy (kcal)	2,410	605	152
Protein (g)	11,629	2,909	729
Fat (g)	2,844	710	180
Saturated fat (g)	4,420	1,106	278
Carbohydrates (g)	5,623	1,408	354
Sugars (g)	3,819	959	242
Fibre (g)	2,693	675	171
Sodium (mg)	2,083	522	131

Discussion

Participant feedback on the UKVS was positive and self-report data suggests that the UKVS did reflect participants' real purchasing decisions. This suggests that it would be feasible to use the UKVS for randomised controlled trials of HRFTS. However, there was a low recruitment rate and high dropout rate and this needs to be addressed prior to the conduct of full trials using the UKVS. This study also suggests that the UKVS could be used to examine the differential impacts of HRFTS by income group as participants from all income groups responded favourably to the UKVS.

Recruitment and retention

The feasibility study revealed a number of issues with participant recruitment and retention in the UKVS context. Facebook advertisements were the main recruitment strategy but very few individuals who clicked on the advertisements went on to become actual participants. The majority of participants were recruited by hearing about the study through friends/family. This suggests social interaction might be important to meet sample size requirements in future UKVS studies.

The main limitation of this study was low completion of the study procedure. In addition, many of the reasons for non-completion were not known. Completion in previous Virtual Supermarket studies was around 80% [123,131,132,146], with a 60% completion rates observed in the NZVS validation study where participants had to complete a series of shopping tasks over a three week period [133].

Where information was provided, non-completion of the study appeared to be down to two main factors: difficulty downloading the software and incorrect entry of email address. Future studies could maximise completion by putting additional checks in place to ensure participants receive user details and adapting the software to be entirely web-based to mitigate against download problems. Personal communication with SURFsara suggests that this would cost €10,000-€20,000 and may result in participants requiring higher computing requirements than the current version.

One method of improving recruitment and retention may be to enable participants to take part in the study in person rather than remotely. The relationship of completion with household income, and participant feedback on problems with the download procedure indicate that some participants may need more support to take part in the study. The sample in this study had high levels of education, 85.4% of participants had degree level or above education compared with 27.2% of adults in England and Wales [153]. This feasibility study has shown that future UKVS studies may warrant a combination of techniques, particularly when aiming to reach low income populations who may have lower levels of education and poorer access to computing facilities than those in higher income groups. Participation in UKVS studies could be made more accessible using mixed recruitment approaches where participants have the option of remote participation or completing the study procedure at set locations where both computers and assistance from researchers is available.

Despite a high number of clicks to the study website from Facebook, few people were recruited. In addition, some participants that reported to have been recruited via Facebook advertisements were probably recruited through Facebook posts about the study from friends/family and not the paid adverts as they were recruited to the study after the advertisements had stopped. In the New Zealand PriceExaM study that was recruiting in the same time period [154], 518 participants were recruited from 1,224 clicks to the study website through Facebook [Waterlander, personal communication]. The NZVS advertisement contained a video and the incentive was a guaranteed NZ$40 payment for the completion of 5 shopping tasks over 5 weeks. Future UKVS studies could consider a guaranteed incentive structure and incorporating videos into advertisements to see whether the recruitment differences reflect these study features or international differences in willingness to participate.

Participant experience

Feedback from completers on their experience of using the UKVS was generally positive: completers found the study easy to use and thought that their purchases were similar to their usual purchases. These responses, coupled with previous data from the New Zealand Virtual Supermarket validation study [133], provide an initial indication that results from UKVS studies would be externally valid. Future studies could consider expanding the assessment of the external validity of the UKVS and quantifying the extent to which virtual purchases align with actual purchases and consumption behaviour. One approach could be to recruit participants from an existing scanner survey sample and compare virtual

purchases with equivalent historical purchases. For example, comparing next-day and weekly virtual shopping tasks with matched real shopping tasks where participants purchased food for a similar time period.

Completers across all three income tertiles appeared to have similar responses to the UKVS; this suggests that if completion rates were improved the UKVS would be suitable for examining the impacts of interventions across different income groups. Whilst feedback was less positive in relation to product choice, nearly half of participants could imagine doing their real life shopping in the UKVS suggesting that the software is suitable for examining purchasing behaviour.

Purchasing data

This feasibility study collected purchasing data across a broad range of outcome measures that could be relevant to examine in a trial of pricing interventions. The data from this feasibility study can therefore be used to establish sample size for a range of different purchasing interventions. There was high variability in purchases across all outcome measures: spending and grams purchased at the food category level, and nutrient quantities purchased. I estimated sample sizes that would be required to detect 5%, 10%, and 20% changes in purchases of selected nutrients. Large sample sizes would be required in order to test the impact of HRFTS on purchases in the UKVS. For example, to detect a 5% change in fruit and vegetable consumption (approximately 1.5 portions) over 2,500 participants would be required.

The proportion of participants that purchased products in particular food categories ranged considerably: nearly all participants made purchases in the 'Bread and cereals' and 'Fruits and vegetables' categories but only a third made purchases in the 'Sugar products' categories. Purchasing data also reveals the types of intervention that are more and less suited to being examined in the UKVS environment. The majority of participants made purchases in the majority of food categories in this feasibility study. This suggests that the UKVS would be an appropriate environment to examine the impacts of interventions that target a broad spectrum of foods. However, the UKVS is less suited to trials of pricing interventions that target some specific food categories. For example, only one third of participants made purchases in the 'Sugar products' category which included chocolates and confectionery. This means that the impact of price changes on chocolates and confectionery would be estimated with poor precision in UKVS studies.

The low completion rate meant that there was not sufficient data to examine income group differences across all purchasing variables. Whilst income group differences in the nutritional content could be compared (all participants had values for e.g. total kcal), it was not possible to assess differences in purchases across food categories as the sample sizes were too small to provide meaningful comparisons of average food category purchases by income group.

Conclusion

This UKVS feasibility study revealed important limitations with recruitment and retention in the UKVS that need to be addressed before the software can be used for a full trial of pricing interventions in the UK. The results of this study suggest that the UKVS would be a feasible tool for examining purchasing behaviour in different income groups if these issues surrounding recruitment were resolved. However, there was considerable variability in nutrient and food category level purchases in the UKVS and this suggests that the sample sizes that would be required to test pricing interventions would be large.

Part B – Modelling research

As argued from the outset of this thesis, more evidence is needed to establish the impacts of HRFTS in the UK, particularly with respect to the differential impacts of HRFTS. In Part A, I examined experimental approaches to building the evidence base around the differential impacts of HRFTS in the UK by systematically reviewing the literature, developing a UK Virtual Supermarket, and testing the feasibility of this approach for examining the differential impacts of HRFTS. This part of the thesis moves to look at an alternative approach to assessing the differential impacts of HRFTS – modelling studies. The following chapter (Chapter 6) reviews existing (modelling) literature on the differential impacts of HRFTS by personal characteristics. Using findings from the modelling review, I then conduct a modelling study that examines the differential impacts of selected health-related food taxes and subsidies in the UK (Chapter 7).

Chapter 6: A review of modelling studies that examine the differential impacts of HRFTS

This chapter contains a review of modelling studies that examine the differential impacts of HRFTS, and mirrors the systematic review of experimental studies presented in Chapter 3. This review looks at the methods that have been used to examine differential impacts, and the extent to which differential impacts have been included at various stages of the modelling process.

Introduction

Modelling studies dominate the literature on the health impacts of HRFTS [20]. Modelling of the health impacts of HRFTS proceeds in several stages: it begins with establishing the impact of HRFTS scenarios on consumer prices, this in turn has an impact on purchases that has an impact on health through changes in the consumption of nutrients and food categories. This chapter presents a review of the modelling literature to establish the extent to which the differential impacts of HRFTS are considered at each stage of the modelling process. The findings of this review were used to inform an assessment of the differential impacts of selected HRFTS scenarios in the UK presented in the next chapter.

Figure 6 re-iterates the pathway by which HRFTS lead to health impacts, introduced at the start of this thesis. Firstly, HRFTS lead to changes in consumer prices. The magnitude of

the price change will depend on the HRFTS scenario and external factors such as the response of the food industry. For instance, the food industry may absorb some of the cost of a tax. Secondly, changes in consumer prices are expected to lead to a change in purchases. Modelling studies can derive estimates of the magnitude of changes in purchases by using existing data on changes in purchases in response to changes in price, typically through the use of own- and cross-price elasticity matrices. Thirdly, changes in purchases are expected to lead to a change in consumption of foods and nutrients relevant to health outcomes. Finally, the health impact of interventions can be estimated using epidemiological estimates of changes in health status that result from changes in foods and nutrients.

Figure 6: Conceptual framework of the stages of modelling health impacts of HRFTS



There is evidence of differential impacts at each stage of the conceptual framework of HRFTS. Differential pass-through rates by retailers may result in different socioeconomic groups experiencing different changes in prices. For example, during the implementation of the Danish saturated fat tax, discount stores used the tax to increase their profit margin on butter whereas in supermarkets, less than the full tax was transmitted to consumers [57]. The change in purchases will depend on own- and cross-price elasticities and current patterns of consumption, both which have been observed to differ by factors related to

socio-economic status [54,116]. Further differential impacts could be introduced if the nutritional composition of typically consumed foods varied for those of different socioeconomic status – though this is likely to be small given evidence suggests branded and unbranded foods have similar nutrient composition [155–158]. Finally, there are underlying differences in health and disease rates and relative risk of disease across different population sub-groups [159–164]. These epidemiological differences may culminate to result in differential impacts at a population level, even in the absence of differential impacts at earlier stages.

The purpose of this review was to examine the methods that existing studies have used to establish the differential impact of HRFTS interventions. Previous reviews of HRFTS have focused on synthesising the outcomes of studies to establish conclusions about the type of HRFTS interventions that may or may not be effective in particular contexts. The findings on the differential impacts of HRFTS are mixed. This is due in part to the diversity of modelled interventions, but diversity in methods may also play a role. This is the first review that explicitly focuses on assessing the methodological aspects of modelling the differential impacts of HRFTS interventions.

Research questions

This review addresses the following research questions:

- Which methods have been used to examine the differential impact of HRFTS by personal characteristic within modelling studies?

- To what extent do current estimates of differential impacts of HRFTS account for differential impacts at each stage of the modelling process?

Methods

I used three recent reviews [20,22,23] as the basis for this review. I screened papers included in the above reviews to determine whether they had assessed the differential effects of food price interventions by personal characteristic. In addition, I replicated the search strategy of the most recent review to extend it from March 2012 to September 2015 for available databases.

Studies were included in this review if they modelled the effect of a food pricing intervention on one or more health related outcome and presented results of differential impact by personal characteristic. The health related outcomes that were included were: nutrient intakes, food/beverage intakes, food/beverage purchases, morbidity (including obesity), and mortality. Studies were excluded if they modelled the impact on only one population subgroup or examined the behaviour of children (under 18 years). Studies were also excluded if they were not available in English.

I documented whether the included studies incorporated differential impacts at each of the following stages of the analysis:

- Differential tax/subsidy pass through rates

- Baseline price differences
- Price elasticities
- Baseline purchases or consumption
- Relative risks (or other epidemiological relationships)
- Baseline health status (e.g. BMI or mortality)

This step was conducted to give an overview of the stages in which differential impacts were considered and was not intended to be a marker of the quality of included studies.

For studies that modelled changes in health (BMI or disease outcomes), I classified studies based on whether differential impacts were assessed. The cut-off values for different outcome measures presented by the studies is given in Table 22. Any studies with differential impacts across one or more groups for one or more outcome measures were classified as demonstrating differential impacts, even if not all scenarios or outcome measures followed the same pattern.

Table 22: Cut-off values for classification of differential impact

Outcome measure	Cut-off value for differential impacts
Obesity prevalence	Absolute difference in change in prevalence of ≥0.2% between groups
Mean BMI	Absolute difference in mean BMI change ≥0.1BMI units
Weight change	Absolute difference in mean weight change ≥0.3kg
Deaths delayed/averted/ avoided/ prevented	≥1% difference from expected deaths based on population

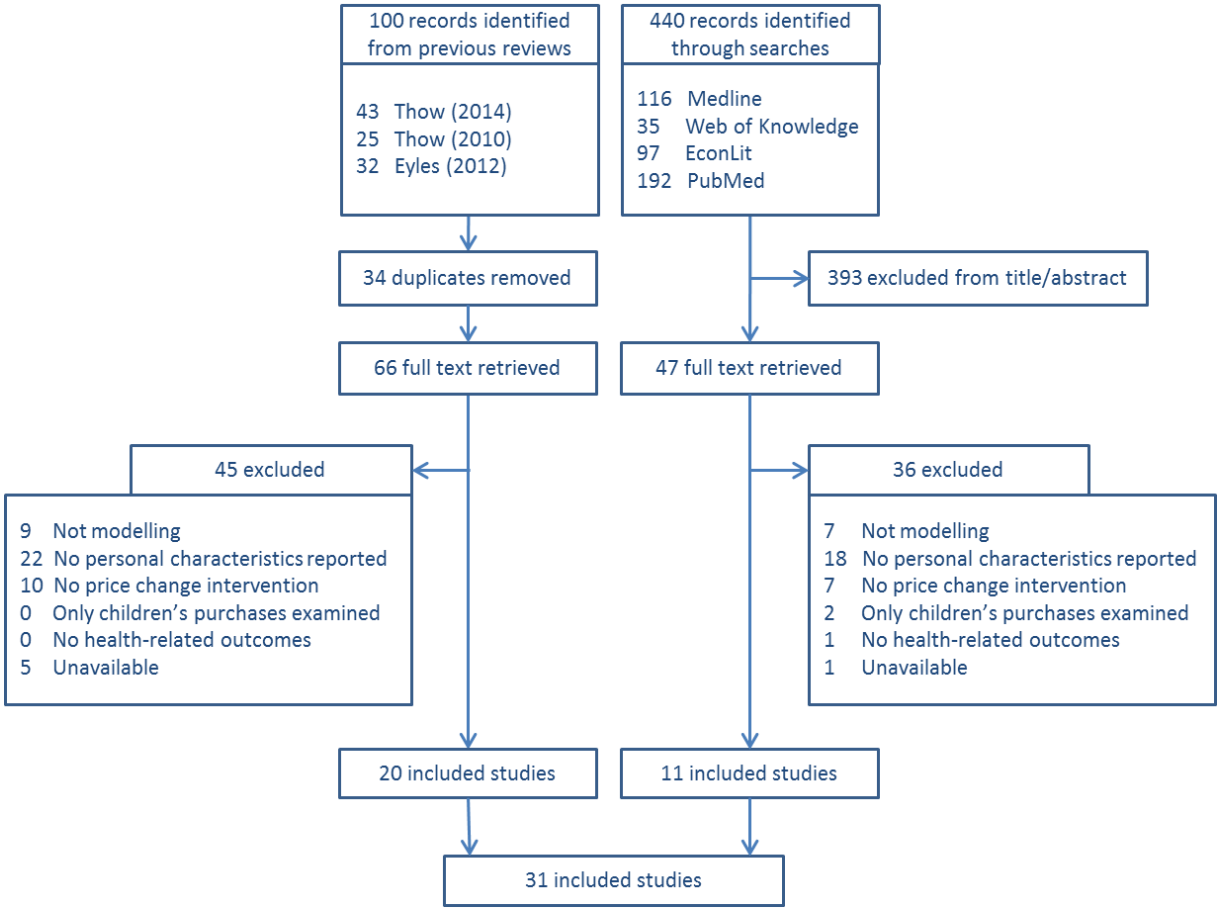
Results

The database search generated 440 hits and 47 full text articles were screened for inclusion; 11 studies met the inclusion criteria. Of the 66 unique papers identified from existing reviews, 20 met the inclusion criteria. This gave a total of 31 papers to include in this review. Figure 7 presents a flow diagram of exclusions at each stage of the searches.

Table 23 provides a summary of included studies. The included studies came from 12 different countries; there were 10 studies from the USA, four from the UK, three from France and Norway, two from India, Sweden and Australia, and one each from Ireland, New Zealand, Finland, South Africa and Denmark.

There was a wide variety of interventions modelled; category level interventions were the most common (n=27 studies). SSB taxes were the most common category level intervention (n=16) followed by fruit and vegetable subsidies (n=6). Nutrient interventions were examined in seven studies and interventions that combined category and nutrient level interventions were assessed in six studies. There were four studies that examined other types of intervention including a palm oil tax, sugar price decreases resulting from EU reforms, taxes on whole milk, and a greenhouse gas emissions tax. Fifteen studies modelled multiple interventions and seven modelled multiple different types of intervention.

Figure 7: PRISMA flow diagram



The studies used data from a combination of national dietary surveys, household expenditure surveys, and commercial scanner data. For the econometric modelling, the almost ideal demand system (or variants thereof) was the most common approach (n=13), followed by the use of existing price elasticity estimates (n=10), and then a censored quantile regression approach (n=3). Five studies used other approaches, such as using hypothetical price elasticity estimates, two-part marginal effects, and random coefficients logit models. Twenty-one studies examined changes in purchases/consumption of food/beverage categories, eight examined changes in nutrients, nine examined energy

intake, 14 examined BMI/obesity/weight, five examined changes in morbidity, and six examined changes in mortality. In addition, four examined healthcare cost impacts and two examined other health-related outcomes (population attributable risk and life years lost). Twenty-four studies examined multiple health-related outcome measures (but differential impacts were not always presented for all outcome measures examined).

Ten personal characteristics were examined by the studies; differential impacts by income were the ones most commonly assessed (n=17) followed by sex/gender impacts (n=10) and then age (n=9). Four studies examined differential impacts based on baseline consumption patterns, two studies based on rural/urban status, two based on ethnicity, and one each for obesity status, education, socioeconomic status, and household type. Twelve studies examined differential impacts for more than one personal characteristic.

Table 24 summarises the stages at which differential effects were considered in each of the included studies. None of the included studies considered differential pass through rates of HRFTS by personal characteristic. Thirteen studies included personal characteristic specific (baseline) prices. Twenty-one studies included differential price elasticity estimates for different groups. Twenty-eight studies included differential values for (baseline) consumption or purchase values by personal characteristic. Of the 22 studies that modelled health impacts beyond purchases or consumption, seven used personal characteristic specific relative risk estimates (though four studies only partially) and 14 used personal characteristic specific values for health status (e.g. disease incidence, BMI) (though three only partially).

Of the 20 studies that gave BMI or disease-related outcome measures, twelve studies showed differential impacts on different sub-groups. Seven studies did not show differential impacts, and it was unclear whether there were differential impacts in the remaining study. On average, the studies that found differential impacts had personal characteristic specific estimates at 2.5 stages of the modelling process. The studies that did not find differential impacts had personal characteristic specific estimates at 1.9 stages.

Table 23: Summary of included studies

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Allais (2010) [165]	France	10% increase in price of: i) cheese/ butter/ cream ii) sugar-fat products iii) prepared meals iv) all of the above	22 food and beverage categories	TNS Worldpanel 1996-2001	Aggregated AIDS	Income	Nutrients BMI/obesity	Category
Basu (2013) [166]	India	20% palm oil tax	Palm oil, other oil categories	Indian National Sample Survey	QAIDS	Sex Rural/urban Age	Nutrient Deaths (CVD)	Other
Basu (2014) [83]	India	20% SSB tax	5 beverage categories	Indian National Sample Survey (wave 2009/10)	QAIDS	Age Sex Income Rural/urban	BMI/obesity Disease (diabetes)	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Bonnet and Requillart (2011) [167]	France	36% decrease in sugar price (as a result of EU reforms)	105 differentiated products that compete on the market comprising 33.8% of total market	TNS WorldPanel 2003-2005	Random coefficients logit model	No. overweight/ obese in housheold	Purchases/ consumption	Other
Briggs (2013) [47]	UK	20% SSB tax	12 drink categories	LCFS 2010 NDNS 2008-10	Bayesian approach to estimate an AIDS	Income Age	Purchases/ consumption Energy intake BMI/obesity	SSB tax
Briggs (2013) [56]	Ireland	10% SSB tax	SSBs	SLAN 2007	Existing price elasticity estimates	Age Sex Income	Energy intake BMI/obesity	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Cash (2005) [168]	USA	1% decrease in the mean price of: i) all fruits ii) all vegetables iii) all fruits and vegetables	Fruits and vegetables	USDA Continuing Study of Food Intakes by Individuals for 1994-1996 and 1998	Existing price elasticity estimates	Income	Disease (CHD and stroke) Cost per statistical life saved	Fruit and veg subsidy
Chaloupka (2011) [169]	USA (Illinois)	Four alternative beverage taxes: i) cent per ounce tax on SSBs and their diet versions ii) cent per ounce excise tax on SSBs only iii) a two cent per ounce tax on SSBs and their diet versions iv) two cent per ounce tax on SSBs	SSBs and non-SSBs	Sales volume data from industry sources NHANES 2007-8	Existing price elasticity estimates	Age Gender	Purchases/ consumption Energy intake BMI/obesity Healthcare costs (diabetes and obesity)	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Dallongeville (2011) [170]	France	Reduction in VAT on fruit and veg from 5.5% to 2.2% (and two non-HRFTS policies)	Fruits and vegetables	Previous literature	Existing price elasticity estimates	Income	Deaths (CVD and cancers) Life years lost Purchases/ consumption	Fruit and vegetable subsidy
Finkelstein (2010) [171]	USA	4 SSB tax scenarios: i) 20% price increase on carbonated SSBs ii) 20% price increase on all SSBs iii) 40% price increase on carbonated SSBs iv) 40% price increase on all SSBs	7 beverage categories	Neilsen Homescan Panel 2006	2-part marginal effects models	Income	Energy intake BMI/obesity	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Gustavsen (2005) [172]	Norway	3 SSB tax scenarios: i) doubling VAT for soda ii) doubling VAT and production tax for soda iii) Swedish (lower) soda prices in Norway	Sugary soda and all other durables	Household expenditure surveys of Statistic Norway 1989-1999 Consumer price index	Censored quantile regression approach	Consumption level (sugary soda)	Purchases/ consumption	SSB tax
Gustavsen (2011) [173]	Norway	Increase in VAT for carbonated sugar sweetened beverages (to 25%, or equivalent to 10.1% price increase)	Carbonated sugary drinks, other beverags, other foods, non-food items	Household expenditure surveys of Statistic Norway 1989-2001 Consumer Price Index	Censored quantile regression approach	Consumption level (sugary soda)	Purchases/ consumption BMI/obesity	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Gustavsen (2013) [174]	Norway	VAT reform (14% to 25% for unhealthy (carbonated soft drinks, candy, ice cream), 14% to 0 for healthy (fruit, veg, fish))	Milk, carbonated soft drinks, juices, candy, ice-cream, fruits, vegetables, meat, fish	Household expenditure surveys from Statistics Norway 1986-2005	Censored quantile regression approach	Consmption level	Purchases/ consumption BMI/obesity	Category
Khan (2015) [41]	USA	i) 10 cent tax on whole milk ii) price rearrangement so that the 10 cent tax on whole milk is offset by a 3.4 cent rebate on other varieties of milk	Milk (sub-categorised based on fat content)	Scanner data provided by IRI (2001-2006) US census data	Demand system (equations stated)	Income	Purchases/ consumption	Other

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Kotakorpi (2011) [40]	Finland	Three tax reforms: i) 1 euro per kg of added sugar applied to each category based on its sugar content ii) abolition of current VAT on fresh fruit, veg, and fish iii) both above reforms combined	8 food and beverage categories	Household Budget Survey of Statistics Finland (1995-6, 1998, 2001, 2006) Health 2000 Survey of the National Institute of Health and Welfare Statistics Finaland Consumer Price Index Data	QAIDS	Income Education Gender	Purchases/ consumption BMI/obesity Population attributable risk	Nutrient Category Combined

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Lin (2011) [175]	USA	20% SSB tax	SSBs	1998-2007 National Consumer Panel 2003-2006 NHANES	Static AIDS	Income	Purchases/ consumption Energy intake BMI/obesity	SSB tax
Manyema (2014) [176]	South Africa	20% SSB tax	4 beverage categories	SANHANES-1	Existing price elasticity estimates	Age Sex	Purchases/ consumption Energy intake BMI/obesity	SSB tax
Marshall (2000) [177]	UK	Extension of VAT to key sources of saturated fat in the British diet	Whole milk Cheese Butter Biscuits Buns, cakes, pastries Puddings and ice cream	Previous literature	Hypothetical price elasticity estimates	Age Gender	Deaths (IHD)	Category

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Mekonnen (2013) [178]	USA (California)	Penny-per-ounce SSB tax	SSBs	2005 California Health Interview Survey	Existing price elasticity estimates	Income Ethnicity	Energy intake BMI/obesity Deaths Disease incidence Healthcare costs	SSB tax
Ni Mhurchu (2015) [63]	New Zealand	5 different pricing scenarios: i) 20% saturated fat tax ii) 20% fruit and veg subsidy iii) 20% sodium tax iv) 20% fruit veg subsidy plus sodium and saturated fat tax iv) greenhouse gas tax (all price changes applied at the food category level)	24 food groups	NZ Household Economic Surveys (2006/7 and 2009/10)	AIDS	Income Ethnicity	Nutrients Deaths	Nutrient Fruit and vegetable subsidy Combined Other

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Nnoaham (2009) [37]	UK	Extension of 17.5% VAT with or without subsidy on fruit and veg. Scenarios: i) VAT extension to major food category sources of saturated fats ii) VAT extention to WXYfm less healthy foods iii) VAT extention to WXYfm less healthy foods plus 17.5% fruit and vegetable subsidy iv) revenue neutral version of iii) (greater fruit and vegetable subsidy)	Food categories (list not stated)	Expenditure and Food Survey 2003-2006	Existing price elasticity estimates	Income	Purchases/ consumption Nutrients Deaths	Nutrient Fruit and vegetable subsidy Combined

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Nordstrom and Thunstrom (2011) [39]	Sweden	4 revenue neutral reforms: i) no VAT on Keyhole bread and breakfast cereals, plus 34.2% VAT on bakery goods and ready meals ii) 50% subsidy for Keyhole bread and breakfast cereals, plus 113.8% VAT on bakery goods and ready meals iii) SEK 0.046/g/kg fibre subsidy for grain products, plus SEK 0.182/g added sugar iv) SEK 0.046g/kg fibre subsidy on grain products, plus SEK 0.325/g saturated fat	8 categories of grain products (with further sub-categories)	Private market research data ("Growth from Knowledge" diary recordings 2003) and household expenditure data from Statistics Sweden	QAIDS	Income	Purchases/ consumption Nutrients	Category Nutrient Combined

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Nordstrom and Thunstrom (2011) [179]	Sweden	4 revenue neutral reforms: i) zero VAT on Keyhole bread and breakfast cereals, plus 34.2% VAT on bakery goods and ready meals ii) 50% subsidy for Keyhole bread and breakfast cereals, plus 113.8% VAT on bakery goods and ready meals iii) SEK 0.046/g fibre subsidy per kg of grain product, plus excise duty of SEK 0.182/g added sugar iv) SEK 0.046/g fibre subsidy per kg of grain product, plus excise duty of SEK 0.325/g of saturated fat	8 categories of grain products (with further sub-categories)	Private market research data ("Growth from Knowledge" diary recordings 2003) and household expenditure data from Statistics Sweden	QAIDS	Household type	Purchases/ consumption Nutrients	Category Nutrient Combined

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Sacks (2011) [180]	Australia	10% 'junk food' tax (unhealthy food categories taxed) and a non-HRFTS intervention	9 'junk food' categories	1995 National Nutrition Survey	Existing price elasticity estimates	Sex	Purchases/ consumption Energy intake	Category
Schroeter (2008) [181]	USA	i) 10% low-kcal food subsidy on fruit and veg ii) 10% low-kcal subsidy on diet soft drinks iii) 10% high kcal tax on food away from home iv) 10% high kcal tax onsoft drinks	Varies by intervention (6 food categories, 16 beverage goods/ categories)	ERS/USDA data	Existing price elasticity estimates	Sex	BMI/obesity	Fruit and vegetable subsidy Nutrient SSB tax
Sharma (2014) [182]	Australia (Victoria)	2 SSB tax scenarios: i) 20% valoric SSB tax ii) 20cents/L volumetric tax on SSBs	10 non-alcoholic beverage categories	ACNielsen Homescan 2010	AIDS	Income	Purchases/ consumption Energy intake BMI/obesity	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Smed (2007) [183]	Denmark	i) tax on fatty meats (beef and pork), butter and cheese (5% price increase) ii) VAT reduction on fresh fruit and vegetables, potatoes and grain products from 25 to 22% iii) tax on saturated fats (7.89 DKK/kg) iv) fibre subsidy (18.00 DKK/kg) v) sugar tax (10.30 DKK/kg) vi) revenue neutral combination of i) and ii) vii) revenue neutral combination of iii) and scenario iv) viii) as vii) with addition of sugar tax	23 food categories	Gfk Consumerscan purchases from Jan 1997 to Dec 2000	Augmented AIDS	Age Social class	Nutrients Purchases/ consumption	Category Fruit and vegetable subsidy Nutrient Combined

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Tiffin (2015) [184]	UK	Various SSB taxes: i) £0.06/litre on regular and diet soft drinks and juice drinks with sweeteners (French scenario) ii) £0.02/litre on regular and diet soft drinks and juice drinks with sweeteners iii) £0.06/litre on regular soft drinks and juice drinks with fruit content lower than 25% iv) £0.02/litre on regular soft drinks and juice drinks with sweeteners (Hungarian scenario)	10 beverage categories	LCFS 2010 Kantar WorldPanel August 2010-12	QAIDS	Consumption level (SSBs)	Purchases/ consumption	SSB tax

Author (date)	Country	Price intervention(s)	Food categories modelled	Data source(s)	Econometric approach	Differential effects modelled	Outcome measures	Intervention type(s)
Wang (2012) [185]	USA	Penny-per-ounce tax on SSBs	SSBs	NHANES 2003-06	Existing price elasticity estimates	Age Gender	Disease (diabetes) Purchases/ consumption Healthcare costs BMI/obesity	SSB tax
Zhen (2011) [186]	USA	Excise tax equivalent to half-cent per ounce on store purchased SSBs	9 beverage categories	Neilsen Homescan Panel 2004 to 2006	Dynamic AIDS model with habit formation incorporated	Income	Purchases/ consumption	SSB tax
Zhen (2013) [187]	USA	Half cent per ounce SSB tax	23 food and beverage categories	2006 Nielsen Homescan Panel (static panel)	Exact Affine Stone Index demand system	Income	Purchases/ consumption Nutrients	SSB tax

Table 24: Summary of stages at which differential impacts are included

	PC specific pass through rates	PC specific baseline prices	PC specific PE estimates	PC specific baseline purchases/ consumption	PC specific RR	PC specific health status	Differential impacts?
Allais (2010) [165]	No	Yes	Yes	Yes	NA	NA	NA
Basu (2013) [166]	No	No	No	UNCLEAR	Yes	Yes	Yes
Basu (2014) [83]	No	UNCLEAR	Partial	Yes	Partial	Yes	Yes
Bonnet and Requillart (2011) [167]	No	No	Yes	Yes	NA	NA	NA
Briggs (2013) [47]	No	No	Yes	Yes	Partial	Yes	Yes
Briggs (2013) [56]	No	No	No	Yes	Partial	Yes	Yes
Cash (2005) [168]	No	No	Yes	Yes	No	Yes	Yes
Chaloupka (2011) [169]	No	No	No	Yes	Partial	Yes	No
Dallongeville (2011) [170]	No	No	Yes	Yes	No	Partial	Yes
Finkelstein (2010) [171]	No	Yes	Yes	Yes	No	No	Yes
Gustavsen (2005) [172]	No	No	Yes	Yes	NA	NA	NA
Gustavsen (2011) [173]	No	Yes	Yes	Yes	No	No	Yes
Gustavsen (2013) [174]	No	No	Yes	Yes	No	No	No
Khan (2015) [41]	No	Yes	Yes	No	No	No	NA
Kotakorpi (2011) [40]	No	Yes	Partial	Yes	No	No	Yes
Lin (2011) [175]	No	Yes	Yes	Yes	No	Yes	NA

	PC specific pass through rates	PC specific baseline prices	PC specific PE estimates	PC specific baseline purchases/ consumption	PC specific RR	PC specific health status	Differential impacts?
Manyema (2014) [176]	No	No	No	Yes	No	Yes	Yes
Marshall (2000) [177]	No	No	No	No	Yes	Partial	No
Mekonnen (2013) [178]	No	No	No	Yes	No	Yes	Yes
Ni Mhurchu (2015) [63]	No	No	No	Yes	No	Yes	Yes
Nnoaham (2009) [37]	No	No	No	Yes	No	Partial	No
Nordstrom and Thunstrom (2011) [39]	No	Yes	Yes	Yes	NA	NA	NA
Nordstrom and Thunstrom (2011) [179]	No	Yes	Yes	Yes	NA	NA	NA
Sacks (2011) [180]	No	No	No	Yes	No	No	No
Schroeter (2008) [181]	No	No	Yes	Yes	No	No	No
Sharma (2014) [182]	No	Yes	Yes	Yes	No	No	No
Smed (2007) [183]	No	Yes	Yes	Yes	NA	NA	NA
Tiffin (2015) [184]	No	Yes	Yes	Yes	NA	NA	NA
Wang (2012) [185]	No	No	No	Yes	Yes	Yes	UNCLEAR
Zhen (2011) [186]	No	Yes	Yes	Yes	NA	NA	NA
Zhen (2013) [187]	No	Yes	Yes	Yes	NA	NA	NA

Discussion

The studies identified in this review examine the differential impacts of HRFTS interventions at multiple stages along the modelling pathway. Many studies only included personal characteristic specific responses at selected stages. This suggests that we might be misestimating the differential impacts of HRFTS interventions by failing to account for potential sources of differential responses across different population sub-groups.

Limitations of included studies

Studies included in this review reveal the variety of different data sources and methods that can be used to examine the differential impacts of HRFTS policy. I identified two key areas that appear to have been overlooked by existing literature. No studies examined the impact of differential pass through rates by personal characteristic and many did not model impacts beyond changes in the purchases or consumption of selected food categories. The failure to examine differential pass through rates probably reflects lack of data in this area as there are few HRFTS that have been implemented and evaluated. Many HRFTS examined in included studies have not been implemented and therefore it is unclear how the food industry might respond. Existing assessments of likely pass through rates conflict, and authors suggest that pass through rates may mainly depend on the nature of the HRFTS implemented rather than the personal characteristics of the individuals affected [82,92].

The health impact of HRFTS will depend on the overall composition of diets following the implementation of an intervention, and not only on purchases of specific foods or nutrients. Ten studies did not consider impacts beyond changes in purchases or consumption. Mytton et al [64] show that HRFTS interventions that reduce consumption of a targeted nutrient may result in negative health impacts through compensatory purchasing behaviours. Crucially for examining differential impacts, patterns of compensatory purchasing could differ by population sub-groups.

Of the 21 studies that did consider impacts beyond changes in purchases or consumption, 10 only considered the differential impact of HRFTS on obesity. The obesity focus probably reflects the predominance of SSB tax interventions aiming to reduce obesity. The focus on obesity may underestimate the differential impacts of SSB taxes as SSB consumption increases risk of diseases through other means besides increasing the risk of overweight or obesity [75,77,78] and many of the diseases that SSB consumption influences have differential distributions across population sub-groups (for UK examples see [188,189]). A more epidemiologically complete analysis of the impacts of HRFTS would also be advantageous for comparing the differential impacts of HRFTS with other public health interventions. This might be especially important to identify complementary interventions that could reduce health inequalities where the HRFTS interventions do not.

Several methodological shortcomings were evident in situations where the differential impacts of HRFTS had been included at particular stages of the modelling process. Three studies that had personal characteristic specific price elasticity estimates did not account

for substitutions to other product categories [41,168,173]. In contrast, other studies had valid methodological reasons for not including personal characteristic specific parameters. In the New Zealand study, the authors noted that the same price elasticity matrix was used for the different ethnic groups owing to the unstable nature of personal characteristic specific price elasticity estimates [63]. The outcomes of sensitivity analyses in the New Zealand study provided insight into the impact of omitted personal characteristic specific estimates, such analyses could be used to justify future research to determine precise values.

Limitations of the review

This review is the first to examine the modelling methods that have been used to assess the differential impacts of HRFTS interventions. The systematic search strategy means that it is unlikely that relevant studies will have been missed.

I characterised studies based on whether they had included differential impacts at each stage of the modelling process. The stages selected reflected areas where existing literature has demonstrated that population sub-groups may respond differently. Evidence of differential impacts is typically restricted to specific personal characteristics in certain contexts. Assuming that there are no differential effects at a particular stage might be valid: e.g. whilst relative risk estimates vary by sex [74,190,191], baseline prices of particular foods are unlikely to.

The cut-off values used for deciding whether studies had differential impacts were arbitrary. There were a few included studies that I judged as not demonstrating differential impacts, where the authors stated differential impacts were present [174,182]. These differences in interpretations of modelled results probably at least in part reflect context-specific perceptions of meaningful differences.

The breadth of data sources and methods used at various stages of the modelling process made it impractical to conduct an assessment of the quality of included studies. There are currently no reporting guidelines for modelling studies of this type and the types of analysis that are appropriate are reliant on the data sources and nature of the HRFTS scenario tested. For example, the use of existing estimates of price elasticities would be appropriate where robust, context-specific estimates that concur with other assumptions made in the modelling process are available. However, there typically was not enough information reported in included studies in order to make these sorts of judgements about study quality.

Finally, there may be additional areas where differential impacts may arise that have not yet been identified. For example, the relationship between purchases and consumption will be modified by the amount of food that is wasted, and wastage may well vary by personal characteristics.

Comparison with previous reviews

Previous reviews of HRFTS have focused on the overall findings of studies examining the health impacts of HRFTS [20,22,23]. These reviews have found evidence that HRFTS may have differential impacts on different population sub-groups, with estimates of the magnitude of such effects varying considerably across included studies. One of these reviews suggests that the magnitude of differential impacts observed may result from included studies targeting different foods [20]. This review offers an additional explanation for the lack of consistency in previous findings: the magnitude of differential impacts at least in part reflects the nature in which differential effects have been included in modelling studies.

Incomplete examination of differential impacts may have led to misestimates of the magnitude of differential effects. In the case of SSB taxes, existing research probably underestimates the impact on low income populations because many studies do not account for impacts on diabetes and other health conditions in which disease rates are often higher in low income populations.

In a recent systematic review of policies to reduce obesity, Olstad et al highlight the need for research on how interventions could be ameliorated to reduce health inequalities [32]. Many of the studies included in this review simultaneously consider the differential impacts of multiple interventions. Modelling the impacts of similar interventions is one way to determine how interventions could be ameliorated to reduce inequalities.

Suggestions for future research

Future studies should clearly document the assumptions made at each stage of the modelling process with respect to the treatment of differential effects. Reporting guidelines such as those available for other study designs might help to ensure that relevant elements are reported. The comparison of multiple interventions within modelling studies should be encouraged in order to identify features of interventions that might promote equity. Finally, we need more comprehensive estimates of the differential impact of HRFTS across a greater breadth of health outcomes, especially where there are well established health impacts of consumption of particular foods as is the case with SSBs.

Conclusion

Modelling studies provide an opportunity to estimate the differential impact of HRFTS. Differential impacts can arise at several stages including through differences in current consumption and purchasing behaviour, own- and cross-price elasticities, and the relationship between consumption and disease. Much of the literature fails to account for the multitude of ways that differential effects may occur. Increased prevalence of HRFTS globally might provide an insight into differential pass through rates of HRFTS that have been neglected in the modelling literature to date. Future studies need to assess differential impacts across epidemiological outcomes, exclusive focus on obesity may mask the true magnitude of differential impacts.

Chapter 7: Modelling the differential impacts of selected HRFTS in the UK

This chapter models the impact of selected HRFTS in the UK by household income using data from the Living Costs and Food Survey (LCFS). I examine the impact of a fruit and vegetable subsidy, a VAT extension, the combination of the subsidy and VAT extension, and a 'healthy VAT' scenario where VAT is applied based on the healthiness of foods. The health impact of these reforms is estimated using the Preventable Risk Integrated ModEl (PRIME).

Introduction

In Chapter 2, I argued that HRFTS that reform VAT to better reflect the healthiness of foods and fruit and vegetable subsidies merit consideration in the UK. There was no UK based experimental evidence of the differential impacts of these interventions identified in the systematic review of experimental studies (Chapter 3). In addition, the findings from the modelling review in the previous chapter (Chapter 6) identified few UK based modelling studies that examined differential impacts. In both reviews, differential impacts by income were the most commonly examined personal characteristics in included studies. The focus on income across multiple studies probably reflects the common concern that HRFTS, particularly taxes, are likely to be regressive and impose a greater financial burden on households with lower incomes [35–37].

Only four UK based studies that examined the differential impact of HRFTS were identified in the modelling review. Two of these examined personal characteristics other than income [177,184]. Of the two studies that examined differential impacts by income, one exclusively examined the impact of a SSB tax [47]. The remaining study used price elasticity estimates from 2000 that are now likely to be outdated, and lacked income specific price elasticity estimates [37]. Better information on the differential impacts of a range of possible HRFTS is needed to determine the extent to which HRFTS may reduce or increase current dietary inequalities in the UK.

This chapter models the differential impact of four HRFTS in the UK, using methods that could be extended to model the impact of a broad range of HRFTS interventions. The four scenarios modelled in this chapter are:

- 20% fruit and vegetable subsidy
- VAT extension across all food groups (no change in prices of foods currently subject to VAT, 20% VAT applied to foods that are currently zero rated)
- Combined scenario (VAT extension plus a 20% fruit and vegetable subsidy)
- Healthy VAT (healthiness based VAT rate where a zero rate of VAT was assigned to food groups judged healthy by the OfCom model and 20% VAT was assigned to those judged unhealthy)

The scenarios were chosen to reflect options that I had identified in Chapter 2 as having the potential to improve health in the UK based on current dietary patterns in the UK. Low

fruit and vegetable consumption is the dietary risk factor that exerts the greatest burden in the UK [2] and existing research suggests that fruit and vegetable subsidies may be an effective way to increase consumption [20,24]. In order to compensate for the cost of the fruit and vegetable subsidy, I also modelled the impact of extending VAT. Results are presented for the VAT extension in isolation as well as in combination with the fruit and vegetable subsidy. Finally, I modelled the impact of assigning VAT based on the OfCom nutrient profile model [192]. The OfCom model is currently used to classify foods for regulatory purposes in the UK (specifically to determine the foods that can be advertised during children's television). As argued in Chapter 2, HRFTS based on nutrient profile models may be advantageous as nutrient profile models provide an objective method of determining the healthiness of foods.

I estimate changes in food purchases using price elasticities calculated from the parameters obtained from estimating a quadratic almost ideal demand system (QUAIDS) using data from multiple years of the Living Costs and Food Survey [193]. I then assess the potential health effects of these changes using the Preventable Risk Integrated ModEl (PRIME), a comparative risk assessment model [194]. I build on the findings of the modelling review by including differential impacts where possible, comparing the impacts of multiple interventions, and assessing multiple health-related outcomes.

Research questions

This addresses the following research questions, examining both overall impacts and differential effect by income:

- What are the effects of selected HRFTS on food purchases?
- How does the nutritional composition of purchases change in response to HRFTS?
- What are the estimated health impacts of changes in food purchases resulting from selected HRFTS?

Methods

Data sources

The Living Costs and Food Survey (LCFS) from 2011-2013 [193,195] was the main data source used in this analysis. The LCFS is a nationally representative survey of purchasing habits in the UK undertaken annually by the Office for National Statistics (ONS). It collects data on household purchases over the course of a two-week period alongside demographic information about the households included in the survey. All household members over 16 years old are asked to complete a daily purchasing diary over the two week period, children aged 7-15 years are asked to complete a simplified diary. Detailed description of food and beverage purchases are provided for each household categorised into 256 food codes. The food codes cover purchases intended for home consumption as well as takeaway

purchases. For this analysis, households were grouped with those whose data was collected in the same year, quarter, and government office region when calculating prices.

OECD equivalisation scales provided in the LCFS were used to divide the households into tertiles and deciles of equivalised income [149]. In addition, household level purchases were converted into a proxy for individual consumption values by splitting the total nutrient content by household members according to age. Average kilocalorie requirements were used to split household purchases to individual food consumption: adults (>18 years) were assigned a value of one; children (2-18 years) a value of 0.7 and toddlers (<2 years) a value of 0.5.

The LCFS contains quantity and expenditure values for each household across 256 food codes. Nutritional information for each food code is also provided within the LCFS dataset. Within the dataset, 10 food codes lacked quantity values. Three of these food codes lacked a quantity value for less than five households and simple imputation was used to assign quantity to the household with the missing value. The remaining seven food codes[g] were excluded as expenditure data were lacking for all households with purchases of that food code. These food codes represented less than 1% of total expenditure in the dataset. Nutritional information was missing for the "Other takeaway food brought home"

[g] These seven food codes were: artificial sweeteners; Bisto, gravy granules, stuffing mix, baking powder, yeast; fruit teas, instant tea, herbal tea, rosehip tea; payment for food, type not specified; spices and dried herbs; vinegar; wine and beer making kits.

category, which was given a zero value for all nutrients (effectively excluding it from the nutritional analyses, but not from the econometric analyses).

I categorised the food codes into seven categories loosely based on the Eatwell Guide [53], each of which was further subdivided to give a total of 23 sub-categories. An iterative process established the final set of categories to maximise the number of sub-categories whilst ensuring that there was sufficient within-category data for the econometric analysis. Multi-stage approaches are a common way of dealing with the problems caused by the availability of large numbers of commodities, and allows for greater disaggregation of price elasticities [196,197]. The categorisation system is given in Table 25.

I excluded non-reporting households from the analysis. Non-reporting households were defined as those that lacked purchases in more than three of the seven food categories. Data on the demographic characteristics and purchases of the included households is provided in the results section.

Table 25: Categorisation system used for analysis

Categories	Sub-categories
Beverages	Alcoholic beverages Hot drinks Sugar-sweetened beverages (SSBs) Non-sugar-sweetened beverages (non-SSBs)
Fruits and vegetables	Fresh fruit Fresh vegetables Other fruits and vegetables
Products high in fat, salt, or sugar	Cakes and pastries Dairy desserts Snacking Sugar and confectionery
Meat, fish, eggs and other protein sources	Fresh meat and fish Processed meat and fish Meat-based composites
Dairy	Milk Cheese Yogurt and cream
Miscellaneous	Composite foods (e.g. ready meals, pizza) Fats and oils Sauces and dressings
Starchy foods	Bread Breakfast and other cereals Pasta, rice, and potatoes

Price elasticity estimates

I obtained price elasticity estimates using a two-stage QUAIDS applied to the LCFS data. To calculate price elasticities, I assumed that purchasing decisions were made in a two-stage fashion; that households allocate their budget to food categories and then to the sub-categories within them. Therefore, I estimated the demand system for purchases at the food category level and then for purchases within each category separately (i.e. in

accordance with the structure specified in Table 25). The price elasticities from these models were combined to give a 23x23 price elasticity matrix. The analysis was conducted in STATA 14 [151] using the -quaids- command suite, full details of which have been published [198]. Information on budget shares and food prices is required to run the -quaids- command.

Budget shares

Budget shares for each food category were calculated at the household level by dividing category level expenditure by total expenditure. Similarly, the budget share for each sub-category was calculated by dividing the sub-category level expenditure by the total category level expenditure. The general formula for the budget share (w) of a sub-category (i) within a food category (r) is as follows:

$$w_{(r)i} = \frac{expen_i}{\sum expen_r}$$

Prices

Sub-category price values

The value required for the demand analysis is the average price of goods for all items within the sub-category and not just the price of the specific goods that were actually purchased. To obtain these price values, I calculated unit values for sub-categories calculated from the LCFS. Unit values were used as it was not possible to obtain prices exogenously (i.e. from outside the dataset). Therefore, a price value for each sub-category was calculated for each government office region (g) and observation time-point (i.e. year and quarter) (t). All

households within a region and time-point were assigned the same price value for a sub-category.

$$p_{(r)i}^{gt} = \bar{x}\left(\frac{q_{i/}Y_i}{Y_r}\right)^{gt}$$

Where Y represents expenditure.

These methods are based on those used for a similar analysis conducted by Agostini [199] and attempt to deal with some of the problems introduced through endogenous estimation of prices in demand systems.

Category price values

Category level prices were calculated using the corrected Stone Price Index described by Moschini [200]. This calculates a price for each category using both the sub-category prices and budget shares according to:

$$log(P_t^S) = \sum_{i=1}^{n} w_{it}\, log\left(\frac{p_{it}}{p_i^0}\right)$$

Where w is the budget share, and p represents the price at time point t.

Application of QUAIDS in STATA

Once budget shares and prices were calculated, I could use the –quaids- command in STATA to estimate a demand system. I estimated the demand system at the food category level, and then separately for the sub-categories within each food category. I calculated

price elasticities using the standard extensions of the –quaids- command that give expenditure elasticities and a price elasticity matrix as a standard output.

Demographic variables can be factored into the demand system estimation procedure in STATA. The primary analyses specified OECD equivalised income tertile as a demographic variable in the demand system using the demographics() option in the –quaids- command. Price elasticity estimates were generated for the sample as a whole, and for each income tertile.

Combining price elasticities from the two-stage demand system

Uncompensated[h] (Marshallian) price elasticity estimates from the category and sub-category level QUAIDS analyses were combined to give a 23x23 price elasticity matrix across all the sub-categories using methods introduced by Edgerton [196]. The Edgerton method assumes that cross-price-elasticities between foods from two different sub-categories are primarily a function of the cross-price elasticity between the categories (as well as budget shares and budget elasticities). The cross-price elasticity (e_{ij}) of a good i in category r with respect to a price increase of good j in category s is calculated as follows:

$$e_{ij} = \delta_{rs} e_{(r)ij} + E_{(r)i} w_{(s)j} (\delta_{rs} + e_{rs})$$

[h] Uncompensated price elasticities assumes that household income is fixed

Where w represents the expenditure share; delta is assigned a value of one if goods i and j are in the same category, and a value of zero otherwise; E represents the unconditional expenditure elasticity of i within group r.

Application of pricing scenarios

The pricing interventions modelled were:

- 20% fruit and vegetable subsidy
- VAT extension across all food groups
- Combined scenario (VAT extension plus a 20% fruit and vegetable subsidy)
- Healthy VAT

For each of the VAT reform scenarios, each food category was assigned a VAT rate of either zero or 20% based on scenario specifications. The relative price changes applied to each category for each scenario are displayed in Table 26. VAT was applied to the current pre-tax value of each sub-category. Current VAT rates were calculated by averaging the VAT rates of each food code provided in the LCFS dataset and weighting by purchase frequency.

For the healthy VAT reform, the Ofcom model was applied to the nutrient content of each sub-category and the VAT rate was changed accordingly. For example, zero rate VAT was applied to non-SSBs under the healthiness based VAT scenario as the sub-category as a whole was judged “healthier” according to the Ofcom model. The OfCom model uses an

algorithm to combine information on the energy, saturated fat, sugar, sodium, fibre, protein, and fruit and vegetable content to classify foods as healthy and less healthy [192].

Table 26: Proportional price changes applied to foods in selected scenarios

	20% fruit and vegetable subsidy	VAT extension	Combined scenario	Healthy VAT
Alcoholic beverages	1.00	1.00	1.00	1.00
Hot drinks	1.00	1.20	1.20	1.00
SSBs	1.00	1.00	1.00	1.00
Non-SSBs	1.00	1.00	1.00	0.83
Fresh fruit	0.80	1.20	0.80	1.00
Fresh veg	0.80	1.20	0.80	1.00
Other fruit and veg	0.80	1.20	0.80	1.00
Cakes and pastries	1.00	1.20	1.20	1.20
Dairy desserts	1.00	1.09*	1.09*	1.09*
Snacking	1.00	1.00	1.00	1.00
Sugar and confectionery	1.00	1.06*	1.06*	1.06*
Fresh meat and fish	1.00	1.20	1.20	1.00
Processed meat and fish	1.00	1.20	1.20	1.20
Meat based composites	1.00	1.20	1.20	1.20
Milk	1.00	1.20	1.20	1.00
Cheese	1.00	1.20	1.20	1.20
Yogurt and cream	1.00	1.20	1.20	1.20
Composite foods	1.00	1.20	1.20	1.20
Fats and oils	1.00	1.20	1.20	1.20
Sauces and dressings	1.00	1.20	1.20	1.20
Bread	1.00	1.20	1.20	1.20
Breakfast and other cereal products	1.00	1.20	1.20	1.20
Pasta, rice, potatoes	1.00	1.20	1.20	1.20
*Some products in this category are currently subject to VAT while others are not and therefore applying VAT to the whole category results in <20% price increase to the category as a whole				

Purchasing impacts

Quantities of each sub-category purchased under the HRFTS scenario were calculated from data on the quantities purchased at baseline, the change in price, and the uncompensated price elasticity matrix. Results for each income group are based on income group specific baseline purchase values and price elasticity matrices. Changes in the quantities purchased were calculated on a per person per week basis.

Health impacts

I modelled the health impact of the scenarios using PRIME. PRIME is a comparative risk assessment model that estimates the deaths delayed or averted under defined counterfactual scenarios with different population distributions of risk factor behaviour [194]. PRIME has previously been used to estimate the impacts of health-related food taxes and subsidies [62,201]. Additional information about PRIME is provided in Appendix (iv), with full details available in [194].

The dietary components included in PRIME are energy intake, fruit, vegetables, fibre, salt, total fat, saturated fat, monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs), and dietary cholesterol [194]. Baseline intakes of these dietary components were derived from per person purchased quantities in the LCFS dataset combined with sub-category level nutritional information. I assumed that the relationship between the amount purchased and the amount consumed would not change under a HRFTS (i.e. that

food waste would remain constant). I did not model the impact of changes in energy intake on obesity.

I modelled the overall health impact of the HRFTS scenarios in terms of the deaths that would have been delayed or averted in 2013 if a HRFTS scenario had been implemented. Age and sex specific population data and age, sex, and cause specific mortality data for 2013 were imported into the model from national datasets [202–205]. I assumed that deaths were equally distributed across the three income tertiles as the age, sex, and cause specific mortality data are not available by income tertile in the UK. Uncertainty intervals around the health impact of the selected scenarios was estimated using 10,000 iterations of a Monte Carlo analysis which allowed the epidemiological parameters (i.e. the relative risks relating risk factors to diseases) to randomly vary according to the distribution described in the literature.

Results

Descriptive statistics

There were 16,319 households included in the LCFS between 2011 and 2013. Of these, 226 (1.38%) were classified as non-reporting households and excluded from the analysis. This resulted in a final sample size of 16,093 households. Table 27 displays the demographic characteristics of the households included in the analysis. The low-income tertile had equivalised household income values between £0 and £245 per week (~<£12,740pa). For

the middle-income tertile, this was £245-£417 per week (~£12,740 - £21,684pa). The high-income tertile had equivalised household income values greater than £417 per week (~>£21,684).

Table 27: Demographic characteristics of households included in the analysis

Number of included participants		16,093
	Low income	5,440
	Middle income	5,440
	High income	5,349
Household size		
	Mean	2.4
	Standard deviation	1.3
Equivalised household income (£/week)		
	Mean	391.53
	Standard deviation	280.50
Household composition		%
	One adult	26.5
	Two adults	35.2
	One adult plus child(ren)	6.1
	Two adults plus child(ren)	20.7
	Other	11.5
Socio-economic classification of household reference person		%
	Higher managerial, administrative and professional occupations	30.1
	Intermediate occupations	13.4
	Routine and manual occupations	19.5
	Never worked and long-term unemployed	1.9
	Students	1.8
	Occupation not stated	1.1
	Unclassified	32.2

Purchasing data

Table 28 displays quantities purchased for the 23 food sub-categories in the sample. The percentage of zero-purchases varied considerably by food sub-category. Alcoholic beverages were not purchased by 46.5% of households, while only 5.0% of households did not purchase bread.

Table 28: Quantities purchased across the 23 sub-categories

Values represent grams per person per week	All households		Lowest Income		Medium income		Highest income	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Alcoholic	836	1,941	593	1,613	840	2,366	1,072	1,724
Hot drinks	67	106	70	116	67	100	64	102
SSBs	932	1,638	1,042	1,805	904	1,508	851	1,583
Non-SSBs	1,400	2,109	1,155	2,042	1,438	2,100	1,604	2,159
Fresh fruit	875	896	741	848	895	903	988	917
Fresh veg	835	787	723	795	838	766	943	785
Other fruit and veg	425	511	429	558	420	487	427	485
Cakes and pastries	220	260	225	277	232	258	202	243
Dairy desserts	281	504	291	564	301	492	251	449
Snacking	246	244	250	261	257	238	231	233
Sugar and confectionery	304	352	329	378	308	330	277	344
Fresh meat and fish	631	647	603	673	632	632	657	637
Processed meat and fish	376	372	374	390	385	369	368	354
Meat based composites	345	437	365	499	344	407	324	397
Milk	1,893	1,542	2,059	1,652	1,936	1,527	1,685	1,415
Cheese	135	151	115	147	133	140	155	163
Yogurt and cream	251	323	202	305	263	336	288	319
Composite foods	241	323	215	315	240	316	268	335
Fats and oils	206	282	228	308	208	293	181	238

Sauces and dressings	197	234	177	234	201	227	214	238
Bread	706	510	751	588	717	477	649	451
Breakfast and other cereal products	311	419	298	469	312	393	324	390
Pasta, rice, potatoes	875	895	947	1,044	903	894	776	709

Relationship between income group and food purchases

Purchases across all food groups are related to household income in the LCFS sample. Figure 8 and Figure 9 show the relationship between mean purchases and household income across each food category.

Figure 8: Relationship between income decile and mean food category expenditure

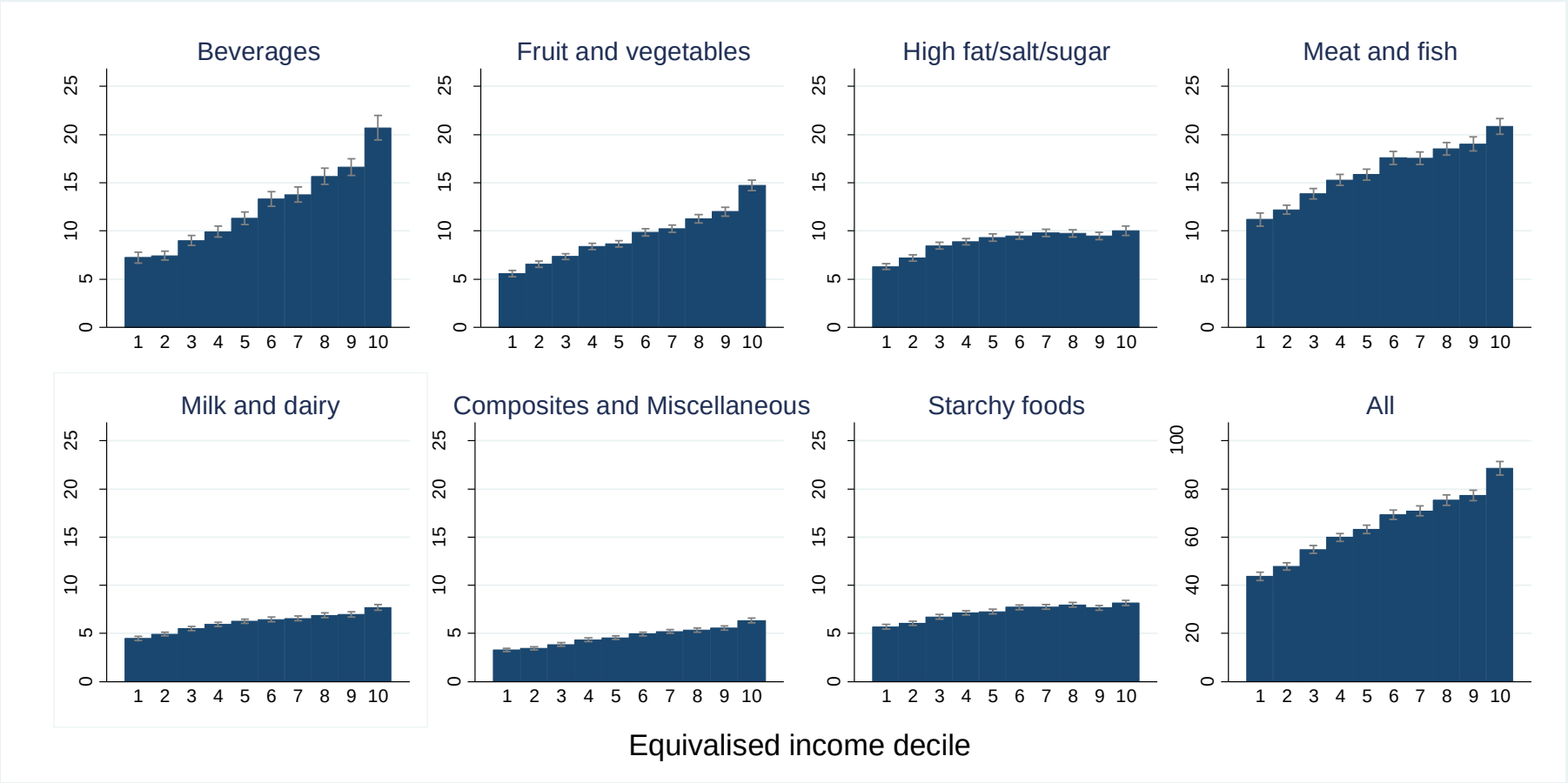
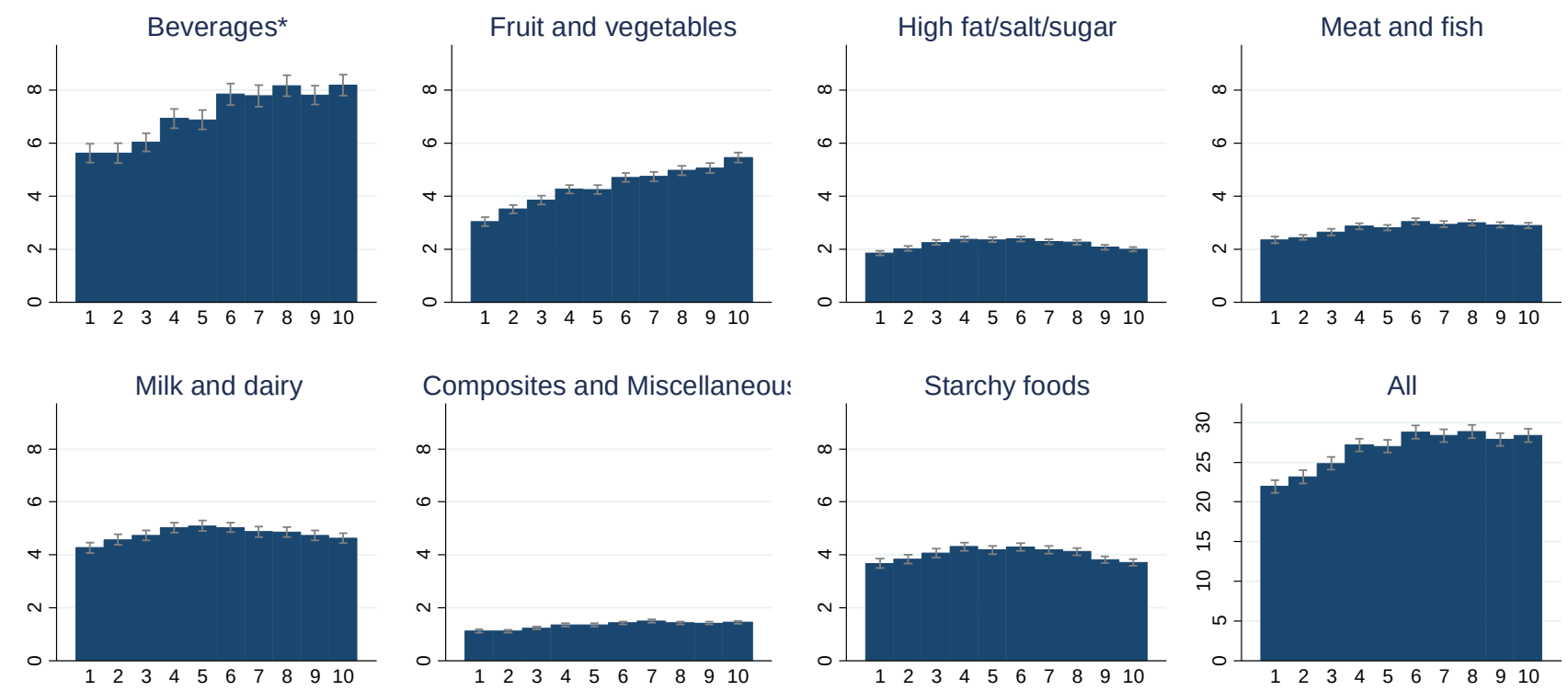


Figure 9: Relationship between income decile and mean food category quantity purchased



* Beverage values are given in litres

Price elasticity matrices

The uncompensated price elasticity matrices for the sample as a whole and each income tertile are displayed in Figure 10 - Figure 13. Differences in own-PEs across the three income tertiles ranged from 0.00 (4/23 sub-categories) to 0.27 (between the highest and lowest income tertile in the “Other fruit and veg” category). The lowest income tertile was more elastic to price changes in 13/23 sub-categories than the highest income tertile, equally elastic to price changes in 2/23 sub-categories, and less elastic in 8/23 sub-categories.

Figure 10: Uncompensated price elasticity matrix for whole sample

Whole sample	Alcoholic	Hot drinks	SSBs	Non-SSBs	Fresh fruit	Fresh veg	Other fruit and veg	Cakes and pastries	Dairy desserts	Snacking	Sugar and confectionery	Fresh meat and fish	Processed meat and fish	Meat based composites	Milk	Cheese	Yogurt and cream	Composite foods	Fats and oils	Sauces and dressings	Bread	Breakfast and other cereal products	Pasta, rice, potatoes
Alcoholic	-1.10	-0.08	-0.06	-0.15	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	-0.08	-0.06	-0.04	-0.10	-0.06	-0.04	-0.01	-0.01	-0.01	0.00	0.00	0.00
Hot drinks	0.18	-0.64	-0.10	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.02	-0.02	-0.04	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00
SSBs	0.16	-0.11	-0.79	0.13	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.04	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
Non-SSBs	0.06	-0.01	0.09	-0.76	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.04	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
Fresh fruit	0.00	0.00	0.00	0.00	-0.62	0.24	-0.05	-0.06	-0.03	-0.08	-0.08	-0.06	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.07	-0.07	-0.05
Fresh veg	0.00	0.00	0.00	0.00	0.22	-0.71	0.09	-0.05	-0.03	-0.08	-0.08	-0.05	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.06	-0.06	-0.05
Other fruit and veg	0.00	0.00	0.00	0.00	-0.05	0.22	-0.50	-0.05	-0.02	-0.07	-0.07	-0.04	-0.03	-0.02	0.01	0.00	0.00	-0.03	-0.02	-0.02	-0.06	-0.06	-0.04
Cakes and pastries	0.01	0.01	0.01	0.01	-0.08	-0.10	-0.05	-0.88	0.04	0.04	0.04	0.01	0.01	0.01	-0.03	-0.02	-0.01	0.03	0.03	0.03	0.00	0.00	0.00
Dairy desserts	0.01	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.06	-0.82	0.09	-0.13	0.01	0.01	0.01	-0.04	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Snacking	0.01	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.02	0.03	-0.81	-0.03	0.01	0.01	0.01	-0.03	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Sugar and confectionery	0.02	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.01	-0.05	-0.04	-0.75	0.01	0.01	0.01	-0.04	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Fresh meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.04	-0.02	0.00	0.00	0.00	0.00	-0.93	-0.07	-0.07	0.03	0.02	0.01	-0.03	-0.03	-0.03	0.03	0.03	0.02
Processed meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.00	0.00	-0.82	-0.04	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.01
Meat based composites	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.00	-0.04	-0.06	-0.77	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.02
Milk	-0.05	-0.02	-0.02	-0.03	0.01	0.01	0.01	-0.02	-0.01	-0.02	-0.02	0.06	0.05	0.03	-0.80	0.03	0.06	0.01	0.01	0.01	0.01	0.01	0.01
Cheese	-0.07	-0.03	-0.03	-0.04	0.02	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.08	0.06	0.05	-0.09	-0.88	-0.04	0.02	0.02	0.02	0.01	0.01	0.01
Yogurt and cream	-0.07	-0.04	-0.03	-0.05	0.02	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.09	0.07	0.05	-0.02	-0.06	-0.94	0.02	0.02	0.02	0.01	0.01	0.01
Composite foods	-0.01	0.00	0.00	0.00	-0.07	-0.08	-0.04	0.04	0.02	0.06	0.06	-0.10	-0.08	-0.06	0.03	0.02	0.01	-0.90	0.05	0.13	-0.07	-0.07	-0.05
Fats and oils	0.00	0.00	0.00	0.00	-0.05	-0.06	-0.03	0.03	0.02	0.05	0.05	-0.08	-0.06	-0.05	0.02	0.01	0.01	0.12	-0.67	0.00	-0.05	-0.05	-0.04
Sauces and dressings	0.00	0.00	0.00	0.00	-0.06	-0.07	-0.04	0.04	0.02	0.06	0.06	-0.10	-0.07	-0.05	0.03	0.02	0.01	0.17	-0.03	-0.79	-0.06	-0.06	-0.05
Bread	0.02	0.01	0.01	0.01	-0.05	-0.06	-0.03	0.00	0.00	0.00	0.00	0.06	0.04	0.03	0.01	0.00	0.00	-0.02	-0.02	-0.02	-0.85	0.13	0.03
Breakfast and other cereal products	0.03	0.01	0.01	0.02	-0.07	-0.08	-0.04	0.00	0.00	0.01	0.01	0.08	0.06	0.04	0.01	0.01	0.00	-0.03	-0.03	-0.03	0.06	-0.94	-0.07
Pasta, rice, potatoes	0.03	0.01	0.01	0.02	-0.07	-0.08	-0.04	0.00	0.00	0.01	0.01	0.07	0.06	0.04	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.05	-0.02	-0.84

Figure 11: Uncompensated price elasticity matrix for lowest income tertile

Lowest income tertile	Alcoholic	Hot drinks	SSBs	Non-SSBs	Fresh fruit	Fresh veg	Other fruit and veg	Cakes and pastries	Dairy desserts	Snacking	Sugar and confectionery	Fresh meat and fish	Processed meat and fish	Meat based composites	Milk	Cheese	Yogurt and cream	Composite foods	Fats and oils	Sauces and dressings	Bread	Breakfast and other cereal products	Pasta, rice, potatoes
Alcoholic	-1.15	-0.07	-0.07	-0.17	-0.02	-0.02	-0.01	0.00	0.00	-0.01	-0.01	-0.09	-0.07	-0.05	-0.15	-0.07	-0.05	-0.01	-0.02	-0.01	-0.01	-0.01	-0.01
Hot drinks	0.15	-0.71	-0.07	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.04	-0.03	-0.02	-0.06	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
SSBs	0.13	-0.07	-0.84	0.11	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.04	-0.03	-0.03	-0.07	-0.03	-0.02	-0.01	-0.01	-0.01	-0.01	-0.01	0.00
Non-SSBs	0.05	-0.01	0.12	-0.76	-0.01	-0.01	-0.01	0.00	0.00	0.00	0.00	-0.04	-0.03	-0.02	-0.06	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
Fresh fruit	0.00	0.00	0.00	0.00	-0.61	0.24	-0.02	-0.06	-0.03	-0.09	-0.09	-0.06	-0.05	-0.04	0.01	0.00	0.00	-0.03	-0.04	-0.03	-0.08	-0.08	-0.06
Fresh veg	0.00	0.00	0.00	0.00	0.21	-0.72	0.16	-0.06	-0.03	-0.08	-0.09	-0.05	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.08	-0.08	-0.06
Other fruit and veg	0.00	0.00	0.00	0.00	0.01	0.29	-0.59	-0.05	-0.03	-0.07	-0.07	-0.04	-0.04	-0.03	0.01	0.00	0.00	-0.02	-0.03	-0.02	-0.06	-0.06	-0.04
Cakes and pastries	0.01	0.01	0.01	0.01	-0.08	-0.09	-0.05	-0.89	0.03	0.03	0.04	0.01	0.01	0.01	-0.04	-0.02	-0.01	0.03	0.03	0.02	0.00	0.00	0.00
Dairy desserts	0.01	0.01	0.01	0.01	-0.07	-0.09	-0.05	0.06	-0.80	0.10	-0.14	0.01	0.01	0.01	-0.04	-0.02	-0.01	0.03	0.03	0.02	0.00	0.00	0.00
Snacking	0.01	0.01	0.01	0.01	-0.08	-0.09	-0.05	0.02	0.04	-0.81	-0.03	0.01	0.01	0.01	-0.04	-0.02	-0.01	0.03	0.03	0.02	0.00	0.00	0.00
Sugar and confectionery	0.01	0.01	0.01	0.01	-0.08	-0.10	-0.06	0.01	-0.06	-0.05	-0.75	0.01	0.01	0.01	-0.04	-0.02	-0.01	0.03	0.03	0.03	0.00	0.00	0.00
Fresh meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.04	-0.02	0.00	0.00	0.00	0.00	-0.93	-0.07	-0.07	0.03	0.01	0.01	-0.03	-0.03	-0.02	0.02	0.02	0.02
Processed meat and fish	-0.01	-0.01	-0.01	-0.01	-0.02	-0.03	-0.02	0.00	0.00	0.00	0.00	0.01	-0.82	-0.03	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.01
Meat based composites	-0.01	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.00	-0.04	-0.06	-0.79	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.01
Milk	-0.04	-0.03	-0.03	-0.03	0.01	0.01	0.01	-0.01	-0.01	-0.02	-0.02	0.06	0.05	0.03	-0.86	0.02	0.06	0.01	0.01	0.01	0.01	0.01	0.01
Cheese	-0.05	-0.04	-0.04	-0.04	0.01	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.07	0.06	0.04	-0.06	-0.84	-0.06	0.02	0.02	0.01	0.01	0.01	0.01
Yogurt and cream	-0.05	-0.04	-0.04	-0.04	0.02	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.08	0.06	0.05	0.04	-0.12	-0.96	0.02	0.02	0.02	0.01	0.01	0.01
Composite foods	0.00	0.00	0.00	0.00	-0.06	-0.07	-0.04	0.04	0.02	0.06	0.06	-0.10	-0.08	-0.06	0.03	0.02	0.01	-0.89	0.04	0.13	-0.07	-0.07	-0.05
Fats and oils	0.00	0.00	0.00	0.00	-0.05	-0.06	-0.03	0.03	0.02	0.05	0.05	-0.08	-0.06	-0.05	0.03	0.01	0.01	0.09	-0.64	0.00	-0.06	-0.06	-0.04
Sauces and dressings	0.00	0.00	0.00	0.00	-0.06	-0.07	-0.04	0.04	0.02	0.06	0.06	-0.09	-0.07	-0.06	0.03	0.01	0.01	0.17	-0.04	-0.78	-0.06	-0.06	-0.05
Bread	0.01	0.01	0.01	0.01	-0.05	-0.05	-0.03	0.00	0.00	0.01	0.01	0.05	0.04	0.03	0.01	0.00	0.00	-0.02	-0.02	-0.02	-0.84	0.12	0.03
Breakfast and other cereal products	0.01	0.01	0.01	0.01	-0.06	-0.07	-0.05	0.01	0.00	0.01	0.01	0.07	0.05	0.04	0.01	0.01	0.00	-0.03	-0.03	-0.03	0.06	-0.94	-0.07
Pasta, rice, potatoes	0.01	0.01	0.01	0.01	-0.06	-0.07	-0.04	0.01	0.00	0.01	0.01	0.06	0.05	0.04	0.01	0.01	0.00	-0.03	-0.03	-0.03	-0.06	-0.01	-0.84

Figure 12: Uncompensated price elasticity matrix for middle income tertile

Middle income tertile	Alcoholic	Hot drinks	SSBs	Non-SSBs	Fresh fruit	Fresh veg	Other fruit and veg	Cakes and pastries	Dairy desserts	Snacking	Sugar and confectionery	Fresh meat and fish	Processed meat and fish	Meat based composites	Milk	Cheese	Yogurt and cream	Composite foods	Fats and oils	Sauces and dressings	Bread	Breakfast and other cereal products	Pasta, rice, potatoes
Alcoholic	-1.09	-0.07	-0.06	-0.15	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	-0.08	-0.06	-0.04	-0.10	-0.06	-0.05	-0.01	-0.01	-0.01	0.00	0.00	0.00
Hot drinks	0.17	-0.65	-0.09	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.02	-0.02	-0.04	-0.03	-0.02	-0.01	0.00	-0.01	0.00	0.00	0.00
SSBs	0.16	-0.11	-0.79	0.14	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.04	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
Non-SSBs	0.06	-0.01	0.09	-0.75	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.03	-0.02	-0.05	-0.03	-0.02	-0.01	-0.01	-0.01	0.00	0.00	0.00
Fresh fruit	0.00	0.00	0.00	0.00	-0.62	0.24	-0.05	-0.06	-0.03	-0.08	-0.08	-0.06	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.07	-0.07	-0.05
Fresh veg	0.00	0.00	0.00	0.00	0.23	-0.71	0.09	-0.05	-0.03	-0.08	-0.08	-0.05	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.07	-0.07	-0.05
Other fruit and veg	0.00	0.00	0.00	0.00	-0.06	0.21	-0.49	-0.05	-0.03	-0.07	-0.06	-0.04	-0.03	-0.02	0.01	0.00	0.00	-0.03	-0.02	-0.02	-0.06	-0.06	-0.04
Cakes and pastries	0.01	0.01	0.01	0.01	-0.08	-0.09	-0.05	-0.88	0.03	0.03	0.04	0.01	0.01	0.01	-0.03	-0.02	-0.01	0.03	0.03	0.03	0.00	0.00	0.00
Dairy desserts	0.01	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.06	-0.82	0.09	-0.13	0.01	0.01	0.01	-0.03	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Snacking	0.01	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.02	0.04	-0.81	-0.03	0.01	0.01	0.01	-0.03	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Sugar and confectionery	0.01	0.01	0.01	0.01	-0.09	-0.10	-0.05	0.01	-0.05	-0.05	-0.75	0.01	0.01	0.01	-0.04	-0.02	-0.02	0.03	0.03	0.03	0.00	0.00	0.00
Fresh meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.04	-0.02	0.00	0.00	0.00	0.00	-0.93	-0.07	-0.07	0.03	0.02	0.01	-0.03	-0.03	-0.03	0.02	0.02	0.02
Processed meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.01	0.00	0.00	0.00	0.00	0.00	-0.82	-0.04	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.01
Meat based composites	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.02	0.00	0.00	0.00	0.00	-0.04	-0.06	-0.77	0.02	0.01	0.01	-0.02	-0.02	-0.02	0.02	0.02	0.01
Milk	-0.05	-0.03	-0.02	-0.03	0.01	0.01	0.01	-0.02	-0.01	-0.02	-0.02	0.06	0.05	0.03	-0.79	0.03	0.06	0.01	0.01	0.01	0.01	0.01	0.01
Cheese	-0.07	-0.04	-0.03	-0.04	0.02	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.08	0.06	0.05	-0.10	-0.86	-0.03	0.02	0.02	0.02	0.01	0.01	0.01
Yogurt and cream	-0.07	-0.04	-0.03	-0.05	0.02	0.02	0.01	-0.02	-0.01	-0.03	-0.03	0.09	0.07	0.05	-0.02	-0.06	-0.94	0.02	0.02	0.02	0.01	0.01	0.01
Composite foods	-0.01	0.00	0.00	0.00	-0.07	-0.08	-0.04	0.04	0.02	0.06	0.06	-0.11	-0.08	-0.06	0.03	0.02	0.01	-0.90	0.05	0.13	-0.07	-0.07	-0.05
Fats and oils	0.00	0.00	0.00	0.00	-0.05	-0.06	-0.03	0.03	0.02	0.05	0.05	-0.08	-0.06	-0.05	0.02	0.01	0.01	0.12	-0.67	0.00	-0.05	-0.05	-0.04
Sauces and dressings	0.00	0.00	0.00	0.00	-0.06	-0.07	-0.03	0.04	0.02	0.06	0.06	-0.10	-0.07	-0.05	0.03	0.02	0.01	0.16	-0.03	-0.79	-0.06	-0.06	-0.05
Bread	0.02	0.01	0.01	0.01	-0.05	-0.06	-0.03	0.00	0.00	0.00	0.00	0.06	0.04	0.03	0.01	0.00	0.00	-0.02	-0.02	-0.02	-0.85	0.13	0.03
Breakfast and other cereal products	0.03	0.01	0.01	0.02	-0.07	-0.08	-0.04	0.00	0.00	0.01	0.01	0.08	0.06	0.04	0.01	0.01	0.00	-0.03	-0.03	-0.03	0.06	-0.94	-0.07
Pasta, rice, potatoes	0.03	0.01	0.01	0.02	-0.07	-0.08	-0.04	0.00	0.00	0.01	0.01	0.07	0.06	0.04	0.01	0.00	0.00	-0.03	-0.03	-0.03	-0.05	-0.02	-0.84

Figure 13: Uncompensated price elasticity matrix for highest income tertile

Highest income tertile	Alcoholic	Hot drinks	SSBs	Non-SSBs	Fresh fruit	Fresh veg	Other fruit and veg	Cakes and pastries	Dairy desserts	Snacking	Sugar and confectionery	Fresh meat and fish	Processed meat and fish	Meat based composites	Milk	Cheese	Yogurt and cream	Composite foods	Fats and oils	Sauces and dressings	Bread	Breakfast and other cereal products	Pasta, rice, potatoes
Alcoholic	-1.07	-0.09	-0.05	-0.15	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	-0.06	-0.05	-0.03	-0.07	-0.06	-0.04	-0.01	-0.01	-0.01	0.01	0.01	0.00
Hot drinks	0.20	-0.50	-0.14	0.04	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.01	-0.02	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
SSBs	0.20	-0.16	-0.71	0.18	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.03	-0.02	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Non-SSBs	0.06	0.00	0.07	-0.75	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.03	-0.02	-0.02	-0.03	-0.03	-0.02	-0.01	0.00	-0.01	0.00	0.00	0.00
Fresh fruit	0.00	0.00	0.00	0.00	-0.64	0.24	-0.09	-0.05	-0.03	-0.08	-0.08	-0.05	-0.04	-0.03	0.01	0.00	0.00	-0.03	-0.02	-0.03	-0.06	-0.06	-0.05
Fresh veg	0.00	0.00	0.00	0.00	0.22	-0.68	0.02	-0.05	-0.02	-0.07	-0.07	-0.05	-0.03	-0.02	0.00	0.00	0.00	-0.03	-0.02	-0.03	-0.06	-0.06	-0.04
Other fruit and veg	0.00	0.00	0.00	0.00	-0.15	0.06	-0.32	-0.04	-0.02	-0.07	-0.07	-0.05	-0.03	-0.02	0.00	0.00	0.00	-0.03	-0.02	-0.03	-0.05	-0.05	-0.04
Cakes and pastries	0.02	0.01	0.01	0.01	-0.09	-0.11	-0.05	-0.87	0.04	0.05	0.05	0.01	0.01	0.01	-0.03	-0.03	-0.02	0.04	0.03	0.03	0.00	0.00	0.00
Dairy desserts	0.02	0.01	0.01	0.01	-0.10	-0.12	-0.05	0.06	-0.83	0.09	-0.12	0.01	0.01	0.01	-0.04	-0.03	-0.02	0.04	0.03	0.04	0.00	0.00	0.00
Snacking	0.02	0.01	0.01	0.01	-0.10	-0.12	-0.05	0.02	0.03	-0.81	-0.02	0.01	0.01	0.01	-0.03	-0.03	-0.02	0.04	0.03	0.03	0.00	0.00	0.00
Sugar and confectionery	0.02	0.01	0.01	0.01	-0.10	-0.12	-0.05	0.02	-0.04	-0.03	-0.74	0.01	0.01	0.01	-0.03	-0.03	-0.02	0.04	0.03	0.04	0.00	0.00	0.00
Fresh meat and fish	-0.03	-0.01	-0.01	-0.02	-0.04	-0.04	-0.02	0.00	0.00	0.00	0.00	-0.93	-0.07	-0.07	0.02	0.02	0.01	-0.03	-0.02	-0.03	0.03	0.03	0.02
Processed meat and fish	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.01	0.00	0.00	0.00	0.00	0.00	-0.81	-0.04	0.02	0.01	0.01	-0.03	-0.02	-0.02	0.02	0.02	0.02
Meat based composites	-0.02	-0.01	-0.01	-0.01	-0.03	-0.03	-0.01	0.00	0.00	0.00	0.00	-0.03	-0.05	-0.75	0.02	0.01	0.01	-0.03	-0.02	-0.02	0.02	0.02	0.01
Milk	-0.06	-0.02	-0.02	-0.03	0.01	0.02	0.01	-0.01	-0.01	-0.02	-0.02	0.06	0.04	0.03	-0.72	0.03	0.05	0.02	0.01	0.01	0.01	0.01	0.00
Cheese	-0.09	-0.03	-0.02	-0.05	0.02	0.02	0.01	-0.02	-0.01	-0.04	-0.03	0.10	0.07	0.05	-0.12	-0.88	-0.01	0.02	0.02	0.02	0.01	0.01	0.01
Yogurt and cream	-0.09	-0.03	-0.02	-0.05	0.02	0.02	0.01	-0.02	-0.01	-0.04	-0.04	0.10	0.07	0.05	-0.07	-0.02	-0.93	0.03	0.02	0.02	0.01	0.01	0.01
Composite foods	-0.01	0.00	0.00	0.00	-0.07	-0.08	-0.03	0.04	0.02	0.06	0.06	-0.11	-0.08	-0.06	0.03	0.02	0.02	-0.90	0.05	0.13	-0.07	-0.07	-0.05
Fats and oils	-0.01	0.00	0.00	0.00	-0.05	-0.06	-0.02	0.03	0.02	0.05	0.05	-0.08	-0.06	-0.04	0.02	0.02	0.01	0.15	-0.67	0.00	-0.05	-0.05	-0.03
Sauces and dressings	-0.01	0.00	0.00	0.00	-0.06	-0.07	-0.03	0.04	0.02	0.06	0.06	-0.10	-0.07	-0.05	0.02	0.02	0.01	0.17	-0.04	-0.79	-0.06	-0.06	-0.04
Bread	0.04	0.01	0.01	0.02	-0.06	-0.07	-0.03	0.00	0.00	0.00	0.00	0.07	0.05	0.03	0.00	0.00	0.00	-0.03	-0.02	-0.03	-0.87	0.13	0.03
Breakfast and other cereal products	0.05	0.01	0.01	0.03	-0.08	-0.09	-0.04	0.00	0.00	0.00	0.00	0.09	0.07	0.05	0.01	0.00	0.00	-0.04	-0.03	-0.03	0.06	-0.95	-0.07
Pasta, rice, potatoes	0.05	0.01	0.01	0.02	-0.07	-0.09	-0.04	0.00	0.00	0.00	0.00	0.09	0.06	0.04	0.01	0.00	0.00	-0.04	-0.03	-0.03	-0.03	-0.02	-0.83

Changes in purchases and nutrients

Full details of the changes in purchases of each food sub-category are given in Appendix (v), both in grams and as a percentage change from baseline. Full details of changes in nutrient intake under each of the HRFTS scenarios are also given in Appendix (v).

Fruit and vegetable subsidy

The fruit and vegetable subsidy resulted in increases in purchases across all fruit and vegetable sub-categories. Purchases across the majority of other categories also increased, with the exception of milk and dairy which experienced a slight reduction in purchases. Changes in purchases under the fruit and vegetable subsidy scenario were broadly similar across all three income tertiles. However, the highest income tertile experienced greater increases in fruit and vegetable purchases than the lower income tertiles.

The fruit and vegetable subsidy resulted in increases in calorie (72kcal/day), fruit and vegetable (24.6g/day), fibre (0.7g/day), salt (0.24g/day), dietary cholesterol (4.3mg/day) and non-milk extrinsic sugar intake (2.8g/day). This scenario resulted in a reduction in the percentage of total energy from fat (-0.1%kcal/day) and marginal changes in fat intakes.

Across all nutrients, the change was greatest for the highest income tertile. The biggest differences were that increase in calorie intake was 7kcal/day higher and the increase in fruit and vegetable intake was 11g/day higher in the highest income tertile compared to the lowest income tertile.

Full VAT extension

The VAT extension resulted in reductions in purchases across all categories. This included large reductions in fruit and vegetable purchases. The lowest income tertile had bigger absolute reductions in purchases than the high income group in eight of the 23 sub-categories, smaller reductions in seven sub-categories, and similar (within 5g) changes in purchases in eight sub-categories.

The VAT extension scenario resulted in large decreases in calories (-367kcal/day) driven by modest decreases in calorie intake across all food categories. The VAT extension resulted in decreases in fruit and vegetable intake (-53.3g/day), fibre (-2.5g/day), salt (-1.36g/day), dietary cholesterol (-49.3g/day) and non-milk extrinsic sugars (-8.4g/day). This scenario resulted in a reduction in the percentage of total energy from fat (-0.36%kcal/day). Within fats, the percentage of total energy from saturated fats, MUFAs and PUFAs decreased (-0.04%kcal/day, -0.05%kcal/day, and -0.16%kcal/day respectively). The absolute change in nutrient intakes was generally greater for the highest income tertile. The exception to this pattern was for saturated fat where the change was -0.04%kcal/day for the lowest income tertile but -0.02%kcal/day for the highest income tertile.

Combined scenario

The full VAT extension combined with the fruit and vegetable subsidy resulted in reductions in purchases across almost all categories. This included a decline in purchases of fruits and vegetables. There were a few exceptions to the overall pattern of reductions in purchases: the snacking and sugar and confectionery sub-categories experienced small

increases in purchases (16g/week and 5g/week, respectively). The reductions in purchases were generally smaller than the reductions under the full VAT extension scenario.

Whilst the low and middle-income tertiles reduced their purchases in all the fruit and vegetable sub-categories, purchases in the highest income tertile increased slightly. Changes in purchases were similar (within 5g) across income tertiles in seven of the 23 sub-categories under the VAT extension combined with fruit and vegetable subsidy scenario. Of the remaining 14 sub-categories, the low income tertile had bigger absolute reductions in purchases than the high income group in 11 sub-categories, and smaller reductions in purchases in the remaining five.

The full VAT extension combined with the fruit and vegetable subsidy resulted in decreases in calories (-223kcal/day), fruit and vegetables (-4.2g/day), fibre (-1.1g/day), dietary cholesterol (-40.6mg/day) and non-milk extrinsic sugars (-2.8g/day). This scenario resulted in a reduction in the percentage of total energy from fat (-0.56%kcal/day). Within fats, the percentage of total energy from saturated fats, MUFAs and PUFAs decreased (-0.26%kcal/day, -0.06%kcal/day, and -0.11%kcal/day respectively). There was no consistent pattern across the nutrients in the income group that experienced the biggest change.

Healthy VAT

The healthy VAT reform resulted in reductions in purchases across the majority of food categories, but of a smaller magnitude than the previous VAT extension related scenarios. There were increases in the purchases of non-SSBs, snacking, and milk sub-categories

(146g/week, 4g/week, and 88g/week, respectively). Changes in purchases were within 5g in 12 of the 23 sub-categories under the healthiness based VAT reform. In the remaining 11 sub-categories, the lowest income tertile had bigger absolute reductions in purchases than the high income group in seven sub-categories and smaller reductions in purchases in the remaining four sub-categories.

The healthy VAT reform resulted in decreases in calories (-238kcal/day), fruit and vegetables (-25.9g/day), fibre (-1.8g/day), salt (-1.07g/day), dietary cholesterol (-21.7mg/day) and non-milk extrinsic sugar intake (-3.8g/day). This scenario led to a reduction in the percentage of energy from fats (-0.27%kcal/day). Within fats, the percentage of total energy from saturated fats, MUFAs and PUFAs decreased (-0.02%kcal/day, -0.01%kcal/day, and -0.17%kcal/day respectively). As with the previous scenario, there was no consistent pattern across the nutrients in the income tertile that experienced the biggest change.

Health impact

Figure 14 displays the estimated deaths delayed or averted (DDA) in 2013 under the selected HRFTS scenarios. The fruit and vegetable subsidy had the greatest positive impact (3,700 DDA, 95%CI 2,600 to 4,800 DDA). The full VAT extension a negative health impact (-5,900 DDA, 95%CI -10,000 to -2,000 DDA). The combined scenario appeared to have a positive health impact, but it was not significant (1,500 DDA, 95%CI -500 to 3,400 DDA).

The healthy VAT reform appeared to have a negative health impact, but again this was not significant (-2,500 DDA, 95%CI -5,300 to 200 DDA).

All scenarios resulted in positive impacts in some diseases and negative impacts in others. These patterns were due to positive health impacts from increased fruit and vegetable intake being counteracted by a negative impact of increased salt or vice versa. All scenarios had a small but positive impact from improved population fat consumption.

Differential health impacts by income tertile

Figure 15 shows DDA by income tertile under the four scenarios. In all cases, the confidence intervals for the impacts in each income tertile overlap. However, there do appear to be gradients in health impacts across the three income tertiles. Both the fruit and vegetable subsidy and the combination of the subsidy with a VAT extension result in the highest income tertile having the greatest health benefit in terms of DDA. In contrast, the VAT extension scenario has the most negative impact on the highest income group. Finally, the healthy VAT scenario produces a consistently negative health impact for all income tertiles.

Figure 14: Death delayed or averted in 2013 under selected health-related food tax/subsidy scenarios in the UK

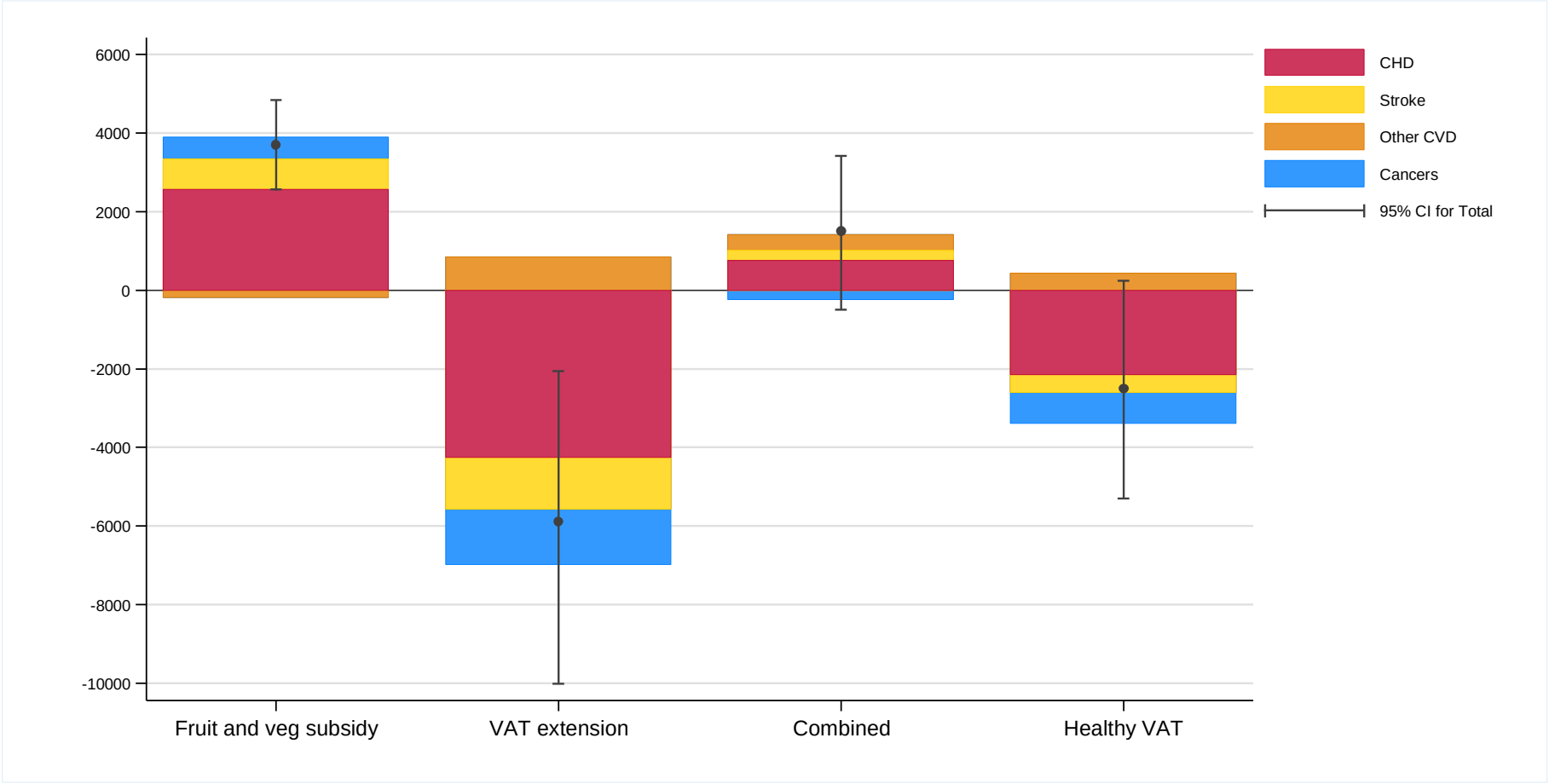
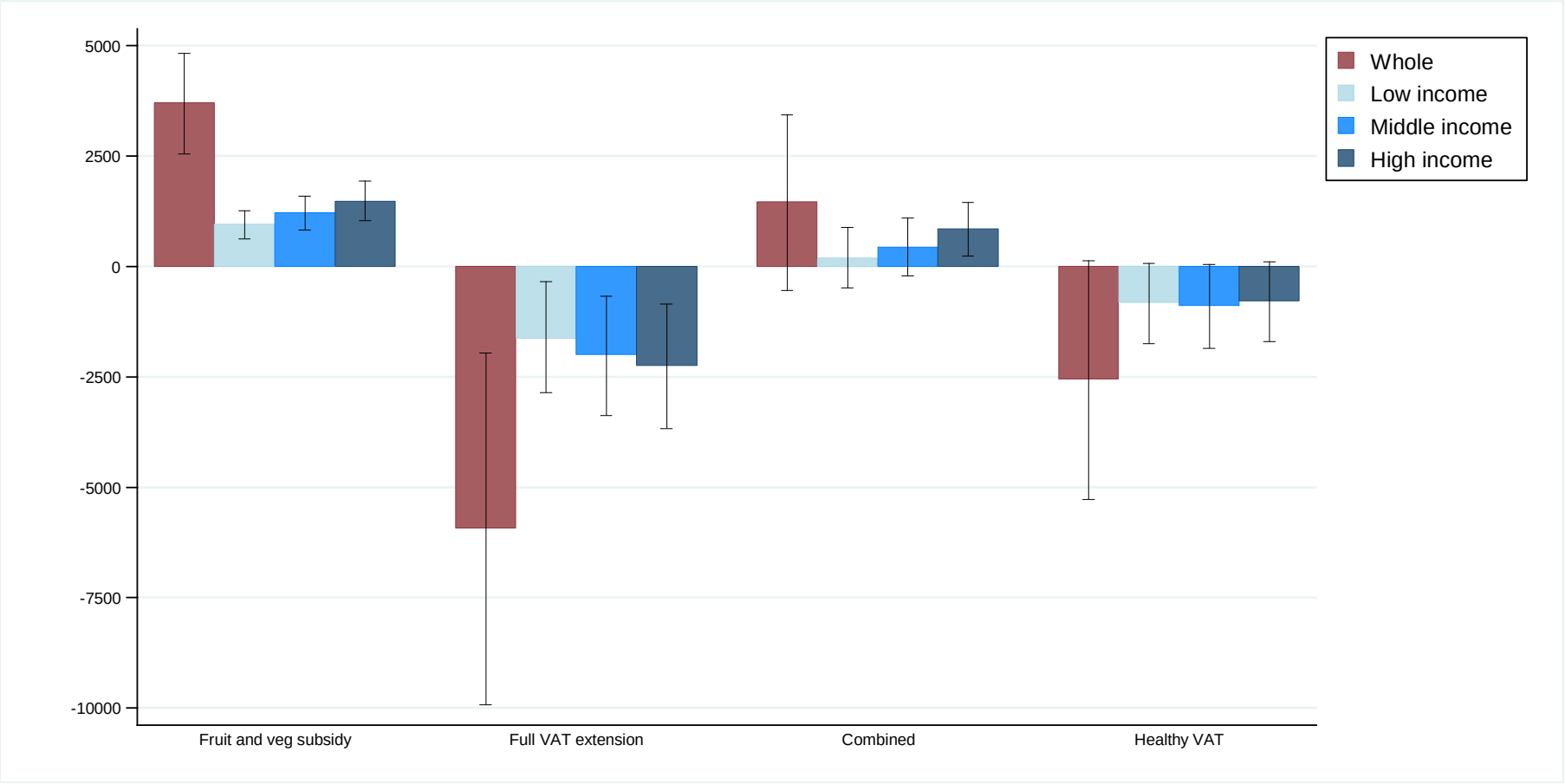


Figure 15: Deaths delayed or averted in 2013 under selected health-related food tax/subsidy scenarios in the UK, by income tertile



Discussion

Summary of observations

Health-related food taxes and subsidies have the potential to have both positive and negative health impacts due to the complex way in which purchases change in response to interventions. These results suggest that fruit and vegetable subsidies have the greatest potential to improve health. There is evidence of differential impacts across all the interventions tested, but the magnitude and direction of differential impact varies by intervention.

Comparison with other studies

Ten studies included in the modelling review examined health impacts beyond changes in purchases using personal characteristic price elasticity estimates. Six of these studies focused exclusively on SSB taxes. Of the remaining four studies, the two that examined differential responses by income only examined fruit and vegetable subsidies. This study is unique in that it used income specific price elasticity values to test the differential impact of varied HRFTS in the UK. It is the first UK study that uses income specific price elasticity estimates to examine the differential impacts of HRFTS that are not SSB taxes.

Direct comparisons of price elasticity estimates are complicated as price elasticity estimates depend partly on the definition of categories, and on the length of time over

which data were collected. However, the own-price elasticities of the seven broad food categories fall between -0.4 and -0.9 – within the range of typical elasticities for food groups in high income countries reported in a recent meta-analysis [116]. The price elasticity estimates also appear similar to UK food price elasticities reported elsewhere [199,206].

Meta-analysis suggests that low income groups are generally more elastic to food price changes than high income groups [116]. This was also true in this study as the lowest income tertile had higher price elasticities (i.e. were more price elastic) in over half the sub-categories examined. However, there were several sub-categories where the lowest income tertile had lower price elasticities.

Strengths and limitations

This analysis was explicitly designed to examine the differential impacts of four different HRFTS scenarios and could be applied to many more. The LCFS is a nationally representative household expenditure survey and is the only such data source that is freely available for use by the academic community. The LCFS has previously been used to examine the health impacts of pricing interventions [37,110,207]. I combined three years of data to be able to examine the differential impact of the selected pricing interventions by equivalised household income through tertile specific consumption values and price elasticity estimates.

I excluded the households in the analysis that were classified as non-reporters as the demand system estimation methods assume that the purchases recorded in the dataset are a complete reflection of the actual purchases made by a household. There were very few households excluded as non-reporting. However, quality assessments of the data collected for the LCFS have highlighted the issue of misreporting and this cannot be ruled out as a potential source of bias [208].

The LCFS collects purchases over a two week period. UK market survey data suggest that households make around 9.65 trips per month to supermarkets [147] and therefore the length of the reporting period is likely to capture the majority of the foods bought for consumption over this time period. An underlying assumption of this analysis is that the purchases made in the LCFS represent all the food eaten in a particular category over the time period examined. However, it is likely that households also consume foods that were purchased prior to the start of the reporting time period. The alternative would be to assume that any categories with zero purchases represented households that were using food up from previously purchased stocks [209]. Whilst this may be accurate for non-perishable foods (e.g. fats and oils), I felt that it was not appropriate for other categories; for example, zero purchases in the fresh meat and fish categories probably reflect the presence of vegetarian households within the sample. Future research could establish the frequency of purchasing across different food groups to enable the economic analysis to be adjusted accordingly, but this would require long-term panel data with high reporting accuracy which was not available within this project.

I excluded away from home food purchases as the reporting requirements for these purchases in the LCFS did not include sufficient data to enable inclusion in the economic analysis. These results therefore do not incorporate any changes in diet composition that may result from changes in the balance of foods eaten out compared to those eaten in the home. In 2013, it is estimated that eating out contributed to 10.2% of energy intake and the nutritional composition of eating out purchases is also different to those of household diets [15].

Zero purchases within categories and sub-categories can bias demand system estimation by artificially inflating price elasticity estimates and therefore it is important to reduce zero purchases as much as possible. This meant that I had to combine the original food codes provided in the LCFS dataset into categories. I grouped food codes with ones that were nutritionally similar and used the Eatwell Guide as a template for grouping similar foods. Originally, I grouped foods into around 40 different sub-categories but eventually it proved necessary to combine some of the sub-categories due to high numbers of zero purchasing households within some categories. In addition, the two stage QUAIDS estimation meant that the available data were used efficiently. Only the households that made purchases were included in the estimation of price elasticities of the sub-categories within a food category. The overall impact of zero purchases was that the most detailed price elasticity matrix that could be developed was the 23x23 matrix. Unfortunately, this means that it was not possible to examine the effects of very specific HRFTS interventions that changed the price of individual foods or small groups of foods within one of the 23 sub-categories.

I grouped the households in the LCFS into equivalised household income tertiles to enable differential effects of HRFTS interventions to be estimated. This is the first time that the differential impacts of HRFTS interventions other than SSB taxes in the UK have been examined using income group specific price elasticity matrices. Previous UK analyses have applied the same price elasticity matrices to households in different income groups [37]. In the UK, there are socioeconomic differences in food purchasing patterns [54], therefore, it is likely that the way in which households respond to food price changes vary depending on socioeconomic and other characteristics. The price elasticity matrices do show some differences in price sensitivity across different income groups. This chapter considers the possibility for differential effects throughout the modelling process, and I believe that this is a considerable strength compared to previous work identified in the modelling review.

The nature of this analysis necessitated the scaling of household level purchases to individual level dietary intakes. A common problem with estimating the effects of HRFTS is the difficulty of translating purchases to consumption. I was able to overcome this problem to some extent with the use of PRIME, as it estimates the health impacts based on changes in consumption rather than absolute consumption values. This assumes that the relationship between purchasing and consumption would not change under a HRFTS intervention. Many of the modelled scenarios resulted in large reductions in energy intake. However, households could respond to a HRFTS by maintaining energy intake through reducing food waste.

The second issue with scaling household level purchases to individual dietary intakes is that the total food consumed by a household needed to be split across household members to provide an estimate of individual level dietary intakes. The values chosen to spread household purchases to give individual values were based on the average calorie requirements of different ages but was limited by the detail of household composition data available.

The use of a comparative risk assessment model enabled positive and negative impacts of each of the interventions to be traded off against each other to give an overall summary of the likely health impact of particular interventions.

I assumed deaths were equally distributed across the three income tertiles across all diseases, sex, and age groups. This meant that I was able to estimate the health impact in terms of the deaths delayed or averted by household income. However, the analysis of the differential health impact of the selected interventions by income group was inhibited by the lack of income specific data on mortality by age, sex, and cause of death. Previous research has shown considerable differences in disease rates based on income. In two Canadian studies, researchers found strong, independent associations between household income and heart disease and diabetes prevalence [164,210]; heart disease prevalence was around three times higher in the lowest income group compared to the highest income group [164]. UK studies have also observed differences in mortality by other socioeconomic indicators: cardiovascular disease mortality is twofold higher in Glasgow compared to the Isles of Scilly [211] and cancer mortality has remained higher in manual occupations

compared to non-manual occupations even after accounting for differences in smoking [212]. Whilst the assumption that deaths are distributed equally across income groups is a clear limitation, the health results reported as DDA give a direct comparison about which income group improved their diet the most in each scenario. This effect would have been obscured if baseline deaths by income tertile were different. The release of cause-specific mortality data by age, sex, and socioeconomic variables should be encouraged in order to improve the precision of estimates of the differential impacts of public health policies such as HRFTS.

In this study, I did not model the impacts of changes in calorie intake on obesity prevalence in the UK. The VAT extension scenario that had the most negative health impact led to a reduction in calories purchased. If the reduction in calories purchased translated to a reduction in calories consumed then this would be expected to lead to a reduction in BMI, and reductions in obesity at the population level. Other modelling studies have included the impact of such reductions in calories on decreased obesity and found positive impacts of interventions that result in increased food prices [37,63]. Conversely, the fruit and vegetable subsidy scenario that had the most positive health impacts also led to an increase in calories. Whilst meta-analysis of interventions that increased fruit and vegetable consumption concluded that promoting fruit and vegetable consumption appears unlikely to lead to weight gain [88], the issue of increasing calorie consumption and weight has previously been noted in studies examining the impact of HRFTS [20,24].

Conclusion

HRFTS have the potential to improve or worsen health in the UK. Interventions that include a subsidy on fruits and vegetables appear to have the greatest potential to improve health in the UK. This analysis reveals the complexity of estimating changes in purchases in response to HRFTS. Interventions that simultaneously raise the price of unhealthy foods and reduce the price of healthy foods may have negative health impacts. This analysis also demonstrates that the differential impact of HRFTS by household income depends on the features of specific interventions. The methods used in this chapter could be used to examine the impacts of other HRFTS scenarios.

Chapter 8: Discussion

Summary of findings

This thesis began with three objectives:

- to identify health-related food taxes and subsidies (HRFTS) with the potential to improve diets in the UK
- to develop and assess the suitability of a UK Virtual Supermarket (UKVS) as an experimental tool for assessing the differential impact of HRFTS in the UK
- to model the health impacts of selected HRFTS scenarios in the UK

The public health imperative of introducing HRFTS is to increase consumption of some foods and reduce the consumption of others with the aim of improving population diets. In Chapter 2, I considered existing evidence of different types of HRFTS intervention, current influences on prices, and dietary patterns and needs to gauge which HRFTS would be expected to lead to public health benefits in the UK. I concluded that HRFTS that target a broad range of foods are likely to be most appropriate as population diets are unhealthy across multiple food groups and nutrients, including low fruit, vegetable, and fibre intake and high salt and saturated fat intake. Specifically, I argued that VAT reforms and fruit and vegetable subsidies are HRFTS that merit consideration in the UK.

Once I had narrowed down the range of HRFTS that I planned to examine, I began my assessment of the likely differential impacts of these HRFTS. I conducted a systematic review of experimental studies that examined the differential impacts of HRFTS (presented in Chapter 3). The evidence was limited – only 8 studies were identified. Included studies had small sample sizes and were heterogeneous. This meant that it was not possible to draw coherent conclusions with respect to the effect of specific personal characteristics – such as income - or the exact magnitude or direction of differences. No UK based studies were identified in the review. The limited evidence base suggested ample opportunity to develop UK based experimental methods to assess the differential impacts of HRFTS.

I developed the UKVS to create an experimental setting which reflects the environment in which the majority of food is purchased in the UK. Chapter 4 outlines the steps taken to adapt the existing Dutch Virtual Supermarket to the UK setting. This included selecting and placing over 500 products into the existing layout, and developing questionnaires and other study procedures. Software testing participants responded favourably to the UKVS, this suggested that the software was robust enough to be used for a study in the general population.

Once the UKVS was developed, I tested the feasibility of using the UKVS to examine differential responses to HRFTS. The feasibility study (presented in Chapter 5) revealed important limitations with recruitment and retention in the UKVS that need to be addressed before the software can be used for a full trial of pricing interventions. Feedback from the participants who did complete the study procedure was positive, suggesting that

the UKVS would be a feasible tool for examining differences in purchasing behaviour if issues surrounding recruitment and retention were addressed. The feasibility study also provided data that can be used to estimate the sample sizes that would be needed to test various HRFTS in a randomised controlled trial.

The thesis then moved on to examine the differential impact of HRFTS using modelling methods. Chapter 6 provides the results of a review of modelling studies that examine the differential impacts of HRFTS. I looked at the extent to which studies included differential impacts at each stage of the modelling process. I found that much of the existing literature fails to account for the multitude of ways that differential effects could occur. The modelling review informed me of the methods that have been used to examine differential impacts, and I was able to take on-board these findings from the review when developing my own modelling study.

Chapter 7 provides an analysis of the overall and income specific impacts of selected VAT reforms and fruit and vegetable subsidies. I find that interventions that include a subsidy on fruits and vegetables appear to have the greatest potential to improve health in the UK. The modelling chapter reveals the complexity of estimating the health impacts of HRFTS and shows that some interventions that simultaneously raise the price of unhealthy foods and reduce the price of healthy foods can have negative health impacts. The extent to which differential impacts are seen depends on intervention specific features such as the food categories that experience price changes and the level of these changes.

In this final chapter, I compare the experimental and modelling parts of my thesis to existing literature, discuss the strengths and limitations of the thesis as a whole, and suggest possible avenues for future research in this area.

Comparison with other literature

Comparison between the findings of review chapters with other literature

Several reviews assess the evidence base surrounding HRFTS. Some reviews have looked at the overall evidence base [20,23,213], others have focused on specific study designs [22,25] or specific types of HRFTS intervention [85]. Existing reviews have commented on differential impacts, but this was not their primary focus. The review chapters in this thesis focus on examining the evidence surrounding the differential impact of HRFTS. My systematic review of experimental studies (see Chapter 3) was the first to examine the differential impacts of food price changes in experimental settings. The specific focus meant that I could provide more detail in the narrative synthesis on differential impacts. I also quantified within study differences in responses to food price changes by different personal characteristics by converting study results to price elasticities.

Later in the thesis (Chapter 6), I examined the evidence from modelling studies on the differential impacts of HRFTS. The focus of the modelling review was on how differential impacts of HRFTS have been modelled, and the stages at which differential estimates were included in the modelling process. While other reviews have noted mixed findings with

respect to differential impacts [20,22], I provide a methodological explanation that may partially account for these mixed findings: I established that failure to account for differential impacts at each stage of the modelling process is probably resulting in poor estimation of the differential effects of HRFTS.

Both the review of experimental studies and the review of modelling studies found inconsistent evidence surrounding income related differential impacts of HRFTS. Whilst both reviews identified methodological shortcomings in existing evidence, it also appeared that the choice of HRFTS and the context in which the HRFTS is implemented could influence the extent to which HRFTS reduce or increase inequalities in diet.

Comparison of the UK Virtual Supermarket with other experimental environments

The UKVS had a comparable product selection to experimental environments used in other studies that look at the differential impacts of HRFTS, as identified in the systematic review. The UKVS contains over 500 different products; previous experimental studies identified in the systematic review included between 60 [122] and 708 [59,136]. The UKVS is also similar to previous Virtual Supermarkets. Purchases in the New Zealand Virtual Supermarket have been validated against real purchases [133] and the Dutch Virtual Supermarket has been used for a number of trials of pricing interventions [123,131,132,214]. Across all the Virtual Supermarket studies, feedback from participants has been positive. The validation and use of previous Virtual Supermarkets, and positive participant experience suggest that the UKVS is a good experimental environment for testing the effects of pricing interventions.

The UKVS feasibility study is the first to examine how suitable the Virtual Supermarket environment is for examining purchases across different income groups. Feedback from participants who completed the study procedure was positive across different income groups; this suggests that the UKVS is suitable for examining differences in purchases across different income groups. To my knowledge, few experimental environments identified in the systematic review assessed their suitability for examining purchasing behaviour across different income groups. The UKVS is not the first experimental study to demonstrate differences in recruitment and retention in different population groups [215]. Efforts to improve retention across different income groups are needed for adequate assessment of differential impacts of HRFTS to be tested in the UKVS – and possibly other experimental settings.

Comparison of modelling chapters

The modelling chapter used standard econometric methods that have been used in previous studies examining the impact of food price changes [39,40,83,166,179,184,199]. The health model has also been used to estimate the health impacts of real and modelled HRFTS [62,63]. I was able to include differential impacts at three stages of the modelling process and used income specific price elasticity estimates. This is the first time that income specific price elasticities have been included in a UK based study looking at the differential impacts of non-SSB tax interventions.

I calculated the combined health impact across nine causes of death, which together account for around 40% of all non-communicable disease deaths in the UK. The studies I identified in the modelling review typically focused on a limited range of diseases, only five studies had health impacts for multiple disease outcomes. However, data on the distribution of deaths by cause and income is not available in the UK - this limited the extent to which I could establish the differential health impacts of interventions.

The results of the modelling chapter generally mirror previous findings in the literature. In common with Nnoaham et al. [37] and Mytton et al. [64], I found that HRFTS that raise the price of unhealthy foods could lead to negative health impacts. I estimated that a fruit and vegetable subsidy would lead to health improvements, this is also consistent with other studies [37,63]. However, it should be noted that similar scenarios across the different studies do not necessarily lead to the same health outcomes. For example, Mytton et al. [64] estimated that a nutrient profile based reform of VAT would have a positive health impact while I estimated a negative health impact from a similar scenario. This difference may be explained by differences in the categorisation of some common sub-categories. For example, bread was classified as “healthy” by Mytton et al. [64] but “unhealthy” in my analysis. Future studies could look at the sensitivity of modelled results to price changes in specific sub-categories of foods to unpick some of the differences observed between similar scenarios.

Strengths and limitations of the thesis

There are four main areas in which I will explore the strengths and limitations of this thesis. Firstly, the thesis primarily considers the shopping behaviour of the primary household shopper in the environment in which most food is purchased. However, as not all household purchasing behaviour is included, my results may not be representative of the totality of dietary changes that would result from the implementation of a HRFTS. Secondly, I assume that changes in purchases would result in proportional changes in consumption. The validity of this, and other assumptions made in this thesis, is discussed below. Thirdly, I focus on household income but do not consider the interactions between different personal characteristics. Finally, I do not consider non-health impacts of HRFTS.

Representativeness

The experimental work in this thesis examines purchases in a small supermarket, and the modelling work is based on purchases classified as "foods brought home" in the LCFS. The UKVS provides an experimental environment that represents the supermarket environment in which the majority of food is purchased in the UK. Whilst the UKVS is smaller than a typical store, the resources required to develop a UKVS based on the existing Dutch Virtual Supermarket were considerably smaller than the resources that would be required to replicate a large supermarket. In addition, the smaller store environment and short, next-day shopping tasks probably result in a lower burden for study participants than in a larger experimental setting.

The LCFS is a large, nationally representative survey with detailed quantity and expenditure data. The quality of data provided in the LCFS is monitored with findings fed back to improve future data collection [208]. Although the LCFS does not capture purchases on foods that are not brought home in sufficient detail to have included these purchases in the calculations of price elasticities, the data on "food brought home" purchases is the most robust data source that is freely available in the UK for this type of analysis.

Whilst there was a good rationale for the use of the UKVS and 'foods brought home' purchases from the LCFS, there are limitations in the extent to which these environments are representative of overall food purchasing behaviour. In addition, it is important to consider whether these data are representative of real behaviour in the environment in question.

Food purchasing settings

Whilst supermarkets account for the majority of food purchased in the UK, purchasing changes in other settings (e.g. canteens, vending machines, fast food vendors, restaurants) may also affect the overall health impact of HRFTS. Changes in purchases in other settings may lead to changes in the magnitude and direction of the health impact. For example, Schroeter and colleagues [181] note that a tax on away from home foods could result in overall increases in food consumption due to substitution behaviour.

Differential impacts could also vary in different settings: there is some evidence that away from home food consumption frequency, nutritional composition, and price elasticities

vary by socioeconomic status [216–221]. I used one experimental environment – the UKVS – to examine the differential impacts of HRFTS. I believe that the choice of a UKVS was justified owing to the large proportion of food purchased in small supermarkets, but it may not be entirely representative of purchases in other settings.

Modelling studies can, at least theoretically, include all food purchases. However, the data on away from home purchases in the LCFS was not sufficient for me to examine differential impacts of HRFTS on all food purchases. This was due to the lack of data on quantity for away from home purchases. Future editions of the LCFS could consider collecting data on the quantity of away from home purchases. Another alternative would have been to use commercial panel data from households who continually record their household purchases. Examples include the Nielsen HomeScan and TNS WorldPanel datasets that were used by some studies included in the modelling review (e.g. [165,171]). Assessments of panel datasets have found that they may also lack data on away from home purchases and/or purchases from some retailers [222].

Realism

Comprehensive assessments of the impact of HRFTS that combine data from multiple settings will only be valid if the settings are an accurate reflection of reality. The UKVS is not a perfect reflection of a real small supermarket, and purchases in the LCFS are not a perfect reflection of all food brought home purchases.

Product availability and substitutions

The range of items that is recorded in research settings does not typically cover the real selection of products that are available. In experimental settings, the number of products available to participants is limited to the selection in that experimental environment. Although the UKVS had a favourable product selection compared to other experimental environments, the selection is still small compared to real stores; the three smaller stores surveyed as part of the UKVS development contained between 2,600 and 3,300 food products, and online supermarkets contain around 30,000 foods [i]. Larger product selections are possible; one recent study included 6,000 different products [223]. However, increases in the product selection need to be weighed against the possibility for increased participant burden. In addition, even with a large number of products, the products available may not reflect typical product availability for everyone as the choices available differ between different supermarkets. For example, Cameron and colleagues found that there are more energy dense snack foods and soft drinks available in supermarkets in disadvantaged neighbourhoods [224].

The LCFS data that are available do not capture purchasing details down to individual foods, and all purchases are grouped into 256 food codes. The analytic implications are similar to that of the limited number of products in the UKVS; we cannot examine current purchases

[i] Based on own estimates of number of products available by counting the number of products in each category for one online supermarket

or changes in behaviour at greater resolution. I further grouped the 256 food codes for the econometric analysis in Chapter 7. This meant that it was not possible to determine changes that could occur within a category by substituting to similar products. For the seven broad food categories in the LCFS, there was some evidence that higher income households spent more money to purchase the same amount (in grams); this suggests that high income households may be more able to substitute for similar products while keeping the overall quantity of food purchased the same under HRFTS scenarios.

The nutritional implications of substitutions depend on the nutritional variation within food categories. The problems introduced with the limited product availability could be overcome to some extent by accounting for the nutritional variation within categories. For example, nutritional variation in similar products could be identified from lists of all the items available in an online supermarket. This could be used to add uncertainty into modelled estimates of the changes that may result from HRFTS. Data on variation in similar products could also be used to inform sampling procedures for products available in experimental environments, and this is something that I tried to incorporate in the development of the UKVS even if the actual product selection was limited.

Offers

Study environments can differ from their real life equivalents in ways other than product selection. A key example is the issue of special offers. Sixty percent of UK respondents in a market research survey listed offers in their top five influences of food purchases [15].

Other research has found that labels suggesting that an item is on special offer can increase purchases, even in the absence of a price discount [225].

The UKVS did not contain foods on special offer. A couple of software testers stated that they thought it was odd that these were absent. However, including offers into the UKVS environment would bias estimates of the variability in purchases – a crucial variable for determining sample sizes required in a randomised controlled trial of HRFTS in the UKVS. If offers were the same in the first and second shopping tasks, then purchases of special offer items may lead to bias in the variation in purchases through increased propensity for participants to purchase special offer items. If offers were different in the first and second shopping task, then participants may change their purchasing decisions to a greater extent than if the offers did not change.

The issue of accounting for special offers are also present in modelling studies. I used endogenous price estimates and the LCFS dataset did not provide details of whether there were offers when households purchased particular items. The lack of knowledge of offers may affect the accuracy of price elasticity estimates as elasticities differ under promotions [226]. It would be possible to estimate the impact with comprehensive store card data linked to a database of store-level offers. This could be used to estimate price elasticities with and without accounting for offers, however no such dataset was available for this project.

Offers are one way in which both experimental and modelled environments differ from real life. The datasets used in modelling studies could collect data on whether the products purchased were on offer at the time of purchase. However, this would either require greater data input from retailers to track down information on offers or would require asking participants to record whether products were on offer resulting in increased participant burden. In simulated supermarket environments, there are plenty of other ways in which the reality may be different, not just through the lack of offers.

Representativeness of purchasing behaviour

Related to the realism of the setting is the representativeness of purchasing behaviour within that setting. The general assumption is that the more realistic the setting, the more representative purchasing behaviour will be. However, there are several reasons why this may not be the case: participant purchases within the chosen setting may differ from real purchasing behaviour, and responses to price changes may differ from responses under a HRFTS.

Purchasing periods

In the UKVS, I collected data on next-day shopping tasks. Next day shopping tasks were used in three of the eight studies included in the systematic review [35,59,126]. UK data suggest that an increasing proportion of grocery spend is due to top-up shops compared to main shopping trips. Currently top-up shops represent 61.2% of spending [137]. In the feasibility study, 50% of participants stated that they would conduct a similar shop to the UKVS task on at least a monthly basis. This means that the purchasing data collected in the

UKVS likely relates to a small sub-section of household grocery purchases. Even if the experimental setting accurately reflects the real life setting it is designed to imitate, there may be different responses to HRFTS for different types of task within the experimental environment. Experimental studies could try and match the experimental task to the typical purchasing behaviour of participants, but this is limited by the diversity of experiences within participants. On average, UK households visit 3.5 different store chains per month [147]. Alternatively, studies may select participants with particular food shopping habits (e.g. [223]) but this may lead to unrepresentative samples, the problems of which are discussed in a later section.

The data used in modelling studies is also limited to a subset of food purchasing behaviour. Whilst all adults in a household are asked to complete a diary of purchasing behaviour, the dataset includes responses from households where some members refused to keep a diary, provided that a diary is completed by the household reference person [195,227]. Household members are asked to record all purchases over a two week period but there is evidence that response rates decrease over the reporting period [208]. A recent quality assessment for the LCFS recommended that further work is needed to establish the trade-offs between maintaining the current diary period or switching to a one week diary [208]. Shorter recording periods could reduce purchasing frequency and result in increased zero purchases, even if response rates are higher. The alternative to budget surveys is the use of scanner data where participants continually record all purchases made for an indefinite

period of time. However, average expenditure levels are markedly lower and there are limited attempts to ensure compliance for participants in scanner surveys [228].

Representativeness of HRFTS responses

Even if we were able to gather truly representative data on current food purchases in experimental and modelled environments, the purchasing changes observed in response to price changes may still not be representative of patterns under real HRFTS. Experiments can estimate the impacts of price changes in settings where participants do not usually use their own money or receive real foods. Modelling studies assume that the patterns seen under unsystematic (and often small) price changes will apply in the event of the systematic (and possibly larger) price changes expected under HRFTS.

The limitations of participants not using real money in experimental studies has been noted in the past [35,133]. One study has tried to overcome this by providing participants with a (large) monetary incentive and charging participants for the purchases made in an experimental supermarket [223]. However, even this study found that participants spent more in the experimental supermarket than they typically would in real life, presumably due to the additional income afforded by the incentive. One alternative would be to ask participants to use their own money without an incentive but this would reduce the ability to recruit participants, and it would be unethical to test price increases (particularly in populations at risk of food insecurity). A better alternative may be to provide an incentive that is decoupled from food shopping behaviour. Households allocate budgets to particular categories of expenditure, and people are reluctant to spend money in one budget on

items that fall under another budget [229,230]. By providing incentives in a different form (e.g. vouchers for clothing or payment of energy bills), experiments may prompt more realistic food purchasing behaviour and provide adequate financial compensation to participants.

Results of modelling studies may not represent how households would actually respond to HRFTS as they assume that past patterns of consumption will hold into the future. The imposition of a health-based tax is a signal to consumers about the quality of a product and may influence behaviour independently of price [231]. As price elasticity estimates used in modelling studies are based on past purchases, they are unable to capture changes in demand that may result from non-price factors.

Unrepresentative sample

A major limitation of the feasibility study was the high (and differential) participant dropout rate. This meant that there were insufficient data on food category purchases to estimate the sample sizes that would be required for a randomised controlled trial of pricing interventions for different income groups. The high dropout rate also suggests that the participant feedback that was collected on the UKVS may not be representative of the wider pool of actual and potential UKVS participants. In Chapter 5, I suggested ways in which recruitment and retention could be improved in future UKVS studies. Response rates for the LCFS are also low, around 50% of invited households responded between 2011 and 2013 [208]. Whilst improvements could be made to improve the response rates in the LCFS, it is comparable to similar studies in other European countries [208]. In Australia,

participation in the LCFS equivalent is compulsory and achieves a 72% response rate [208]. Compulsory survey participation is unlikely to be acceptable in the UK context; continued monitoring and evaluation of the representativeness of study samples, and efforts to ease study participation are probably the best approach.

Converting purchases to consumption

Food purchases are made, and data is collected, at the household level. However, health impacts from changes in diets accrue at the individual level. Throughout this thesis, I have collected data on household purchasing behaviour and used it to assume individual consumption values for food groups and nutrients. The methods to convert purchases to consumption values may bias estimates of the overall and differential impact of HRFTS.

Food waste

Not all food that is purchased is eaten. A UK report estimated that 22% of the food that is purchased is wasted – 60% of this is avoidable [232]. The proportion of food that is wasted varies considerably across different foods: only 5% of alcoholic drinks but 37% of leafy salads are (avoidably) wasted [232]. Scaling purchases to account for the proportion of food that is wasted, and different levels of food waste across foods, may help to improve the accuracy of consumption estimates derived from purchasing behaviour.

I did not scale purchases in the experimental or modelling work to account for the proportion of food that is wasted. In the UKVS, I was primarily interested in differential responses to the software and the purpose of the purchasing data was to enable sample

size calculations and not to estimate consumption values per se. Estimates of the health impact of modelled interventions are based on percentage changes in consumption and therefore the lack of scaling in the modelling work should not impact the results. This approach assumes that food waste will remain constant under HRFTS. Food waste in the UK declined substantially between 2007 and 2012 amidst rising food prices [15,232] but it is unclear whether these trends are related and whether household waste patterns would change rapidly following rapid changes in price that might follow the implementation of HRFTS.

Splitting across household members

In Chapter 7, I scaled household purchase values to individual consumption using estimated calorie requirements for different age groups. Whilst the LCFS did provide data on household composition, the age ranges given were wide and this is likely to have reduced the accuracy of consumption estimates. Splitting purchases based on calorie requirements assumed that purchases within each food group are divided based on calorie needs alone. This is simplistic as dietary recall data shows different food consumption patterns by age and sex [7].

Household purchases could be divided more accurately across the household if purchasing data were collected in tandem with individual consumption within a household. The LCFS does not collect data on individual consumption, and the National Diet and Nutrition Survey only collects consumption values for selected individuals within households and does not collect purchasing data [7,193]. Converting purchases to individual consumption

is also important for assessing the differential impacts of HRFTS as there may be different distributions of purchases to individuals within household based on personal characteristics. For example, UK data suggest that children's diets appear to be protected from food insecurity and hunger in low income households [233].

Experimental studies could be used to fill this gap. In the UKVS feasibility study, I focused on purchasing behaviour and did not collect data on consumption. However, future experimental studies could consider administering a 24-hour recall or food diary to all household members in addition to the completion of shopping tasks. This may help to give a better indication of how purchases are currently divided across the household, even if it does not tell us how changes in purchases may be divided under HRFTS.

Longitudinal perspective

Neither the experimental nor modelling work conducted as part of this thesis look at the long term impacts of HRFTS. The resources required to test the long term impacts of HRFTS experimentally are large. The longest intervention period that I identified in the systematic review was that of the New Zealand SHOP study, at 24 weeks [121]. However, even this length of follow up is not sufficient to examine changes in health and disease outcomes without prohibitively large sample sizes. This is a research gap that is unlikely to be filled by evidence from studies using the UKVS or similar experimental environments; the gap will need to be filled with high-quality evaluations of natural experiments.

Modelling the long term health impacts of changes in diet is possible (e.g. [234]) but is not common in the literature modelling the differential impacts of HRFTS. The primary reason for not modelling the health impacts of HRFTS probably reflects the uncertainty in modelled changes in dietary intakes, particularly over long time horizons. Ideally, price elasticity data for HRFTS should reflect medium- and long-term changes that result from price changes [235]. Whilst I used data from multiple years of the LCFS (2011-2013), the health impacts of HRFTS may occur decades into the future and therefore extrapolation of long-term health impacts based on shorter-term changes in diets may not be accurate.

In addition, socio-economic characteristics may change over time and this may influence the dietary changes observed under HRFTS. For example, incomes generally rise over working-age and then decline following retirement [236]. By focusing on individual personal characteristics at a specific point in time, the longitudinal impacts of changes in personal characteristics over time are missed. Ignoring changes over time in modelled estimates of the differential impacts of HRFTS misses an important source of uncertainty of the impacts of HRFTS over long timescales.

Non-health impacts

This thesis has focused on the health impacts of HRFTS from changes in population diets. However, there has been limited consideration of other impacts of HRFTS including revenue impact, political feasibility, and food industry responses.

Revenue impact

I did not calculate changes in government revenue associated with the interventions modelled in Chapter 7.The current cost of zero-rating foods in the UK has been estimated at £16,800 million [97], this suggests that VAT-related reforms that remove zero-rating would be unlikely to raise more than this amount. Aside from the fruit and vegetable subsidy, the interventions I modelled would be expected to raise revenue as administrative costs for similar interventions are low (generally below 1% of revenue collected) [92]. HRFTS that raise revenue and improve health are cost-saving interventions. It is unclear whether the fruit and vegetable subsidy would be a cost-effective intervention without data on the revenue impacts for the health service and the long term impact on burden of disease. Without revenue data, it is impossible to compare the HRFTS to other public health interventions that could be implemented in the UK in terms of cost-effectiveness. An Australian study found that a HRFTS and traffic light labelling were both cost-effective [180]. Further UK based work is needed to compare the cost-effectiveness of different public health interventions to determine optimal interventions combinations.

Political feasibility

I did not examine the political feasibility of the interventions I concluded had the potential to improve health in the UK in Chapter 2. This means that the results of the modelling conducted in Chapter 7 do not provide evidence on HRFTS that are currently being considered by government. However, both the modelling and experimental methods developed in this thesis are flexible enough to explore other scenarios. This means that the

capacity is there to provide estimates of various scenarios in the future, including scenarios suggested by government or other stakeholders as being likely for implementation in the UK.

Food industry responses

The way in which the food industry responds to HRFTS may fundamentally alter the impacts. The simplest way that the food industry may change the impact of a HRFTS is through pass through rates. The majority of the studies identified in the modelling review assumed a 100% pass through rate, though some did examine the sensitivity of results to this assumption [56,176]. Analysis from the implementation of the Danish saturated fat tax demonstrates that pass through rates may not be 100%, and that there may be differential pass through rates for different retailers [57].

There are other responses to HRFTS that could differ by retailer, and therefore lead to differential impacts of HRFTS. Reformulation could result in dietary changes that increase or decrease the impact of a HRFTS. The Hungarian Public Health Tax seems to have contributed to reformulation [82]. Retailers might also respond to HRFTS by changing store layouts and this could help or hinder the impacts of HRFTS. In real stores, surface area is allocated according to profit maximisation [82]. If HRFTS change the profitability of different foods, or categories of foods, then the shelf space allocated to different foods may also change. Given differences in store choice and purchasing behaviour between different socioeconomic groups [54,147], the response of the food industry could also play an important role in determining the differential impacts of HRFTS.

Contribution of the thesis

This thesis contributes to improving the methods for examining the differential impacts of HRFTS. The development of the UKVS means we now have a way to test HRFTS interventions experimentally; interventions that would be unlikely to be tested in a real supermarket environment. The feasibility study also shows that the UKVS is suitable for examining differential impacts, and therefore it could be used to examine non HRFTS to help untangle the effects of access and availability from the impacts of interventions.

The modelling work contributes to the field by providing more data on specific interventions. The modelling framework was designed to be able to test the impacts of a range of different HRFTS interventions. The modelling structure I have developed is flexible enough to enable multiple interventions to be tested, and therefore could be used in conjunction with policymakers to help develop HRFTS strategies that improve health, but that also meet the needs of policymakers in terms of ease of implementation and popularity. The modelling structure could also be used beyond the UK context, though caution is warranted as the categorisation of foods may not be appropriate in different contexts where dietary patterns are different from dietary patterns in the UK.

Suggestions for future research

Combining methods

Many of the limitations in both the experimental and modelling work are shared across all studies with a particular design, albeit to a greater or lesser extent. No single study, and no single design, can account for the diversity of food purchasing behaviour. To identify the likely health impacts of HRFTS, we need to combine the evidence from different study designs.

The review chapters in this thesis provided a narrative synthesis of evidence from experimental and modelling studies that examined the differential impacts of HRFTS. Where possible, the systematic review also converted the findings of studies to a common metric (price elasticity) to allow for easier comparisons. Combining evidence within a study design is difficult enough due to heterogeneity in study populations, interventions, and outcome measures. These difficulties could be reduced through more consistent reporting of the outcomes of interventions.

One of the key issues that appeared in the experimental and modelling reviews was that studies reported on different outcome measures, and often only presented data for one or two outcomes. Diets have multiple health outcomes; for instance, the Global Burden of Disease Project includes 14 dietary risk factors that influence risk across multiple disease outcomes [1]. Evidence on the health impacts of HRFTS should reflect the many ways in which diets influence health (even if the HRFTS targets very specific foods). If all

experimental and modelling studies looking at the impacts of HRFTS reported across an agreed set of health-related outcomes, synthesis of the evidence across different designs would be much easier.

When examining the likely differential impacts of HRFTS, the personal characteristics need to be reported consistently too, not just the health outcomes. Six of the studies included in the experimental review and 17 studies in the modelling review examined differential impacts by income. There were multiple measures of income used across the studies that examined income. Measures included researcher assigned budgets for shopping tasks [122], household income tertiles [35], and daily grocery budgets [59]. Improving reporting consistency and reaching agreement for how to report different personal characteristics would make it possible to assess whether there were consistent effects of specific personal characteristics across different contexts and types of intervention.

Post-hoc synthesis of results from different study designs is unlikely to be sufficient to get around the inherent limitations in individual designs. We also need studies that combine different approaches from the outset to overcome the boundaries of specific designs. Possible combinations include: using epidemiological models to estimate the overall health impact of changes observed in experimental studies, and using experimental studies to calculate price elasticities that are not available from econometric data. The latter approach is currently being trialled in New Zealand to try to obtain more accurate price elasticity estimates [154].

Interactions between personal characteristics

This thesis, and the majority of other research on the differential impacts of HRFTS, focuses on a single personal characteristic at a time. This approach does not account for interactions between personal characteristics. The implicit assumption that is made when we examine a single personal characteristic at a time is that households (or individuals) that share that personal characteristic are more similar to each other than to households that do not share the personal characteristic. In addition, this approach assumes that the most relevant differential impacts will be based on the personal characteristic under analysis. Data from the National Diet and Nutrition Survey show that food consumption patterns vary by income, occupation, and education, and there is some evidence that these socioeconomic variables interact with sex [9]. Given that there are differences and interactions across multiple personal characteristics when we look at current dietary patterns, it seems simplistic to assume that single personal characteristics are sufficient to assess the differential impacts of HRFTS. Future research should consider examining differential impacts across multiple personal characteristics and assess the extent to which the choice of personal characteristic influences the magnitude of differential impacts observed.

Conclusion

This thesis set out to assess the differential impact of HRFTS in the UK by household income. I set out with the hope that I would identify HRFTS that would simultaneously improve health and reduce dietary inequalities. Although this ideal HRFTS scenario remains elusive, I believe that combining experimental and modelling approaches puts us in a better position to evaluate the possible impacts of HRFTS on inequalities prior to implementation. The development of the UKVS and modelling methods in this thesis provide us with UK specific tools with which to assess the overall and differential impacts of an increasing repertoire of HRFTS possibilities.

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Appendices

i) Systematic review protocol

ii) Protocol for software testing the UK Virtual Supermarket

iii) Protocol for a UK Virtual Supermarket feasibility study

iv) Full details of changes in purchases under selected health-related food taxes and subsidies

i) Systematic review protocol

Title: Differential responses to food price changes by personal characteristic: a systematic review of experimental studies

Diet related risk factors contribute significantly to the burden of disease. In high income countries, the combined influence of dietary factors and physical inactivity are attributable for over a quarter of deaths[1]. Fiscal measures have been proposed as one way of influencing consumers to make healthier choices as there is a growing body of research suggesting that lowering the price of healthier foods and raising the price of less healthy foods shifts purchases toward healthier options[2] and that healthier dietary options currently tend to be more expensive than less healthy options[3]. Fiscal interventions aimed at improving diets can differ in the dietary problem they set out to address, products targeted by the intervention, and the magnitude and direction of price changes. Although fiscal interventions may incorporate non-pricing elements such as labelling, coupons or advertising restrictions, here we concentrate exclusively to pricing elements of fiscal interventions as there is at least some evidence to suggest that non-pricing elements operate on other decision making mechanisms and behavioural frameworks[(e.g. 4,5)].

Before introducing food-related fiscal measures, it is important to gain in-depth evidence on the effectiveness of the measures with regard to the food purchases, and eventually population diets. In particular, it may also be important to assess how fiscal measures may affect those with particularly poor diets (regardless of income) or other personal characteristics to ensure that fiscal measures do not introduce additional or exacerbate existing health inequalities. Concerns with respect to the regressive nature of fiscal measures to improve population diets have been raised[6,7] and the effectiveness of a fiscal policy will necessarily rely on the extent to which fiscal measures are able to prevent or mitigate detrimental effects.

Experimental studies provide an effective way of examining the differential effects of fiscal policies on population sub-groups for a number of reasons. Experimental studies are able to expose study participants to the precise food pricing conditions that may come about as a result of fiscal measures to improve population diets and are less subject to the problems of extrapolating that are inherent in other methods of estimating the effects of fiscal policies. Experimental studies can collect individual level data and therefore compare the responses of different groups, and examine interactions between multiple personal characteristics (e.g. the interaction between budget and weight status in dietary choices[8]). Finally, the controlled nature of experimental settings can help to

disentangle the effect of the pricing intervention from exogenous factors such as the accessibility of foods which may confound traditional price elasticity estimates.

Recent reviews of the effects of fiscal policies to improve population diets[2,7,9] highlight the need to gain a greater understanding of socioeconomic and other differential effects in responses to fiscal measures. To date, there has not been a review that specifically addresses how personal characteristics may influence responses to fiscal measures to improve population diets. This systematic review sets out to address this gap by examining the experimental literature. The research questions that form the focus of this review, and the methods by which this systematic review will be conducted are outlined below.

Primary research question

How do personal characteristics[j] (such as socioeconomic status, gender, impulsivity, income) moderate changes in purchases of targeted foods in response to food/beverage price changes in experimental settings?

Secondary research question

- How do personal characteristics moderate changes in purchases of non-targeted foods in response to food/beverage price changes in experimental settings?
- How do the following factors influence differential responses to food/beverage pricing intervention by personal characteristic:
    - Magnitude (i.e. do larger taxes have an effect that is greater than the absolute difference in price compared to smaller taxes?)
    - Target (i.e. do interventions that target a broad range of products result in a greater shift than interventions targeting a narrow range of products?)
    - Direction (i.e. do individuals react to price increases and decreases in an equivalent fashion or does the direction of the price change have an independent effect?)
    - Information (i.e. does the method by which individuals are informed about the price change result in different responses?)
- How will changes in food price affect the total price of the diet for different groups defined by socioeconomic or other personal characteristics?

[j] Personal characteristics rather than individual characteristics will be the focus due to the expectation that included studies may look at households' rather than individuals' purchases

Search strategy

PubMed, EMBASE, Web of Science, PsychInfo, and EconLit will be searched to identify potentially relevant studies. The search strategy for PubMed is as follows, with equivalent searches conducted in the other databases:

1) food OR foods OR snack OR snacks OR beverage* OR "soft drink" OR soda OR "carbonated drink"
2) fruit* OR vegetable* OR cereal* OR candy OR sweets OR confectionary OR chocolate* OR meat OR dairy
3) sugar OR sugars OR sugary OR "energy dense" OR "energy density" OR fat OR fats OR saturates OR "saturated fat" OR salt OR sodium OR fibre OR fiber
4) 1 OR 2 OR 3
5) tax OR taxation OR taxes OR taxed OR subsidy OR subsidies OR price OR prices OR discount OR discounts
6) experiment OR experimental OR trial OR test OR supermarket* OR shop OR shops OR store OR stores OR controlled OR participant* OR intervention OR interventions OR random OR randomised OR randomized
7) 4 AND 5 AND 6

In addition to the above, the reference lists of included papers and relevant reviews[7,10,11] will be hand searched to identify any additional articles of interest. The title and abstract of identified studies will be screened for the inclusion criteria and full text versions of relevant articles will be retrieved.

A single researcher will complete the screening process with a second researcher cross-checking a 10% sample of excluded titles for relevance.

Inclusion criteria

An article will be included if it:

- is a controlled experimental study[k]
- reports results stratified by the socioeconomic or other personal characteristics[l] of study participants. These could be secondary analyses, and the study need not be adequately powered to examine differences by personal characteristics.

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[k] Both studies with an independent control group and studies which use individuals' previous purchases as the control will be included. The study setting may include studies of real-life price changes and choice experiments where real-life purchasing behaviour is not measured.

[l] Personal characteristics refer to both modifiable and unmodifiable individual level features that may plausibly influence the response of an individual to a change in

- examines the effect of price change[m] on food or beverage purchases
- collects individual level[n] data to determine the effect (i.e. excluding single site studies such as vending or cafeteria studies where the outcome is sales of targeted food)
- has one of the following outcome measures:
- price elasticity
- changes in purchases/consumption of targeted or non-targeted foods

An article will be excluded if it:

- examines price changes of alcoholic drinks in isolation
- is a review or commentary article where no original data are presented
- does not test pricing interventions in isolation from other interventions (e.g. tailored nutrition education[o]
- examines exclusively children's (<18 years of age) purchases
- was published prior to January 1980
- full text not available in English

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food/beverage prices. This includes factors such as age, sex, personality measurements (e.g. impulsivity as measured by the stop-signal task), socio-economic status, income and education.

[m] Experimental studies may phrase the price changes applied as a tax/subsidy or may refer simply to the value of the price change. In this review, we will not discriminate on studies based on the description of the pricing intervention, provided that a price intervention is applied independently of other interventions

[n] Experimental studies focusing on food price are concerned with food purchasing behaviour, and food purchasing is often conducted at the household-level. Therefore, the use of 'individual' in this protocol includes household-level studies, but does not include studies where total volumes of sales of specific food products are the units of analysis.

[o] Where the price change is accompanied by information to participants about the extent of a price change, the study will be included. However, where an additional behavioural intervention is implemented, or where the information given to participants goes beyond mere information about the magnitude of the price (e.g. if price change reduction label was applied in combination with a health message), the article will be excluded from this review

Analysis

Due to the anticipated heterogeneity in price changes tested, experimental settings, and populations investigated, no meta-analysis of the data will be conducted. However, results will be collated to allow for comparison across similar study types and outcomes, complemented by a data extraction table to summarize relevant information from the extracted studies. The full data extraction table will be collated in Microsoft Excel.

The first table presented in the report will be a summary table to provide the reader with an overview of the characteristics of the studies included in the review. The following data will be presented:

- Author name (year)
- Country
- Setting
- Study design
- Intervention(s)
- Personal characteristic(s) examined
- Analysis method

Where possible, the results from included studies will be reported as the price elasticity for the targeted food(s), by personal characteristic. Studies will be grouped according to the type of personal characteristic that is analysed: non-modifiable (age, sex), individual (personality (e.g. impulsivity, restraint), BMI, hunger) and societal (income, socio-economic status, education). Results from indirect measures (e.g. impact of budget where budget is determined by a combination of income and household size) will not be reported. Where applicable, the results of fully adjusted models will be the results reported in the data extraction table. In situations where an effect by a personal characteristic is reported but complete data are not given, study authors will be contacted and asked to provide the numeric results.

Following a description of the characteristics of the included studies, the following table will be presented in order to synthesise the information relevant to the primary research question of the review. The table has been populated with some example studies to demonstrate layout and reporting. An effort will be made to contact the authors where price elasticity estimates cannot be derived from the article; numerical results will be reported as given in the paper where it remains impossible to determine price elasticities.

Personal characteristic	Personal characteristic measure	Author name (year)	Target food	Price elasticity result (95% confidence intervals)
Non-modifiable - Sex	a) Male b) Female	Example (2014)	Fruit	a) -1.0 (-0.8, -1.2) b) -0.6 (-0.7, -0.5)
		Example (2014)	High-calorie foods	a) -1.2 (-1.0, -1.4) b) -0.6 (-0.7, -0.5)
Modifiable - Income	a) >NZ$60,000 b) <NZ$60,000	Example (2014)	Fruit and vegetables	a) -1.0 (-0.8, -1.2) b) -0.6 (-0.7, -0.5)
	a) £0-£10k b) £10k-£20k c) £20k-£50k d)>£50k	Example (2014)	Fruit and vegetables	a) -1.0 (-0.8, -1.2) b) -0.6 (-0.7, -0.5) c) -1.2 (-1.0, -1.4) d) -0.6 (-0.7, -0.5)

In addition, to give an overview of the types of study that have been conducted and the extent to which the review will be able to address the secondary research questions, a count of the number of studies according to the following characteristics will be presented:

- Does the study give the differences in purchases of non-targeted products?
- Were substitution effects examined? (Yes/No)
- Did the study look at multiple price conditions for the target product(s)? (Yes/No)
- Did the study examine both increases and decreases for the target product? (Yes/No)
- Did the study examine more than one target product/product group? (Yes/No)
- Were individuals informed about the price change and how? (Yes (methods)/No)
- Did the study examine change in the total diet cost?

If there are no studies examining a secondary research question, then it will be noted that further research is needed to build the evidence base in this area. If there are between one and three studies addressing a secondary research question, the evidence will be summarized narratively. If there are more than three studies addressing a particular research question, then relevant data will be tabulated in addition to a narrative commentary so as to provide an accessible summary for the reader

Study quality

Study quality will be assessed according to the Cochrane Risk of Bias tool[12]. The following criteria will be used to present study quality (in relation to the primary research question) for all included studies and will be summarised in the report of the systematic review.

Bias domain	Relevant questions	Scoring	Support for judgement
Selection bias	Were participants randomised to the study [price] condition? Were participants representative of the target population? Were participant recruitment methods independent of personal characteristics?	Low risk if Yes High Risk if No Unclear if No Information Given	Quote from included study where available, comment where not.
Performance bias	Were participants blinded to the aims of the research study (i.e. blinded to price changes)? Did the study design require participants to make actual purchases using their own money?		
Detection bias	Were participants blinded to the outcome of interest (i.e. the reasons why prices had changed)? Were researchers blinded to the allocation of participants?		
Attrition bias	Was complete outcome data obtained? Was attrition unrelated to the personal characteristics examined?		
Reporting bias	Did the study set out to look at differences by personal characteristics?		

In addition, a narrative sensitivity analysis will be conducted to determine the extent to which the conclusions drawn are dependent on whether the study aimed to investigate differential responses by personality characteristic(s). This narrative sensitivity analysis will be conducted in lieu of a numeric sensitivity analysis or funnel plot; this is due to the anticipated heterogeneity of included studies and the anticipated inability to determine whether included studies were sufficiently powered to detect differences in responses by personal characteristics.

Conclusion

Increasing the price of unhealthy foods and decreasing the price of healthy foods has been suggested as one method by which to improve population diets. Prior to the implementation of such policies, an understanding of the anticipated effect of such policies is required. This includes an understanding of how personal characteristics may moderate the effectiveness of fiscal measures to improve population diets. Experimental studies are able to provide evidence as to the potential effect of price changes on purchases, diets, and health outcomes. This systematic review aims to synthesise the evidence from experimental studies in order to determine how individuals respond to food/beverage price changes in experimental settings. It differs from a previous review of experimental studies[11] in the systematic approach adopted and the precise research questions of interest.

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ii) Protocol for software testing the UK Virtual Supermarket

Version: 14th January 2016

Overview

The UK Virtual Supermarket is a tool designed to be used to examine supermarket shopping behaviour. The Virtual Supermarket was initially developed in the Netherlands and more details about the initial development of the software are available elsewhere . The UK Virtual Supermarket uses the same floorplan as its Dutch counterpart, but the products available were chosen to represent the choice available in UK stores. As the software has not been previously used in the UK, it is important to conduct tests to determine the usability of the Virtual Supermarket as a tool in the UK context.

Rationale

Software testing is an important element of the development of the Virtual Supermarket as a tool to examine shopping purchases in the UK. Factors such as the extent to which participants understand the task, the ease of completion of the procedure, and comprehension of questionnaires could potentially have a considerable impact on the validity of the results obtained and influence the withdrawal of participants from the study. The aim of the software testing phase of the development of the UK Virtual Supermarket is to ensure that the instructions are sufficiently well explained, and that the Virtual Supermarket is sufficiently easy to use, to prevent problems in the future use of the UK Virtual Supermarket.

Study objectives

The primary focus of this study is to determine whether the UK Virtual Supermarket is functioning sufficiently for participants to be able to complete the study procedure.

The primary research question that will be addressed is:

- Are participants able to complete the planned study procedure (automated recruitment, UKVS download, shopping tasks, and questionnaires)?

In addition, this software testing study aims to collect feedback from participants with respect to possible modifications to improve the usability of the software and the participant experience more generally. The secondary research question that this study aims to address is:

- Does participant feedback suggest that there are any modifications that need to be made for future studies with respect to:
    - Ease of participation
    - Participant information
    - Questionnaire layout

- Questionnaire wording
- Inclusion/exclusion criteria
- Product selection
- Realism of the UK Virtual Supermarket

Participants

A convenience sample of adults who identify themselves as being the primary household shopper will be recruited. Participants will be recruited from family and friend networks and via snowballing techniques until 20 complete sets of data are obtained.

A complete set of data is defined as consent form, baseline demographic data, UKVS data (purchases and questionnaires), and the completion of the semi-structured interview.

Inclusion and exclusion criteria

The inclusion criteria for the software testing phase will be the same as those planned for the feasibility study, and are based on the inclusion criteria used in previous Virtual Supermarket studies.

To be eligible to take part, potential participants must fulfil the following requirements:

- Adult (over 18 years)
- Speaks and reads English
- Primary household shopper (buys most or all of the groceries for the household)
- Has access to a desktop or laptop computer with working internet connection
- Has an email address
- Confident using basic computer skills (e.g. internet and word processing)

Participants in the software testing study will be excluded if another member of the household is taking part in the study.

Study procedure

Potential participants will be contacted with the study information, and will have the opportunity to ask the researcher questions about the study. The eligibility of interested participants will be determined, and if individuals are eligible, they will be directed to the UK Virtual Supermarket website to complete consent forms.

Once participants have been recruited, they will be automatically emailed their unique participant identifier, instructions, and a link to the UK Virtual Supermarket software. Participants will be asked when they intend to complete the virtual shopping task and a meeting for the post-study semi-structured interview will be scheduled. Where possible, this will be planned to take place immediately following participant completion of the study procedures. Participants will be prompted that the software is new and that the purpose of the study is to help to improve the software prior to completing the task. They

will be asked to note down any comments about the software that they may wish to share with the researchers following the task.

Participants will be asked to conduct two next day shopping tasks in the UK Virtual Supermarket, with questionnaires integrated into the software at the start and end.

The post-study semi-structured interview will be conducted in person or via the phone following participants' completion of the study procedure. The questions that form the basis of the semi-structured interview are provided below. The purpose of the interview will be to gauge participants' experiences of the Virtual Supermarket and possible improvements to make prior to the feasibility study.

Semi-structured interview questions

- Participant number
- Were you able to complete the UK Virtual Supermarket study (Yes/No/Don't know)?
- What was the best thing about the UK Virtual Supermarket?
- What was the worst thing about the UK Virtual Supermarket?
- What advice would you provide to future UK Virtual Supermarket participants?
- To what extent do you agree with the following statements (1 (strongly agree) to 5 (strongly disagree)):
    - The UK Virtual Supermarket was easy to use
    - I understood the instructions that were provided
    - I could find my way around the supermarket easily
    - I understood how to "buy" things in the Virtual Supermarket
    - The questionnaires were easy to understand
    - I found it confusing being a participant in this study
    - I could find all the products that I wanted to find
- If you could change anything about the software, what would it be?
- Is there anything else you would like to add about your experience of using the UK Virtual Supermarket software?

Outcomes

Participant feedback will be used to improve the UK Virtual Supermarket. Responses to the semi-structured interviews will be used to collate a list of possible improvements that participants suggest would result in a better experience. The items on this list will be prioritised by the research team and a decision will be made as to which of these may be considered as "necessary" and "desirable" (given the perceived magnitude of the improvement and resources required to make the change) prior to progression to the feasibility study.

Participant feedback to the UK Virtual Supermarket software is expected to lead to additions to the participant information sheet and FAQs which should make participation in future UK Virtual Supermarket studies more straightforward for future experiments. Alpha testing of the software should ensure that the software runs smoothly, but participant feedback may result in changes to the inclusion/exclusion criteria on the basis of factors such as computer age or operating features.

iii) Protocol for a UK Virtual Supermarket feasibility study

Protocol version: 14th January 2016

Funding
This project is funded by the British Heart Foundation through a Non-Clinical PhD Studentship (no. FS/13/37/30295).

Background
The UK Virtual Supermarket (UKVS) could facilitate the testing of a wide variety of supermarket based interventions where the evidence base for such interventions is not currently available owing to the difficulty in conducting randomised controlled trials in real life supermarkets. The UK Virtual Supermarket may be particularly suited to testing income group differences in responses to pricing interventions. Prior to the conduct of trials specifically aimed at testing the differential effects of pricing interventions, it is important to ensure that it is feasible to examine this in the UK Virtual Supermarket environment. This feasibility study aims to examine whether there are income group differences in participant responses to task completion in the UK Virtual Supermarket, and examine whether Facebook and free online recruitment methods are a sufficient way by which to recruit a diverse (based on income) sample. This feasibility study also aims to collect data to inform sample size calculations for future studies.

Rationale
Participants in the UKVS will be asked to conduct two next day shopping tasks. In future, interventions can be tested by randomising participants to either intervention or no intervention in one of the next day shopping tasks. A prior estimate of the variability in purchasing behaviour will enable an assessment of the sample size required to conduct trials in the UKVS. This will give an indication of the appropriateness of the UKVS for testing the effect of interventions with varying expected effect sizes.

In addition, it is important to gauge the extent to which participants engage with the experimental task, and whether there are income group differences in this engagement that may create difficulties in full trials of pricing interventions in the UK Virtual Supermarket. Previous supermarket based trials have found differences in the recruitment, retention and data completeness across different groups and therefore it is important to examine this potential impact. For example, the New Zealand based SHOP study found that recruitment from the existing base of Maori and Pacific store card holders was low and a much higher percentage of Maori and Pacific participants were new to the store card scheme and this resulted in higher drop-out rates [1].

Finally, it is important to determine the effectiveness of various strategies in recruiting participants. Therefore, this feasibility study will specifically track the number of

participants recruited, and the methods by which they were recruited. This will help to determine the timescales and recruitment methods for future UKVS studies, and adaptations that might need to be considered in order to ensure that a diverse range of participants are recruited.

Objectives

This feasibility study aims to address the following research questions:

- How effective are online methods, plus snowballing, for the recruitment of participants for a UK Virtual Supermarket study?
    - Do recruitment rates vary by income group?
- What are the dropout rates for a UK Virtual Supermarket study?
    - Do dropout rates vary by income group?
- How much variability is there in next-day shopping behaviour in the UK Virtual Supermarket?
    - Does variability in next day shopping behaviour vary by income group?
- How do participants report ease of participation and appreciation of the UK Virtual Supermarket?
    - Does ease of participation and appreciation vary by income group?

Study setting

Participants will complete the study remotely from a convenient location where they have access to a computer and internet connection. Participants will be recruited online, will complete the study online, and data will be transferred to the IMSU-hosted server via the internet.

Eligibility criteria

The inclusion criteria for the feasibility study are based on the inclusion criteria used in previous Virtual Supermarket studies. Note that there may be some modification based on the results from the software testing phase.

To be eligible to take part, potential participants must fulfil the following requirements:

- Adult (over 18 years)
- Speaks and reads English
- Primary household shopper (buys most or all of the groceries for the household)
- Has access to a desktop or laptop computer with working internet connection
- Has access to an email address
- Confident in using basic computer skills (e.g. internet and word processing)

Participants in the feasibility study will be excluded if another member of the household is taking part in the study as data collection in the Virtual Supermarket is conducted at the household level.

Sample size

The feasibility study aims to have 30 participants in each UK OECD equivalised income tertile. Based on drop-out rates of ~25% in previous Virtual Supermarket studies, it is anticipated that recruiting 30 participants in each income group will result in approximately 23 study completers per income tertile.

The cut-off values for the three OECD equivalised income groups are as follows:

	OECD Equivalised household income range	
Income tertile	£/week	£/annum
Low	0 – 247	0 – 12,844
Medium	247 – 411	12,844 – 21,372
High	411 +	21,372 +

Recruitment methods

Participants will be recruited via a free online participant recruitment website (*www.callforparticipants.com*) and through Facebook advertisements. Participants will also be encouraged to pass on details of the study to friends and family members ('snowballing technique'). In addition, details of the study will be sent to an email list of individuals interested in taking part in Virtual Supermarket studies (collected in software testing phase and through direct web interest). As the effectiveness of this recruitment method is not known, there will also be additional strategies (described below) in place if an insufficient number of participants have been recruited by a given time point.

Recruitment will take place for a maximum of 8 weeks. The callforparticipants.com advertisement will be displayed for the entirety of the recruitment period, or until the required sample size is reached. Facebook advertisements will be shown between 6am and midnight for the first 30 days of the recruitment period.

The lifetime budget for Facebook advertisements will be initially capped at £250. This is estimated to generate an average of 58 clicks of the advertisement per day and 3.6 participants recruited daily based on estimates from previous studies using Facebook as a recruitment method for research studies [2-5]. Facebook advertisements alone should be sufficient to recruit the required sample size in the first 30 days of the recruitment period based on these previous estimates.

Facebook advertisements views can be restricted based on demographic characteristics and interests. For the first 10 days of recruitment, the advertisements will only be restricted to UK adults (18+ years). If 30 participants have been recruited in any of the income tertiles by day 10, the Facebook advertisement will be further restricted to exclude members of income tertiles that have been fully recruited based on Facebook estimated household income values. This restriction process will also be repeated on day

21 of the recruitment period. Recruitment will be stopped early if the required number of participants has been reached by days 10, 20, or 30 when recruitment rates are checked.

If between 25 and 29 participants per income tertile have been recruited by day 30, then the Facebook advertisements will be extended. Up to £100 will be allocated in order to display the advertisements for up to 15 additional days, with demographic restrictions applied as appropriate. The advertisements will be stopped if the required number of participants is recruited prior to day 45.

If fewer than 25 participants in each income tertile have been recruited after 30 days then the recruitment strategy will be amended. Community groups including community centres, church groups, mother-and-baby classes and others will be emailed to ask them to pass on study details to their members/participants. The groups contacted will be a convenience sample of organisations that the research team are aware of, and will depend on the spread of participants recruited prior to day 30. For example, if participants from the lowest income tertile are under-represented, then email recruitment will be disproportionately targeted towards community groups in lower income areas.

The planned Facebook and callforparticipants.com advertisements are displayed in the Supplementary Material at the end of this protocol. Note that the Facebook advertisements differed from the advertisement on callforparticipants.com as they had a smaller word limit and therefore less detail could be provided in the advertisement itself.

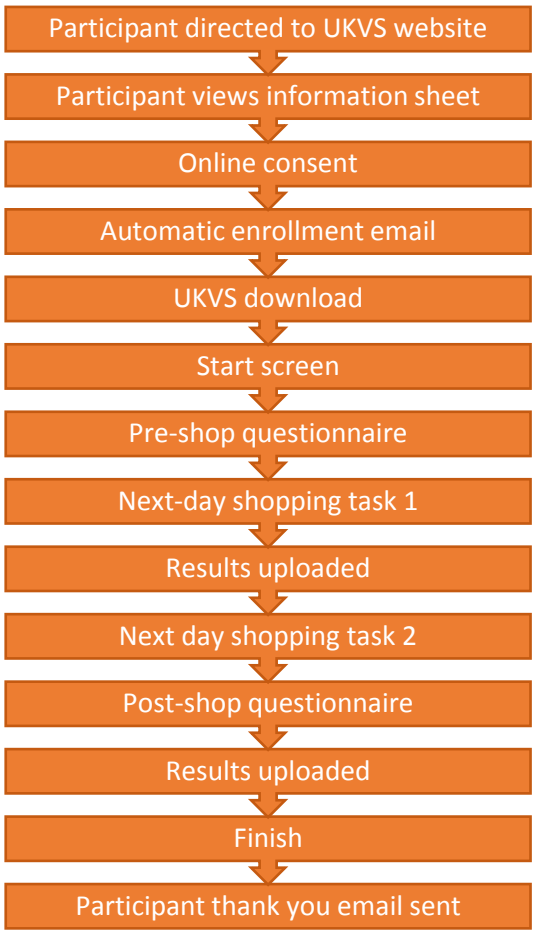
Incentives

Participants will be offered entry into a prize drawer to win £25 shopping vouchers as an incentive for participation. A total of 10 vouchers will be available, giving participants a 1-in-9 chance of winning if exactly 30 participants are recruited in each income tertile. Winning participants will be selected using a random number generator in Excel, with the results verified by the supervisor. Participants will be notified whether or not they were successful in obtaining the voucher at the close of recruitment via an email from the dedicated study email address.

Study procedure

A flow chart of the study procedure is provided below (figure 1). Interested parties will access the participant information sheet via the dedicated study website. The eligibility of interested parties will be determined and if eligible, potential participants will be asked to complete consent forms online. The submission of the consent form will trigger an automated email containing the UKVS software, unique participant identifier, and study instructions. This will be sent to the participants' email address, as recorded as part of the consent process. The study instructions booklet contains detailed participant instructions, a map of the UKVS, and an FAQ section built on the basis of previous Virtual Supermarket studies.

Figure 1: Flow chart of study procedure



Participants will download the UKVS to their computer. They will then be asked to conduct two next day shops in the Virtual Supermarket. They will be told to imagine that they have no food at home (other than herbs/spices/oil) and need to purchase all the food and beverages (but no other products) that their household would need for the next day. Participants will be told to imagine that it is a few weeks later when entering the UKVS to complete the second next-day shopping task. Participants will be told that they may take a break between the two shopping tasks if they wish.

Prior to entering the Virtual Supermarket, participants will complete a questionnaire integrated into the Virtual Supermarket software. This will collect data about the characteristics of the household and typical family food shopping behaviours. In addition, once the participants have completed the shopping tasks, they will complete a questionnaire on their experiences of using the Virtual Supermarket. Further details on the questionnaires can be found in the Supplementary Materials. Data will upload automatically to a secure server after the first shop, and at the end of the study procedure.

Participants will have 14 days from the date of consent to complete the study procedure, with reminders sent on day 5 and day 10.

<u>Outcome measures</u>

There are four domains of outcome measure; these are listed below for reference. The relationship of the outcome measures with the research questions, and the nature in which they will be presented is described under 'Analysis'.

Recruitment: number of consenters and completers (in each week of study recruitment by strategy), reasons for non-completion, reasons for withdrawal

Socio-demographic characteristics of participants: age, sex, household size, household income, education, occupation, typical grocery spend, ethnicity

Grams purchased: categories as displayed in table 4 below; reported separately for shop 1 and shop 2, with variability of each category recorded as the participants' average difference between shop 1 and shop 2. Nutrient equivalent will also be displayed for the "big 8" nutrients: kilocalories, protein, total fat, saturated fat, carbohydrates, sugars, fibre, and salt.

Expenditure: overall expenditure and expenditure in each food category. Again, variability of each category will be recorded as the participants' average difference between shop 1 and shop 2

Participant perceptions of the UKVS: software perceptions, next-day shopping task perceptions, price perceptions

Data management

Participants fill in some basic demographic information and their email address on the dedicated study website following consent. This is done via an online form that emails the result to the dedicated study email address which is only accessible to a single researcher (AM). The dedicated study email address then sends the participant their UKVS username, a link to the UKVS software download and detailed study instructions.

The UKVS uploads .csv files containing participants' UKVS purchases and responses to the embedded questionnaires to a secure IMSU server. This server is accessible only to the researcher and to the corresponding personnel at the Medical Sciences Division IT Services office.

Analysis/ statistical methods

Recruitment efficacy

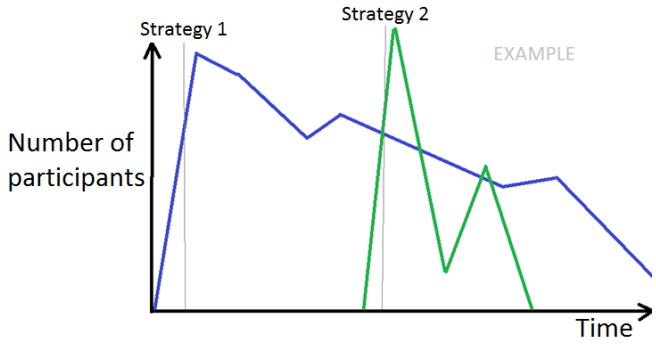
The effectiveness of the recruitment strategies used will be determined by presenting the number of participants recruited, and the number that complete the study, for each week in the recruitment period. An example of the planned presentation of this data is shown in the figure below. This will enable an assessment of the length of time that would be required in order to recruit a sufficient number of participants for various randomised controlled trials, and whether the recruitment methods are sufficient for collecting an appropriate sample size in the timeframe available.

In addition to the number of participants recruited, data on the number of participants that withdraw from the study, and that do not complete the study procedure will also be recorded. Reasons for withdrawal from the study will be collected where possible. Although participants will not be required to provide a reason for withdrawal, the email to confirm that they have withdrawn from the study will encourage them to contact researchers with any problems that they had completing the study procedure.

As some personal characteristics will be collected when participants are recruited, it will also be possible to tabulate participant characteristics based on those who did, or did not

complete the study procedure. Characteristics that will be collected at recruitment will be age, household grocery shopping responsibility, and computer type.

Planned figure 1: Recruitment rate, by strategy, over time



Planned table 1: Non-completion characteristics

	Total	Completers	Partial completers*	Non-Completers
Age				
Responsibility for household grocery shopping All Most Half				
Computer type Windows 7 Windows 8 Windows Vista Mac OS Other Don't know				
Recruitment method Callforparticipants.com Snowballing Other				
Recruitment week				

*i.e. those who only complete the first shopping task

Planned table 2: Reasons for non-completion

Reason	Number of participants
Software problems Could not install Could not play Security issue	
Personal reasons Study too long Not enough compensation Just decided not to	
Unknown	

Demographic spread of participants

The characteristics of participants who complete the study will be tabulated to convey the demographic recruited by the trialled recruitment method. Characteristics will be compared with participants in the Living Costs and Food Survey sample, and with the UK population as a whole. This will enable comment on the spread of the participants recruited by the trialled recruitment methods, and will indicate whether additional recruitment strategies should be employed in the future to recruit a more representative sample.

Planned table 3: Participant characteristics (completers)

Characteristic	
Sex	% female % male % other
Age (years)	Mean, SD
Education None GCSE or equivalent A level or equivalent Bachelor's degree or higher	%
Household income	Mean, SD
OECD equivalised household income	Mean, SD
Occupation	%
Usual weekly grocery budget	Mean, SD

Variability in next-day shopping behaviour in the UK Virtual Supermarket

Purchases (in grams and amount spent) will be tabulated by food category for the first and second shops. In addition, the difference in purchases at a category level (between the first and second shop) will be averaged across all of the participants.

Based on the variability in the purchases, it will be possible to calculate the required sample size for future UKVS studies examining different food categories and/or nutrients. The planned methodology for future UKVS studies is for participants to conduct a baseline next-day shop with usual prices, and then to repeat the task under an intervention condition. If the purchases in the first shop are systematically different to those in the second shop then this may indicate that additional adjustments are needed to the study methods (e.g. wording of instructions or sample size calculation methods).

Planned table 4: Food purchases in the UK Virtual Supermarket

Category	Percentage of non-consumers		Mean (SD) grams purchased in consumers	Mean (SD) expenditure purchased in consumers	Average difference between shops (CIs)	
	Shop 1	Shop 2			Grams purchased	Amount spent
Bread and cereals	15%	18%	400g (150g)	£1.15 (£0.20)	50g (35g, 65g)	£0.15 (£0.10, £0.20)
Fruit and vegetables						
Meat and fish						
Milk and dairy						
Sugar products						
Non-alcoholic beverages						
Alcoholic beverages						
All food and drink	N/A	N/A				

The above table will be presented for all participants combined, with equivalent tables for each income group presented separately.

Planned table 5: Nutrient purchases in the UK Virtual Supermarket

	Overall		Income tertile 1		Income tertile 2		Income tertile 3	
Category	Mean (SD)	Average difference between shops	Mean (SD)	Average difference between shops	Mean (SD)	Average difference between shops	Mean (SD)	Average difference between shops
Kcal								
Protein (g)								
Carbohydrates (g)								
Sugars (g)								
Fats (g)								
Saturated fats (g)								
Fibre (g)								
Salt (mg)								

Participant feedback on the UK Virtual Supermarket

Questionnaires will collect contextual information about participants and their experiences of the UKVS that will help to inform future amendments to the study methodology. Some of the questions will relate to participants typical shopping behaviour, thereby helping to gauge how atypical the UKVS task is for participants. The responses to these questions will be tabulated alongside the other participant characteristics (planned table 3).

To determine if responses to the UK Virtual Supermarket vary by income group, responses relating to the ease of UKVS use will be condensed to three categories (agree, neutral, disagree) and chi squared tests will be conducted to indicate income group differences in positive responses. Other questions will relate to participants' perceptions of the UKVS which will serve the dual purpose of helping to inform future improvements to the UKVS software and will also help to assess the extent of bias that the artificial environment may be introducing. These will be tabulated separately, as illustrated below.

Planned table 6: Questionnaire results

Statement	Strongly disagree (1)		Neither agree nor disagree		Strongly agree (5)	Mean (SD)
I found the UKVS easy to understand						
There was sufficient product choice in the UKVS						

Planned table 7: Income group differences in questionnaire responses

	Percentage of positive responses (strongly agree or agree)				Percentage of negative responses (strongly disagree or disagree)			
Statement	Overall	Tertile 1	Tertile 2	Tertile 3	Overall	Tertile 1	Tertile 2	Tertile 3
I found the UKVS easy to understand								
There was sufficient product choice in the UKVS								

Additional analyses

There are a number of additional, exploratory analyses which whilst not directly related to the research questions, may help to inform the methods of future studies. The most likely exploratory analyses are detailed below, but owing to the exploratory nature, the specific conduct will be determined post-hoc and based on the findings from the primary analyses.

Firstly, the analysis could be repeated with the exclusion of participants that had low appreciation of the UKVS, and with the exclusion of participants for whom the next-day shopping task could be deemed anomalous (e.g. participants who buy little of their food in the supermarket and/or usually buy food on an every other week/monthly basis and/or who spent a vastly different amount in the UKVS than would be predicted based on their usual grocery spend).

Secondly, cross-tabulations of participant characteristics alongside reported participant characteristics could be presented to determine the specific socio-demographic spread of

participants recruited in different ways. This analysis would be worth conducting if the back-up recruitment strategies need to be employed to recruit a sufficient number of participants.

Thirdly, participants could be grouped into high and low appreciation of the UKVS and differences in the participant characteristics across these two groups could be used to inform changes to the inclusion and exclusion criteria. For example, if participants with a household size of over 6 all had a low appreciation of the UKVS then it might be deemed appropriate to exclude participants with very large household sizes from participating in future UKVS studies.

Fourthly, for the purchase related variables, alternative category groupings could be used to determine what was variable within the categories. For example, to determine if the variability is driven by people buying different products within a sub-category (e.g. a different white bread) or by people not buying products (e.g. someone not buying bread in one shop but buying it in the other).

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Supplementary materials

Recruitment advertisements

The planned advertisements for the UK Virtual Supermarket feasibility study can be found below; this includes Facebook advertisements and the information that will be provided directly on the Call for Participants website. Please note that all participants will be required to read the participant information sheet and complete the online consent form prior to enrolment, regardless of the method by which they find out about the study.

Facebook advertisements



Take part in a UK Virtual Supermarket study for a chance to win £25 shopping vouchers



Volunteers wanted for a UK Virtual Supermarket study. It takes under one hour and you could win £25 in vouchers.



Want to win £25 shopping vouchers? Simply take part in our UK Virtual Supermarket study to be in with a chance.

*Call for participants (*www.callforparticipants.com*)*

Title: Take part in a UK Virtual Supermarket study for a chance to win £25 shopping vouchers

Requirements:

Age 18+

Speak and read English

Primary household shopper (buys most or all of the groceries for the household)

Access to a desktop or laptop computer with working internet connection

Access to an email address

Confident in using basic computer skills (e.g. internet and word processing)

Study description:

A variety of factors influence the foods we buy and eat including taste, price, brand, labelling, and habits. In the UK, many people do not eat a healthy diet and research is needed to work out how we can encourage people to buy more healthy food options. The Virtual Supermarket could be a way to find out what changes could be made in real supermarkets to encourage people to eat more healthily. The purpose of this research is to determine how different people use the supermarket so that we can decide what sorts of changes can be tested using the Virtual Supermarket.

If you decide to take part we will ask you to complete two shopping tasks in the Virtual Supermarket and answer some questions about yourself and your experience of using the Virtual Supermarket. We estimate that this will take 30-45mins to complete. The price, look and other characteristics of foods in the Virtual Supermarket may be different to foods in the supermarket you normally use. You will not use real money in the Virtual Supermarket and will not receive the foods you 'purchase' in the Virtual Supermarket. You will receive an email with the software materials to complete the task in your own home at a time of your convenience.

Key words:

University of Oxford, food, supermarket, paid experiment, diet, shopping

Ethical approval:

This study has been approved by the Oxford Central University Research Ethics Committee

About the researcher:

Hi, my name is Anja Mizdrak. I am a PhD student in Public Health at the University of Oxford, UK.

Pre-shop questionnaire

Before you enter the UK Virtual Supermarket, please fill in the questionnaire below so that we know a little bit more about you and your household.	
What is your gender?	Male Female Prefer not to say
What is your age? (in years)	<open>
What is your ethnic group? Choose one option that best describes your ethnic group or background.	White Mixed/ multiple ethnic background Asian/ Asian British Black/ African/ Caribbean/ Black British Other ethnic group Prefer not to say
How many adults (persons 18 years or older) are in your household (including yourself)?	1 2 3 4 5+
How many older children (14 years and over) are in your household?	0 1 2 3 4 5+
How many younger children (0-13 years) are in your household?	0 1 2 3 4 5+
What is your annual household income?	<open>
Which of these qualifications do you have? Please tick the highest that applies	No qualifications O levels/CSEs/GCSEs or equivalent A levels or equivalent Degree (for example BA, BSc) Higher Degree (for example MA, PhD, PGCE Foreign qualifications Other
Which best describes your current work status?	Unemployed Employed full-time Employed part-time Self-employed Looking after children/family

	Other
Which best describes your occupation?	Higher managerial and professional occupations Lower managerial and professional occupations Intermediate occupations (clerical, sales, service) Small employers and own account workers Lower supervisory and technical occupations Semi-routine occupations Routine occupations Never worked OR long-term unemployed Other Don't know/ prefer not to say
Which proportion of your/your household's food and drink are purchased in the supermarket?	All Most About half A small amount None
How often do you buy food and drink in a supermarket?	Every day Every other day Three or four times a week Twice weekly Once weekly Every other week Monthly or less
Which best describes your normal grocery shopping routine?	I do a big shop once a week or fortnightly to purchase all the food for that week I do a big shop once a week or fortnightly but will buy additional items (e.g. fresh bread) throughout the week I do a smaller shop to purchase food for a few days at a time I purchase food for myself/the household on a daily basis Other (please describe below)
If you responded Other above, please describe:	<open>
Does anyone in your household have any special dietary requirements that	Yes No

influence the foods you purchase?	
If yes, please describe how these requirements influence the foods you purchase:	<open>
Which supermarket do you use most often?	Tesco Sainsbury Asda Morrisons Waitrose Ocado Lidl or Aldi Other
Thank you for completing the pre-shop questionnaire. You will now be asked to complete two consecutive next-day shopping tasks in the UK Virtual Supermarket. Imagine that you have no food or drink in the house (apart from herbs and spices). It is the evening and you are going to the supermarket to buy all the food and drinks for your household for tomorrow. You only need to buy the foods that you would normally purchase in the shop. For example, if you have lunch in the canteen at work, you don't need to buy lunch in the UK Virtual Supermarket. When you click 'Continue', you will enter the UK Virtual Supermarket. You can navigate around the supermarket with the arrow keys on the keyboard, and click on products to add them to the cart. When you have finished, head to the check out. Please refer to the Participant Information PDF document for further information.	
Have you read and understood the instructions given?	Yes No

Post-shop questionnaire

Finally, we would just like to ask you a few questions about how you've found the UK Virtual Supermarket.	
The Virtual Supermarket program was easy to understand	1 (Strongly agree) to 5 (Strongly disagree)
The products I purchased in the Virtual Supermarket resemble my usual food purchases	1 (Strongly agree) to 5 (Strongly disagree)

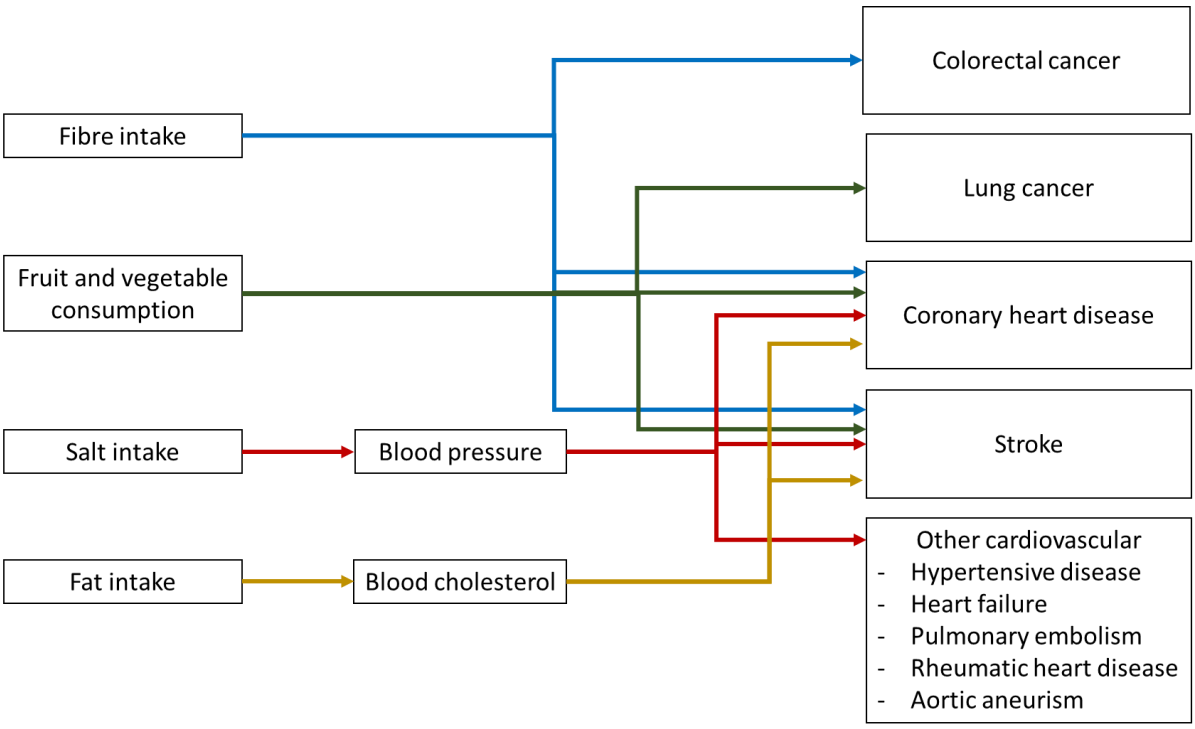
I could find my way around the Virtual Supermarket easily	1 (Strongly agree) to 5 (Strongly disagree)
The Virtual Supermarket contained sufficient product variety	1 (Strongly agree) to 5 (Strongly disagree)
I felt I had sufficient product choice options in the Virtual Supermarket	1 (Strongly agree) to 5 (Strongly disagree)
Stock in the Virtual Supermarket is representative of stock in an actual supermarket	1 (Strongly agree) to 5 (Strongly disagree)
I could find the products I wanted to find in the Virtual Supermarket relatively easily	1 (Strongly agree) to 5 (Strongly disagree)
I could imagine doing my real-life shopping in the Virtual Supermarket	1 (Strongly agree) to 5 (Strongly disagree)
Prices in the Virtual Supermarket are similar to prices in an actual supermarket	1 (Strongly agree) to 5 (Strongly disagree)
In the next-day shopping tasks, I spent the same amount of money in the Virtual Supermarket as I would have in the same task in real life	1 (Strongly agree) to 5 (Strongly disagree)
In the next-day shopping tasks, I bought the same sorts of food and drink as I would have in the same task in real life	1 (Strongly agree) to 5 (Strongly disagree)
On average, how often do you do your household grocery shopping?	Never A few times a year Every few months Monthly A few times a month Weekly A few times a week Every day
How often, on average, do you think you end up doing a "next day" shop like the ones in this study?	Never A few times a year Every few months Monthly A few times a month Weekly A few times a week Every day
Were there any products that you could not find in the Virtual Supermarket?	Yes No

	Don’t know
If yes to the above, please list the products you could not find.	<open>
Would you be happy to be contacted by the research team to discuss your experiences of using the UK Virtual Supermarket?	Yes No
Would you like to be contacted about future UK Virtual Supermarket studies?	Yes No
Do you have any comments about taking part in this study that you would like to share with the study team?	<open>
Thank you again for taking part, and feel free to get in touch with the study team (virtualsupermarket@dph.ox.ac.uk) if you have any other comments or questions.	

iv) Additional information about the Preventable Risk Integrated ModEl (PRIME)

The Preventable Risk Integrated ModEl (PRIME) is a comparative risk assessment model that links behavioural risk factors with non-communicable disease mortality. Full details of PRIME are available in [194]. Figure 16 summarizes the dietary risk factor to mortality relationships that are included (smoking, alcohol, and obesity related risks are included in PRIME but were not modelled as part of this DPhil project).

Figure 16: Dietary risk factor to mortality relationships in PRIME



The links in PRIME are parameterised using meta-analyses of epidemiological studies. Estimates of the impact of salt and fat intake on blood pressure and blood cholesterol respectively are taken from meta-analyses of randomised controlled trials and the remaining relationships are taken from meta-analyses of prospective cohort studies.

v) Full details of changes in purchases under selected health-related food taxes and subsidies

Table 29: Change in nutrient purchases under selected health-related food tax/subsidy scenarios

Quantities given per person per day	Scenario			
	Fruit and vegetable subsidy	Full VAT extension	Combined scenario (VAT extension + fruit and vegetable subsidy)	"Healthiness" based VAT
Δ Energy (kcal/day)				
Whole population	72	-367	-223	-238
Lowest income	68	-371	-234	-244
Middle income	72	-372	-228	-242
Highest income	75	-356	-205	-227
Δ Fruits and vegetables (g/day)				
Whole population	24.6	-53.3	-4.2	-25.9
Lowest income	19.0	-47.2	-9.2	-25.7
Middle income	24.3	-53.6	-5.0	-26.4
Highest income	30.5	-59.0	1.9	-25.4
Δ Fibre (g/day)				
Whole population	0.7	-2.5	-1.1	-1.8
Lowest income	0.6	-2.5	-1.2	-1.9
Middle income	0.7	-2.6	-1.1	-1.9
Highest income	0.8	-2.6	-0.9	-1.8
Δ Salt (g/d)				
Whole population	0.24	-1.36	-0.89	-1.07
Lowest income	0.22	-1.33	-0.89	-1.06
Middle income	0.24	-1.39	-0.90	-1.09
Highest income	0.25	-1.38	-0.87	-1.07
Δ Total fat (% total energy)				
Whole population	-0.10	-0.36	-0.56	-0.27
Lowest income	-0.08	-0.32	-0.48	-0.24
Middle income	-0.10	-0.34	-0.54	-0.25
Highest income	-0.13	-0.35	-0.61	-0.27

Δ Saturated fat (% total energy)				
Whole population	-0.10	-0.04	-0.26	-0.02
Lowest income	-0.08	-0.04	-0.22	0.01
Middle income	-0.10	-0.04	-0.25	-0.01
Highest income	-0.12	-0.02	-0.29	-0.03
Δ MUFA (% total energy)				
Whole population	-0.01	-0.05	-0.06	-0.01
Lowest income	0.00	-0.03	-0.03	0.00
Middle income	-0.01	-0.04	-0.05	0.00
Highest income	-0.01	-0.07	-0.09	-0.01
Δ PUFA (% total energy)				
Whole population	0.02	-0.16	-0.11	-0.17
Lowest income	0.01	-0.16	-0.11	-0.17
Middle income	0.02	-0.16	-0.11	-0.17
Highest income	0.02	-0.17	-0.11	-0.16
Δ NME sugars (g/day)				
Whole population	2.8	-8.4	-2.8	-3.8
Lowest income	2.7	-8.6	-3.1	-4.2
Middle income	2.8	-8.5	-3.0	-4.0
Highest income	2.9	-8.1	-2.4	-3.5
Δ Dietary cholesterol (mg/d)				
Whole population	4.3	-49.3	-40.6	-21.7
Lowest income	4.3	-48.9	-40.4	-21.9
Middle income	4.4	-49.9	-41.2	-22.1
Highest income	4.4	-49.1	-40.4	-21.1

Table 30: Change in sub-category purchases under the fruit and vegetable subsidy

Quantities given as grams per day	Whole	Lowest income	Middle income	Highest income
Alcoholic beverages	1	1	1	1
Hot drinks	0	1	0	0
SSBs	0	1	0	0
Non-SSBs	0	0	0	0
Fresh fruit	9	8	9	10
Fresh veg	8	7	8	9
Other fruit and veg	7	6	7	8
Cakes and pastries	5	4	4	5
Dairy desserts	5	4	5	5
Snacking	5	4	5	5
Sugar and confectionery	5	5	5	5
Fresh meat and fish	2	2	2	2
Processed meat and fish	1	1	1	2
Meat based composites	1	1	1	1
Milk	-1	-1	-1	-1
Cheese	-1	-1	-1	-1
Yogurt and cream	-1	-1	-1	-1
Composite foods	4	4	4	4
Fats and oils	3	3	3	3
Sauces and dressings	3	3	3	3
Bread	3	3	3	3
Breakfast and other cereal products	4	4	4	4
Pasta, rice, potatoes	4	3	4	4

Table 31: Change in sub-category purchases under the VAT extension scenario

Quantities given as grams per day	Whole	Lowest income	Middle income	Highest income
Alcoholic beverages	-11	-14	-11	-9
Hot drinks	-16	-20	-17	-12
SSBs	-6	-7	-6	-6
Non-SSBs	-4	-5	-4	-4
Fresh fruit	-19	-19	-19	-19
Fresh veg	-17	-17	-17	-17
Other fruit and veg	-15	-14	-15	-16
Cakes and pastries	-21	-21	-21	-21
Dairy desserts	-11	-10	-11	-12
Snacking	-3	-3	-3	-3
Sugar and confectionery	-8	-8	-8	-9
Fresh meat and fish	-23	-23	-23	-23
Processed meat and fish	-18	-18	-18	-18
Meat based composites	-18	-19	-18	-18
Milk	-11	-12	-11	-9
Cheese	-15	-15	-15	-14
Yogurt and cream	-15	-16	-15	-15
Composite foods	-24	-24	-24	-24
Fats and oils	-19	-19	-18	-17
Sauces and dressings	-22	-22	-22	-22
Bread	-15	-15	-15	-15
Breakfast and other cereal products	-20	-20	-20	-20
Pasta, rice, potatoes	-19	-19	-19	-19

Table 32: Change in sub-category purchases under the combined scenario (VAT extension plus fruit and vegetable subsidy)

Quantities given as grams per day	Whole	Lowest income	Middle income	Highest income
Alcoholic beverages	-9	-11	-9	-7
Hot drinks	-16	-19	-16	-12
SSBs	-5	-6	-5	-5
Non-SSBs	-3	-4	-3	-3
Fresh fruit	-1	-4	-2	1
Fresh veg	-1	-3	-1	1
Other fruit and veg	-1	-3	-1	1
Cakes and pastries	-11	-12	-12	-11
Dairy desserts	-1	-2	-2	-1
Snacking	6	6	6	7
Sugar and confectionery	2	1	1	2
Fresh meat and fish	-19	-19	-19	-19
Processed meat and fish	-15	-15	-15	-15
Meat based composites	-15	-16	-15	-15
Milk	-12	-13	-12	-10
Cheese	-17	-16	-17	-17
Yogurt and cream	-17	-18	-17	-17
Composite foods	-17	-17	-16	-17
Fats and oils	-13	-13	-13	-12
Sauces and dressings	-15	-15	-15	-15
Bread	-9	-9	-9	-9
Breakfast and other cereal products	-13	-13	-13	-12
Pasta, rice, potatoes	-12	-12	-12	-11

Table 33: Change in sub-category purchases under the healthy VAT scenario

Quantities given as grams per day	Whole	Lowest income	Middle income	Highest income
Alcoholic beverages	-2	-4	-3	-1
Hot drinks	-2	-3	-2	-2
SSBs	-4	-5	-4	-4
Non-SSBs	10	10	10	11
Fresh fruit	-9	-10	-9	-8
Fresh veg	-8	-9	-8	-7
Other fruit and veg	-7	-8	-7	-7
Cakes and pastries	-16	-16	-16	-16
Dairy desserts	-6	-6	-6	-6
Snacking	2	2	2	2
Sugar and confectionery	-3	-3	-3	-3
Fresh meat and fish	-2	-2	-2	-2
Processed meat and fish	-17	-17	-17	-17
Meat based composites	-16	-17	-16	-15
Milk	5	5	4	4
Cheese	-14	-14	-14	-14
Yogurt and cream	-16	-17	-16	-15
Composite foods	-19	-19	-19	-18
Fats and oils	-14	-15	-14	-13
Sauces and dressings	-17	-17	-17	-17
Bread	-14	-13	-14	-14
Breakfast and other cereal products	-19	-19	-19	-19
Pasta, rice, potatoes	-18	-18	-18	-18