University of Oxford

Essays on Health Care Operations Management

Rodolfo Catena

Green Templeton College

A thesis submitted for the degree of

Doctor of Philosophy

Trinity, 2015

“Qual è ’l geomètra che tutto s’affige
per misurar lo cerchio, e non ritrova,
pensando, quel principio ond’elli indige,
tal era io a quella vista nova:
veder voleva come si convenne
l’imago al cerchio e come vi s’indova;
ma non eran da ciò le proprie penne:
se non che la mia mente fu percossa
da un fulgore in che sua voglia venne.
A l’alta fantasia qui mancò possa;
ma già volgeva il mio disio e ’l velle,
sì come rota ch’igualmente è mossa,
l’amor che move il sole e l’altre stelle.”

Dante, Canto XXXIII Paradiso

(Ed. Petrocchi)

"As the geometrician, who endeavours
To square the circle, and discovers not,
By taking thought, the principle he wants,
Even such was I at that new apparition;
I wished to see how the image to the circle
Conformed itself, and how it there finds place;
But my own wings were not enough for this,
Had it not been that then my mind there smote
A flash of lightning, wherein came its wish.
Here vigour failed the lofty fantasy:
But now was turning my desire and will,
Even as a wheel that equally is moved,
The Love which moves the sun and the other stars."

Translation by Henry Wadsworth Longfellow

(Available online at http://www.gutenberg.org/)

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The aim of operations management in health care is to enhance the provision of services to patients and to decrease costs. Overall worldwide health care expenditures represent around 10.5% of the global GDP and are projected to increase at an annual rate of 5.3% from 2015 to 2017 [74]. In order to investigate how to curb health care costs, I study the English NHS, a health care system that provided universal care to around 54 million people in 2014 [243]. The NHS has launched many initiatives to improve the performance of hospital operations such as the "QIPP" program, which has the objective to save £20 billion of costs by 2015 [98]. Given this framework, this research aims to contribute to the theory that is guiding these operational changes, using data on all admissions to hospitals and focussing on the inguinal hernia, one of the most common surgical procedures [86]. In the next chapters, this research describes inguinal hernia care delivery in the English NHS, examines the impact of spillovers and complementarities on costs, and investigates the effects of length of stay reduction on risk of re-admission and risk of death. The findings of this thesis indicate that one of the possible problems in the delivery of inguinal hernia care in the NHS is the decrease in the number of elective operations performed and the increase in re-admission rates. They also clarify how decisions on allocation of resources can affect hospital expenditures by showing that loss in focus can increase health care costs and by pointing out that there is little evidence to support the theory of spillovers and complementarities in the surgical context. Finally, the results of this research can be used to suggest the logic of a policy to decrease length of stay that can inform hospital decisions and can decrease hospital costs.

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Chapter 1

Introduction

Researchers, policy makers, entrepreneurs, hospital managers, and medical staff are all trying to suggest a solution to the increase of global health care expenditures that is, clearly, becoming unsustainable for many countries in the world [167]. In the United States the money spent in health care is greater than the value of the whole French economy and the money spent in the United Kingdom accounts for 9.4% of its Gross Domestic Product (GDP) [351].

In this thesis I focus on England and I investigate the National Health Service (NHS). While other health care systems such as Medicaid and Medicare cover only certain segments of the population, the NHS is universal; and, therefore, we do not have to restrict this research only to some segments of the population. Moreover, the English system for collecting data is one of the best in the world since it includes information for every patient admitted to NHS hospitals and for NHS patients admitted to private hospitals and, consequently, provides large amounts of high quality data [237].

The NHS has launched many operations management initiatives (which I describe in more detail in Chapter 3) to enhance health care delivery and decrease costs. One of these initiatives is the "Quality, Innovation, Productivity and Prevention" ("QIPP") program, launched in 2011, which is trying to save, with the adoption of new operations management techniques, £20 billion of costs by the end of this year [98] (or 17.65% of the 2014/2015 NHS budget [98, 323]).

This thesis investigates operations management in the NHS, using data on inguinal hernia. One of the reasons that motivates the choice of this low complexity surgical operation is that it is the fifth most common general surgery procedure performed in English hospitals. The processes of inguinal hernia care delivery are also highly standardizable [32]. Moreover, since PM Blair's reform, which has introduced private care in the NHS, the number of hernia procedures performed in private centers has increased significantly [107]. In the mind of the reformers, in fact, private hospitals can achieve the outcomes of the Shouldice hospital in Canada, a hernia center that is an example of health care excellence [144].

This thesis presents three essays that contribute to the health care operations management literature. Before the essays, the **"Literature review"** positions this work in the management literature and describes the research context [132]. The aim of a literature review is, in fact, not only to provide knowledge on the topic but also to take a critical stance on it.

While the literature review following this introduction presents the views of different authors on the topic, the literature reviews in the three essays lead the reader, through gradual refinement, to the research gap [132], which is what needs to be further explored in the health care operations management literature. After identifying what is known about the topic and what needs to be investigated further, the relevant variables are presented, the problem structured and its significance established [133].

One question that arises is how I chose the body of literature to include in this research and why I discarded other material. The aim of this thesis is to make a contribution to the health care operations management literature and, for this reason, I chose to include the studies that contribute to this area of research. In order to provide an overview of what is currently being investigated, the chapter following this introduction summarizes the papers presented at the Production and Operations Management Conference in 2014. This conference is considered in our academic community as the point of reference for our work and has speakers that come from all over the world. The literature reviews in the three essays include also older material since their objective is to provide a complete review of the studies that contribute to the academic debate in the health care operations management community on the topics investigated in this dissertation. Differently from the second and the third essay and despite contributing to the health care operations management literature, the first essay targets a medical audience and, consequently, its literature includes also medical research.

Chapter 3, as suggested in [132], places the thesis in its historical context, discussing the history of the NHS. The English health care system was founded in 1948 and is undergoing a series of reforms aimed at ensuring its sustainability in the long-term [81, 341].

The first essay **"Inguinal hernia surgery in England from 1999 to 2011,"** which is co-authored with M. Goldacre, S. MacMahon, and M. Woodward, is an overview of inguinal hernia surgery, that describes the trends in admission rates, length of stay, re-admissions, and deaths in the English health care system. This work provides context on the functioning of the NHS and background for the following chapters, which assess the possible areas of improvement for inguinal hernia care in the NHS and their framework.

One of the topics this research investigates is the variation in the usage of emergency and elective care for inguinal hernia surgery. The second topic this essay investigates is length of stay, measured as the number of days between admission and discharge. As discussed in more detail in the next chapters, length of stay is a factor affecting hospital costs and patient outcomes. The more time a patient spends in the hospital, the more time he/she will spend under the monitoring of medical professionals. However, longer length of stay is also associated with a greater risk of acquiring a hospital infection. The current policy in the NHS is to decrease length of stay, which introduces the next topic of this chapter: re-admissions. Re-admissions are due to multiple reasons such as chronic diseases, new pathologies, or complications related to the operation. Length of stay can have an effect on re-admission rates since, for example, it affects the probability that a patient develops a hospital-acquired infection (HAI) and, consequently, the probability that he/she has to go back to hospital to treat it. This essay also investigates trends in death rates. It compares the mortality rates in the general population and among patients that undergo inguinal hernia surgery and calculates the Standardized Mortality Ratio (SMR). The values of the SMRs suggest that there is a selection effect and that patients who undergo elective surgery are more likely to be healthier than the general population. General Practitioners (GPs) and doctors are sometimes reluctant to recommend a surgical operation to unhealthy patients because of the risks associated with anesthesia and with the surgical procedure. This behavior can cause higher rates of emergency admissions for this class of patients. Finally, this work analyzes the proportion of patients that are admitted to hospital during the weekend since previous research has shown that patients that are admitted on Saturday or Sunday are more likely to experience worse outcomes than patients admitted during the rest of the week, e.g., [14, 349].

The main findings of this essay are that admission rates in the NHS for inguinal hernia surgery are decreasing significantly, that women are twice more like than men to undergo inguinal hernia surgery in emergency settings, that re-admission rates are increasing significantly, and that in-hospital mortality in emergency settings has not shown any significant variation in the study period.

The second essay **"Spillovers and complementarities for surgical proce-**

dures? Evidence from the NHS" is solo-authored and examines the impact of focus on related surgical procedures on hospital costs. While national policies and programs are having an impact on the operational scope of NHS providers [82, 233], this study investigates how the variation in the mix of procedures performed affects hospital costs.

Hospital focus is at the center of a lively debate in academia, e.g., [172, 202, 255], and the creation of new specialty hospitals has been proposed by Herzlinger [142] as the solution to increasing health care expenditures. The intuition is to follow the example of Nucor that has leveraged focus to become the largest producer of steel in the United States. The argument, presented to a group of representatives of the United States Senate, is that specialization "makes things cheaper" and "better" [142].

The theory about focus is not restricted to specialty hospitals but can also be extended to general hospitals. While the proportion of patients treated in specialty hospitals is increasing, the focus of general hospitals on certain procedures is decreasing considerably [16]. In this study, I investigate the impact of focus on a surgical procedure, hypothesizing that, also in the case of general hospitals, specialization leads to more learning and integration and, therefore, to lower costs [201].

Since increasing the operational scope of a firm can generate spillovers and complementarities [272], a focused firm can decide to diversify into other businesses. Roberts [272] defines *spillovers* and *complementarities* as the positive effects of co-specialization: while spillovers are *the direct effects of co-specialization* on a firm's performance in providing a service, complementarities are *the effects of co-specialization on the benefits of focus.*

The findings of this essay support the hypothesis that focus decreases costs also in general hospitals and that the theory of spillovers and complementarities in the surgical context may need to be revised.

After studying health care costs through the lens of focus, spillovers, and complementarities and given the strong relationship between length of stay and costs, the third essay **"When faster is (not) better: Quantifying the effect of health care improvement policies on patient outcome,"** which is co-authored with S. Dopson and M. Holweg, examines the significance of the relationship between length of stay and re-admission/death rates. Moreover, since unhealthy patients need, in general, to spend more time under observation than healthy patients, this essay also argues that length of stay reduction decreases probability of re-admission and death for this group of patients. Then it extends this hypothesis to old people and it hypothesizes that they should spend more time in the hospital.

Patients that go back to the hospital are an additional cost for the health care system because they require additional resources for their treatment. Patients that die are a cost for society and a cost for hospitals when their families sue for medical negligence and malpractice.

This research finds evidence to support the hypothesis that a decrease in length of stay is correlated with a decrease in risk of re-admission or death. A decrease in length of stay is correlated with worse outcomes if the patient is sick, suggesting that cutting length of stay could increase risk of re-admission and risk of death for old patients. The findings of this research criticize the current policy of many health care systems which are cutting length of stay indiscriminately, regardless of patients' state of health and age. Hence, this research suggests that short-term savings can lead to higher long-term costs and to a general decrease in the quality of care we provide to patients.

At the end of the thesis, the **"Conclusions"** chapter summarizes the findings and discusses the directions for future research. It discusses the contributions and limitations of the dissertation.

Chapter 2

Literature review

2.1 Operations management

Slack et al. [307] define operations management as "how organizations produce goods and services" and identify its three components: "design," "planning and control," and "improvement," a classification widely accepted in the management literature, e.g., [165, 248]. We can think of operations management as a loop because "design," "planning and control," and "improvement" determine a firm's performance which informs the firm's operations strategy which, in turn, determines how the firm manages its operations [307]. In order to explain in more detail what operations management is, I discuss its components in the next paragraphs, building on [307] and to a lesser extent on [291].

The first component of operations management, as mentioned, is "design," that is, how a firm makes a product or delivers a service. "Design" is not only about the design of products or services, but it is also about the design of the processes to manufacture or deliver them. The "design" of the processes has an impact on the costs and the quality of the products or services a firm produces and we can study it also at the supply chain level. At this higher level, a product or a service is the result of the collaboration of a network of firms, which compete with other networks of firms, to deliver value to the customer. Process design is a fundamental step for managing a firm's operations; however, excessive standardization in how a firm produces its services or products can hinder innovation because creativity is based on testing new ideas and solutions to improve a firm's performance.

The technology and the demand for products or services produced are other elements that a firm has to take into account for the "design" of its processes. These elements also affect the "design" of the layout of the firm since the higher the volumes, the more likely a firm will move toward a continuous process configuration [135]. Finally, the human dimension, which can also depend on the use of communication technologies, has an impact on the productivity of the processes.

The second component of operations management is "planning and control" and is about how a firm matches the demand from its customers. One of the first decisions a firm has to make is about capacity management and how to employ its resources to satisfy the demand of its products or services. This decision takes into account the forecasts of the demand and, clearly, its seasonality and variation across time. Once the forecasts are available, we can use queuing models to determine if the allocation of resources is sufficient to match customers' expectations. Since forecasts are never accurate and since there is little evidence that complex models are better than basic methods to predict the demand of a product/service [304], we can use inventory as a buffer to address the uncertainty of the demand and the possible adverse events that can slow down a firm's ability to manufacture products or deliver services.

In general, there are two production philosophies that we can follow: the push philosophy, which is based on pushing products and services in the market, and the pull philosophy, which is based on waiting for the market to pull products from the firm. The first philosophy uses technologies such as the Material Requirement Planning system, that based on forecasts and inventory, defines when and what to produce. As mentioned, the second philosophy, which is one of the pillars of a lean production system, waits for the market and produces products/services just-in-time after the arrival of the order. Ideally, lean production systems do not use forecasts but they may need to do so when the lead times to serve the customers are too high. After a firm has chosen a push or a pull production strategy, or an hybrid strategy that mixes them, managerial and statistical techniques such as Total Quality Management (TQM) and Six-Sigma can be useful to enhance its results.

The management of projects, that is the production of unique products or services [262], is another activity that firms need to undertake. The statistical and mathematical tools available for Project Management balance the three conflicting objectives of every project: minimizing costs, meeting deadlines, and satisfying a project's requirements. One of the limitations of project management is that there is not a rule to balance these objectives and project managers need to make choices on the basis of the context in which they work.

The third component of operations management is "improvement" and is about how to change operations to increase quality and decrease costs. It is a direct result of the "planning and control" phase because a firm can improve only if it is aware of its current performance. There can be drastic improvement or, as suggested by the Japanese philosophy of production, continuous improvement (kaizen) [160]. In order to implement change, firms, typically, model the processes that produce products and services and find ways to reduce their component of waste and inefficiencies. The most famous approaches to change are TQM, lean, Six-Sigma, and Business Process Re-engineering (BPR).

In order to improve, a firm has also to learn how to manage risk and how to manage failure, by decreasing their impact on a firm's operations. The first objective of risk management is the identification of the risks that can affect a firm's performance, which can be done by investigating the factors that lead to operational failure, their likelihood, and their potential impact on a firm's operations. A firm can then take measures to prevent failure with approaches such as Total Productive Maintenance (TPM) that have the aim to decrease down-times with preventive maintenance and by empowering employees. Risk management is also about managing the failure when it occurs. Managers should, first, assess the failure and collect as much information as possible about it, then, take action informing the clients and avoiding the spreading of the failure to other projects, and, finally, understand what caused the failure and prevent it from occurring again [17].

One of the most common mistakes in implementing an improvement strategy is not considering its behavioral aspects: an organization that supports "improvement" is an organization in which there is a culture that emphasizes the importance to change and in which employees have the motivation to pursue it. As a firm attempts to improve, the support of top-management is also fundamental for the success of any transformation initiative.

There is a "line of fit" that motivates change, which is required when market and operational requirements are not balanced. For example, a firm is not on the "line of fit" when it is not able to satisfy customers' needs with its operations or when its operations have additional capacity that it does not exploit. The first question a firm needs to answer is what to change since there are different processes it may need to modify. One possible answer to this question is the sand cone model [292], which gives priorities to the different changes a firm needs to implement. However, the results from the sand cone and other models are not sufficient alone and need to be integrated with the management understanding of the priorities to tackle.

2.2 Health care operations management (HCOM)

As discussed in Chapter 1, one of the objectives of most health care systems is to curb costs and, while a possible solution to reduce health care expenses is to close hospitals and decrease the level of care provided to the population, another possibility is to increase their efficiency with the adoption of the principles of health care operations management. However, despite the emphasis on costs, the health care problem is also about improving quality, decreasing waiting times, and managing long-term outcomes [180]. The next paragraphs, which are based on [180, 207], discuss in more detail the issues that health care providers face in delivering care and what needs to be done to address them.

The Committee on Quality of Health Care of the Institute of Medicine has identified the areas of improvement that need to be tackled to enhance hospitals' performance, finding that, ideally, care provided by hospitals should be [65]:

- "safe,"
- "effective,"
- "patient-centered,"
- "timely,"
- "efficient," and
- "equitable."

While "safe" entails minimizing the cases of medical malpractice and decreasing the rates of HAIs, "effectiveness" is about decreasing the provision of unnecessary services to patients that do not need them. The third area of improvement is "patient-centered" care and is about satisfying patient's needs. Health care delivery needs also to be "timely" and "efficient" since patients should avoid unnecessary delays and hospitals should minimize waste. Finally, health care delivery needs to be "equitable," in other terms, accessible to anyone who needs it.

In order to address these issues, the Institute of Medicine has identified the following principles that hospitals can follow [65]:

- "Care based on continuous healing relationships,"
- "Customization based on patient needs and values,"
- "The patient as the source of control,"
- "Shared knowledge and the free flow of information,"
- "Evidence-based decision making,"
- "Safety as a system property,"
- "The need for transparency,"
- "Anticipation of needs,"
- "Continuous decrease in waste,"
- "Cooperation among clinicians."

The first principle is that care should be based on continuous relationships, regardless of patients' location. Health care technologies can be used to reach patients when they are in remote locations and to monitor them constantly. The second principle states that health care solutions should be customized and should respond to a patient's specific needs. The third and fourth principles are that patients should decide about the care they receive and they should have all the information required to make these decisions. The fifth principle is about standardization and that physicians should deliver the best care possible based on scientific evidence. The sixth principle is that a hospital, as a system, should be safe and that routines and processes should be adopted to minimize the risk of medical malpractices and HAIs. The seventh principle is about information and is not only about patients being able to access their medical information but is also about recording and making data on hospital performance available to everyone who wants to access it. The eight, ninth, and tenth principle are about predicting accurately what a patient needs during the course of care, minimizing inefficiencies, and increasing collaboration among clinicians.

Evidence-Based Medicine (EBM) "is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients" [279] and is at the basis of many of the principles expressed by the Institute of Medicine. As described in [139], EBM relies on a list of steps that physicians need to take in order to treat the patient. The first step for a physician is to understand the problem of the patient, identifying similarities and differences with other cases he/she has treated. After having defined the problem, the physician has to use his/her experience to decide how to treat the patient. When the physician has chosen the course of action, he/she needs to compare it to what standard care would prescribe to do. The next step is to collect information and, based on the empirical evidence on the outcomes of each alternative, make a final decision on the treatment for the patient. The last step of EBM is to assess if the outcomes expected correspond to the actual outcomes for the patient. One of the possible negative aspects of EBM, that this work discusses in more detail in Chapter 6, is the risk of 'one-size fits all' solutions, since standardized policies can be a successful approach for some patients but not for others.

Another philosophy that inspires the recommendations of the Institute of Medicine is patient-centered care, a model of health care in which every process of care has at the center the needs of the patients [143]. In general, there are two main schools of thought on how to design a health care system which is able to achieve this objective. The first school argues that the best system to satisfy a patient's needs is a system in which the patient is the decision maker [140, 141, 142, 143]. The second school argues, instead, that, overall, medical professionals have the best chance to make the right decisions about a patient's treatment [81, 191]. While these schools of thought propose distant solutions to the health care problem, it is often the case that the path of care a patient follows is a joint decision of the patient with his/her physician.

Knowledge management, which views organizations as "knowledge engines" [301], also inspires the principles of the Institute of Medicine. Knowledge diffusion and quality are interdependent and there are factors that strengthen their relationship [189, 214]. Knowledge creation in an organization exists when workers have autonomy and can make decisions on how to perform their job [189]. Process control, which is the use of statistical tools to monitor process outcomes, and relationships with customers and suppliers also enhance the diffusion of knowledge [214]. While teamwork is another factor to take into consideration, it is not always associated with knowledge transfer [214]. In their analysis of the nature of these relationships, Linderman et al. [189] emphasize also the context as an element to consider when studying knowledge management in an organization.

Another element characterizing the study of health care operations management is the existence of multiple levels of analysis that can be investigated [99]. It is possible to study the single patient and how health care delivery affects his/her outcomes. At a higher level, it is possible to investigate how a medical team manages a group of patients or how a hospital delivers care. Finally, the health care system of a country, in which the objective is to minimize costs and achieve a certain standard of quality of care, can also be a unit of study. While this categorization is useful as a framework of investigation, there is an interaction among these levels that needs to be taken into account when studying health care delivery.

As a final consideration, the generalizability of the findings of this research is not the same for the three essays because it depends on the level of analysis considered. While the results in Chapter 4 cannot be applied to other health care systems even if it is likely that similar trends can be observed in other developed countries, the results in the second study on spillovers and complementarities provide evidence that has the potential to be useful also to analyze other health care systems similar to the NHS. Finally, since the paper on length of stay is about individual patients, it is plausible to assume that the influence of the health care system on the findings is lower than in the second paper and, consequently, that the generalizability of the empirical results is greater. For example, it does not seem reasonable that the average length of stay in a health care system affects the relationship between the number of days a patient spends in the hospital and his/her risk of re-admission/death. Nevertheless, we need also to take into account other factors, such as average rate of HAIs, that can clearly have an impact on this relationship and limit the generalizability of the results.

Given this overview in health care operations management, in the next section I discuss the main topics of research in this field, grouping them in macro research areas and illustrating the potential avenues for future research.

2.3 Research in health care operations management

In order to provide an overview of the research that universities and other institutions conduct on this subject, I reviewed the health care operations management papers presented at the Production and Operations Management conference in Atlanta in 2014.

One of the limits of this section is that it is only one of the possible reviews of the salient issues currently investigated in operation management. Nevertheless, this conference is, generally, recognized as one of the most important or as the most important in the field of operations management and academics from all over the world join it to update their knowledge on the status quo of the research in this field.

As for the methodology of this analysis, I follow the recommendations in [94, 132] and present the topics of research thematically. After listing all the tracks presented at the conference, I group them in areas of research (see Figure 2.2), which, in turn, I group in macro-areas of research (see Figure 2.1). At the highest level, the research in health care operations management investigates **process management**, the use of **IT** to enhance the delivery of care, and **patient experience**. There is also an interest on **mathematical modeling** as a tool to support decisions, the most common topics being operations research, stochastic modeling, network analysis, and econometrics.

In Section 2.1, I introduced the main components of operations management, as defined by Slack et al. [307]: "design," "planning and control," and "improvement." These three components are also the components of every macro-area of research I defined in this section. For example, **process management** is about the design of the operational processes, the monitoring of their performance, and the definition of new ways to improve them. Similarly, **mathematical modeling** offers tools for the design of operations; for planning, for instance, with forecasting; and for improvement, by informing the best possible decisions. Regarding **IT**, the "design" of processes is based on the analysis of the information flows in the company; the "planning and control" requires the use of feedback loops supported by technological tools; and the "improvement" is driven by the adoption of new technologies. Finally, while considerations on **patient experience** need to be taken into account for the "design" phase, they inform "planning and control" decisions, and guide the "improvement" of the products and services.

In order to complete this overview of the research in health care operations man-

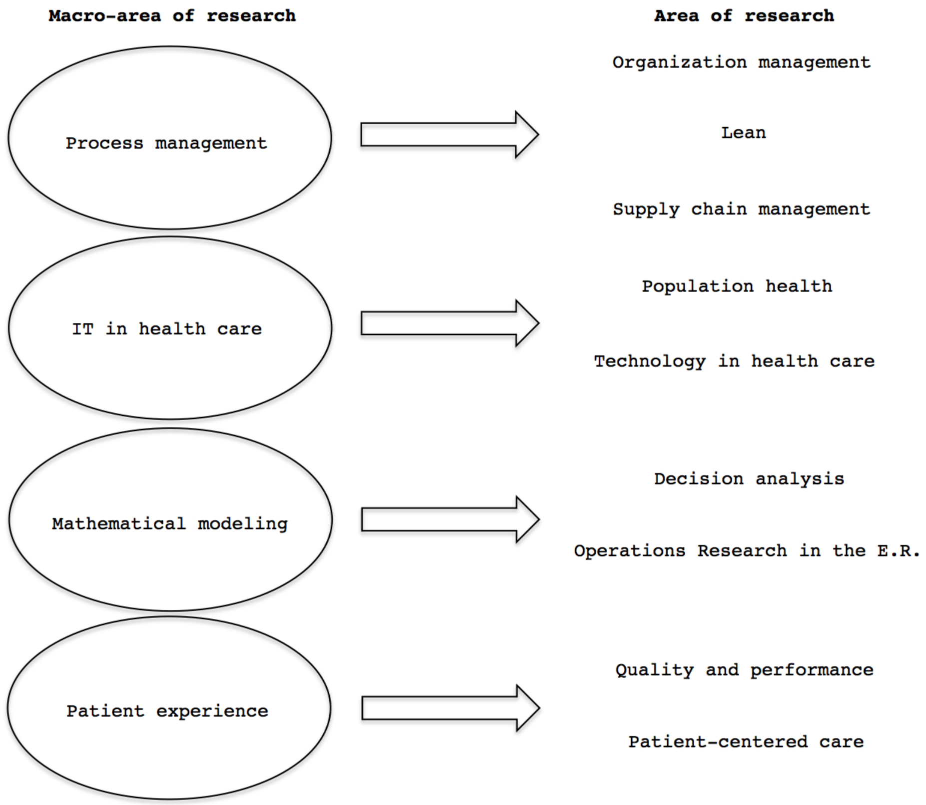


Figure 2.1: Macro-areas of research in operations management based on the tracks of the Production and Operations Management Conference (Atlanta, 2014)

agement, beyond the papers presented at the conference, in the next paragraphs I also include the descriptions of the tracks provided by the conference chairs and other operations management research related to the topics presented.

2.3.1 Process management

In any organization we can describe the steps that lead to the creation of a product or to the delivery of a service with a process that we can formalize in a flow diagram. We usually start with very detailed processes and then create more general ones that describe the functioning of an organization at a higher level, aggregating more and more activities. At the highest level, we can consider an organization as a part of the supply chain that generates value for the customer. Research in this macro-area

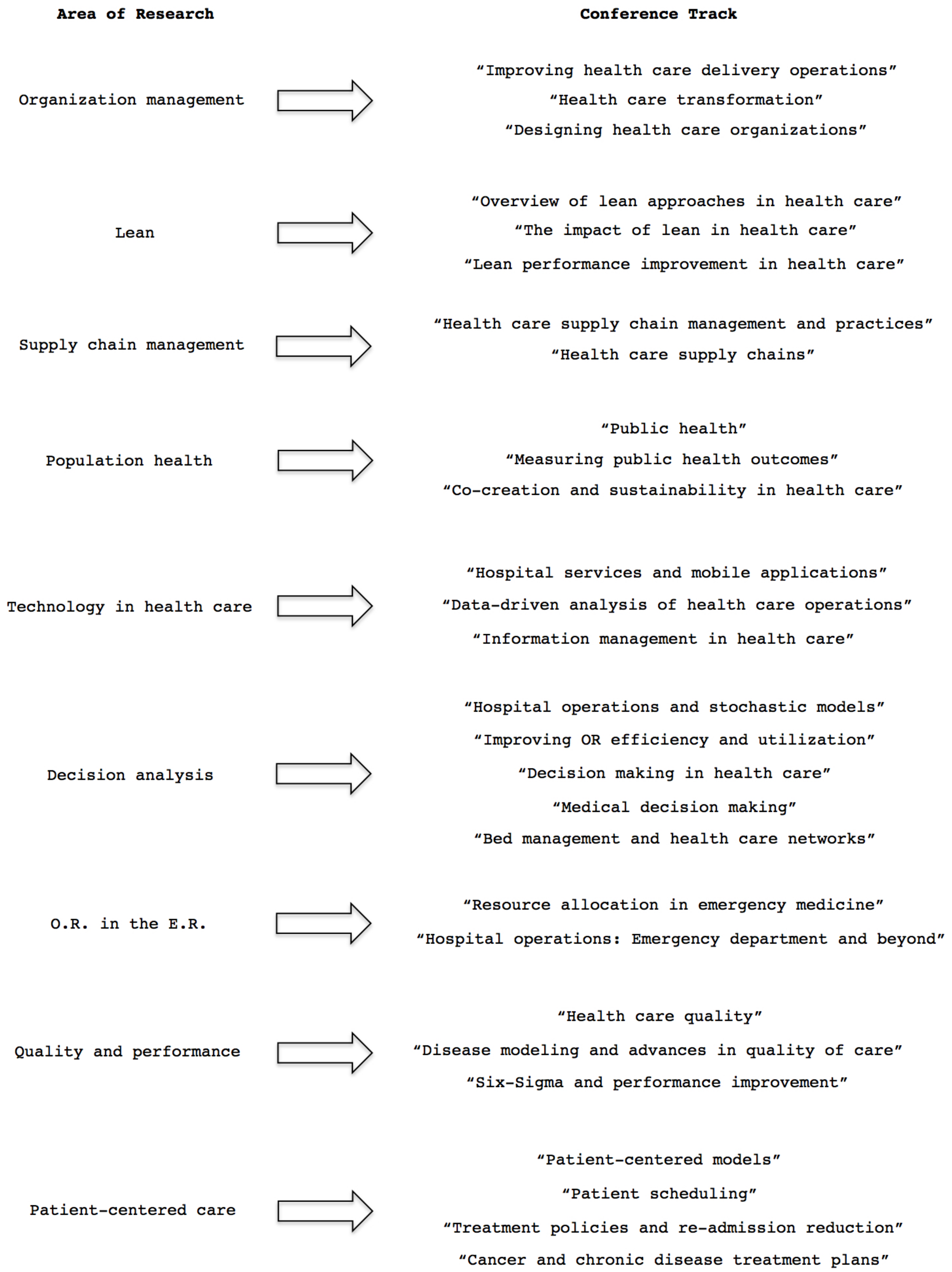


Figure 2.2: Areas of research in Operations Management based on the tracks of the Production and Operations Management Conference (Atlanta, 2014)

investigates the tools that enhance the management of the processes of an organization or of the whole supply chain.

Organization management

This area of research studies the organization of health care delivery. Since **organization management** is about capacity planning, managing calamities, and finding new methodologies to support the re-design of health care processes, it requires the collaboration of many groups inside of the hospital. While the findings of these studies inform management decisions, one of their weaknesses is that they can depend on the context in which decisions are made. The tracks of this area of research are:

- "improving health care delivery operations";
- "health care transformation";
- "designing health care organizations."

"Improving health care delivery operations" This track focuses on health care delivery, a term which carries with it the concept of providing care and is virtually comprehensive of all the services provided to patients. In general, health care delivery is not only about the management of daily operations but is also about the management of calamities. An example of studies in this track is the investigation of the demand of care, which depends on several variables, and that Laker et al. [183] explore using a stochastic model. Another example is the investigation of "surge capacity," which is the additional capacity needed to manage emergency situations [339].

"Health care transformation" This track investigates the elements that hinder the process of "health care transformation" and how to implement change in health care. It studies the factors to consider when a hospital merges with another hospital and the impact of the economies of scale deriving from this decision [330]. Another aspect of "health care transformation" is capacity planning, for example, the investigation on how to satisfy hospitals' targets on waiting-times, minimizing capacity requirements [73].

"Designing health care organizations" One of the steps to take for the design of a new organization is the definition of the management processes which describe how an organization delivers its products or services to its customers [247]. Since modeling management processes in health care is very complex, this track studies new methodologies to describe health care operations [18]. This track also investigates how to enhance the design of the health care value chain, for example, through the implementation of "shared service organizations" [2].

Lean

This area of research, as described in the following paragraphs, investigates how to make the process of health care delivery more efficient with the tools of lean management. Lean management, which used to be called just-in-time, is about serving the patient at the right time, with the right service, and in the right place [307]. Given its relevance in the operations management literature, while some researchers investigate how hospitals have implemented these approaches, other studies focus on the context and the factors that influence a successful implementation of lean management. While lean has been praised as the solution to many health care problems [190], critics argue that the implementation of lean is challenging, has negative effects on job satisfaction, and limits the opportunities of workers to develop professionally [208]. The tracks of this area of research are the following:

- "overview of lean approaches in health care";

- "the impact of lean in health care";
- "lean performance improvement in health care."

"Overview of lean approaches in health care" This track focuses on the study of the role of **lean** to enhance health care delivery in order to identify the best practices to implement this management philosophy. Illustrating the various approaches and discussing their impact is useful to verify how to implement lean in a hospital [95]. After reviewing how a hospital implements lean management, it is also possible to develop a measure that quantifies the hospital's lean results [60].

"The impact of lean in health care" Given the success of lean in other industries [198], this track assesses the effects of lean management on health care operations. It investigates how lean management informs hospital strategy [197] and how the context of implementation affects lean adoption [265].

"Lean performance improvement in health care" This track of research is about assessing the improvement associated with the adoption of lean management techniques. In this case, researchers investigate a variety of topics, including human resources management [345] and the effect of lean management on the overall safety of the hospital and its finances [89].

Supply chain management

This area of research investigates **supply chain management** which, as explained in [304], studies the interactions in the value chain and has the objective to minimize the overall costs of all the entities that are part of it. The tracks of **supply chain management** are:

- "health care supply chain management and practices";

- "health care supply chains."

"Health care supply chain management and practices" Coordinating different layers of the supply chain is a complex problem because different actors have different priorities and strategic objectives. With these considerations in mind, "health care supply chain management and practices" investigates topics that are related to the multiple ways the actors of the supply chain interact, for example, how medical devices manufacturers price their products [72], or how hospitals outsource medical procurement services to specialized companies [71].

"Health care supply chains" "Health care supply chains" expands the section on "health care supply chain management and practices" by investigating other aspects of the same topic. For example, it studies how the use of supply chain management techniques is also required to improve the efficiency of public health care systems [120]. Another aspect that this section investigates is risk management and how it can be an effective technique to decrease the overall quantity of inventory managed by the supply chain [360].

2.3.2 IT in health care

The study of **IT in health care** has the objective to investigate how information technologies affect the efficiency and effectiveness of health care delivery. On one side, information technology offers opportunities to investigate "public health" and make "public health" programs sustainable in the long-term; on the other, the availability of new technological devices to support patients in every step of the cycle of care generates large amounts of data that can be used to improve health care delivery.

Population health

Research on **population health** is about the study of "public health" to make a health system sustainable in the long-term and the investigation of "public health" measures to achieve this objective. Since **population health** is not only about top-down decisions, co-creation is another factor to investigate in order to enhance patient participation into medical programs. One of the main limitations of the research in this subject is that data on a large scale is available only for a limited number of health care indicators [28]. In summary, the tracks of this area of research are:

- "public health";
- "measuring public health outcomes";
- "co-creation and sustainability in health care."

"Public health" According to the World Health Organization glossary [263], "public health" is about "the assessment and monitoring of the health of communities and populations at risk to identify health problems and priorities" and "the formulation of public policies designed to solve identified local and national health problems and priorities." The objective of "public health" is "that all populations have access to appropriate and cost-effective care, including health promotion and disease prevention services." Areas of study in this track are the impact of "public health" policies [26] and the formulation of guidelines for common diseases [327].

"Measuring public health outcomes" One aspect of **population health** is "measuring public health outcomes," for example, to assess the impact of "public health" programs [322]. Research in this section involves also creating new measures, for instance, the National Health Security Preparedness Index which puts together 128 different measures to assess how a health care system is able to manage emergencies such as the Ebola epidemic or natural disasters [162, 238]. Another area of investigation is cost assessment since, while costs are very difficult to measure, they are required to control how health care managers allocate resources and if they do it efficiently [322].

"Co-creation and sustainability in health care" According to Prahalad and Ramaswamy [258], co-creation "is about joint creation of value by the company and the customer" which happens when customers collaborate with firms to customize the service/product they receive. In health care, where the customers are the patients, the firms are the hospitals, and the services are the procedures that the patients undergo; research on co-creation investigates, for example, the relationship between patients and doctors [303].

Similar to co-creation, sustainability is about the interactions among multiple entities in the health care system, however, its objective is to minimize the environmental and social impact of operations [91]. Since sustainability affects the delivery of care, there is a need to investigate how to make a hospital a sustainable organization [35] and the impact of sustainability on financial performance [6].

Technology in health care

We study mobile technology, big data, and information management because they have the potential to improve health care operations. Mobile technology can generate large amounts of information and, therefore, is related to big data. Also, since it is portable, it is accessible from everywhere. Big data and information management are, instead, related because information management provides the framework to collect big data, which can then be used to provide insight on health care management. A question that arises is whether the collection of data and the adoption of new technologies is always useful and whether the financial and operational returns justify the investments on it. The tracks of this research area are:

- "hospital services and mobile applications";
- "data-driven analysis of health care operations";
- "information management in health care."

"Hospital services and mobile applications" As mentioned, mobile applications offer an opportunity to improve health care delivery and increase the efficiency of hospital operations. An area of interest in this topic is how to design mobile applications to increase the cooperation among teams in a hospital [357]. This track also investigates how to use traditional technology in an innovative manner to improve efficiency [41].

"Data-driven analysis of health care operations" Another aspect of **information technology in health care** is the use of large databases to enhance health care delivery. This track investigates, for example, tele-ICU and the use of technology to manage an intensive care unit remotely [105]. The use of large amounts of data can also be used to estimate how hospital marginal costs increase with increasing re-admission rates [335].

"Information management in health care" "Information management in health care" overlaps with "data-driven analysis of health care operations"; however, instead of focusing on the analysis of the medical databases, it investigates the dissemination of information in health care [303]. For example, when patients undergo a medical procedure, they see many doctors which may or may not be talking to each other [303]. Another question that this track studies is how different health care institutions communicate among each other and how technology systems can improve their exchange of information [75].

2.3.3 Mathematical modeling

Mathematical modeling supports decision making and provides insight for the strategies of health care managers. The problem of "decision making in health care" arises because of lack of resources and multiple conflicting objectives in an uncertain environment which leads to very complex models that many times cannot be solved optimally. One of the criticisms of **mathematical modeling** is when it moves its focus from solving a health care problem into solving a mathematical problem with little impact on health care operations [4]. Given these considerations, there are two main areas of research related to this topic: **decision analysis** and **operations research in the emergency room** which expands the first area and applies it to an emergency context.

Decision analysis

Decision analysis is about making optimal decisions using mathematical models and is not only applied to operations management but to all the branches of management such as marketing or finance, e.g., [148, 283]. While stochastic tools are used to investigate uncertainty and include Markov chains, stochastic optimization, and renewal processes; mathematical programming finds solutions when all the elements that determine them are available. However, difficult models may not be solvable with current technologies and, for this reason, another objective of **decision analysis** is the development of heuristic algorithms that can find quasi-optimal solutions. Research in this area also investigates networks to find algorithms to apply in the study of **supply chain management**. The decision on the factors to include in the mathematical models can be made using, for example, econometrics [5]. In summary, the tracks of this area of research are the following:

- "hospital operations and stochastic models";

- "improving OR efficiency and utilization";
- "decision making in health care";
- "medical decision making";
- "bed management and health care networks."

"Hospital operations and stochastic models" The "hospital operations and stochastic models" track of the Production and Operations Management conference is about the idea to use probabilistic models to investigate health care. Stochastic models are useful to describe a problem in which the element of uncertainty plays a major role and we can divide them into queuing models and stochastic optimization models. While queuing models optimize the flow of patients in the hospital [297], stochastic optimization models optimize how patients access health care [298].

"Improving OR efficiency and utilization" Research in this track is about the formulation of mathematical models to minimize or maximize an objective function when there are constraints on the resources available. An example of a problem involving operations research is determining the utilization of a limited resource such as the operating room [325]. Since the number of components of a team is limited, another example of a problem involving operations research is the selection of the best possible medical team to perform a surgery [310].

"Decision making in health care" Research in "decision making in health care" is about the choice of the optimal course of action to maximize the quality and minimize the cost of health care delivery like, for example, in the case of drug surveillance [114] and of blood transfusion policies [278]. Since decision makers are at different levels of the supply chain and can have conflicting interests, the final outcomes of these models can lead to local optima that can affect the probability to achieve a global optimal solution.

"Medical decision making" There are many factors that affect the decisions that physicians make including economic constraints, personal knowledge, and interactions with other physicians. Research in this track investigates, for example, the relationship between knowledge and learning and how physicians learn from experience, others' experience, and scientific papers [5]. Another area of interest of this research track is how patients influence medical decisions, for example, their impact on the choice of the treatment to follow on the basis of the results of a medical examination [15].

"Bed management and health care networks" Since the management of a health network can decrease the number of beds needed in a hospital, this section investigates two topics that are only apparently unrelated. Research in this track studies the coordination of hospitals with long-term facilities [152], how to decrease length of stay, death rates, and waiting-times using dynamic models [57], and how to manage scheduling in a network of clinics [340].

Operations research in the emergency room

Since emergency patients are more costly and experience higher rates of re-admission and death, many researchers focus on models that are applied to optimize the use of resources in the emergency room. While it is true that the methods used in this area of research are the same as those used in the **decision analysis** area, the application of mathematical models to the emergency context provides further insight on health care operations. The tracks of this area of research are:

- "resource allocation in emergency medicine";

- “hospital operations: Emergency department and beyond”

“Resource allocation in emergency medicine” Whereas waiting times for NHS emergency admissions are increasing every year [166], another question that health care operations management needs to answer is about “resource allocation in emergency medicine.” This track of research investigates how to optimize the configuration of health care delivery to maximize productivity; for example, it studies how to use simulation tools to optimize the management of ambulances, [268, 269].

“Hospital operations: Emergency department and beyond” “Hospital operations: Emergency department and beyond” is a further investigation of the management of operations in an emergency context with a greater emphasis on management practices rather than on resource allocation. In order to optimize management decisions, research in this area analyzes, for example, the unavailability of beds (bed blocking) for the transfer of patients from the emergency ward [280]. Another problem that this track investigates is the minimization of the time different classes of patients spend in the emergency ward [100].

2.3.4 Patient experience

This area of research investigates how patients experience the health care system, how to maximize the quality of care offered, and how to minimize costs. While one of the topics of investigation is **quality and performance**, another is “patient satisfaction,” since as mentioned in Section 2.2, there is an increasing interest on **patient-centered care**. However, “patient satisfaction” is only one of the dimensions of patient outcomes studied in this area of research; long-term outcomes and waiting times are examples of other dimensions considered [286, 327]. Another topic of interest builds on a systemic view of the provision of care and investigates how the characteristics of a health care system affects its performance [53, 143]. In this case, the emphasis is on how changing a patient's experience can curb health care expenses.

Quality and performance

Measuring quality in health care is a complex problem because patients have different preferences. For example, while some want to stay in the hospital as little as possible, others want to stay until they fully recover. Besides, while doctors have, in most cases, the objective to provide the best possible care to patients, hospital managers also have the objective to minimize costs. As a consequence, one of the aims of the research in **quality and performance** is to identify a framework that can put together and prioritize all these different objectives [55, 337]. The tracks of this area of research are:

- "health care quality";
- "disease modeling and advances in quality of care";
- "Six-Sigma and performance improvement."

"Health care quality" Since the level of satisfaction of hospital patients is often subjective, a first question that this track investigates is whether there is an objective measure of quality in hospitals. Questionnaires, such as the Adult Inpatient Survey in the NHS, ask patients several questions and provide important feedback on how to improve health care delivery [234]. However, other parameters, such as the proportion of Clostridium difficile cases offer a more objective measure of quality [249]. The SERVQUAL framework can also be used to identify the determinants of satisfaction [55]. Checklists that record whether a hospital has adopted a specific diagnostic tool to support doctors are an example of another measure of quality, which could be used as an instrument for hospital accreditation [25].

"Disease modeling and advances in quality of care" "Disease modeling" can clearly affect the "quality of care" of a health care provider, especially in a context in which bacteria are becoming increasingly resistant to antibiotics. In order to identify the hospitals where there is a problem with this type of bacteria, one area of investigation of this track is how to rank hospitals by "antimicrobial resistance rates" [40]. Similar to the research proposed in the "health care quality" track, another area of investigation in "disease modeling and advances in quality of care" is the steps needed to offer the best possible care [187].

"Six-Sigma and performance improvement" The Six-Sigma approach starts with the analysis of the output of a process but then investigates every step of it in order to improve its efficiency and effectiveness [307]. This track of research investigates, for example, the elements that need to be considered when implementing Six-Sigma in health care [337] and how to use organizational learning to improve the output of a process [179].

Patient-centered care

An area of investigation in **patient-centered care** is patient satisfaction, which is mutually related to quality of care because, while quality of care can lead to patient satisfaction, patient satisfaction can lead to quality of care. While it is clear why quality of care leads to patient satisfaction, patient satisfaction leads to higher quality of care, for example, because satisfied patients are more likely to comply with doctors' recommendations. Another topic that this area of research studies is how to organize a health care system in such a way that the patients are at its center and receive the care they need. As discussed in Section 2.2, one of the main limitations with this research is that there is not a unique interpretation of how to put the patient at the center of the health care system, which causes a lack of consensus in the definition of the objectives to follow to enhance health care delivery. The tracks of research of this area are:

- "patient-centered models";
- "patient scheduling";
- "treatment policies and re-admission reduction";
- "cancer and chronic disease treatment plans."

"Patient-centered models" Areas of investigation in this track study how to design health care systems whose constituent values come from the schools of thought described in Section 2.2, e.g., [53, 110].

"Patient scheduling" Since the flow of patients that go to a hospital varies, "patient scheduling" is required to increase the efficiency of health care delivery. There are, in general, two types of delay that this track investigates [358]: the first is when patients are late for their appointments; the second, instead, is when doctors are late because they are seeing other patients. "Patient scheduling" is also about simulation, which can be used, for example, to test the effect of adverse events that disrupt the delivery of care and to minimize wait-times for patients and working hours for doctors [327].

"Treatment policies and re-admission reduction" Since one of the failures of health care is an emphasis on short-term decisions that do not look at the overall cycle of care [255], the "Patient Protection and Affordable Care Act" and the "Health Care and Education Reconciliation Act" in the United States penalize hospitals with high re-admissions rates for Medicare patients [203]. This decision led many researchers to investigate how to decrease re-admission rates with the identification of the optimal treatments for the patients [286, 361].

"Cancer and chronic disease treatment plans" Since chronic conditions generate repeated episodes of care, strategies for "cancer and chronic disease treatment plans" are required to curb health care costs [218]. While one area of investigation is how to prevent the disease, for example, with optimal screening policies [270], another area of interest is how to optimize medical treatments to minimize the number of times a patients needs to go to the hospital [260].

2.4 Research context

This thesis is about the study of inguinal hernia care in the NHS and how to organize the health care system and health care delivery to satisfy patients' needs. For this reason, its objective is consistent with the values expressed by patient-centered care and the rigorous recommendations of EBM. As we will discuss in Chapter 5 with a description of the implications of Nonaka's work [239] on the impact of spillovers and complementarities in health care, the study of how knowledge affects outcomes is also part of this work. In general, this thesis attempts to follow the principles outlined by the Institute of Medicine [65], emphasizing the need to focus on the whole cycle of care rather than on immediate needs, the need for customization, the need to collect information on patients and on how care is delivered, the need to make decisions based on evidence, and the need for safety.

If we consider the essays in this thesis rather than the whole body of work, Chapter 4 is about "public health" and trends in the NHS. In the context of the research in health care operations management, I classified "public health" and trends as being part of the studies on **population health**, which, in turn, belong to the macro-area of research on **IT**. The research in this chapter is, in fact, based on the electronic collection of medical records, which are used to study the health of the English population, and the effectiveness and efficiency of the NHS.

Chapter 5 is about spillovers and complementarities, which are part of the research on "patient-centered models," that investigate how to organize resources in the health care system. In this case, I investigate the effect of focus in general hospitals and the consequences of increasing the number of NHS patients that go to private specialty hospitals. "Patient-centered models" are part of **patient-centered care**, which, as mentioned, has the objective to satisfy patients' needs. In relation to the debate on how to define patients' needs discussed in Section 2.2, since I investigate the English health care system, I adopt the views expressed in the constituent values of the NHS, which emphasize the need for universal care [231]. Finally, **patient-centered care** is also part of **patient experience** because it investigates how a patient receives care in a health care system.

The last essay in Chapter 6 investigates standard and custom policies in health care and their impact on re-admission/death rates. This research is part of the studies on "treatment policies and re-admission reduction," which also belong to **patient-centered care** and **patient experience**. The management of re-admissions is about patients and their long-term outcomes. When the health care system emphasizes the reduction of short-term costs to manage its day-to-day operations, then the risk is to have higher long-term costs and, more importantly, to lose the focus on the primary objective of health care delivery, that is, the health of the patient. This change in priorities affects **patient experience** because, when the health of the patient is not the primary objective of a hospital, then the value of the care delivered to the patient decreases.

2.5 Medical literature

The objective of this thesis is to provide a contribution to the operations management literature in health care; however, it is also useful to mention how this work relates to the medical literature. A comparison between the highest impact factor journals in operations management (e.g., Journal of Operations Management, Management Science) and medicine (e.g., British Medical Journal, New England Journal of Medicine) suggests that, in general, while quantitative papers in empirical operations management develop hypotheses based on the literature and then test them, papers in medicine that investigate associations do not have a literature section for hypothesis development. Since there is a need for comprehensive literature reviews that summarize every paper published on a subject, whereas systematic literature reviews are common in medicine, this term is not very common in operations management. Rather operations management literature reviews discuss what is known about a topic and what needs to be investigated further but do not necessarily list every single paper published on a subject.

The first essay in this dissertation, which provides an overview of inguinal hernia in the NHS, is, perhaps, the paper that most relates to the medical literature. For this reason, it has the structure of a British Medical Journal paper and provides also a contribution to the medical literature. Its research framework are the papers published by the Oxford School of Medicine, and, more specifically, by Goldacre's school which studies the provision of health care in England. In the global context, the research framework of this essay is the papers that investigate public health and trends in outcome measures.

The second essay provides a contribution to the research in the medical literature that studies specialization. Most of the medical research on specialization emphasizes the study of specialty hospitals, e.g., [159, 288], or use a single measure to capture the overall diversification of a health care provider, e.g., [108, 125]. Some papers even measure specialization with volumes of surgical operations, e.g., [87, 199], which in operations management usually measure economies of scale. The theories on spillovers and complementarities that this essay investigates can provide insight for the results found in the medical studies and suggest new avenues of research to explore.

The third essay discusses standard policies in health care, contributing to the body of empirical knowledge on this topic and giving actionable tools to medical doctors to decide patient length of stay. While the element of tacit knowledge characterizes a good part of medical decisions, there is an ongoing process of transformation of this knowledge into explicit knowledge [31]. The example cited in [31] explains clearly that in 1977 there was only anecdotic evidence on the effects of weight and sodium intake on hypertension [163] but in 2003 there was clear evidence on the relationship between weigh loss and decrease in sodium intake and blood pressure reduction [164]. Similarly, this essay provides a framework to identify healthy patients and to measure the outcomes of length of stay decisions, contributing to the attempt of the medical literature to investigate the impact of length of stay reduction.

Chapter 3

History of the NHS

3.1 History of the NHS

A reflection on the history of the NHS is necessary to illustrate the opportunities and the problems within the English health care system. On this matter, Arnott [13] and Catena [52] provide an exhaustive account of the historical developments of public health care before and after the institution of the NHS.

At the beginning of the twentieth century, patients had to pay if they wanted to see a doctor or if they needed to go to the hospital. While there were some insurance options which offered coverage to individuals that could afford their premiums, only a few hospitals in affluent communities provided free care to poor people [113].

The National Insurance Act proposed by David Lloyd George in 1911 was the first attempt to provide national insurance to British residents [194]. Workers contributed their salary to a national insurance and received in exchange free primary care. However, this insurance did not cover secondary care and hospital treatments, not all professions could participate to the program, and women and children were excluded.

In 1932, the Labour party approved a document that affirmed the necessity of a universal health care system in the United Kingdom [256]. During the Second World

War, it became clear that individuals with war-related injuries had the right to receive free medical treatment and, for this reason, the Government created the Emergency Medical Service (EMS). This service had the flexibility to treat injured patients in any hospital in the United Kingdom and, as a result, hospitals started to depend financially on the central government [3].

In 1944, the British government approved the white paper underlying the creation of the NHS which encountered, initially, the hostility of the British Medical Association (BMA) that supported the creation, instead, of a health care system based on health insurance. Despite the resistance of the BMA, the National Health Service Act received Royal Assent in 1946. At the very beginning, the BMA decided not to be part of the NHS but it finally reached an agreement and joined the new medical system in July 1948 [341].

The NHS, at its onset, was organized into 14 regional boards and included primary care, secondary care, community services, dentistry, and eye care [341]. While medical drugs were free at the start, in 1952, pharmacies started to charge 1 shilling for every medical prescription [126] (the NHS currently charges in England £8.20 per prescription [230]).

In the 1960s conglomerate diversification became a must in many industries in Western economies [205], inspiring the Hospital Plan, presented by the Minister of Health Enoch Powell in 1962. The Hospital Plan was an ambitious project to restructure the NHS with the objective to build new district general hospitals covering areas with populations ranging from $100,000$ to $150,000$ residents and offering a wide range of services. These large and diversified hospitals are still the cornerstone of health care delivery in England [177].

In 1974, the Government approved a new reform of the NHS putting Regional Health Authorities in charge of supervising Local Health Authorities that, in turn, were responsible to control hospitals. At the end of the 1970s, it started to become clear that, with an aging population and with individuals living for many years with multiple chronic conditions, offering universal care was becoming an increasingly challenging problem [177].

Margaret Thatcher became Prime Minister in 1979 and in 1983 she commissioned a report by Roy Griffith, previously director of Monsanto Europe, on how to increase efficiency in the NHS. In this report there was a new emphasis on how management could improve health care delivery and the ideas that lead to the creation of the NHS Trust, a new organizational unit responsible of providing primary and secondary care. The report also suggested the development of an internal market in the NHS and, as a result, health authorities and GPs became the buyers of primary and secondary care for their patients [127].

New organizational changes aimed at improving the efficiency of the delivery of care took place when Tony Blair became Prime Minister. A maximum wait of 18 weeks was set to limit the time patients had to wait for their treatment. Despite the initial claims to bring back the NHS to what it was before PM Thatcher [30], at the end of PM Blair's first mandate, the Government introduced budgets limiting how much GPs could spend. Moreover, the Government introduced new measures to standardize health care processes and to close hospitals that were not efficient. Private care was also introduced with the motivation that small and specialized private hospitals have a cohesiveness of purpose and, therefore, can streamline their processes to achieve better outcomes than large and diversified public providers [107].

In order to facilitate the establishment of new providers, the NHS decided not to fund private hospitals on the basis of the volumes they achieved. The belief was that when there is competition, there is no need for volume-based incentives [315].

The Coalition Government lead by PM David Cameron approved a new NHS reform that received Royal Assent in 2012. At the beginning of his mandate, PM Cameron realized that, due to the economic recession, the rate of increase of health care expenditures was becoming unsustainable (see Figure 3.1 for the cost time series). In order to curb costs, the new reform, that shapes the organization of today's NHS, introduced a new organizational unit, the Clinical Commissioning Group (CCG) including all the GPs who have their practices in a specific geographical area. This GP consortium is in charge of buying health care services for the residents of the area that it covers.

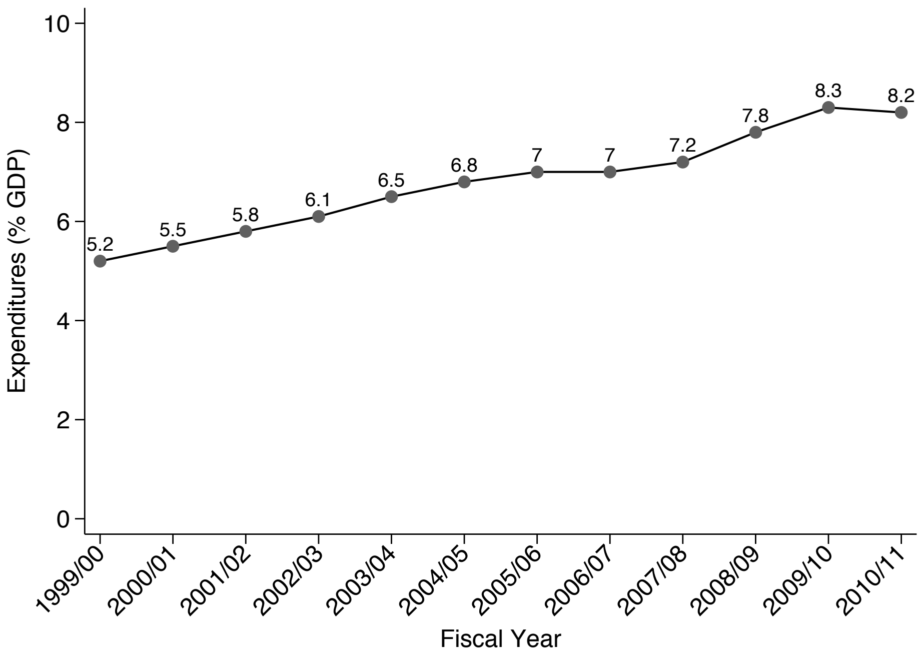


Figure 3.1: NHS Expenditures (% Gross Domestic Product (GDP)) from 1999 to 2010. House of Commons Library [130]

The distinctive aspect of PM Cameron's reform is that GPs are free to choose to buy health care services either from public or private providers [318], under the supervision of a new administrative unit within the Department of Health called NHS England. In order to facilitate this supervision, one of the provisions of the reform is to increase the amount of information available on the health status of the population. If a CCG does not achieve the expected results, NHS England can cut its resources, replace the members of its board, and even dissolve it [85].

The success of PM Cameron's reform is still uncertain and will depend on whether it will increase competition among hospitals. If there will be an increase in competition, costs will decrease and the supply of care will increase. On this ground, the resource partitioning model provides a framework to predict how the NHS will (possibly) evolve [48]. Whereas PM Blair's reform had the effect to increase the number of high volume/low complexity surgical procedures performed in private hospitals, PM Cameron's reform will, very likely, exacerbate this trend. In fact, since private providers do not yet have the means to treat complex procedures, they will target, at least initially, low margin patients, that is patients that need less complex procedures such as inguinal hernia surgery [1]. Public providers will, instead, prioritize high margin patients, leaving a door open for small specialized private centers to target low margin procedures. At the same time, private hospitals will try to cherry-pick their patients to exclude those cases for which costs are higher than revenues[1], leaving public hospitals with the additional burden to treat patients with comorbidities.

While, at the beginning, small specialized private centers will concentrate on low margin patients, it is unclear whether, eventually, they will move to high margin patients. In this case the risk is that the once unified English hospital system will become a fragmented ensemble of small providers. In spite of everything, because of the high economies of scale that characterize the health care industry [104], the changes introduced by this reform will progress very slowly.

3.2 Operations management initiatives in the NHS

It is a rather complex task to list all the operations management initiatives that hospital managers and clinical institutes have introduced in the NHS to reduce the costs of

[1] KC and Terwiesch provide empirical evidence of cherry-picking in specialty hospitals in [172]

care and increase its quality. This difficulty arises because of the large number of operations management measures that hospitals have implemented across the years. Hurst and Williams's report [157] summarize and classify these measures into four categories: "leadership, management and staff management," "technology adoption," "hospital operational processes," and "optimising the use of staff and improving staff productivity." In the next paragraphs, I explain the potential impact of these four areas of improvement, describing the main initiatives discussed in this report.

When there is a need for leadership, a hospital has two possibilities: changing the leaders in the executive teams or creating task-forces to deal with specific problems. Both initiatives need time to work but can be a successful approach to implement change. M. E. Celmer, the Chief Executive Officer of the DeGraff Memorial hospital in New York is an example of a leader able to transform health care operations successfully and to engage employees in this effort [54]. At the Lancaster general hospital in Pennsylvania, a task force, put together by the Trauma department, is, instead, an example of a team able to improve outcomes for patients with spinal chord injury [154]. Another possible initiative to implement change is increasing the collaboration between doctors and managers in making decisions on the allocation of hospital resources, for example, with the implementation of a service-line reporting system. A service-line reporting system informs doctors on the resources they use when they make a clinical decision and increases their knowledge on the impact of their choices on hospital finances. According to Hurst and Williams [157], reward programs can also achieve operational improvement, for instance, by having an impact on "nurse management."

The second area of operational improvement is "technology adoption" which is, typically, slow in health care. As discussed by Hurst and Williams [157], the NHS has introduced day case surgery for inguinal hernia in 1955 but the adoption of this pathway of care is still an ongoing challenge [221, 275]. There are three publications that are about the adoption of new technology in the NHS: "Statistics on NHS productivity" ([79], as cited in [157]), "Revision to the operating framework for the NHS in England 2010/11" ([78], as cited in [157]), and "The operating framework for the NHS in England 2011/12" ([77], as cited in [157]). Examples of technologies introduced in hospitals in recent years include robots for blood tests and medicine dispensing, information infrastructures, and computer systems for paperless clinics.

At a higher level, hospital managers can focus on "process re-engineering and pathway design," following the guidance of "the productive ward" that is part of the "Releasing Time to Care" program [235]. The adoption of lean management techniques is another initiative which has been pushed recently by the NHS Institute for Innovation and Improvement, following the implementation of the "Productive Operating Theatre" program [235]. "Hospital operational processes" is an area of improvement which has been increasingly crucial since the approval of the 18-week waiting time initiative [232], which, as mentioned in Section 3.1, sets a limit on the maximum number of weeks a patient has to wait for an elective operation.

Hurst and Williams [157] also explain how process improvement can affect hospital performance. For example, the decrease in length of stay at the Royal Wolverhampton Hospitals NHS trust has lead to a decrease in mortality rates. Hospitals can also outsource activities such as cleaning and catering through the so-call private initiative schemes, although it has not been shown that this leads to a reduction of costs. The Foundation Trust Network is one of the examples of how hospitals can decrease their costs with a re-design of their processes ([102], as cited in [157]), achieving £600 million of savings per year through the centralization of back off activities across trusts. Finally, the size of a hospital can also affect costs and Hurst and Williams [157] suggest that hospitals with a number of beds between 200 and 600 achieve the lowest costs.

The National Audit Office in 2010 has emphasized the need for "optimising the use of staff and improving staff productivity," given that the NHS is failing in controlling staff costs. In the recent years there were both initiatives aimed at decreasing and increasing the staff working for the NHS: in general, when there was a decrease in staff, there was an increase in productivity and, when there was an increase in staff, there was a decrease in productivity [157]. The "turnaround" scheme [157], launched in 2005, is an example of an initiative that has decreased staff levels and has increased productivity, for example, with the appointment of more qualified personnel [157]. The last initiative described in the report follows the Boorman Review [36] and is the reduction of the time NHS staff spends on sick leave. Since the time the NHS personnel spends on sick days is higher than in many other industries, the objective is to decrease it by 30%, for example, with the implementation of programs that reduce the health risks for the clinical staff.

3.3 The "Quality, Innovation, Productivity, Prevention" ("QIPP") program

I provide in the following paragraphs a description of the "QIPP" program which is aimed at improving NHS operations based on the reports published by the British Medical Association [39] and the Royal College of Nursing [274]. The "QIPP" program started with the 2008 recession and had the objective to achieve between £15 and £20 billions of savings from 2011 to 2014 [39]. In 2011, the Department of Health re-formulated the original objective of the "QIPP" program into a plan for saving £20 billions by 2015 [76] or, in other terms, to increase NHS productivity by 4% every year.

The aim of the program is to keep patients at the centre of health care, to emphasize quality, and to make NHS resources more productive. It does not include only initiatives at the national level but also at the regional and local level. In order to clarify the priorities of the program, the national director for the "QIPP" program, Jim Easton, has defined twelve work streams for operational improvement [219]:

- "long-term conditions," which is about improving community and primary care;
- "right care," which is about delivering the best possible care to patients;
- "right care for patients - shared decision making," which is about engaging patients in decision making;
- "safe care," which is about patient's safety during the process of health care delivery;
- "urgent and emergency care," which is about improving the management of emergency care;
- "end of life care," which is about the support of patients at the end of their lives;
- "medicines use and procurement," which is about making inventory management in the NHS more efficient;
- "productive care," which is about the increase of standardization and efficiency of health care;
- "back office efficiency," which is about the efficiency of the back office activities of hospitals;
- "procurement," which is about the procurement of services and devices for NHS hospitals and practices;
- "mobilisation," which is about engaging the NHS staff in the operational changes;
- "clinical support rationalisation (pathology)," which is about facilitating the work of the pathologists;

- "primary care commissioning and contracting," which is about the management of primary care;
- "workforce," which is about the management of human resources in the NHS.

Since hospital profits depend on reimbursements, one of the instruments that the "QIPP" program employs at the national level to achieve operational improvement is the use of tariffs. Another tool is the revision of the contracts with the GPs to include sanctions to penalize the practices that do not achieve a minimum standard of quality of care. The involvement of strategic health authorities (before they were phased-out), of CCGs, and of clinicians is how the "QIPP" program aims to achieve bottom-down change at the regional and local level.

3.4 The NHS today

After describing the history of the NHS and of the initiatives undertaken to enhance its operations, in this last section I introduce the NHS today and I discuss some of the challenges it has to address.

Andrew Lansley and Jeremy Hunt are two of the key figures of the NHS today; the first was Secretary of Health from 2012 to 2014, the latter is, instead, currently covering this role and is the co-author of a book that suggests to replace the NHS with a system of health savings accounts [138, 318].

The current politics of the NHS has been named as the "politics of confrontation" [177] because of the widespread hostility encountered by the reforms of the Coalition and of the current Government, e.g., [56, 348], which has brought, inter alia, to the more than 1,000 amendments presented to change the "Social and Health Care Bill" [177].

The "Social and Health Care Bill" has clashed against the pillars of the Labour view of the NHS, based on increasing the importance of the Primary Care Trust, an organization abolished with the current reform that had the responsibility to manage 80% of the resources in the NHS [146]. Another aspect of the health care reform that has clashed with the Labour view of the NHS is the abolition of the Strategic Health Authorities, that were in charge of coordinating primary and secondary care. The relationships between CCGs and hospitals are today mainly transactional and GPs buy health care services from hospitals at their discretion.

Regardless of the organizational reforms, the NHS has still a very good reputation in the UK and, in comparison to other developed countries, British patients are more likely to receive the best treatment that is available to address their problems [161, 290]. According to the Commonwealth Fund report [161, 290], the British health care system has very low costs per capita, the quality of care in the UK is higher than the quality of care in other developed countries for most of the performance measures investigated, and patient's satisfaction is the highest, with 92% of patients who believe that the British health care system provides them with the best possible care.

The culture of the NHS affects how patients perceive the treatments they receive, contributing to these beliefs. It is, in fact, based on the following values [228]:

- "that it meet the needs of everyone;"
- "that it be free at the point of delivery;"
- "that it be based on clinical need, not ability to pay."

Despite the high levels of satisfaction, the NHS has to address many issues that undermine its short and long-term sustainability. In the next paragraphs I introduce some of the most relevant challenges the NHS has to tackle, basing this description on the more detailed discussion provided in [128, 321].

One of the problems that NHS hospitals have to take into consideration is the high turnover of their senior executives; for instance, the Chief Executive Officers (CEOs) of NHS hospitals leave their position, on average, within 700 days after their appointment [151]. When the senior management changes continuously, questions on the long-term strategy of the hospital start to arise at every level of the organization. Reasons of the high turnover of NHS executives are perhaps related to their relatively low level of compensation, to the stress due to the working conditions of a high pressure environment, and to the limited powers they have to address the conflicts with the clinicians.

Another challenge the NHS has to take into account is related to its new organizational structure, which is based on CCGs that buy health care services from hospitals and private providers. GPs are now responsible to manage the health care delivery in the geographical area where their practice is based without the support of local authorities, a task that requires new skills that they need to acquire [123]. In order to fill this skills gap, the NHS has the challenge to train younger and older GPs on this new component of their job.

The increase of cancer survival rates is another aspect of health care delivery in the NHS that needs further consideration, since post-treatment recovery performance for cancer patients is under the average in comparison to other European countries. One of the aspects that needs to be further explored is related to Managed Cancer Networks which are "supposed to lead the evidence-based reconfiguration of cancer services" [97]. The management of these networks is extremely complex because of the existence of the so-called "wicked problems" [97], which are difficult to address since it is not possible to define them and they do not have "optimal solutions" [271].

Although there has been an increasing emphasis on data analytics and despite the provisions of the new health care reform which highlights its role in achieving efficiency and improving outcomes [81], the management of information remains one of the key issues of the NHS. For instance, one of the challenges to tackle, is the creation of a dataset that collects information on all the drugs prescribed to NHS patients and to link this data, for example, to medical records and death certificates.

Finally, financial management is another issue that needs to be further explored in the UK since, as already mentioned, health care expenditures are soaring worldwide. One possibility to curb health care expenses is, for example, to transition from a model of care based on Diagnosis Related Groups (DRGs), which include only hospital procedures when calculating health care costs, to a model of care based on bundled payments, which include also accessory services [209]. Since hospitals can be penalized if patients need accessory services after receiving hospital care, this new model of funding has greater chances than DRGs to align the incentives of the health care providers with the overall necessity to decrease total health care costs [209]. Raising health taxes [45], such as the tax on alcohol consumption, is another option to increase, instead, the sources of funding of the British health care system and to contrast negative behaviors, which, in this case, are causing a rise in the rates of hepatic cirrhosis in the British population [145].

Chapter 4

Inguinal hernia surgery in England from 1999 to 2011 [1]

4.1 Introduction

A hernia is the protrusion of a viscus through a defect in the wall of the cavity that contains it [92]. While herniae can develop in various parts of the body, for example the brain or the abdomen, the protrusion of a viscus through the inguinal canal is called inguinal hernia [206].

Inguinal hernia repair is the most common general surgery procedure in North America and more than 20 million people across the world undergo this operation every year [20]. Inguinal herniae are more likely to occur in men than in women: the estimated lifetime risk of repair is 27% for men and 3% for women [261]. Burcharth et al. [44], who study Danish data, also found that children and elderly patients are more likely to undergo this type of procedure.

Ideally, inguinal herniae "should be repaired by elective surgical operation" [69], the benefits of which exceed, in most cases, its costs [66]. Despite low levels of mortality

[1] This essay is co-authored with M. Goldacre, S. MacMahon, and M. Woodward

for elective surgery, emergency surgical operations are, instead, associated with high mortality rates [261]. Using the Swedish Hernia Register, Haapaniemi et al. [124] found that patients undergoing an emergency inguinal hernia repair are from five to ten times more likely to die in the 30 days following the operation compared with the general population. Another study [176] found that the 30-days rate of mortality for emergency inguinal hernia surgery in Denmark is around 7%, while, for elective surgery, a previous study by Bay-Nielsen et al. [20] found a 0.02% mortality rate in patients under 60 years old and a 0.48% mortality rate in patients aged 60 or more.

In this study, we investigate inguinal hernia surgery in the NHS from 1999 to 2011, expanding previous research on elective admission rates [192], and we report statistics on four key performance indicators: length of stay, re-admissions, weekend admissions, and mortality.

4.2 Materials and methods

We used NHS data on patients admitted in English hospitals from the Hospital Episode Statistics (HES) data warehouse from 1999 to 2011, linked together using the Oxford record linkage system with data from death certificates provided by the Office for National Statistics up to 2012 [111]. We analyzed the data using SAS 9.3 and Stata 11.2 and we investigated continuous inpatient spells (CIPSs), which refer to the whole cycle of care from admission to the hospital to discharge, and that are derived from finished consultant episodes (FCEs), which, instead, refer to the care of a single consultant.

From this dataset, we extracted data on emergency and elective admissions for all patients that have at least one diagnosis of inguinal hernia (ICD-10 code K40 [43]) in their records. For this cohort of patients, we analyzed the records that have an inguinal hernia repair procedure code (OPCS-4 codes T20 and T21 [308]). We calculated statistics overall and by sex and age group (0-6; 7-18; 19-65; and more than

65 years) and average length of stay, measured as number of days from admission to discharge. We investigated re-admissions, analyzing whether a patient re-entered the hospital within 180 days after the inguinal hernia operation. We computed the number of patients admitted on Saturday and Sunday to calculate the percentage of weekend admissions. The death rates presented include in-hospital mortality, mortality within 29 days after discharge, and mortality within 364 days after discharge and every cause of death is included in the calculations. Mortality rates were derived from HES data for in-hospital death and from death certificates after hospital discharge. Admission rates were estimated per 10 thousand residents, re-admission rates per 100 operations, weekend admissions per 100 operations, mortality rates per 1000 operations. Rates of change across years and their 95% confidence interval were calculated using linear regression. We age/gender adjusted admission rates, emergency admission rates, length of stay, re-admission rates, weekend admissions, and mortality rates using data available from the Office for National Statistics (ONS) website [243] and applying the direct method with the English population in 2011 as reference population. Since we had data available until 2011 for medical records and until 2009 for death certificates, re-admission rates were reported until 2010 and death rates until 2009.

The age/sex Standardized Mortality Ratio (SMR) was calculated using the indirect method. In order to compute the ratio, we used data on total number of deaths in England and Wales in 2009. We estimated SMR values for each of the first 12 months after surgery. The SMR computed for the first month includes in-hospital mortality.

4.3 Results

Figure 4.1 displays the rates of admission for number of inguinal hernia procedures in the NHS by year for emergency and elective patients. Overall, the average admission rate was 15.11 patients admitted for every 10,000 people from 1999 to 2004 and 14.25

patients admitted for every 10,000 people from 2005 to 2011. The rate of decrease for emergency procedures per year from 1999 to 2011 was 1.90% (95% C.I.: 1.37%, 2.44%) and the rate of decrease for elective procedures was 0.82% (95% C.I.: 0.38%, 1.25%). The peaks for emergency and elective procedures were in 2000 and in 2003, with 0.92 patients admitted for every 10,000 people and 14.54 patients admitted for every 10,000 people, respectively.

Emergency operations were on average 5.58% of the total number of procedures performed in the NHS each year. While the percentage of elective repairs has been increasing across years at a rate of 0.06% (95% C.I.: 0.03%, 0.09%), the percentage of emergency procedures has been decreasing at a rate of 1.04% (95% C.I.: 0.55%, 1.52%). Women were about twice as likely to undergo inguinal hernia surgery in emergency settings than men, with the ratio between emergency and elective admissions for women reaching a peak value of 2.10 in 2011. While the rate of inguinal hernia surgery in emergency settings has been decreasing for men at a rate of 0.17% (95% C.I.: 0.09%, 0.26%), it has been increasing for women at rate of 1.10% (95% C.I.: 0.56%, 1.65%). Table 4.2 further breaks down the percentages into age groups. When considering the age group composed by patients older than 65, the percentage of women treated in emergency settings was consistently greater than the percentage of women aged 19-65. While the proportion of men older than 65 has been decreasing at a rate of 0.24% (95% C.I.: 0.09%, 0.38%), the proportion of women has been increasing at a rate of 1.24% (95% C.I.: 0.48%, 2.01%). The trends for male patients show that children aged 0-6 had lower percentages of surgical procedures in elective settings than children aged 7-18. Conversely, the percentages of surgical procedures for female patients aged 0-6 were greater than the percentages of surgical procedures for female patients aged 7-18. While in the case of female patients aged 19-65 the percentage of surgical procedures was lower than for children aged 7-18, for male patients aged 19-65 the percentage of surgical procedures was higher.

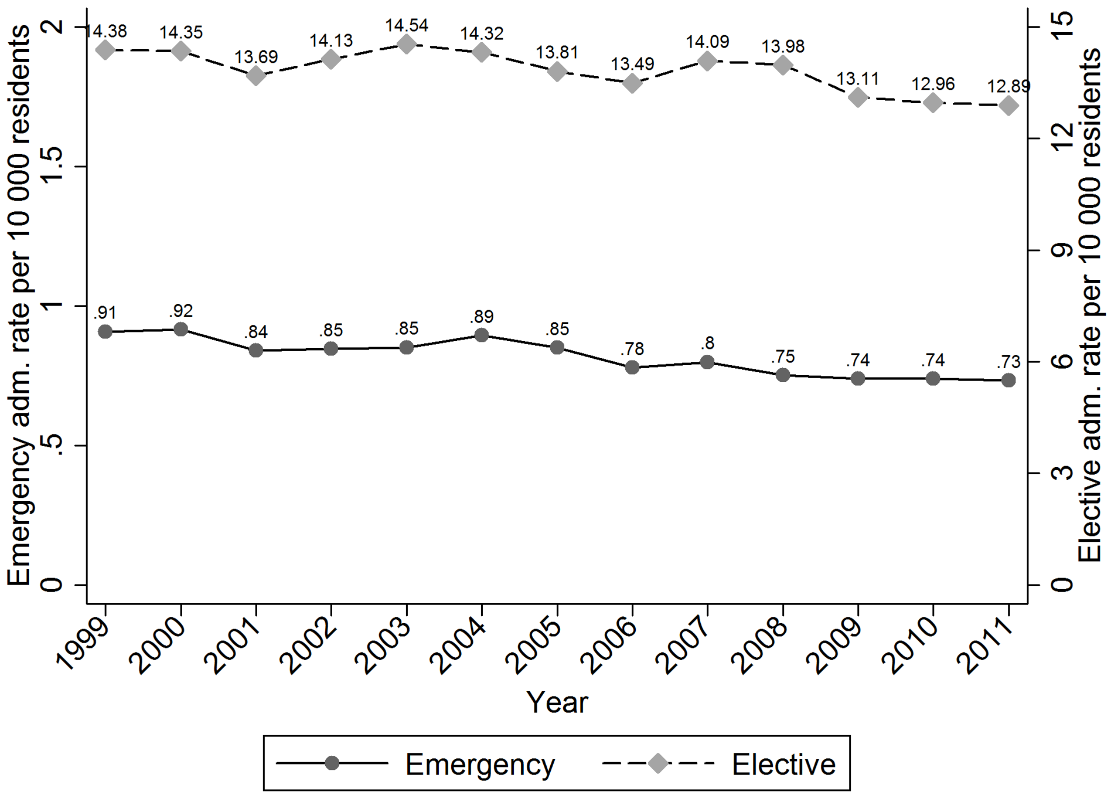


Figure 4.1: Admission rates for NHS inguinal hernia patients in England from 1999 to 2011

4.3.1 Length of stay

As displayed in Figure 4.2, length of stay has been decreasing for both emergency patients and elective patients: length of stay has been decreasing in the first group at a yearly rate of 1.53% (95% C.I.: 0.65, 2.40) and at a rate of 13.26% (95% C.I.: 6.76, 19.31) in the second. On the basis of the confidence intervals, the rate of decrease was greater for elective than for emergency patients. When considering both emergency and elective patients, average length of stay has been decreasing from the 1.72 days per patient in 1999 to the 0.79 days per patient in 2011.

4.3.2 Re-admissions

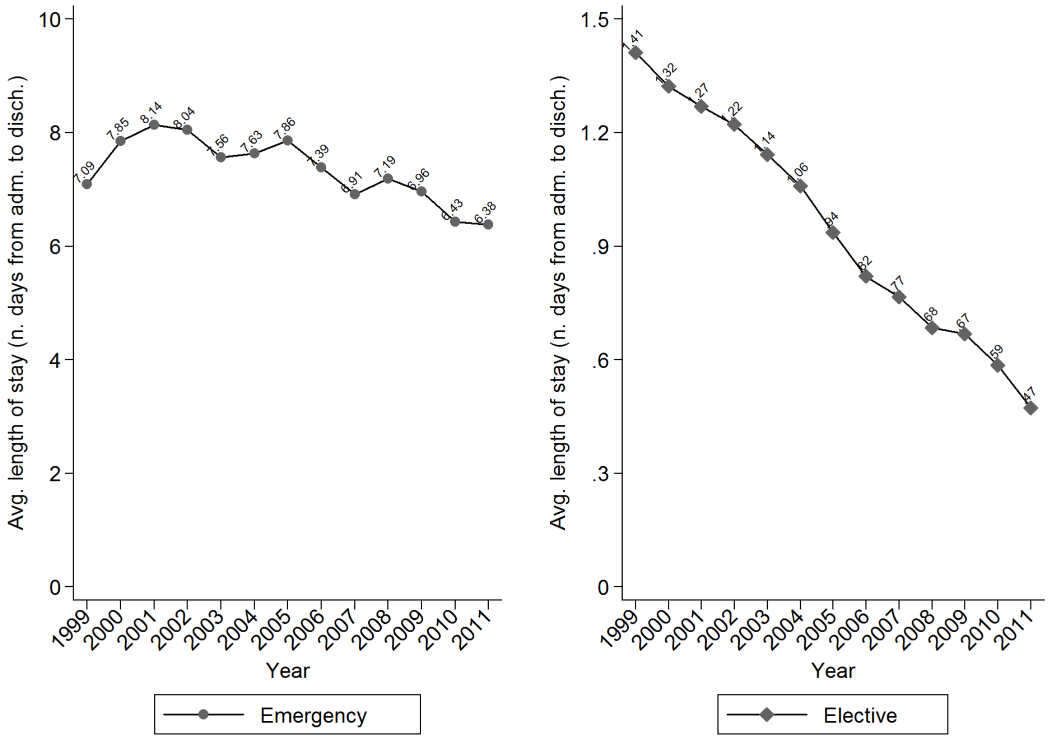
In Figure 4.2, we report re-admission rates after hernia surgery. The percentage of re-admissions between 1999 and 2010 has been increasing for both emergency and elective patients: for emergency patients at a rate of 2.25% (95% C.I.: 1.80%, 2.71%) and for elective patients at a rate of 2.07% (95% C.I.: 1.63%, 2.50%). The rate of re-admissions for emergency patients reached a peak in the last year of our period of study: in 2010 a re-admission was required every 2.93 hernia operations.

4.3.3 Weekend admissions

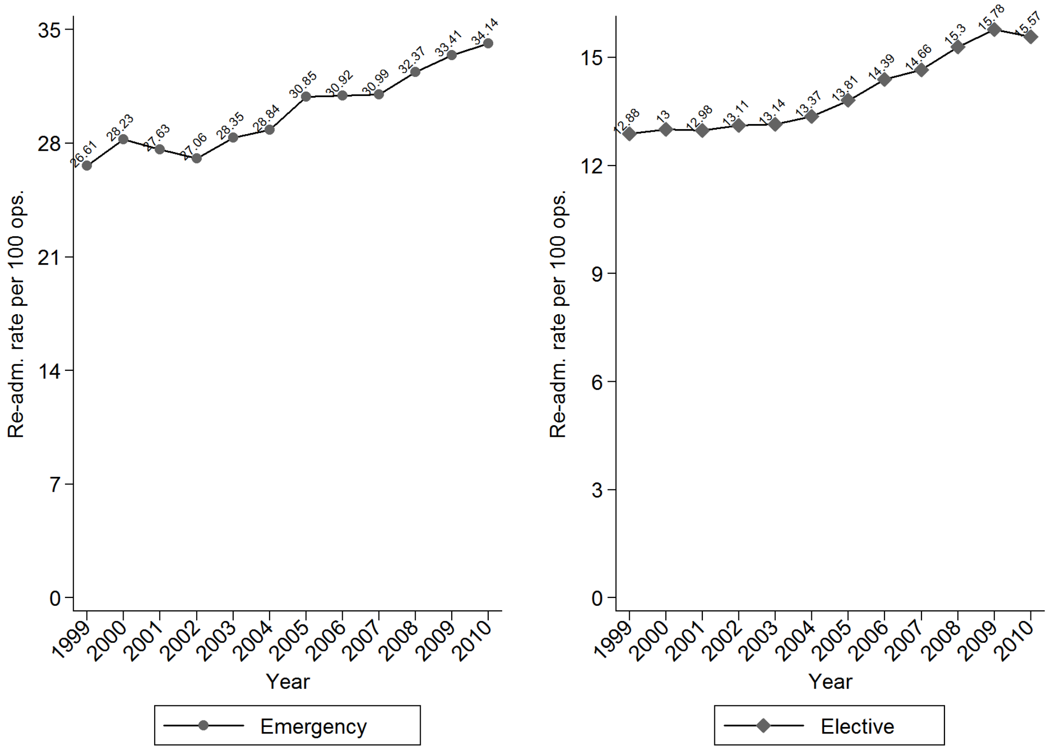
Weekend admissions are decreasing in both emergency and elective settings: the proportion of emergency admissions has been decreasing from 1999 to 2011 at a rate of 0.44% (95% C.I.: -0.12%, 1.01%), and the proportion of elective admission at a rate of 7.26% (95% C.I.: 3.47%, 10.90%). As reported in Table 4.1, the peak of weekend admissions was in 2006 for emergency patients and in 2002 for elective patients, when, respectively, 22.2% of emergency patients and 8.17% of elective patients had their admission during the weekend. Weekend admissions were at their lowest in emergency settings in 2010 and in elective settings in 2006, when, respectively, 19.5% and 2.71% of patients had an admission during the weekend.

4.3.4 Mortality

The mortality rates within 364 days after discharge for emergency and elective patients are illustrated in Figure 4.3. In the case of emergency surgery, the rates of growth for in-hospital and within 29 days mortality did not show any significant variation from 1999 to 2009 ($p = 0.97$ and $p = 0.67$, respectively). The within 364 days mortality was on average 11.46% and has been decreasing across time at a rate of 1.08% (95% C.I.: -0.05%, 2.19%). The rates of mortality for elective patients were all decreasing in the



(a) Average length of stay for inguinal hernia patients



(b) Percentage of hospital re-admissions within 180 days after discharge

Figure 4.2: (a) Average length of stay and (b) percentage of hospital re-admissions for emergency and elective inguinal hernia NHS patients

period of interest. The rate of decrease for in-hospital mortality was 7.33% (95% C.I.: 4.99%, 9.61%), the rate of decrease for within 29 days mortality was 5.82% (95% C.I.: 3.52%, 8.06%), and the rate of decrease for within 364 days mortality was 3.96% (95% C.I.: 3.64%, 4.29%).

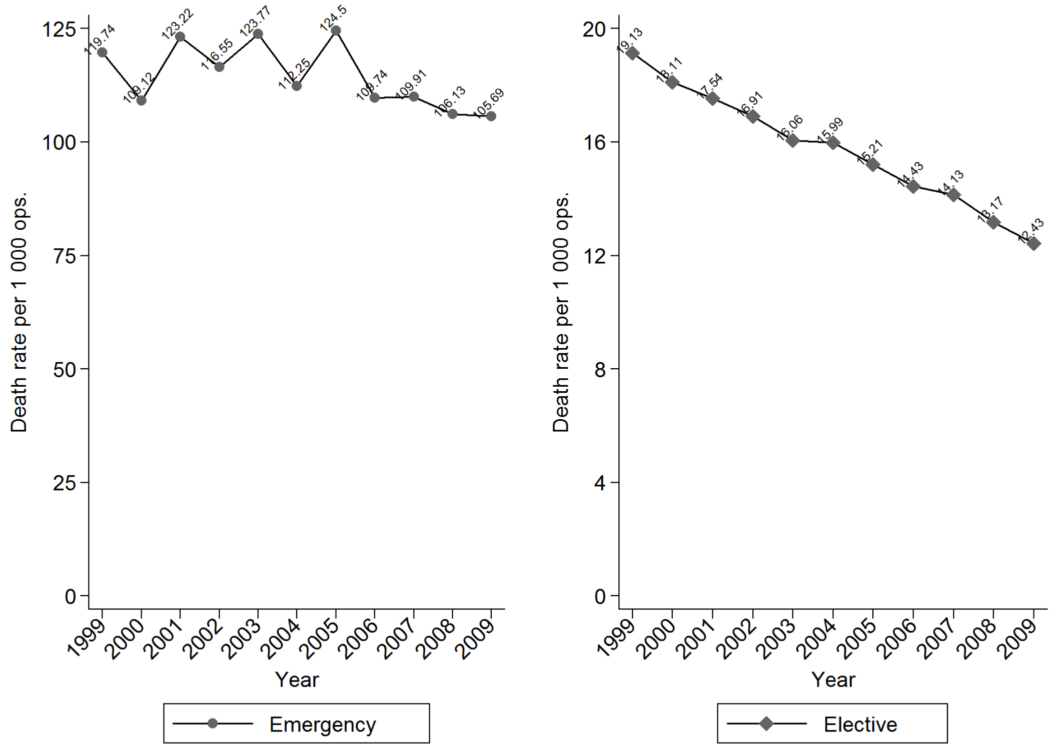


Figure 4.3: Death rates for emergency and elective inguinal hernia NHS patients within 364 days after discharge

Table 4.3 reports the SMR for emergency and elective patients by month. For emergency patients the SMR reaches its peak in month 1 and decreases sharply in month 2. However, it always remains greater than 1 for the whole period of interest. At month 12 the likelihood of mortality for emergency hernia patients is still around 1.39 times the likelihood of mortality in the general population. Conversely, elective hernia patients are less likely to die than individuals from the general population. The SMR is constantly below 1 and reaches its minimum in month 2.

Table 4.1: Characteristics of patients that underwent an inguinal hernia repair

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Emergency and Elective													
Admission rate (‱)	15.28	15.26	14.53	14.98	15.39	15.21	14.66	14.27	14.89	14.73	13.85	13.7	13.62
Female (%)	7.19	7.38	7.29	7.07	7.17	7.37	7.4	7.42	7.68	7.48	7.36	7.71	7.49
Emergency (%)	5.94	6	5.78	5.65	5.53	5.88	5.79	5.46	5.36	5.1	5.34	5.39	5.37
Age (n. years)													
65+ (%)	38.49	37.82	38.02	38.29	38.78	39.41	39.36	38.95	39.18	39.29	40.04	39.53	40.08
Mean	57.14	57.01	57.21	57.36	57.65	57.86	57.89	57.79	57.7	57.86	58.31	57.96	58.2
Std	18.8	18.73	18.65	18.53	18.43	18.46	18.56	18.6	18.9	18.99	18.8	19.02	18.71
Length of stay (n. days)													
Mean	1.72	1.67	1.64	1.59	1.49	1.41	1.31	1.17	1.1	1.03	1.01	0.9	0.79
Re-admission (%)	13.61	13.82	13.76	13.86	13.96	14.2	14.72	15.28	15.53	16.22	16.72	16.57	NA
Weekend (%)	7.72	8.42	8.26	8.9	7.79	6.02	4.98	3.76	4.01	5.47	4.63	4.53	4.98
Mortality (‰)	24.54	23	23.22	22.26	21.85	21.16	21.08	19.55	19.28	18.17	17.44	NA	NA
Emergency													
Admission rate (‱)	0.91	0.92	0.84	0.85	0.85	0.89	0.85	0.78	0.8	0.75	0.74	0.74	0.73
Female (%)	12.56	13.57	13.6	12.74	12.78	13.85	13.87	13.17	14	14.27	14.18	14.91	14.56
Age (n. years)													
65+ (%)	61.61	61.15	61.76	61.87	61.98	59.02	59.5	58.8	59.09	58.61	61.28	60.37	61.77
Mean	64.77	64.95	65.28	65.29	65.67	64.27	63.99	63.19	63.34	63.51	65.21	64.05	64.99
Std	21.94	21.77	21.22	21.19	20.87	21.74	22.44	23.44	23.69	23.46	22.36	23.69	22.83
Length of stay (n. days)													
Mean	7.09	7.85	8.14	8.04	7.56	7.63	7.86	7.39	6.91	7.19	6.96	6.43	6.38
Re-admission (%)	26.61	28.23	27.63	27.06	28.35	28.84	30.85	30.92	30.99	32.37	33.41	34.14	NA
Weekend (%)	20.94	21.15	21.52	21.9	20.79	21.13	20.06	22.22	20.66	20.36	19.9	19.5	21.25
Mortality (‰)	119.74	109.12	123.22	116.55	123.77	112.25	124.5	109.74	109.91	106.13	105.69	NA	NA
Elective													
Admission rate (‱)	14.38	14.35	13.69	14.13	14.54	14.32	13.81	13.49	14.09	13.98	13.11	12.96	12.89
Female (%)	6.87	7	6.91	6.74	6.85	6.98	7.01	7.1	7.32	7.12	6.97	7.3	7.09
Age (n. years)													
65+ (%)	37.1	36.39	36.61	36.92	37.47	38.22	38.15	37.83	38.06	38.27	38.86	38.34	38.85
Mean	56.68	56.52	56.73	56.9	57.19	57.47	57.53	57.48	57.39	57.56	57.93	57.62	57.81
Std	18.49	18.42	18.37	18.26	18.17	18.17	18.23	18.24	18.54	18.68	18.5	18.66	18.37
Length of stay (n. days)													
Mean	1.41	1.32	1.27	1.22	1.14	1.06	0.94	0.82	0.77	0.68	0.67	0.59	0.47
Re-admission (%)	12.88	13	12.98	13.11	13.14	13.37	13.81	14.39	14.66	15.3	15.78	15.57	NA
Weekend (%)	6.97	7.7	7.51	8.17	7.05	5.16	4.13	2.71	3.07	4.62	3.76	3.68	4.06
Mortality (‰)	19.13	18.11	17.54	16.91	16.06	15.99	15.21	14.43	14.13	13.17	12.43	NA	NA

Table 4.2: Percentage of inguinal hernia surgery procedures performed on female and male patients by age group

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Emergency and Elective													
Female													
0-6 years	21.16	18.9	21	21.7	21.03	21.57	19.61	20.27	21.32	20	20.3	23.17	21.41
7-18 years	13	12.02	10.99	10.3	10.4	11.5	10.67	12.65	10.85	11.55	10.8	14.7	15.02
19-65 years	5.67	5.93	5.83	5.53	5.62	5.82	5.8	5.73	6	5.78	5.49	5.72	5.73
65+	8.64	8.98	8.85	8.79	8.96	9.05	9.22	9.29	9.43	9.23	9.33	9.56	9.12
Male													
0-6 years	78.84	81.1	79	78.3	78.97	78.43	80.39	79.73	78.68	80	79.7	76.83	78.59
7-18 years	87	87.98	89.01	89.7	89.6	88.5	89.33	87.35	89.15	88.45	89.2	85.3	84.98
19-65 years	94.33	94.07	94.17	94.47	94.38	94.18	94.2	94.27	94	94.22	94.51	94.28	94.27
65+	91.36	91.02	91.15	91.21	91.04	90.95	90.78	90.71	90.57	90.77	90.67	90.44	90.88
Emergency													
Female													
0-6 years	14.39	10.26	20.59	12.05	15.79	11.21	13.74	12.5	13.09	16.48	12.06	13.78	11.93
7-18 years	1.92	12.9	13.33	4.17	7.14	8.77	10.53	14.89	5.08	3.92	10.81	15.38	11.43
19-65 years	8.71	9.15	9.91	8.5	9.27	8.93	8.69	9.34	9.11	10.73	10.17	9.82	9.25
65+	14.78	16.23	15.37	15.32	14.77	17.17	17.08	15.5	17.16	16.47	16.59	17.83	17.62
Male													
0-6 years	85.61	89.74	79.41	87.95	84.21	88.79	86.26	87.5	86.91	83.52	87.94	86.22	88.07
7-18 years	98.08	87.1	86.67	95.83	92.86	91.23	89.47	85.11	94.92	96.08	89.19	84.62	88.57
19-65 years	91.29	90.85	90.09	91.5	90.73	91.07	91.31	90.66	90.89	89.27	89.83	90.18	90.75
65+	85.22	83.77	84.63	84.68	85.23	82.83	82.92	84.5	82.84	83.53	83.41	82.17	82.38
Elective													
Female													
0-6 years	21.97	19.88	21.04	22.6	21.51	22.91	20.52	21.78	22.72	20.51	21.31	24.58	22.75
7-18 years	13.68	11.96	10.88	10.61	10.54	11.66	10.68	12.53	11.21	11.95	10.8	14.67	15.21
19-65 years	5.57	5.82	5.69	5.43	5.5	5.71	5.69	5.61	5.89	5.62	5.34	5.59	5.62
65+	8.03	8.23	8.2	8.16	8.42	8.29	8.49	8.75	8.76	8.64	8.69	8.82	8.36
Male													
0-6 years	78.03	80.12	78.96	77.4	78.49	77.09	79.48	78.22	77.28	79.49	78.69	75.42	77.25
7-18 years	86.32	88.04	89.12	89.39	89.46	88.34	89.32	87.47	88.79	88.05	89.2	85.33	84.79
19-65 years	94.43	94.18	94.31	94.57	94.5	94.29	94.31	94.39	94.11	94.38	94.66	94.41	94.38
65+	91.97	91.77	91.8	91.84	91.58	91.71	91.51	91.25	91.24	91.36	91.31	91.18	91.64

Month of Discharge	Emergency	Elective
1^{st}	13.24 (0.3)	0.92 (0.03)
2^{nd}	2.51 (0.13)	0.61 (0.02)
3^{rd}	2.27 (0.12)	0.68 (0.02)
4^{th}	1.93 (0.11)	0.73 (0.03)
5^{th}	1.86 (0.11)	0.82 (0.03)
6^{th}	1.58 (0.1)	0.81 (0.03)
7^{th}	1.78 (0.11)	0.82 (0.03)
8^{th}	1.59 (0.1)	0.83 (0.03)
9^{th}	1.39 (0.1)	0.9 (0.03)
10^{th}	1.43 (0.1)	0.88 (0.03)
11^{th}	1.21 (0.09)	0.9 (0.03)
12^{th}	1.39 (0.1)	0.88 (0.03)

Table 4.3: Age/sex adjusted SMR (standard deviation) by month after surgery

4.4 Discussion

The trend analysis illustrated in Section 4.3 indicates that emergency and elective inguinal hernia admission rates are both decreasing in the period of interest and that emergency admission rates are decreasing at a faster rate than elective admission rates. The decrease of the percentage of inguinal hernia procedures for emergency patients and the increase of the percentage of procedures for elective patients are consistent with this result.

The analysis of emergency trends by gender shows that women are more likely than men to undergo inguinal hernia surgery in emergency settings, a result consistent with reports in a study on Swedish data [124]. Gender bias leading to late diagnosis has been identified as one of the possible sources of this phenomenon [129]. As a matter of fact, the percentage of women that undergo emergency surgery reaches its maximum in the oldest segment of the population, however, delay in the surgical treatment may also explain the high percentage of female patients aged 0-6 that need an emergency repair.

Section 4.3 also shows that length of stay for inguinal hernia patients is decreasing. As length of a stay is a driver of health care costs [112], it is plausible to suppose that this effect is due to the efforts of hospitals managers to curb expenses. While length of stay is decreasing for elective patients, it is decreasing also in emergency settings but at a lower rate. The success in reducing length of stay for elective patients may reflect the diffusion of day case surgery [284], while the lower rates of decrease for emergency patients may be due to longer wait-times caused by the decreasing admission rates for elective patients.

Given the proliferation of guidelines and protocols for the management of inguinal hernia, e.g., [175, 220, 305], the increase of re-admissions for both emergency and elective patients is definitely surprising. Of course, the evolution of the patient population in the NHS may be having an effect on this outcome measure. An older population and an increasing number of individuals living with a chronic condition may have increased the case-mix complexity of the patient base [80].

The decrease of weekend admissions may indicate that hospital administrators and doctors are prioritizing admissions during the rest of week for both emergency and elective settings. Since hospitals tend to concentrate their resources on providing care during weekdays [171], empirical findings suggest that patients admitted during the weekend are more likely to experience worse outcomes than patients admitted during the rest of the week, e.g., [14, 349]. This result may suggest that the NHS is re-organizing its operations to provide care when it is likely to be more effective. Alternatively, it may indicate that patients are more hesitant to undergo the surgery during the weekend, for example, because they are increasingly aware of the risks of undergoing a surgery on a Saturday or on a Sunday.

While guidelines and protocols do not appear to have reduced re-admission rates, they may have had an effect on decreasing mortality rates for elective patients. Yet, in emergency settings, in-hospital and within 29 days mortality rates are not decreasing. The introduction of protocols for the management of inguinal hernia on emergency patients, such as the guidelines of the World Society of Emergency Surgery [282], could be beneficial for also reducing these rates.

The SMRs reported in column 2 of Table 4.3 are never lower than 1, indicating that hernia surgery in emergency settings is a high-risk operation. Conversely, the SMR values for elective patients are always less than 1 indicating a possible selection bias: a patient undergoes an inguinal hernia operation only if he/she is in healthy conditions. As suggested in [295], the exclusion of patients that are not healthy and not young from elective surgery can be one of the causes of high SMR values in emergency settings.

Chapter 5

Spillovers and complementarities for surgical procedures? Evidence from the NHS

5.1 Introduction

The Shouldice hospital in Canada specializes on abdominal wall hernia surgery which includes inguinal, femoral, incisional, spigalian, umbilical, and ventral hernia surgery. The patients of this Canadian hospital enjoy a 5 star resort-like experience: satisfaction rates are at their maximum and re-admission/re-operation rates at their minimum. Despite the high quality provided, the costs of care are among the lowest in the industry [144]. The theory of focus, spillovers, and complementarities explains the success of this experience and in this chapter I analyze whether it can be extended also to NHS general hospitals.

The study of focus, spillovers, and complementarities investigates how the operational scope of an organization affects its performance. An organization can engage in an increasing number of activities that can be related or unrelated to the core business (*related* vs. *unrelated* diversification) [193]. While organizations that are very focused can decide to diversify in order to leverage their core competencies on other services [257], other organizations that are very diversified can choose to divest activities when the operational complexity becomes too costly to manage [27]. Some managers also choose to diversify the activities of their corporations in order to expand their power and influence, in other words, to build an empire [328].

Whereas many studies investigate the general impact of diversification without considering its determinants, e.g., [62, 353], Roberts [272] proposes to classify the benefits of diversification into two major categories: spillovers and complementarities. Spillovers occur when the performance of a firm in providing a service depends on its level of co-specialization on related activities. For example, the experience that Mercedes-Benz accumulates in Formula 1 can prove to be useful for the manufacturing of consumer cars [312]. Complementarities occur when co-specialization enhances the benefits of specialization. An example of complementarities is Microsoft, a company specialized in operating systems that has decided to enter the mobile phone manufacturing industry. Complementarities occur when the co-specialization on mobile phones manufacturing enhances the benefits of focus on mobile phone operating systems [211].

The topic of focus in health care has been at the centre of a very lively academic debate. According to Christensen et al. [61], the best approach to deliver health care is to consider it as a sequential process. The first step is the understanding of the problems of the patient which may require knowledge from a diversified group of specialists. Once there is a diagnosis, the patient is ready for the next step, that is the treatment of his/her problem by a specialized centre, the so-called Value-Adding Process clinic [61]. In the same spirit, Porter et al. [253] suggests the creation of Integrated Practice Units that center around a patient's medical condition. Herzilinger [143] shares similar views and calls general hospitals the "killers of health care." However, it is not clear if the idea of specialized units can be extended to any type of treatment since economies of scope can have an important impact on reducing average costs for low volume procedures. Also, the creation of specialized units can have an impact on the efficiency of the operations of general hospitals, for example, reducing the opportunities to train new surgeons on a variety of surgical techniques.

Huckman and Zinner [156] review the studies that investigate the impact of focus and divide them according to their level of analysis. The study of the departmental level starts with Skinner's seminal work [306] and has been mainly investigated in the operations management literature, e.g., [42, 136, 317]. The study of the firm level has mainly interested the financial and strategy literature and investigates either the overall performance of the firm, e.g., [336, 343], or the performance of one of its divisions, e.g., [289, 302]. While other studies in health care investigate the hospital level, e.g., [62, 88], this research analyzes the impact of focus, spillovers, and complementarities in one of its operating units, the general surgery department. Despite the ongoing discussions on the "hospital within a hospital" model, e.g., [202, 242], there are few empirical studies that consider this level of analysis [156].

As explained in Chapter 1, the choice to study hernia care is motivated by four main considerations. First, hernia surgery is one of the most common general surgery procedures [86]. Second, hernia care is a highly standardizable process [61]: as it happens in Derriford hospital in Plymouth, a hospital that aims to be one of the most successful in England for the management of inguinal hernia care [294], it is possible to define a protocol guiding the delivery of care for the majority of patients. Third, while the number of procedures performed in private specialty hospitals is increasing, the focus of public general hospitals on this surgical procedure is decreasing. Fourth, as mentioned, one of the most famous examples of success in the health care industry is a hernia hospital [144].

In order to assess the impact of focus, spillovers and complementarities, I use administrative data from the NHS, using the medical records employed in Chapter 4. Since the NHS provides universal health care, hospitals have a lower incentive to cherry-pick their patients and, therefore, the selection effect that characterizes other datasets and that could bias other studies on focus, e.g., [172, 201], is highly reduced. Also, as discussed in Chapter 1, some datasets such as Medicaid and Medicare contain information only on specific segments of the population, e.g., individuals with a low income or individuals older than 65.

Inguinal hernia operations are a focal activity for general surgery departments in England [86]. Spillovers exist when other abdominal hernia procedures have a beneficial impact on inguinal hernia patients, for example, when a hospital provides training sessions on umbilical hernia surgery that can also be useful for surgeons that perform inguinal hernia operations.

An example of complementarities is curbside consultations which happen when physicians share information informally, for instance, when they drink a coffee in the cafe of the hospital [62, 241]. These informal meetings are more likely to become curbside consultations when a hospital is specialized on related activities.

Since knowledge diffusion processes have an impact on both spillovers and complementarities, we need to consider the settings of this research study. More specifically, in the study of the surgical procedures context, the element of tacit knowledge, defined by Polanyi [252] as the "knowledge that cannot be put into words" and by Grant as the knowledge that is "stored within" the members of an organization [117], plays a major role.

Bohmer [31] provides a detailed description of tacit and explicit knowledge in health care. The case of diabetes care is an example of a type of knowledge that used to be tacit but has become explicit. The management of serum glucose, at the beginnings of the twentieth century, was based on experience, and mentorship and trial-and-error was how young physicians were learning how to treat a patient with diabetes. Doctors today follow, instead, a list of codified rules: knowledge is acquired in large part in classrooms or with the study of medical textbooks. This type of contexts, where the balance between tacit and explicit knowledge is tipped in favor of the latter, characterizes most of the current research on complementarities and spillovers, e.g., [62, 314, 319].

On the other hand, in surgical settings, tacit knowledge is still relevant. Reading a manual on hernia surgery is not sufficient to learn how to perform an inguinal hernia procedure since, for instance, it is difficult to express in words the pressure needed to cut the abdomen of a patient. The only possible way to learn how to perform a surgical operation is to practice with a mentor, which is what Polanyi [252] indicates in his book as a mechanism of diffusion of tacit knowledge. Since tacit knowledge develops with experience, it is task-specific.

Given that tacit knowledge affects the diffusion of knowledge, it has a direct effect on spillovers and complementarities. In the case of curbside consultations, a cardiologist that has a coffee with an endocrinologist can learn important information on how to manage a patient with diabetes. Conversely, when knowledge cannot be codified, like in the case of surgical procedures, the presence of surgeons specialized in related operations may not have a significant impact on learning. Since tacit knowledge is task-specific, the impact of spillovers is also highly reduced. These considerations lead us to test whether the theory of spillovers and complementarities is still valid in the surgical context.

To summarize, I investigate NHS general hospitals which are less likely to cherry-pick their patients than hospitals of a private health care system. In particular, I propose to study spillovers and complementarities at the departmental level, instead of the firm level. Finally, I introduce the element of tacit knowledge as a factor that can affect the impact of focus, spillovers, and complementarities.

In conclusion, I find that a 5% increase in focus corresponds to a 4.14% decrease in hospitals costs. Moreover, consistently with the ideas I previously expressed, I do not find evidence to support the hypothesis that spillovers and complementarities affect costs.

5.2 Literature review

The word focus is used to describe the emphasis of an organization on a specific product or service [201]. As explained by Siggelkow [302], while it is possible to examine the impact of focus on the overall performance of the firm, it is also possible to investigate how focus on a certain task affects the way the firm performs on that task. This second approach examines focus in more detail and can be used to draw conclusions on its impact on the overall performance of the firm. In this work, I adopt this approach and I investigate how focus on inguinal hernia affects the average cost of a repair for an inguinal hernia patient in a public general hospital.

This work also expands previous research on related diagnostic areas with the investigation of related surgical procedures [62] and responds to the call to investigate the application of the theory of spillovers and complementarities to general hospitals [201] and to costs [62]. Moreover, it responds to the need to research variety in a knowledge-intensive setting [314] and in a setting that is not cardiac surgery [170]. Finally, it attempts to contribute to the investigation of the departmental level which, according to [333], needs to be further explored.

Despite having discussed only about product focus, there are two other major types of focus to consider: process focus and geographical focus [201]. In a health care setting, process and product focus are very difficult to distinguish [201]. It also makes little sense in the United Kingdom to investigate geographical focus since hospitals typically serve only one market [253].

Most of the studies on focus in health care investigate process/product focus, one of their most common limitations is the use of cross-sectional data instead of panel data, and their unit of analysis is the hospital, e.g., [172, 200, 201]. While [155] reports a complete list of the advantages and disadvantages of using cross-sectional data, a possible drawback of this approach is the lack of longitudinal variation to control for omitted variables.

McDermott and Stock [201] provide a complete overview of the different theories on the mechanisms that generate the benefits of focus which I review and extend in the following paragraphs.

In the monograph "The Principles of Scientific Management," Taylor argues that specialization leads a worker to perform a job in the best possible way [320] since the greater the focus of a worker, the greater the number of times he/she will perform that task.

However, while the relationship between greater cumulative volumes and learning has been established, it is not clear whether learning, especially at the organizational level, reaches a saturation point [347]. This is particularly relevant in the case of hernia operations, given that hernia procedures have existed since ancient Egypt [23].

Although some studies suggest that learning is the main mechanism that leads to the benefits of focus, e.g., [88, 172], as illustrated by Christensen et al. [61], another possible beneficial effect of focus is integration. Hyer et al. [158] argue that the benefits of integration can be articulated in four dimensions: the human and technical resources dimension, the spatial dimension including physical closeness, the process flow dimension, and the institutional dimension.

The human and technical resources dimension is about the resources that a hospital department allocates to achieve its goals. For instance, it has been shown that similarities between candidates and interviewers affect the likelihood of candidates to be hired, the so-called "similarity-attraction" effect [204]. Because of this "similarity-attraction," surgeons of a department that is more focused on inguinal hernia repairs are, for example, more likely to hire candidates that have an expertise on this type of abdominal surgery.

The second dimension is the spatial dimension including physical closeness. For instance, if a general surgery department focuses on inguinal hernia then, more likely, it will organize its space for the benefits of inguinal hernia patients. In order to achieve physical closeness, a general surgery department can replicate part of what has been done in the Shouldice hospital in Canada, an example of a facility that has made significant investments on ergonomics to facilitate patient recovery after surgery [144].

The process flow dimension is about standardization. For example, if a hospital focuses on inguinal hernia then, more likely, it will develop standardized processes and programs for the management of this type of patients.

Finally, there is the institutional dimension that is about the relationship between focus and cohesiveness of purpose. Focus can bolster the development of a team culture involving everyone inside of the hospital department and aimed at optimizing every aspect of health care delivery [158]. In the steel industry, Nucor is a firm specialized on mini-mills where everyone feels as part of a team with a "never-ending desire" for improvement [143, 240].

While these mechanisms can explain the relationship between focus and performance, there are other factors that need to be taken into consideration when assessing the benefits of focus. Focus leads workers to tunnel vision and does not always enhance learning since complex cases may require competencies that focused profiles do not have [103, 131]. Also, focused environments tend to hinder innovation and decrease motivation [314].

Nevertheless, in the case of inguinal hernia surgery, there are elements that mitigate the negative influence of these factors. It has been said that the impact of focus on learning is negative in environments with high uncertainty [245], yet the level of uncertainty of inguinal hernia operations is very low [259]. Even when complex cases undergo inguinal hernia surgery, the operation is much easier than other surgeries and case-mix complexity has a lower impact on outcomes [326]. Moreover, while focus can affect motivation and inclination to innovate, the work environment in a department specialized on hernia surgery is less stressful than the work environment of a department specialized on more complex procedures [144]. Hence, I formulate the following hypothesis:

HYPOTHESIS 1. *The greater the focus of a hospital department on a surgical procedure, the lower are the costs for the hospital department to perform that surgery.*

Assuming that $\texttt{cost} = f(\texttt{focus}, \mathbf{W})$ where $\mathbf{W}$ represents all the other variables that affect costs, the first hypothesis can be expressed as $\frac{\delta\texttt{cost}}{\delta\texttt{focus}} < 0$.

Spillovers also occur because of learning [355]: the knowledge that a general surgery department develops on a related surgical procedure can affect the outcomes of an inguinal hernia repair. For example, knowledge on local anesthesia and on whether to administer it to patients may be transferable from one surgery to another related surgery.

As for focus, another mechanism that can generate spillovers is integration, and the framework developed by Hyer et al. [158], including the human and technical resources dimension, the spatial dimension, the process flow dimension, and the institutional dimension, can be used to articulate its benefits. For example, if a good umbilical hernia surgeon is also a good inguinal hernia surgeon then there is a spillover for the human dimension when a general surgery department hires a good umbilical hernia surgeon.

There is spillover for the spatial dimension when a layout that is optimal for managing umbilical hernia surgery is also optimal for managing inguinal hernia patients. As already mentioned, a general surgery department can replicate the strategy of the Shouldice hospital in Canada which has made significant investments on ergonomics for the benefits of all abdominal wall hernias patients, so both inguinal and umbilical hernia patients [144].

There is a spillover for the process flow when, instead, the standardized procedures for umbilical hernia patients are similar to the standardized procedures for inguinal hernia patients. This spillover exists because the incentives to create standardized protocols and routines increase when patients in a hospital department require similar treatments.

Finally, there is a spillover for the institutional dimension when co-specialization on related surgical procedures reinforces the cohesiveness of purpose of an organization, rather than decreasing it. An example of this type of spillovers is the stroke centre in North Central London that treats patients with both haemorrhagic and ischaemic strokes [254].

Wan et al. [338] provide an exhaustive review on accomplishments and opportunities in the diversification literature and claim that, even if it is evident that diversification is beneficial as long as it is related, it is not clear when it becomes unrelated. They assert that the measures of relatedness that are currently available are still unsatisfactory and do not explain the passage from related to unrelated diversification.

This study defines relatedness in terms of product/process similarities following a long tradition in the management literature, e.g., [212, 226, 302]. However, as already discussed, knowledge and development of knowledge affect the relatedness of two activities, especially when tacit knowledge plays a dominant role.

Nonaka [239] models the mechanisms of diffusion of knowledge with a matrix which formalizes the diffusion of tacit and explicit knowledge in other tacit and explicit knowledge, and which defines two main mechanisms of diffusion of tacit knowledge: socialization and externalization. In a surgical setting, the transfer of knowledge through socialization happens, for example, when two surgeons that are operating on the same patient learn from each other. There is a transfer of knowledge trough externalization, instead, when surgeons record their own operations and share these videos with other surgeons.

While tacit knowledge affects the transfer of knowledge in an organization, it also leads to greater specialization. Grant [117] argues that "due to the cognitive limits of the human brain, (tacit) knowledge is acquired in a highly specialized form: an increase in depth of knowledge implies reduction in breadth" and, therefore, its application to other activities is extremely limited.

As much as the impact of knowledge spillovers is greatly reduced because of the settings of this study, managerial spillovers such as ergonomics, standardization, and culture can still have an impact on the outcomes of inguinal hernia patients. For this reason, I formulate the following hypothesis:

HYPOTHESIS 2. *The costs of a hospital department to perform a surgical operation are negatively related with the hospital department co-specialization on related surgical procedures.*

Assuming that $\texttt{cost} = f(\texttt{focus}, \texttt{cospec}, \mathbf{W})$ where $\texttt{cospec}$ represents co-specialization of a hospital department, the second hypothesis can be expressed as $\frac{\delta \texttt{cost}}{\delta \texttt{cospec}} < 0$.

Complementarities exist when co-specialization reinforces the beneficial impact of focus, for example through the development of abstract schemas and implicit learning ([287], as cited in [62]). Schilling et al. [287] suggest that individuals working in environments characterized by co-specialization are more likely to develop abstract schemas. For example, surgeons that learn how to manage an emergency on a related procedure can use this knowledge to learn how to manage an emergency in the focal procedure [170]. Moreover, when individuals are exposed to a number of related events, they tend to learn unconsciously because they are exposed to many co-variations of the same cause-effect association (implicit learning) [287].

It has also been argued that the impact of focus decreases at high level of specialization since environments specialized only on one focal activity lead workers to boredom and, for this reason, to initiate unrelated tasks [170, 314]. Although to a lesser extent than in specialty hospitals, related activities still have the potential to increase motivation in public general hospitals.

Given these considerations, I formulate the following hypothesis:

HYPOTHESIS 3. *The benefits of hospital department focus on the costs to perform a surgical operation increase with the co-specialization of the hospital department on related surgical procedures.*

Assuming that $\texttt{cost} = f(\texttt{focus}, \texttt{cospec}, \texttt{focus} * \texttt{cospec}, \mathbf{W})$, the third hypothesis can be expressed as $\frac{\delta^2 \texttt{cost}}{\delta \texttt{focus} \delta \texttt{cospec}} < 0$.

5.3 Method

5.3.1 Study data

In order to investigate focus, spillovers, and complementarities, I combine information from the HES and the Hospital Estates and Facilities Statistics (HEFS) data warehouse, using SAS 9.3 and Stata 11.2 to link the datasets and to perform the statistical analysis.

HES data records diagnoses, procedures, and demographic information for every single patient admitted to a NHS hospital in the form of continuous inpatient spells (CIPSs) and of finished consultant episodes (FCEs). As mentioned in Chapter 4, CIPS are derived from FCEs and include every single day case and ordinary admission to English hospitals from April 1998. While FCEs refer to the care of a single consultant, CIPSs refer to the whole cycle of care from admission to the hospital to discharge. Since HES is used to calculate hospital tariffs[1], it is crucial for the data to be accurate in reflecting the actual care delivered [84].

HEFS data is, instead, the most inclusive collection of information about facilities in the NHS [236]. Every year, hospital trusts are required to submit an Estates Return which then becomes part of this data warehouse. The dataset contains information on type of hospital, size, teaching status, and number of occupied beds, and includes observations from primary care trusts and mental health providers.

The total number of observations in HEFS data from April 1, 1999 to March 31, 2012 is 5,775. Despite being available from 1999, HEFS data reports information on number of beds by hospital only from 2000. Since the information this dataset reports is by fiscal year, I link HEFS to HES data using the variable date of admission from the patient-level dataset.

As discussed in Chapter 4, from a dataset of 183,712,784 observations, I extract

[1]Hospital tariffs determine the payments made to hospitals for the reimbursement of the services they provide to patients

all the records of patients that have a diagnosis of inguinal hernia (ICD-10 code K40 [43]). Since (at the time I am writing) HES data from 2012 is still incomplete, I only consider the individuals with a diagnosis of inguinal hernia that have a surgical procedure (OPCS-4 codes T20 and T21 [308]) in the time frame between 1999 and 2011.

Since pediatric hernia surgery is for some aspects very different from surgery on adults, I remove from my sample patients aged less than 18 [266]. Since comorbidities are more likely to be present in elderly patients and since the benefits of specialization derive in large part from the homogeneity of the input, I do not consider procedures on individuals that are aged more than 65. Next, I exclude emergency patients because an emergency hernia operation can be a very complicated procedure [50]. I also remove from the sample observations from private hospitals, first because they are specialty hospitals and second, because as shown in [49], they are completely different from public hospitals and they can bias the results of a study. Lastly, I investigate only the patients treated in the general surgery department because this is the unit of analysis of this study. The final dataset consists of $398,921$ observations.

In Section 5.5, I re-run my analyses with different cohorts to assess whether this patient selection has an effect on my results.

Since old hospitals can shut down their operations and new hospitals can open or because there is not enough information available for the whole time period, the number of years observed is not the same for every hospital. Table 5.1 reports number of patients and number of observations by number of years observed per hospital and shows that the number of years observed per hospital is equal or more than 4 for 97.96% of the observations. It is also worth observing that, since a single patient can have multiple operations, the total number of patients for the whole time period is smaller than the sum of the patients by year.

N. of yrs. observed	N. of patients	% of patients	N.of obs.	% of obs.
1	146	0.04	149	0.04
2	4,470	1.18	4,509	1.13
3	7,333	1.93	7,442	1.87
4	4,265	1.12	4,364	1.09
5	4,065	1.07	4,152	1.04
6	2,198	0.58	2,260	0.57
7	3,518	0.93	3,636	0.91
8	14,939	3.93	15,456	3.87
9	29,597	7.79	30,901	7.75
10	35,215	9.27	36,818	9.23
11	26,576	7.00	27,864	6.98
12	247,605	65.17	261,370	65.52
Total	378,205	100	398,921	100

Table 5.1: Number and percentage of patients and observations by number of years observed per hospital

5.3.2 Dependent variable

The dependent variable I consider is costs and I calculate it using the standard cost allocation protocol defined by the Department of Health [83]. While this definition of costs informs the decisions of the Department of Health, it has some limitations which I discuss in Section 5.6.

In order to calculate costs, for every CIPS in the dataset, I list all the FCEs in the spell. Then, based on this list of FCEs, I create a CSV file that becomes the input for the HRG Grouper Software v2.34. This file includes, for every medical episode, information such patient demographics and the diagnoses and procedures he/she underwent. For every record in the input file, the HRG Grouper creates one or more Health Related Groups (HRGs).

The cost allocation described in [83] is based on HRGs, on reference costs, on whether the patient is a day case or not, and on a length of stay trimpoint. The Department of Health provides 2011/2012 reference costs and trimpoints for every HRG by type of admission [83]. The total cost of a medical episode for a day case patient is the sum of the primary HRG day case reference cost and of the unit reference costs of the remaining HRGs. The total cost of a medical episode for an ordinary admission is the sum of the primary HRG ordinary admission reference cost, of the cost of every day of stay exceeding the trimpoint, and of the reference costs of the remaining HRGs. After computing the costs for every hernia medical episode, I calculate the average cost by hospital.

To summarize, given a patient i, a hospital j, and a HRG h, I use the following information:

- Day case reference cost for primary HRG h: c_h^d;
- Ordinary admission reference cost for primary HRG h: c_h^o;
- Excess ordinary admission reference cost per diem for primary HRG h: e_h^o;
- Trimpoint for primary HRG h: p_h;
- Unit reference cost for every additional HRG u: c_u;

Given a binary variable r_{ijht}^d that is 1 if there is a day case admission i to the general surgery department of a hospital j in year t for a primary HRG h, and 0 otherwise, and a binary variable z_{ijut} that is 1 if there is an admission i to the general surgery department of a hospital j in year t for an additional HRG u, and 0 otherwise, the total cost of day case admissions to hospital j in year t is the following:

$$\mathtt{cost}_{\mathtt{jt}}^{\mathtt{d}} = \sum_i \sum_h c_h^d r_{ijht}^d + \sum_i \sum_u c_u z_{ijut}$$

Given a binary variable r^o_{ijht} that is 1 if there is an ordinary admission i to the general surgery department of a hospital j in year t for a primary HRG h, and 0 otherwise, and a variable l_{ijht} that measures the number of days required by an ordinary admission i to the general surgery department of a hospital j in year t for a primary HRG h, the total cost of ordinary admissions to hospital j in year t is the following:

$$\mathtt{cost^o_{jt}} = \sum_i \sum_h c^o_h r^o_{ijht} + max(0, \sum_i \sum_h e^o_h r^o_{ijht}(l_{ijht} - p_h)) + \sum_i \sum_u c_u z_{ijut}$$

Hence, the average cost for hospital j in year t is:

$$\overline{\mathtt{cost}}_{jt} = \frac{\mathtt{cost^d_{jt}} + \mathtt{cost^o_{jt}}}{\sum_i \sum_h (r^o_{ijht} + r^d_{ijht})}$$

An example can further illustrate the methodology presented and clarify its details. Let us consider an elective patient that undergoes an inguinal hernia operation. After we run the HRG Grouper Software v2.34 for this procedure, we find that the primary HRG of the operation is FZ18B and that there is an additional HRG XD34Z. In the reference costs tables we find the descriptions of these HRGs and their costs: the first HRG is "Inguinal, Umbilical or Femoral Hernia Procedures, 19 years and over with Intermediate CC" with a cost of £2,050, the second HRG is, instead, "Immunoglobulins, Band 1" with a cost of £1,288. If we further assume that this episode is exceeding its trimpoint by two days, we need to take into account of the excess ordinary admission reference cost per diem which is £340. We can now calculate the total cost of this surgery, which equates to £2,050+£1,288+£340*2=£4,018.

Since an organization makes decisions based on opportunity costs[2], the rationale behind using costs in management research is to drive behaviors. The methodology used by the Department of Health, discourages long stays in the hospital, gives an

[2]Opportunity costs are what is foregone when a choice is made [47]

incentive to hospitals to admit patients on a day case basis rather than with ordinary admissions, and, finally, penalizes hospitals that provide unnecessary services.

5.3.3 Controls

In order to perform the empirical analysis, I consider the control variables in Table 5.2, where the first column shows the name of the variables used in the models, and the second their definition. All the variables I include are at the hospital level.

From HES data, I include variables to control for age and gender. I compute the average age by hospital and the proportion of male patients. I also calculate the average level of comorbidities of the patients in the hospital using the Charlson index [58, 172, 181]. For each of the 400,098 observations in the sample, I control whether any of the 18 possible diagnoses in the record corresponds to one of the more than 280 comorbidities of the Charlson index, using the SAS macro *CharlsonICD10* [267, 331]. If this is case, I add the relative comorbidity score to the total Charlson index of the record. Next, I compute the average Charlson index by hospital.

In order to control for income level, I use a measure of deprivation: the Index of Multiple Deprivation (IMD) score [174]. This score is assigned to every Lower Super Output Area (LSOA) in England which is around 1,500 people and 650 households. The IMD score of a medical record is based on the income, employment, disability, education, barriers to education, crime, and living environment levels of the LSOA where the patient lives.

I also include the proportion of patients that are paying for the treatment because these patients, generate a revenue for the hospital, and, therefore, there is a lower incentive to cut costs for them. Additionally, I consider a variable indicating the proportion of patients that entered during the weekend since it has been argued that patients admitted during the weekend tend to spend more days in the hospital because of staffing shortages [171]. Finally, I include the proportion of patients that are admitted from the wait list because surgeries that are not performed timely can become more problematic.

I also consider variables that describe the type of operation. First, I consider the proportion of surgeries performed with minimally invasive surgery, a type of procedure performed with small incisions. Second, I include the proportion of repairs of recurrent inguinal hernia[3], since this type of surgery is more complex: the scar tissue of a previous procedure affects the ability of a surgeon to identify the anatomy of the groin.

In addition to the type of operation, I include a variable that measures the size of a hospital: number of beds. Moreover, I have a variable to measure the number of occupied beds since it has been argued that fatigue decreases a worker's productivity [171]. Foundation status is another variable I use in the models since these hospitals have an élite status that translates in more powers in the hands of its CEO. In particular, the CEO of a foundation trust can raise debt to finance operations or retain its surpluses which can affect the costs of the hospital since its Chief Financial Officer (CFO) is less affected by liquidity constraints [217]. I also include the teaching status of the hospital. Since university hospitals tend to be more prestigious places to work than other medical institutions, it might be easier for them to attract the best resources in the job market. Given that the information about foundation/teaching status is by fiscal year, for every admission year, I calculate the proportion of records in which the hospital has a teaching/foundation status.

Finally, in order to control for trends in the data, I include year fixed-effects, even if it is possible to argue that this is not required since using 2011/2012 reference costs accounts for the possible endogeneity caused by omitted variables such as inflation rates and cost of energy. However, reference costs can be thought as weights that the

[3]A patient with a recurrent hernia is a patient with a history of inguinal hernia that needs an additional operation

Department of Health gives to its priorities such as reducing length of stay or increasing the rate of day case surgery. Given that these priorities can change across years, year fixed-effects control for their impact on hospital outcomes.

5.3.4 Independent variables

The independent variables of this research measure the departmental focus and co-specialization of a hospital. I consider a general surgery department as a system that has an input and an output, investigating the proportion of patients in a department that undergo a specific treatment. I identify inguinal hernia surgery patients using the 12 procedure codes of a hospital record and searching for OPCS-4 codes T20 and T21 [308]. I compute the ratio between number of patients treated for inguinal hernia in the general surgery department of a hospital j in year t and total number of patients that are admitted to that department in year t.

Given a variable r_{ijt} that is 1 if a record i belongs to an inguinal hernia patient treated in the general surgery department of a hospital j in year t, and 0 otherwise, and a variable s_{ijt} that is 1 if a record i belongs to the general surgery department of a hospital j in year t, and 0 otherwise, I compute the focus of a general surgery department in year t with the following formula:

$$\texttt{focus}_{\texttt{jt}} = \frac{\sum_i r_{ijt}}{\sum_i s_{ijt}}$$

In order to calculate the co-specialization of a general surgery department in a hospital j, I compute its focus on related surgical procedures in year t. Given a variable w_{ijt_k} that is 1 if a record i belongs to a patient treated for a related surgical procedure k in the general surgery department of a hospital j in year t, and 0 otherwise, and a variable s_{ijt} that is 1 if a record i belongs to the general surgery department of

Table 5.2: List of control variables

Name	Explanation
`age`	Average age of the patients admitted to the hospital at the start of their stay
`charl_ind`	Average Charlson index of the patients admitted to the hospital
`foundation`	Hospital foundation status
`imd_score`	Average IMD score of the patients admitted to the hospital
`laparoscopic`	Proportion of laparoscopic procedures performed in the hospital
`male`	Proportion of male patients in the hospital
`n_beds`	Number of beds in the hospital
`occupied`	Proportion of occupied beds in the hospital
`private`	Proportion of private patients in the hospital
`recurrence`	Proportion of recurrent procedures in the hospital
`teaching`	Teaching status of the hospital
`waitlist`	Proportion of patients admitted to the hospital from the wait list
`week_ind`	Proportion of patients admitted to the hospital during the weekend (Saturday or Sunday)

a hospital j in year t, and 0 otherwise, I compute the co-specialization of a general surgery department in year t with the following formula:

$$\texttt{cospec}_{\texttt{jt}_\texttt{k}} = \frac{\sum_i w_{ijt_k}}{\sum_i s_{ijt}}$$

I use $k = 1$ for ventral hernia surgeries; $k = 2$ for cholecystectomies[4]; and $k = 3$ for colorectal resections[5]. For ventral hernia surgeries I use OPCS-4 codes T25, T26, T27, and T98 [308], excluding the sub-codes that do not identify ventral hernia surgery, for cholecystectomies I use OPCS-4 code J18 [308], and for colorectal resections OPCS-4 codes H04, H05, H06, H07, H08, H09, H10, H11, and H33 [222, 308].

As mentioned, the Shouldice hospital is an example of a hospital that leverages the benefits of spillovers and complementarities and it is plausible that its strategies can be replicated in other health care systems such as the NHS. The Canadian hospital specializes on abdominal wall hernia surgery, admitting only patients that need an inguinal hernia procedure or other types of abdominal wall hernia surgeries. I study the co-specialization on ventral hernia surgery because it is a high volume surgery and it has low correlation with focus on inguinal hernia surgery. To minimize the risk of selecting a specific hernia surgery, I also re-run the tests using co-specialization on all abdominal wall hernia surgeries other than inguinal hernia. Despite the correlation with focus on inguinal hernia, the results of these tests are consistent with what found using co-specialization on ventral hernia surgery.

Like inguinal and ventral hernia repairs, cholecystectomies are another very common and low-risk procedure [86, 229] that can be performed laparoscopically and under local anaesthetic. Even if gallbladder removal is less similar to inguinal hernia surgery than ventral hernia surgeries, there exists a certain degree of relatedness between these

[4] A cholecystectomy is a surgical procedure to remove the gallbladder of a patient

[5] A colorectal resection is a surgical procedure to remove a part of the large intestine of a patient

two procedures, which has justified the creation of treatment centers in the NHS that co-specialize on these two operations.

Despite being a very complex surgery which is, clearly, less related to inguinal hernia repairs than other types of abdominal wall hernia surgeries [196], colorectal resection has a number of potential spillovers and complementarities with inguinal hernia. In the same way a pianist that plays a difficult piece is likely to be able to play well an easier piece, a surgeon that is specialized on a complex procedure is likely to be able to perform an easier procedure with good results. Surgeons that are able to perform complex techniques are also an asset for other surgeons in the hospital to increase their range of skills.

In order to further validate my theories at the surgical level, I discussed the benefits of co-specialization with three general surgeons. The interviews with the general surgeons indicate that there are considerable similarities between inguinal and ventral hernia surgery because of the surgical techniques employed to perform these operations. The interviews also suggest that the expertise gained on performing laparoscopic cholecystectomies and colorectal resections can benefit the outcomes of keyhole surgery on inguinal hernia patients. Finally, there is a consensus that the pre and post-operative management of the patients that undergo these four operations is very similar.

I report correlation values and summary statistics for the variables of interests of this research in Table 5.3 and 5.4.

5.3.5 Statistical models

Random-effects models assume that hospital specific effects are not correlated with other covariates in the model [90]. Given that this assumption does not hold when specific management practices are correlated with the regressors[6], I use a fixed-effects

[6]For example foundation hospital trusts are more likely to attract more capable CEOs than other hospitals because they can offer more managerial powers and a greater financial flexibility [217]

	cost	n_beds	focus	$cospec_1$	$cospec_2$	$cospec_3$
cost	1					
n_beds	0.099	1				
focus	-0.159	-0.216	1			
$cospec_1$	-0.342	0.030	0.340	1		
$cospec_2$	-0.334	0.028	0.422	0.565	1	
$cospec_3$	-0.115	-0.029	0.439	0.332	0.400	1

Table 5.3: Correlation table

	Mean	Std. Dev	Min	Max
cost(£)	1,649.57	137.47	1,422.84	2,309.82
n_beds	774.76	383.41	0.00	2,927.05
focus	5.00%	1.40%	0.10%	10.80%
$cospec_1$	1.00%	0.30%	0.00%	2.20%
$cospec_2$	3.70%	0.90%	0.20%	8.00%
$cospec_3$	2.30%	0.60%	0.10%	5.30%

Table 5.4: Summary statistics

model.

Fixed-effects models investigate how predictors affect outcomes within a single entity and can be used under the assumption that all hospitals are different from each other. As suggested in [62], I consider only hospitals with at least 4 years of data, so that there is enough variation to assess hospital fixed-effects. While I include fixed-effects to control for unobserved hospital specific effects, I use clustered standard errors to account for the possible correlation of hospital observations over time [11].

That said, the choice of eliminating hospitals with less than 4 observations may remove from the sample providers that have performed poorly and, therefore, had to shut down their operations. This study does not assess the impact of focus, spillovers, and complementarities in these specific circumstances.

Since the measures of focus and co-specialization that I use are also indirect measures of how much time a hospital needs to discharge a patient, the choice to use fixed-effects controls also for the unobserved endogeneity caused by hospitals that are very fast in treating their patients. Additionally, in order to eliminate any other possible concern on the direction of the relationship between cause and effect, I lag focus and co-specialization variables by one year.

I take the logarithm of average costs per hospital because its distribution is more similar to a normal distribution. I also demean focus and co-specialization variables to facilitate the interpretability of the interaction term since the centering of the variables allows for the interpretation of the marginal effects of one variable at the mean level of the other.

Given $\mathbf{x}_{jt}$, a vector of control and independent variables, α_j representing hospital fixed-effects, γ_t representing year fixed-effects, and u_{it} representing the error term, the fixed-effects model has the following mathematical formulation:

$$\log(\overline{cost}_{jt}) = \mathbf{x}_{jt}\boldsymbol{\beta}_k + \alpha_j + \gamma_t + u_{it} \quad j = 1, \ldots, N \quad t = 1, \ldots, T$$

where N and T represent, respectively, the number of hospitals and of years of admission.

Table 5.5 lists the variables I use to test the hypotheses.

While I use Models (1), (3), (4), (6), (7) ,(9), (10) to test the hypothesis that focus has an impact on costs; Models (2), (3), (5), (6), (8), (9) provide evidence on the hypothesis about spillovers; and Models (4), (7), (10) on the hypothesis that complementarities affect costs.

After including the 4 years restriction, the panel has a time span of 12 years with an average of 10.6 observed years per provider. Table 5.6 summarizes number and percentage of patients and of observations by year of admission.

In order to assess whether the impact of focus, spillovers, and complementarities

Table 5.5: Regression models and their variables

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
`focus`	•		•	•		•	•		•	•
$\texttt{cospec}_1$		•	•	•						
$\texttt{focus} * \texttt{cospec}_1$				•						
$\texttt{cospec}_2$					•	•	•			
$\texttt{focus} * \texttt{cospec}_2$							•			
$\texttt{cospec}_3$								•	•	•
$\texttt{focus} * \texttt{cospec}_3$										•
Hospital fixed-effects	•	•	•	•	•	•	•	•	•	•
Control Variables	•	•	•	•	•	•	•	•	•	•

Year of admission	N. of patients	% of patients	N.of obs.	% of obs.
2000	20,976	5.46	21,119	5.46
2001	29,271	7.62	29,502	7.63
2002	33,545	8.73	33,800	8.74
2003	38,332	9.98	38,601	9.98
2004	37,189	9.68	37,424	9.67
2005	35,747	9.3	36,006	9.31
2006	34,399	8.95	34,618	8.95
2007	34,549	8.99	34,761	8.99
2008	33,203	8.64	33,447	8.65
2009	30,108	7.84	30,331	7.84
2010	28,296	7.37	28,480	7.36
2011	28,579	7.44	28,732	7.43
Total	366,933	100	386,821	100

Table 5.6: Number and percentage of patients and observations by year of admission

derives only from shorter length of stay, that is from the reduction of hospital days for ordinary admissions, I test whether the results are robust to the inclusion of length of stay as a control variable.

5.4 Results

As explained in the previous section, this study investigates the impact of focus, spillovers, and complementarities for surgical procedures using a fixed-effects model, using data from 1999 to 2011 and including only patients in the age range 18-65. The analysis is at the departmental level, that is, I consider only patients treated by the general surgery department. Focus and co-specialization variables are centered and I take the natural logarithm of the average hospital costs.

Table 5.7 reports the results of the panel regression. All the models include control variables and hospital fixed-effects and the coefficient of determination of all the regressions is greater than 0.53.

The coefficient of `focus` is negative and significant at the 1% level in all the models we test the variable. This result provides support for the first hypothesis I made, that is, the greater the focus, the lower the average hospital costs. The value of the coefficient of `focus` in Model (1) is −0.846, implying that a 5% increase in `focus` corresponds to a 4.14% decrease in average hospital costs. Also, in all the models the coefficient of `focus` is always lower than −0.8.

As mentioned earlier, $\texttt{cospec}_1$ measures the co-specialization on ventral hernia surgeries, $\texttt{cospec}_2$ the co-specialization on cholecystectomies, and $\texttt{cospec}_3$ the co-specialization on colorectal resections.

While the coefficients of $\texttt{cospec}_1$ and $\texttt{cospec}_2$ are negative and not significant in Model (2) and Model (5), the coefficient of $\texttt{cospec}_3$ is negative and significant at the 10% level in Model (8). However, the value of the coefficient of determination in Model (8) is lower than in Model (1), which suggests that Model (1) is more likely to be the true model than Model (8). Moreover, we can expect that the variable `focus` has a greater impact on performance than the variable `cospec` and, as a consequence, that a model with only the variable `focus` is more likely to be the true model than a model with only the variable `cospec`.

While Model (2), Model (5), and Model (8) do not include `focus`, Model (3), Model (6), and Model (9) include `focus` and `cospec` in the same model. The coefficients of $\texttt{cospec}_1$ and $\texttt{cospec}_2$ are positive in Model (3) and (6), while the coefficient of $\texttt{cospec}_3$ is negative in Model (9). These values have opposite signs and are not significant so they do not provide evidence to support the second hypothesis that spillovers reduce costs.

The hypothesis about complementarities is tested considering the interaction between `focus` and `cospec`. In Models (4) and (7) the coefficients of $\texttt{focus} * \texttt{cospec}_1$ and

$\texttt{focus} * \texttt{cospec}_2$ are positive, while in Model (10) the coefficient of $\texttt{focus} * \texttt{cospec}_3$ is negative. All the values are not significant and do not provide evidence to support hypothesis 3.

Table 5.8 includes length of stay as a control variable since cost benefits should not be achieved at the expense of patients that are sent home too early.

In all the models the coefficient of `focus` is negative and significant at the 1% level. The value of `focus` in Model (1) is -0.713 which implies that a 5% increase in `focus` corresponds to a 3.50% decrease in average hospital costs. While in Model (1) in Table 5.7, the 95% confidence interval of `focus` is $(-1.288, -0.404)$, the confidence interval is $(-1.164, -0.262)$ in Model (1) in Table 5.8. Therefore, although the data suggests a decrease, it is not possible to establish whether the impact of `focus`, when controlling for length of stay, changes significantly.

The coefficients of $\texttt{cospec}_1$, $\texttt{cospec}_2$, $\texttt{cospec}_3$ in Model (2), Model (5), and Model (8) are negative and not significant, a result that does not provide sufficient evidence to support the second hypothesis.

Models (3), (6), and (9) provide a robustness check of the results found previously. Model (3) and (6) suggest that co-specialization is positively related with costs, while in Model (9) $\texttt{cospec}_2$ has a negative sign. All the values are not significant at the standard levels.

The results in Table 5.8 confirm, also, that there is no evidence supporting that complementarities have an impact on costs. Although the coefficients of the interaction terms $\texttt{focus}*\texttt{cospec}_1$ in Model (4), $\texttt{focus}*\texttt{cospec}_2$ in Model (7), and $\texttt{focus}*\texttt{cospec}_3$ in Model (10) are all positive, they are all not significant at the standard levels.

As discussed, the value of the coefficient of determination in Model (2), Model (5), and Model (8) is lower compared to the other models suggesting that these models may not be the true models.

Table 5.7: Regression models

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
focus	-0.846***		-0.922***	-0.931***		-1.029***	-1.029***		-0.808***	-0.793***
	(-3.78)		(-3.72)	(-3.76)		(-4.19)	(-4.21)		(-3.37)	(-3.21)
$cospec_1$		-1.006	0.666	0.544						
		(-1.30)	(0.77)	(0.63)						
$focus * cospec_1$				25.78						
				(0.78)						
$cospec_2$					-0.302	0.463	0.462			
					(-0.89)	(1.21)	(1.19)			
$focus * cospec_2$							0.114			
							(0.01)			
$cospec_3$								-0.835*	-0.270	-0.247
								(-1.80)	(-0.56)	(-0.52)
$focus * cospec_3$										-8.978
										(-0.47)
N. Hosp.	162	162	162	162	162	162	162	162	162	162
N. Obs.	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723
R^2	0.543	0.535	0.544	0.544	0.534	0.544	0.544	0.536	0.544	0.544

Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: `age`, `charl_ind`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 5.8: Regression models when length of stay (`lostay`) is included as a control variable

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
`focus`	-0.713***		-0.785***	-0.793***		-0.865***	-0.868***		-0.700***	-0.700***
	(-3.13)		(-3.09)	(-3.11)		(-3.43)	(-3.44)		(-3.00)	(-2.94)
$\texttt{cospec}_1$		-0.793	0.628	0.523						
		(-1.31)	(0.92)	(0.77)						
$\texttt{focus} * \texttt{cospec}_1$				22.05						
				(0.85)						
$\texttt{cospec}_2$					-0.259	0.384	0.373			
					(-0.96)	(1.29)	(1.24)			
$\texttt{focus} * \texttt{cospec}_2$							2.638			
							(0.28)			
$\texttt{cospec}_3$								-0.582	-0.0950	-0.0953
								(-1.54)	(-0.26)	(-0.26)
$\texttt{focus} * \texttt{cospec}_3$										0.120
										(0.01)
N. Hosp.	162	162	162	162	162	162	162	162	162	162
N. Obs.	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723
R^2	0.666	0.659	0.666	0.666	0.659	0.666	0.666	0.660	0.666	0.666

Notes. Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: `age`, `charl_ind`, `foundation`, `imd_score`, `laparoscopic`, `lostay`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

In order to further investigate whether Model (3), Model (4), Model (6), Model (7), Model (9), and Model (10) are more likely to be the true model than Model (1), I use the F-test for nested models. In the first column of Table 5.9 I report the model, in the second the F-statistics, and in the third the test of significance. From the table, we see that there is no evidence to support the hypothesis that any of the models with `focus` and `cospec` or any of the models with `focus`, `cospec`, and `focus` ∗ `cospec` are the true models. In Table 5.10, I report the same data for the same models when length of stay is included as a control variable. Also in this case, there is no evidence to argue that any of these models is the true model.

Model	F-Statistics	P>F
(3)	0.60	0.4393
(4)	0.57	0.5659
(6)	1.47	0.2274
(7)	0.74	0.4792
(9)	0.31	0.5780
(10)	0.24	0.7836

Table 5.9: F-statistics tests for regression models

Model	F-Statistics	P>F
(3)	0.86	0.3562
(4)	0.71	0.4936
(6)	1.68	0.1962
(7)	0.90	0.4075
(9)	0.07	0.7963
(10)	0.03	0.9659

Table 5.10: F-statistics tests for regression models when length of stay (`lostay`) is included as a control variable

In order to summarize, the results found are consistent with the first hypothesis but do not support neither hypothesis 2, nor hypothesis 3. The values reported should only be interpreted in the range of values that focus, $\texttt{cospec}_1$, $\texttt{cospec}_2$, and $\texttt{cospec}_3$ assume (see Table 5.4). It is also to notice that the inclusion of length of stay leads, as expected, to a much better fit of the models. More interestingly, the inclusion of spillovers and complementarities does not always increase the value of R^2. For example, in Table 5.7, the coefficient of determination does not increase from Model (3) to Model (4), from Model (6) to Model (7), and from Model (9) to Model (10). Similarly, in Table 5.8, R^2 does not increase from Model (1) to Model (3), from Model (3) to Model (4), from Model (1) to Model (6), from Model (6) to Model (7), from Model (1) to Model (9), and from Model (9) to Model (10).

5.5 Robustness

In Table 5.7 and Table 5.8 focus and cospec enter the models as linear variables but it can be argued that the impact of focus and co-specialization is not linear since, at lower levels, focus and co-specialization can affect costs more than at higher levels. In fact, the greater the focus on a specialty, the more likely a hospital has already adopted procedures and routines to manage that specialty efficiently which, in turn, leads to lower marginal benefits of specialization.

In order to model this possible non-linearity, I take the natural logarithm of focus and cospec and re-run all the models with the new specifications. Table 5.11 shows that focus is still significant at the 1% level in all the models. While the value of the coefficient of $\texttt{cospec}_1$ is negative and significant at the 5% level in Model (2) and the value of the coefficient of $\texttt{cospec}_3$ is negative and significant at the 10% level in Model (8), the value of the coefficient of $\texttt{cospec}_2$ is negative and not significant in Model (5). Since the coefficient of determination of these models is again lower than the coefficient of determination of Model (1), it is likely that these models are not the true models, which, in turn, leads to argue that this result does not provide enough evidence to support the second hypothesis. There is also still no evidence to support the second hypothesis in the models that include the variables focus and cospec at the same time. The coefficient of $\texttt{cospec}_1$, $\texttt{cospec}_2$, and the coefficient of $\texttt{cospec}_3$ are all positive in Model (3), in Model (6), and in Model (9), however none of these values is significant at the standard levels. The evidence to support the third hypothesis is relatively greater than in the previous models but is still not sufficient to conclude that complementarities affect hospital costs. While this time the values of the coefficients of $\texttt{focus} * \texttt{cospec}_1$ and $\texttt{focus} * \texttt{cospec}_2$ are negative in Model (4) and in Model (7), the coefficient of $\texttt{focus} * \texttt{cospec}_3$ is negative and significant at the 10% level in Model (10). The coefficients of determination are lower than the coefficients reported in Table 5.7 for Model (3), (4), (9) and are the same for Model (1), (6), (7), and (10). These results suggest that taking the logarithm of focus and cospec does not increase the fit of the models. Therefore, for the set of values that focus assumes in the sample, there is not enough evidence to support the theory of the decreasing marginal benefits of focus.

Although I have motivated the use of fixed-effects in the methodology section, I run a further check to test whether I should use a random-effects model instead. Since the standard errors are clustered at the hospital level, I use the Stata command *xtoverid* to calculate a modified version of the Hausman test that computes the Sargan-Hansen statistics [62, 285]. The tests that I report in Table 5.12 confirm that a random-effects model would produce inconsistent results for all the 10 regressions I consider.

In order to test whether the results are still valid when I increase the variation to assess hospital-effects, I set the minimum number of observed years to 5. Instead of 162 hospitals and $1,723$ observations, the new sample has 155 hospitals and $1,695$ observations. I re-run the models and I report the results of the tests in Table 5.13. The coefficients of determination are slightly greater than the coefficients reported in

Table 5.11: Regression models when the independent variables are in logarithmic scale

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
focus	-0.0354***		-0.0373***	-0.0394***		-0.0441***	-0.0444***		-0.0358***	-0.0395***
	(-3.53)		(-3.22)	(-3.26)		(-3.74)	(-3.61)		(-3.15)	(-3.42)
$cospec_1$		-0.0132**	0.00280	0.00164						
		(-2.00)	(0.33)	(0.19)						
$focus * cospec_1$				-0.00411						
				(-0.90)						
$cospec_2$					-0.0133	0.0149	0.0145			
					(-1.36)	(1.17)	(1.08)			
$focus * cospec_2$							-0.000784			
							(-0.12)			
$cospec_3$								-0.0150*	0.000784	-0.00445
								(-1.84)	(0.07)	(-0.39)
$focus * cospec_3$										-0.00881*
										(-1.93)
N. Hosp.	162	162	162	162	162	162	162	162	162	162
N. Obs.	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723
R^2	0.543	0.536	0.543	0.543	0.535	0.544	0.544	0.535	0.543	0.544

Notes. Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: age, charl_ind, foundation, imd_score, laparoscopic, male, n_beds, occupied, private, recurrence, teaching, waitlist, week_ind.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Model	Sargan-Hansen statistics	p-value
(1)	95.922	<0.0001
(2)	105.195	<0.0001
(3)	93.518	<0.0001
(4)	147.464	<0.0001
(5)	122.857	<0.0001
(6)	99.950	<0.0001
(7)	170.904	<0.0001
(8)	99.238	<0.0001
(9)	97.598	<0.0001
(10)	92.004	<0.0001

Table 5.12: Hausman-like test

Table 5.7. The coefficient of `focus` is still negative and significant in all the models at the 1% level. While the variables $\texttt{cospec}_1$, $\texttt{cospec}_2$, $\texttt{cospec}_3$ are all negative in Model (2), Model (5), and Model (8), only $\texttt{cospec}_3$ is significant at the 10% in Model (8). However, since the coefficient of determination of Model (8) is lower than the coefficient of determination of Model (1) and because of the considerations mentioned in Section 5.4, we can argue again that this result does not provide enough evidence to support hypothesis 2. In the models with both the variables `focus` and `cospec`, I find that the coefficients of $\texttt{cospec}_1$ and $\texttt{cospec}_2$ are positive in Model (3) and (6), while $\texttt{cospec}_3$ is negative in Model (9). All the values are not significant and, therefore, do not provide evidence to support hypothesis 2 either. In Model (4) and (7) the coefficients of $\texttt{focus} * \texttt{cospec}_1$ and $\texttt{focus} * \texttt{cospec}_2$ are positive, while in Model (10) the coefficient of $\texttt{focus} * \texttt{cospec}_3$ is negative. However, also in this case the values are not significant at the standard levels and, therefore, do not provide enough evidence to support the hypothesis that complementarities affect hospital costs.

In the next robustness check, instead of studying the average cost of hospital j in year t, I study the cost of an admission i to hospital j. Formally, given $\mathbf{x}^p_{ij}$, a vector of

Table 5.13: Regression models when the minimum number of observed years is 5

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
`focus`	-0.839***		-0.906***	-0.915***		-1.032***	-1.033***		-0.792***	-0.772***
	(-3.72)		(-3.62)	(-3.66)		(-4.18)	(-4.20)		(-3.27)	(-3.09)
$\texttt{cospec}_1$		-1.076	0.579	0.462						
		(-1.37)	(0.66)	(0.53)						
$\texttt{focus} * \texttt{cospec}_1$				24.83						
				(0.74)						
$\texttt{cospec}_2$					-0.279	0.488	0.486			
					(-0.82)	(1.26)	(1.24)			
$\texttt{focus} * \texttt{cospec}_2$							0.478			
							(0.04)			
$\texttt{cospec}_3$								-0.910*	-0.328	-0.307
								(-1.92)	(-0.66)	(-0.63)
$\texttt{focus} * \texttt{cospec}_3$										-10.91
										(-0.56)
N. Hosp.	155	155	155	155	155	155	155	155	155	155
N. Obs.	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695
R^2	0.544	0.536	0.545	0.545	0.536	0.546	0.546	0.537	0.545	0.545

Notes. Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: `age`, `charl_ind`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

patient-level covariates, $\mathbf{x}_j^h$, a vector of hospital-level covariates, and u_i, the error term, the model formulation becomes the following:

$$\log(cost_{ij}) = \mathbf{x}_{ij}^p \boldsymbol{\beta}_k^p + \mathbf{x}_j^h \boldsymbol{\beta}_k^h + \alpha_j + \gamma_t + u_i \quad i = 1, \ldots, M_j \quad j = 1, \ldots, N$$

where M_j is the number of admissions to hospital j and N is the number of hospitals.

I report the results of the regression models in Table 5.14, where we see that the value of the coefficients of determination is equal or less than 14.0% in all the models since it is, clearly, more difficult to predict the cost of a single patient than the average cost of a hospital. The coefficient of `focus` is significant at the 1% levels in Model (1), (3), (4), (6), and (7), and at the 5% level in Model (9) and (10). While the variables $\texttt{cospec}_1$, $\texttt{cospec}_2$ are all negative and not significant in Model (2) and Model (5), $\texttt{cospec}_3$ is negative and significant at the 10% level in Model (8). The values of the coefficients of $\texttt{cospec}_1$, $\texttt{cospec}_2$, and $\texttt{cospec}_3$ in Models (3), (6), and (9) are, respectively, positive, positive, and negative. They are all not significant, which suggests that when we control for `focus`, `cospec` is not significant. The value of the coefficients of $\texttt{focus} * \texttt{cospec}_1$ and $\texttt{focus} * \texttt{cospec}_2$ are positive in Models (4) and (7), while the value of the coefficient of $\texttt{focus} * \texttt{cospec}_3$ is negative in Model (10). Moreover, they are all not significant at the standard levels. Also in this test, we see that there is little evidence to support hypotheses 2 and 3, which may indicate that Models (2)-(10) are not the true models.

Finally, I verify whether the results are robust to the inclusion of data on individuals aged 65 or more. Before, I argued that these patients tend to be more complicated and that the outcomes of their surgeries tend to be more uncertain. They also tend to spend more time in hospital because they often live alone and there is no-one that can take care of them at home. In this case, a more specialized general surgery department has a cost advantage whenever it can hire dedicated nurses to support an early discharge

Table 5.14: Patient-level regression models

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
focus	-0.553***		-0.581***	-0.586***		-0.641***	-0.643***		-0.482**	-0.440**
	(-2.79)		(-2.65)	(-2.68)		(-3.06)	(-3.09)		(-2.35)	(-2.06)
$cospec_1$		-0.766	0.257	0.224						
		(-1.08)	(0.33)	(0.28)						
$focus * cospec_1$				8.340						
				(0.25)						
$cospec_2$					-0.234	0.230	0.225			
					(-0.75)	(0.67)	(0.63)			
$focus * cospec_2$							1.395			
							(0.11)			
$cospec_3$								-0.880*	-0.559	-0.485
								(-1.94)	(-1.22)	(-1.07)
$focus * cospec_3$										-20.33
										(-1.34)
N. Hosp.	162	162	162	162	162	162	162	162	162	162
N. Obs.	386,821	386,821	386,821	386,821	386,821	386,821	386,821	386,821	386,821	386,821
R^2	0.140	0.139	0.140	0.140	0.139	0.140	0.140	0.140	0.140	0.140

Notes. Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: `age`, `charl_ind`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, `week_ind`.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

program. This is what used to happen in Derriford hospital in Plymouth, where there was a dedicated nurse managing the early discharge of hernia patients and answering the phone 24 hours a day in case a problem arose.

I report the results of these regression models in Table 5.15, which shows that the coefficient of `focus` is always negative and significant at the 1% level. These results support hypothesis 1 that focus affects costs, even when elderly patients are included. In Model (2) and Model (5), $\texttt{cospec}_1$ and $\texttt{cospec}_2$ are negative and not significant, however, $\texttt{cospec}_3$ is negative and significant at the 5% level in Model (8). Despite this result, the coefficient of determination in Model (8) is still lower than in Model (1). In the models that include both `focus` and `cospec`, while the coefficients of $\texttt{cospec}_1$ and $\texttt{cospec}_2$ are positive in Model (3) and Model (6), the coefficient of $\texttt{cospec}_3$ is negative in Model (9). They are all not significant at the standard levels. The coefficients of $\texttt{focus} * \texttt{cospec}_1$ and $\texttt{focus} * \texttt{cospec}_3$ are negative in Models (4) and (10), however, the coefficient of $\texttt{focus} * \texttt{cospec}_2$ in Model (7) is positive. Also in this case, all the coefficients are not significant at the standard levels. Including elderly patients does not affect the results for hypotheses 2 and 3: there is still not enough evidence to support the hypotheses that spillovers and complementarities affect hospital costs.

5.6 Discussion

The results of this study indicate that focus at the departmental level may have an impact on efficiency: the degree of specialization of a general surgery department has a negative relationship with hospital costs in all the models I tested. However, several limitations suggest to be cautious when interpreting the results. First, this research investigates only one specific surgical procedure performed by organizations all belonging to a single entity, the NHS. Nevertheless, as discussed in Chapter 1, inguinal hernia is the most common general surgery, health care costs represent around 10.5%

Table 5.15: Regression models, patients aged 19 or more only

Coefficient	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)	Model (9)	Model (10)
`focus`	-0.900***		-0.974***	-0.972***		-1.107***	-1.108***		-0.855***	-0.846***
	(-4.04)		(-3.93)	(-3.95)		(-4.64)	(-4.69)		(-3.46)	(-3.34)
$\texttt{cospec}_1$		-1.117	0.651	0.684						
		(-1.63)	(0.86)	(0.92)						
$\texttt{focus} * \texttt{cospec}_1$				-6.880						
				(-0.19)						
$\texttt{cospec}_2$					-0.306	0.519	0.516			
					(-0.93)	(1.42)	(1.40)			
$\texttt{focus} * \texttt{cospec}_2$							0.735			
							(0.06)			
$\texttt{cospec}_3$								-0.921**	-0.313	-0.298
								(-2.09)	(-0.66)	(-0.64)
$\texttt{focus} * \texttt{cospec}_3$										-5.640
										(-0.33)
N. Hosp.	162	162	162	162	162	162	162	162	162	162
N. Obs.	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723	1,723
R^2	0.688	0.681	0.688	0.688	0.680	0.689	0.689	0.682	0.688	0.688

Hospital and year fixed-effects are included in the models and the standard errors are clustered at the hospital level. Asymptotic t-tests are in parentheses. The control variables are: `age`, `charl_ind`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

of the global GDP [74], and many health care systems of the world have a structure that is very similar to the English one [67]. Second, while the measure of focus I use in this study captures the proportion of patients that are treated in one single specialty, there are other measures that assess the proportion of resources that a hospital spends on a certain segment of patients. On the other hand, it has been shown that measures based on resource consumption have similar results to the measure I chose [201].

The existence of omitted variables may also have an impact on the findings. Although, endogeneity should always be considered in retrospective studies, the availability of many years of observations for every hospital reduces its potential impact.

Another aspect to consider is the definition of costs I used, which is based on the NHS guidelines. While it includes some important cost drivers of health care expenses, it does not reflect all the possible sources of waste in the English public health care system[7].

The second finding of this study is that the data does not support the hypothesis that spillovers and complementarities affect costs. This result is partially in contrast with the current health care policies in England that tend to group procedures such as inguinal hernia and cholecystectomy together in treatment centers called independent sector providers. This finding is less in contrast with other examples of success in health care such the Shouldice hospital in Canada or the Lichtenstein Amid Hernia Clinic in Los Angeles. Since these centers compete in a free market, providing all types of hernia surgery generates marketing spillovers.

A reason that could explain why there are no spillovers or complementarities between related surgical procedures is that, as I already argued, surgical settings are

[7] For this reason, I also ran some tests using the outcome variable average re-admission rates and found results consistent with what illustrated in the previous sections. However, when I ran the same tests with the outcome variable average mortality rates, the results provided little evidence to support the theory of the benefits of focus and no evidence to support the theory of the benefits of spillovers and complementarities

characterized by a high level of tacit knowledge. This aspect of the surgical context hinders the process of knowledge transfer and, therefore, the effects of spillovers and complementarities. This research challenges the current definitions of relatedness based on process/product similarities and highlights the need for the definition of a new measure capturing the effects of tacit knowledge.

Notwithstanding the foregoing, I argued that spillovers at the managerial level may exist and, therefore, that co-specialization may have an impact on costs. There are several reasons that may explain why co-specialization does not affect costs instead. First, in the NHS, resources tend to work near their saturation point and, therefore, benefits associated with slacks are greatly reduced. Second, as mentioned, inguinal hernia is a very common general surgery that has been performed since ancient Egypt and, for this reason, there has been an effort over the years to reduce its costs through standardization. Given that central institutes such as the National Institute for Clinical Excellence and the Royal College of Surgeons have participated in this effort with protocols and guidances, e.g., [175, 220], this push for standardization at the national level has decreased the opportunities for co-specialization to generate process flow spillovers.

Another reason as to why co-specialization may not decrease costs is that the proportion of patients that undergo related procedures in this study is too low to have an impact on a general surgery department culture. Since there is no general consensus on many aspects of it, such as on whether trolleys are better than beds after a surgical operation, the ergonomics dimension may also not be relevant. Furthermore, like for managerial spillovers, regulations coming from the higher levels of the NHS may have limited the opportunities to exploit spatial dimension spillovers.

As already mentioned, this research does not find evidence to support the benefits of complementarities either. I argued that complementarities exist because of abstract schemas and implicit learning, however, these results suggest that the surgical knowledge relatedness I investigated is not sufficient to decrease costs. An alternative hypothesis that could explain this result is that the cumulative proportions of inguinal and related procedures considered in this study are too low for this type of effects to exist.

This study gives a contribution to the debate on specialization in the context of a general surgery department inside of a NHS hospital and emphasizes the need to define new instruments to measure all the dimensions that lead to the benefits of focus. Whereas this study contributes to investigate the elements that lead to the benefits of diversification, there is an opportunity to further analyze the micro-foundations of focus which include the four dimensions defined by Hyer et al. [158].

In summary, this research supports the idea that focus at the departmental level affects hospital costs, however, it does not reach the same conclusion in the case of spillovers and complementarities. More specifically, it does not find evidence that process/product co-specialization in the surgical context has an impact on efficiency, providing new insight on the theory of spillovers and complementarities in contexts where tacit knowledge plays a major role. While the NHS is moving routine operations such as inguinal hernia to specialty hospitals, I have evidence to claim that general hospitals may incur higher costs due to loss of focus and that it may be difficult for them to offset this increase in expenditures with spillovers and complementarities.

Chapter 6

When faster is (not) better: Quantifying the effect of health care improvement policies on patient outcome[1]

6.1 Introduction

As mentioned in the previous chapters, health care costs represent a considerable proportion of the GDP across most developed countries; for instance, in 2012, health care expenses amounted to $2.9 trillion in the United States (17.9% of the GDP, or $9,217.8 per capita), and $245.8 billion in the United Kingdom (9.4% of the GDP, or $3,859 per capita) [351]. As a consequence, there has been a growing political emphasis on curbing health care expenditures, with a major focus on improving the efficiency of hospital operations [168]. The adoption of standard policies in hospitals has become a priority [31]: as an example, more and more hospitals have been adopting clinical

[1]This essay is co-authored with S. Dopson and M. Holweg

guidelines to manage the delivery of care [10], and hospital managers have been increasingly using process improvement methodologies from the manufacturing context such as lean production [188, 215].

Despite the increasing levels of adoption of standard policies, 'one-size fits all' solutions could have negative consequences in health care. Several studies, e.g., [101, 251, 313], have suggested that customized solutions can increase the value offered to customers and decrease integration costs. We propose that, in some contexts, increasing length of stay for some patients can decrease long-term failure costs since tailored solutions can decrease the proportion of re-admissions and, in turn, lead to a reduction of costs due to complications.

We examine the link between length of stay and patient outcome using the 183,712,784 medical records of patients from the NHS employed in the previous essays since there is a growing interest in the adoption of standard policies in the English health care system [81]. Standard policies are one of the key features of the "QIPP" program, which has the objective to enhance the management of operations in the NHS [39]. Given the high correlation between length of stay and hospital expenditures, this program is pushing hospital managers to decrease patients' length of stay [223, 224]. The motivation behind this decision is that empirical evidence suggests a positive relationship between length of stay and risk of hospital-acquired infections (HAIs) [134, 213]. However, we argue that shorter length of stay can expose some groups of patients to avoidable risk factors such as stress and lack of care.

As a result of NHS policies aimed at decreasing length of stay and as shown in Figure 6.1 that illustrates age/gender adjusted average length of stay and re-admission/death rates, computed using the $183,712,784$ medical records, inguinal hernia patients have been spending less time in NHS hospitals. However, re-admission rates have been increasing sharply, suggesting that they are not receiving adequate care and, for this reason, need to be re-admitted to hospital. It is important to note that, while re-admission rates have been increasing, mortality has been decreasing at a steady pace, indicating that length of stay reduction may not be a significant contributor to a patient's likelihood of death.

One of the reasons to keep patients in the hospital for more time is to monitor them, especially, when they have previous conditions or they are very old. In this paper, we specifically consider the empirical boundaries of this decision, investigating whether the impact of length of stay reduction is the same for sick and healthy patients, and for old and young patients.

We choose to concentrate on NHS inguinal hernia patients, because, as already mentioned, this operation is the fifth most common general surgery procedure performed in the English health care system, accounting for 0.62% of all procedures performed, and because it has a length of stay that has declined from the about 6 weeks in the 1940s to the less than one night in the hospital of the present days [275, 284]. In order to assess the overall impact of re-admissions on NHS costs, we calculated the average cost of a hospital re-admission using the methodology illustrated in [83] (see Table 6.1). Although decreasing, the average cost of a hospital re-admission after inguinal hernia surgery is still more than £1,400 in 2009.

We study the effects of length of stay reduction using the aforementioned HES and HEFS data. As discussed in Chapter 4 and Chapter 5, while HES data provides information on NHS patients such as their demographic profile, the diagnoses from the physicians, and the procedures they undergo, HEFS data provides information on NHS hospitals such as number of beds and teaching status. We concentrate on patients admitted to NHS public hospitals and we consider the number of days from admission to discharge of every single episode of care. We control for other factors that can

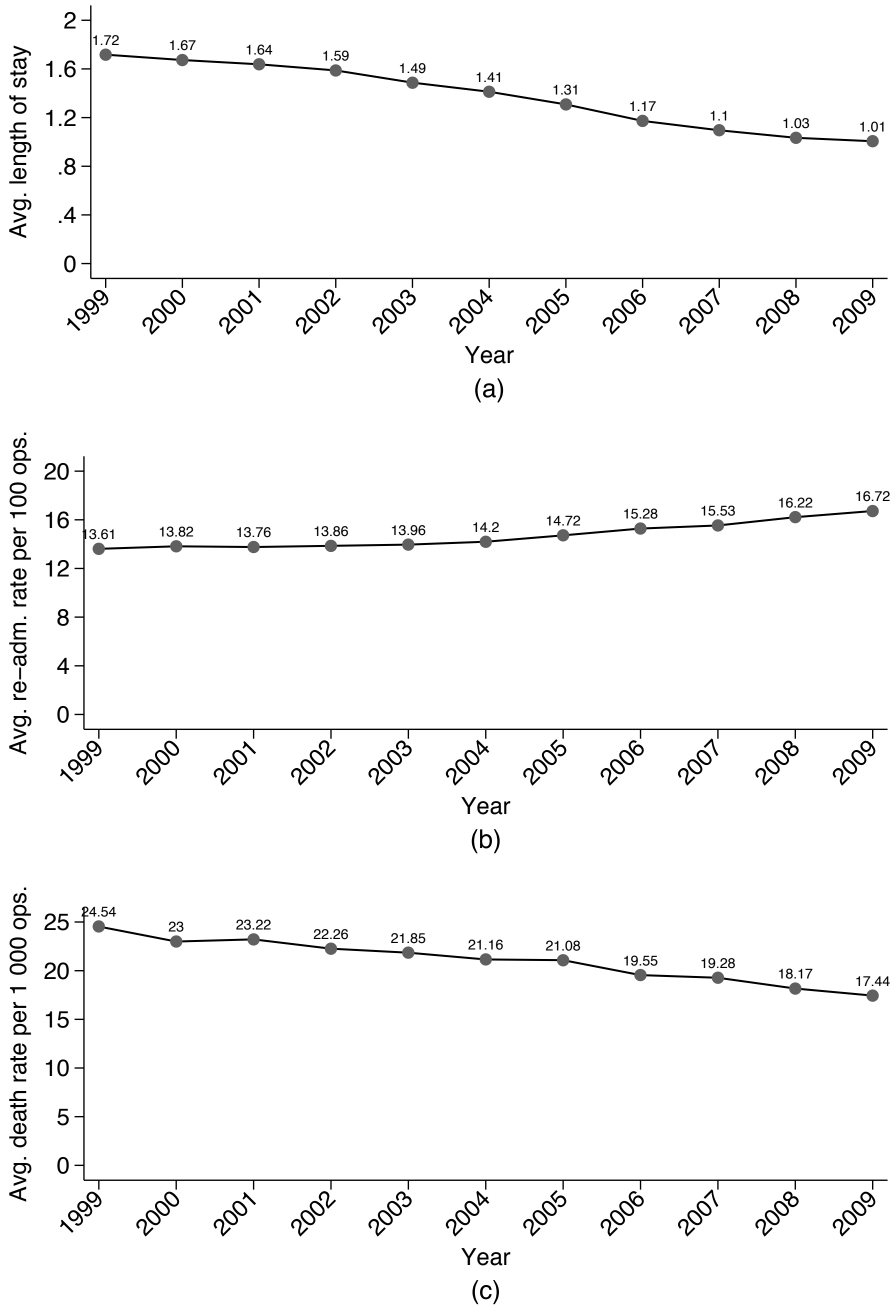


Figure 6.1: (a) Average length of stay (number of days from admission to discharge), (b) percentage of hospital re-admissions, (c) mortality for inguinal hernia patients between 1999 and 2009, computed using 183, 712, 784 medical records from the HES data warehouse

Year of Admission	Cost (£)
1999	1,801.43
2000	1,751.83
2001	1,739.07
2002	1,672.06
2003	1,638.38
2004	1,578.55
2005	1,522.67
2006	1,484.07
2007	1,447.85
2008	1,430.26
2009	1,408.45

Table 6.1: Average cost of a hospital re-admission after inguinal hernia surgery (2011 prices)

affect hospital outcomes, including previous chronic conditions[2]. Finally, we model the impact of state of health and age on length of stay using an interaction term.

On a theoretical level, we find that shorter length of stay on aggregate decreases hospital costs, yet, at its boundaries, it can have negative long-term consequences. In spite of this consideration, the increase of health care expenditures is pushing hospital managers toward short-term strategies, such as length of stay reduction, that do not look at the whole cycle of care, but often address only the immediate needs of the patients and result in higher long-term costs [255].

The economic implication of this research is that health care policies may need to consider the case-mix complexity of their patient base when they implement length of stay reduction strategies. Despite the negative long-term effects for sicker and older patients, this research suggests that decreasing length of stay for healthy patients can be an effective strategy to curb health care expenditures. By diversifying the

[2]We measure chronic conditions with the Charlson index [58]

policy, one could both reap the benefits from shorter length of stay for the majority of patients, while reducing the risk (and associated cost) of re-admission for certain patient groups at higher risk of complications. On balance we conservatively estimate that such a diversified policy could save up to £354 (US$565) per elective procedure[3], which equates to a 19.97% reduction in total cost for all elective hernia procedures performed on adults.

The next section will introduce the literature review, Section 6.3 develops the research hypotheses, Section 6.4 explains the method used in this research, and Section 6.5 presents the results of the empirical analyses. Finally, the last section discusses our contributions to theory and policy.

6.2 Literature review

Henry Ford famously stated that his customers could buy his cars in any colour they wanted "so long as it is black" [356], words that reflect a time period in which custom solutions were not seen as a source of competitive advantage. The concept of standard comes from the principle that processes and procedures should be "repeatable," "reliable," and "capable" [29] and is, generally, assumed to be a viable solution to enhance operational performance. Standard solutions are about improvement and adopting the best practice possible to complete a task [147]. While empirical evidence has reinforced the views expressed in these statements, e.g., [37, 106], companies have invested an increasing amount of resources in the attempt to adopt standard solutions and decrease costs. This trend has also driven hospitals (for which, as already discussed, standard policies have historically been seen as unwanted or not applicable) to introduce guidelines and protocols to streamline their processes.

[3]We focus on elective procedures to exclude emergency admissions, which are likely to have a different risk profile due to other acute conditions of the patient

The investments on adopting standard solutions that companies make, fall short when they do not consider the diversity of their customer base. Custom solutions are required to manage the complexity of different needs and preferences, for which a range of strategies can be used [153, 184].

Lampel and Mintzberg [184] identify five strategies that manufacturing firms can adopt to customize their products. The first strategy a firm can choose is "pure standardization," which means that a firm decides not to customize its products. The second strategy is "segmented standardization" and a firm implements it when it segments a market into homogenous subgroups and it serves each subgroup with a standard product. The third strategy is "customized standardization," which is about the involvement of the customer in the assembly of the product. The fourth strategy is "tailored customization" and is implemented when a company considers the needs and the preferences of the customers at the manufacturing stage. Finally, the last option is "pure customization" and is implemented when a customer is also involved in the design of the product. Ideally, a firm is able to combine these five strategies to reach an equilibrium between maximizing customers' satisfaction and minimizing costs.

Holweg and Pil [153] identify another framework that we can use to study standard solutions based on push and pull strategies. The authors describe push strategies as the production of high volumes of standardized products which, gradually, become more customized as the firm transforms the push strategy into a pull strategy. As discussed in the study, between the two extremes of offering standard and custom products, there are three intermediate strategies: "locate-to-order," "amend-to-order," and "hybrid-build-to-order." The last strategy before customization, "hybrid-build-to-order," involves the production of high volumes of standard products and small volumes of customized products. This strategy is particularly interesting when we consider the context of hernia care because, while most inguinal hernia patients can undergo a standard process of care, a small proportion of them needs a process of care tailored to their needs [31, 305].

As a result of these considerations, the ability to combine custom and standard solutions is an example of an ambidextrous operational capability because it generates value balancing different objectives [178, 273]. This operational capability is called mass customization when the firm produces high volumes of a product or a service or, in the case of health care, when a hospital delivers high volumes of a surgical procedure. As an an ambidextrous operational capability, mass customization links the flexibility in strategic planning to the efficiency of operations because greater flexibility is associated with higher levels of mass customization and higher levels of mass customization are associated with better operational performance [178].

Fogliatto et al. [101] examine the reasons that motivate the implementation of customized solutions for mass-produced products and services suggesting that customized solutions have benefits for both the companies and their customers. The companies can, in fact, charge a "premium price" for customized products and enjoy "economies of integration" [101, 251]. While the reason why companies can charge a higher price to a certain group of customers when they offer them a customized product is clear, "economies of integration" exist, because, as suggested by Piller et al. [251], customized solutions do not only increase the information companies gather about their customers but also reinforce customer loyalty. Furthermore, Piller et al. [251] suggest that postponement of customization offers additional tools to decrease operational costs such as storage and lost sales costs. On the customers side, customized solutions bring more value to the client because of the extrinsic and intrinsic value components they generate [101, 210].

One aspect that has received little consideration is the long-term outcomes of the implementation of customized solutions for mass-produced products and services, for example, their impact on failure costs. Failure costs exist when customers have to return a product or ask for a new service because the product or service they bought is "not conforming to requirements or customer/user needs" [8]. In these cases, they are sometimes granted refunds and, more rarely, they receive additional compensation. In this study, we argue that customized solutions can be an effective approach to reduce also this type of costs. Since empirical work in the area of customized solutions for mass-produced products and services has been struggling to keep the pace with the body of theoretical work [101], we decide to employ an empirical approach analyzing all public hospitals in the English NHS in our study period.

6.3 Hypothesis development

In health care the determinants of length of stay can be classified into two categories: patient and hospital level [354]. Patient level determinants include all the characteristics of the individuals and of the surgery they undergo [296, 354]. For example, state of health, surgical outcomes, and type of admission, since elective patients spend on average less time in hospital than emergency patients [50].

Hospital level determinants include all the characteristics of the health care providers where the patients undergo the operation. Length of stay depends, in fact, on the resources available in a hospital and on how efficiently hospital administrators use them [354]. For example, theaters dedicated only to day case surgery whose throughput depends on the efficiency of surgery scheduling [281], or, perhaps, hospital culture, which affects physicians' embedded routines and behaviors, such as rate of adoption of local anesthesia [169].

There is a lively debate in academia on whether length of stay is associated with poor patient outcomes. While some researchers support the hypothesis that shorter length of stay leads to poor outcomes, e.g., [171, 299], others suggest that shorter length of stay either has no impact at all or leads to better outcomes, e.g., [34, 158, 344].

In the first group of studies, KC and Terwiesch [171] investigate cardiovascular surgery in the United States and find a relationship between shorter length of stay and higher risk of death. However, they do not investigate hospital re-admissions and their results are based on the analysis of only one hospital. Conversely, Shulan et al. [299] study re-admission rates for a variety of Diagnosis Related Groups (DRGs[4]), analyzing the Veterans Healthcare Network Upstate New York dataset. However, since they use a cross-sectional approach, they cannot use longitudinal variation to control for omitted variables.

In the second group of studies, Bohmer et al. [34] investigate discharge destination and re-admission rates for coronary artery bypass graft operations in Massachusetts, emphasizing that, while length of stay is a common strategy in health care to reduce costs, its impact on outcomes such as re-admission and death is not well understood. Since their dataset includes observations only from Massachusetts, they remove patients from other states, concluding that there is no evidence that longer length of stay decreases re-admission and mortality rates. However, like in the study by Shulan et al. [299], Bohmer et al. use a cross-sectional approach based on logistic regression and, for this reason, cannot use longitudinal variation to control for omitted variables. Moreover, not only do they not include variables to control for hospital characteristics, but also they do not consider patients' deprivation, a variable which is likely to have an impact on likelihood of re-admission/death, especially in the United States.

The other two studies we cited adopt a case study approach and analyze a limited number of hospitals. Hyer et al. [158] study an integrated trauma center in the United States using, as already mentioned, a framework based on four dimensions: the human and technical resources dimension, the spatial dimension including physical closeness,

[4]As mentioned in Chapter 3, a DRG is a classification of a hospital episode adopted in the United States for cost accounting purposes

the process flow dimension, and the institutional dimension. They find that hospital stay is not necessarily correlated with higher mortality rates and suggest that focus can offset the negative effects of shorter length of stay. Wester and Lagoe [344] claim that length of stay is “a major variable” to consider for the management of hospitals and use it to investigate hip replacement in two hospitals in the United States and two hospitals in the Netherlands. They analyze its variation for patients aged 65 or more and conclude that lower length of stay increases the quality of health care delivery.

One of the aspects to consider, when interpreting studies that use administrative datasets, is the analysis of what length of stay measures. Given the structure of the most common datasets, e.g., [64, 237], control variables include, typically, patient and hospital characteristics but exclude information on whether the operation was successful. Therefore, an increase in length of stay is not only associated with more days of recovery but, also, with complications.

Another question that arises is whether the class of a procedure affects the impact of a variation in its processing time and whether longer length of stay leads to better outcomes only for certain types of operations [173]. Since recovery times are associated with the complexity and the length of the surgery, the positive effects of longer length of stay such as monitoring and support of patient recovery are plausibly lower for easier procedures such as inguinal hernia surgery.

While the operations literature, traditionally, does not contemplate the negative effects associated with number of days spent in the hospital, longer length of stay can also expose healthy patients to the risk of avoidable infections [134, 213]. In the 1800s wound infections were considered as part of the healing process [277] and, after more than two hundred years, around 8.2% of patients still acquire an infection when they enter a NHS hospital [216]. Methicillin-resistant Staphylococcus aureus (MRSA) infections, which occur in the surgical site or after the operation and affect open wounds and the bloodstream, and Escherichia coli (E. coli) infections, which affect the urinary tract, are among the most common [22, 216]. Clostridium Difficile (C. Difficile) and Acinetobacter infections are also very common and affect the gastrointestinal system and the respiratory tract [216]. Since longer length of stay is associated with higher risk of acquiring a hospital infection and since patients that develop an infection during or after the hospital stay need more time to recover and are more likely to experience complications after the hospital discharge, we formulate the following hypothesis:

HYPOTHESIS 1. *Longer patient length of stay is associated with worse patient outcomes such as higher risk of re-admission and higher risk of death.*

Assuming that $h(t) = f(\texttt{lostay}, \mathbf{W})$ where $h(t)$ is the instantaneous risk of re-admission or death, `lostay` is length of stay, and $\mathbf{W}$ represents all the other variables that affect this risk, the first hypothesis can be expressed as $\frac{\delta h(t)}{\delta \texttt{lostay}} > 0$.

This study responds to the call to investigate the impact of case-mix "severity" on early discharge[5] [171]. Patients in poor physical conditions need more time to recover and, for this reason, we expect the benefits of longer length of stay to have a greater impact on them. There is another factor to consider: the need to monitor vital signs is greater for sicker patients since failure to do that can lead to hospital re-admission or death.

Patient mobility after the operation, which contributes to the healing process, requires also special attention when considering sick patients [21]. One of the critical factors of success of the Shouldice Clinic in Canada is that nurses engage with patients and ask them to do exercises and walk after the surgery [144]. Similarly, at the Virginia Mason Medical Center, patients follow a chart to complete the activities they need to perform before the hospital can discharge them [115]. However, while healthy patients

[5] We adopt the point of view of the NHS and define early discharge as the progressive decrease in length of stay shown in Figure 6.1

are generally able to walk and follow a program of exercises by themselves, sick patients need to stay in the hospital if they require the support of the medical staff to perform these activities.

Since infections are, intuitively, more likely to develop in sicker patients, we need also to consider that longer length of stay could expose this class of patients to a higher risk of acquiring an infectious disease. However, there is empirical evidence showing that infections are not more likely to develop in patients with some common pre-existing conditions, e.g., [12, 59]. Also the absence of specific protocols to manage HAIs for high-risk patients suggests that the marginal effect of state of health on the risk of acquiring an hospital infection is limited. In contrast to this absence of guidelines, when there was the Ebola emergency, protocols for the management of Ebola patients were quickly put together [346].

The idea that length of stay should not be the same for sick and healthy patients is, as discussed, also related to the concept of standard solution. As suggested in [31], patient selection is one of the possible ways to standardize health care processes and hospitals should use different protocols to meet the needs of different types of patients. For example, patients with multiple chronic conditions need a tailored and longer process of care in the same manner products in a “job-shop” require a flexible production system and longer lead times [31].

We can apply standard policies to inguinal hernia surgery because, when we consider healthy patients, we can formalize the treatments they need to receive [305]. We know that the majority of these patients does not need to spend the night in the hospital which implies that hospital managers can increase day case surgery rates without the fear of causing higher re-admission or mortality rates. Conversely, we are required to manage complex hernia patients with a process of care tailored to their needs.

Given these considerations, we formulate the following hypothesis:

HYPOTHESIS 2. *The severity of a patient's illnesses affects the relationship between length of stay and hospital outcomes: the sicker is a patient, the greater are the benefits of longer length of stay on risk of re-admission and risk of death.*

Assuming that $h(t) = f(\texttt{lostay}, \texttt{lostay} * \texttt{charl\_ind}, \mathbf{W})$ where `charl_ind` measures state of health, the second hypothesis can be expressed as $\frac{\delta^2 h(t)}{\delta \texttt{lostay} \delta \texttt{charl\_ind}} < 0$.

One of the challenges of discharging patients from a hospital is to find someone that can monitor their conditions when they go home [186]. This problem becomes more complicated with old people that live alone. When the pressure to cut costs push doctors to send home patients that would need a longer period of monitoring, then risk of re-admission and risk of death increase.

It is also well known that old people spend more time in hospital because the likelihood of poor surgical outcomes increases with age, e.g., [9, 63, 195]. The same considerations about standard policies we illustrated for sick and healthy patients are also valid when we consider old and young patients.

When we consider very old people it also becomes less clear whether the benefits of a surgical procedure offset its risks, which causes GPs to often delay the decision to refer patients for surgery [276]. Delayed referrals cause hernias to become more complex and patients to need more time to recover after surgery.

Given these considerations, we formulate the following hypothesis:

HYPOTHESIS 3. *The age of a patient affects the relationship between length of stay and hospital outcomes: the older is a patient, the greater are the benefits of longer length of stay on risk of re-admission and risk of death.*

Assuming that $h(t) = f(\texttt{lostay}, \texttt{lostay} * \texttt{charl\_ind}, \texttt{lostay} * \texttt{age}, \mathbf{W})$ where `age` measures age, the third hypothesis can be expressed as $\frac{\delta^2 h(t)}{\delta \texttt{lostay} \delta \texttt{age}} < 0$.

In summary, these hypotheses suggest that, in some cases, the overall benefits of longer length of stay are greater than its risks and that, for this reason, vulnerable and old patients should spend more time in hospital.

6.4 Method

6.4.1 Data collection and empirical model

In order to study the effects of length of stay reduction, we use the same database of 183, 712, 784 medical records we employed in Chapter 4 and that I employed to test the hypotheses in Chapter 5. As already mentioned, this database includes medical records from the HES data warehouse, capturing diagnoses, procedures, date of admission and discharge, and demographic information about NHS patients, which have been linked with death certificates provided by the Office of National Statistics using the Oxford record linkage system [111]. Also in this case, we analyze the data using SAS 9.3 and Stata 11.2 and we include information on hospital facilities such as foundation status and number of beds linking HES to HEFS data.

This research investigates patients diagnosed with inguinal hernia (ICD-10 code K40 [43]) that undergo a surgical procedure (OPCS-4 codes T20 and T21 [308]) in a NHS public hospital using data from 1999 and 2009. We exclude patients after 2009 because death information is incomplete after January 2011.

We use the variables `age`, `charl_ind`, and `lostay` to test the three hypotheses. The variable `age` measures the age of the patient in years at the start of the hospital stay. We use the variable `lostay` to calculate the number of days between admission and discharge, one of the measures most commonly used in the literature, e.g., [46, 149, 150]. In order to increase the interpretability of the results, we divide it by its standard deviation. Finally, we include the variable `charl_ind` to calculate the Charlson index, a measure of an individual's state of health [58, 172, 181]. We compute it on the basis of more than 280 different diagnoses, using the SAS macro *CharlsonICD10* [267, 331].

In order to calculate the statistical association between `lostay` and probability of death and re-admission, this research uses Cox regression [121]. The time variables are number of days to death and to re-admission[6]. The censoring date is 12/31/2010 for time to death and 12/31/2011 for time to re-admission. This choice is consistent with the data available, since information from death certificates is complete up to January 2011 and information from medical records is complete up to January 2012.

As already discussed, HES data includes variables that can be used as controls in the Cox regression models. The first column of Table 6.2 reports the names of the variables that we use in the regression models and the second reports their description. We include the binary control variable `eme_ind` to account for type of admission. This variable is 1 if the patient is an emergency patient and 0 if he/she is an elective patient. We include the variable `imd_score` to measure the Index of Multiple Deprivation (IMD). This index reflects the patient's social, economic and housing issues [174]. There are several reasons why individuals that suffer social, economic and housing deprivation are more likely to be re-admitted to hospital and die. One of them is lack of healthy eating [93]. On similar grounds, we use the variable `private` indicating whether the patient is paying for the treatment out of his/her pockets. Probability of re-admission or death depends also on whether a patient has to be in a waitlist before the operation [182]. The variable `waitlist` is 1 if the patient comes from the waitlist, and 0 otherwise. Since having a surgery in the weekend is riskier than having a surgery in the rest of the week [171], we introduce the variable `week_ind` that is 1 if the patient enters the hospital during a weekend, and 0 otherwise. Risk factors are also gender

[6] We add to them an arbitrarily small constant to account for re-admissions and deaths in the last day in the hospital. As explained in Section 6.5.4, we run two checks to investigate the robustness of our results when considering in-hospital mortality

and key-hole surgery [305]. We use the binary variable male to indicate whether the patient is a male and the binary variable laparoscopic to indicate whether the surgeon performs the operation laparoscopically. Finally, since, as mentioned, re-operating the same hernia is more complex [293], we include the binary variable recurrence that is 1 if the hernia is recurrent, and 0 otherwise.

At the hospital level, we include the control variable focus that measures the focus of the hospital on inguinal hernia surgery, the variable foundation, the variable n_beds, the variable occupied, and the variable teaching. A foundation trust has a governance model with more managerial and financial flexibility [217] that can be used, for example, to increase the cleanliness of the hospital, which can lead to a lower number of re-admissions/deaths caused by infections. The variable occupied measures the hospital workload that, as shown in [171], can affect hospitals outcomes. Finally, large and teaching hospitals are, typically, more likely to attract the best resources in the job market which can lead to lower re-admission and mortality rates.

We use the interaction term lostay * charl_ind to test the second hypothesis that the impact of length of stay depends on the state of health of the patient, and the interaction term lostay * age to test the third hypothesis that the impact of length of stay depends on the age of the patient. We demean the components of the interaction terms to increase the interpretability of the variables.

The two measures of hospital outcomes we consider are risk of re-admission and risk of death. Table 6.3 reports correlation values for the variables of interest in this study. The binary variable readm, indicating if a patient is re-admitted to hospital and the binary variable death, indicating if a patient dies after surgery, are positively related to each other. They are also positively related to age, charl_ind, and lostay.

Table 6.4 lists the models and the variables we use to test the hypotheses.

One of the main drawbacks of using dummy variables to model fixed-effects in non-

Table 6.2: List of control variables

Name	Explanation
`eme_ind`	Emergency patient
`focus`	Proportion of patients that undergo inguinal hernia surgery in the general surgery department of the hospital
`foundation`	Foundation status of the hospital
`imd_score`	IMD score of the patient
`laparoscopic`	Surgery performed laparoscopically
`male`	Male patient
`n_beds`	Number of beds in the hospital
`occupied`	Proportion of occupied beds in the hospital
`private`	Private patient
`recurrence`	Recurrent procedure
`teaching`	Teaching status of the hospital
`waitlist`	Patient admitted from the wait list
`week_ind`	Patient admitted during the weekend (Saturday or Sunday)

	Mean(Std. Dev.)	readm	death	age	charl_ind	lostay
readm	0.665 (0.472)	1				
death	0.146 (0.353)	0.215	1			
age	57.902 (18.539)	0.306	0.384	1		
charl_ind	0.160 (0.547)	0.083	0.197	0.171	1	
lostay	1.320 (4.580)	0.077	0.206	0.173	0.204	1

Table 6.3: Summary statistics and correlation table

	Model (1)	Model (2)	Model (3)	Model (4)
age	•	•	•	•
charl_ind	•	•	•	•
lostay	•	•	•	•
lostay ∗ charl_ind		•		•
lostay ∗ age			•	•
Control Variables	•	•	•	•

Table 6.4: Regression models and their variables

linear models is the incidental parameters problem [7]. The estimation of fixed-effects introduces an error that bias the estimation of the other coefficients. For this reason, in order to include hospital fixed-effects, we stratify the regressions. For every observation, we include a baseline hazard that depends on the hospital j where the patient undergoes the operation. For example, given a vector $\mathtt{x}$ representing the control variables and N hospitals in the sample, the original formulation of Model (4):

$$h_1(t) = h_0(t)e^{\beta_1 \mathtt{lostay} + \beta_2 \mathtt{charl\_ind} + \beta_3 \mathtt{age} + \beta_{12} \mathtt{lostay} * \mathtt{charl\_ind} + \beta_{13} \mathtt{lostay} * \mathtt{age} + \mathtt{x} \boldsymbol{\beta_4}}$$

becomes the following system of equations:

$$h_{1j}(t) = h_{0j}(t)e^{\beta_1 \texttt{lostay}+\beta_2 \texttt{charl\_ind}+\beta_3 \texttt{age}+\beta_{12}\texttt{lostay}*\texttt{charl\_ind}+\beta_{13}\texttt{lostay}*\texttt{age}+\mathbf{x}\boldsymbol{\beta_4}} \qquad j = 1, \ldots, N$$

In order to calculate the economic impact of a change in length of stay, we compute the marginal effects of this variation. When we consider Model (4), for a hospital j, the partial derivative of the hazard function with respect to `lostay` has the following mathematical formulation:

$$h_{2j}(t) = \frac{\delta h_{1j}(t)}{\delta \texttt{lostay}} = h_0(t)(\beta_1 + \beta_{12}\texttt{charl\_ind} + \beta_{13}\texttt{age})e^{\beta_1 \texttt{lostay}+\beta_2 \texttt{charl\_ind}+\beta_3 \texttt{age}+\beta_{12}\texttt{lostay}*\texttt{charl\_ind}+\beta_{13}\texttt{lostay}*\texttt{age}+\mathbf{x}\boldsymbol{\beta_4}}$$

The impact of the variation of `lostay` on risk of re-admission or death is the following:

$$h_{3j}(t) = \frac{h_{2j}(t)}{h_{1j}(t)} = (\beta_1 + \beta_{12}\texttt{charl\_ind} + \beta_{13}\texttt{age}) \tag{6.1}$$

We calculate the standard errors of a variation in `lostay` using the formula [38]:

$$\sigma^2_{h_{3j}(t)} = var(\beta_1) + \texttt{charl\_ind}^2 * var(\beta_{12}) + \texttt{age}^2 * var(\beta_{13}) + \\ 2 * \texttt{charl\_ind} * Cov(\beta_1, \beta_{12}) + 2 * \texttt{age} * Cov(\beta_1, \beta_{13}) \tag{6.2}$$

In order to validate the findings, we run a competing risk analysis for the dependent variable probability of re-admission, censoring from the study the patients that die. Additionally, we run the same analysis for the dependent variable risk of death. Patient re-admission can, in fact, prevent a patient's death.

We employ a two-way ANOVA to study the impact of the interaction terms `lostay`∗

`charl_ind` and `lostay*age` on `readm` and `death` and further verify if they are significant. A two-way ANOVA is an extension of a one-way ANOVA which, differently from the t-test that is used when there are only two groups to analyze, is used when there are three or more groups [342]. While a one-way ANOVA employs only one variable to define the groups, a two-way ANOVA employs two variables which, in this case, are `lostay` and `charl_ind` or `age`.

Finally, we suggest the logic of a customized policy with the objective of minimizing costs without increasing the risk of re-admission or death for any patient. In order to run the algorithm, we propose to use the thresholds for `age` and `charl_ind` identified by solving Equation 6.1 with the values obtained from the Cox regressions and the competing risk analysis models. Since we want to exclude high-risk patients, we apply the algorithm only to elective patients and patients aged more than 18, that are approximately 92% of the patient population. We argue that emergency patients and patients aged 18 or less are high-risk because of the increased likelihood of obstruction in an emergency setting [50] and because, while the probability of an adverse event for young patients is low, the cost associated with it is very high.

6.4.2 Limitations

Our findings should be considered in the light of the limitations of the data available. Although one of the most comprehensive datasets on patient records, HES data does not have a variable to measure the success of a surgical procedure and the number of days we spend to monitor a patient is only one of the components explaining the length of stay of a patient.

Another factor to take into account is that while death data comes from death certificates, we only use HES data to calculate re-admissions and, consequently, we do not account for patients that leave England or go to a non-NHS hospital. However, we expect these patients to be a minority since the NHS is a universal system and the probability of undergoing inguinal hernia surgery and, at the same time, leaving England is very low (< 4 cases per million patients[7]).

A further possible limitation is also the choice of the Charlson Index as a measure of a patient's state of health. However, the Charlson Index is one of most common measures in the medical literature [300], it captures more than 280 comorbidities [267, 331], and it has been called the "best known measure" of a patient's state of health [227, 309].

This research is also based on data from NHS public hospitals and, therefore, it is not clear whether certain aspects of it can be extended to other health care systems. Nevertheless, health care systems similar to the NHS have been adopted in several countries [67]. Moreover, excluding private hospitals eliminates providers that have a lower incentive to decrease re-admission rates [109].

Finally, we have to consider a possible limitation of the competing risk analysis models which censor patients that die when we study risk of re-admission and patients that go back to hospital when we study death. In the case of re-admissions, the assumption to censor patients that die seems reasonable since they are leaving the study. In the second case, censoring patients re-admitted to hospital is equivalent to removing the most difficult cases, and, for this reason, the Cox regression models may offer better insight on the hypotheses we test.

[7] We extrapolated this number on the basis of the statistical data provided in [246]

6.5 Results

6.5.1 Cox regression models

Table 6.5 and Table 6.6 report the results of the Cox regression models and include the total time at risk, that is the sum of the time from discharge to re-admission, death or censor date for every patient. The likelihood ratio is consistently less than 0.0001, the number of hospitals is 238, and the total number of observations including emergency and elective patients is 636, 616. The tables also report odds-ratios and z-tests for all the independent variables.

As reported in Table 6.5, the values of the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are significant and greater than 1 in all the models. The odds-ratios of the first two variables support the common assumption that older and sicker patients are more likely to be re-admitted. The values of the odds-ratios of the variables `lostay` ∗ `charl_ind` and `lostay` ∗ `age` are significant and less than 1 in all the models which provides evidence to support the hypothesis that the impact of length of stay variation depends on the state of health/age of the patient.

Table 6.6 reports the results for the outcome variable risk of death and we see that the value of total time at risk is greater than in Table 6.5. The values of the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are significant and greater than 1 in all the models like in Table 6.5. Not surprisingly, the variables `lostay` ∗ `charl_ind` and `lostay` ∗ `age` are also significant and less than 1.

The results reported in Table 6.5 and Table 6.6 provide evidence to support the first, the second, and the third hypothesis for both the outcome variables.

If we consider Equation 6.1 and Equation 6.2, we can calculate when a variation in length of stay is significant and decreases re-admission and death rates. Table 6.9 reports these thresholds and shows that an increase in length of stay decreases, for

Table 6.5: Cox regression models for the dependent variable risk of re-admission

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0255***	1.0253***	1.0255***	1.0254***
	(84.21)	(83.58)	(84.91)	(84.11)
`charl_ind`	1.1440***	1.1910***	1.1474***	1.1897***
	(31.72)	(40.06)	(32.38)	(39.96)
`lostay`	1.0126***	1.0276***	1.0193***	1.0299***
	(5.47)	(8.40)	(6.58)	(8.53)
`lostay` * `charl_ind`		0.9690***		0.9708***
		(-16.28)		(-15.22)
`lostay` * `age`			0.9993***	0.9997***
			(-5.94)	(-3.16)
N. Obs.	636,616	636,616	636,616	636,616
N. of. Hospitals	238	238	238	238
Total time at risk	853,760,626	853,760,626	853,760,626	853,760,626
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

instance, re-admission rates for patients with a Charlson index greater than 2, for patients with a Charlson index of 2 and aged 18 or more, and for patients with a Charlson index of 1 and aged 89 or more.

We can also use Equation 6.1 to calculate the impact of increasing length stay by one standard deviation. For example, if we have a 66 years old patient with a Charlson index of 7, increasing length of stay by 4.580 days decreases the risk of re-admission by 18.10% and the risk of death by 8.05%, respectively.

6.5.2 Competing risk analysis models and ANOVA

Table 6.7 and Table 6.8 report the results of the competing risk analysis for risk of re-admission and risk of death. The total time at risk is, clearly, the same for both tables and is lower than the total time at risk illustrated in Table 6.5 and Table 6.6. The likelihood ratio is less than 0.0001 in all the models and number of observations and number of hospitals is the same as the number of observations and the number of hospitals in the Cox regression models.

In Table 6.7, we see that the values of the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are again significant and greater than 1. While the values of the odds-ratios of the variable `lostay` $*$ `charl_ind` are still significant and less than 1, the value of the odds-ratio of the variable `lostay` $*$ `age` is significant in Model (3) but not in Model (4).

Table 6.8 displays the results for risk of death. The odds-ratios of the variables `age`, `charl_ind`, and `lostay` are, not surprisingly, significant and greater than 1 and the odds-ratios of the variable `lostay` $*$ `charl_ind` are significant and less than 1. The odds-ratios of the variable `lostay` $*$ `age` are not significant.

These results provide evidence to support the first and the second hypothesis for both the outcome variables. While they provide some evidence to support the third

Table 6.6: Cox regression models for the dependent variable risk of death

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.1034***	1.1032***	1.1038***	1.1036***
	(118.12)	(117.78)	(118.14)	(117.40)
`charl_ind`	1.3943***	1.4319***	1.3966***	1.4291***
	(41.00)	(44.69)	(41.90)	(44.98)
`lostay`	1.0354***	1.0457***	1.0582***	1.0617***
	(8.11)	(9.48)	(13.68)	(11.45)
`lostay` * `charl_ind`		0.9863***		0.9879***
		(-5.66)		(-5.36)
`lostay` * `age`			0.9988***	0.9991***
			(-7.87)	(-4.24)
N. Obs.	636,616	636,616	636,616	636,616
N. of. Hospitals	238	238	238	238
Total time at risk	1,270,369,583	1,270,369,583	1,270,369,583	1,270,369,583
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.7: Competing risk analysis regression models for the dependent variable risk of re-admission

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0272***	1.0271***	1.0272***	1.0271***
	(81.84)	(81.59)	(82.12)	(81.71)
`charl_ind`	1.2564***	1.2699***	1.2572***	1.2696***
	(49.13)	(50.32)	(49.50)	(50.37)
`lostay`	1.0352***	1.0386***	1.0377***	1.0396***
	(11.14)	(9.49)	(10.67)	(9.60)
`lostay` * `charl_ind`		0.9911***		0.9915***
		(-4.98)		(-4.67)
`lostay` * `age`			0.9998**	0.9999
			(-1.96)	(-0.79)
N. Obs.	636, 616	636, 616	636, 616	636, 616
N. of. Hospitals	238	238	238	238
Total time at risk	753, 424, 721	753, 424, 721	753, 424, 721	753, 424, 721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

hypothesis for the outcome variable risk of re-admission, the evidence for the outcome variable risk of death is limited to the coefficients of the odds-ratios being less than 1.

In Table 6.9, we also report the thresholds at which length of stay decreases significantly re-admission and death rates for the competing risk analysis models. Increasing length of stay decreases risk of re-admission for patients with a Charlson index greater than 8, for patients with a Charlson index of 8 and aged 11 or more, and for patients with a Charlson index of 7 and aged 46 or more. Length of stay does not decrease risk of death for any value of `charl_ind` and `age`.

If we consider the same patient with a Charlson index of 7 and aged 66 of the previous example, increasing length of stay by one standard deviation decreases his/her risk of re-admission by 2.66%.

Finally, we employ a two-way ANOVA to further investigate the impact of the interaction terms and assess whether the effect of `lostay*charl_ind` and `lostay*age` on `readm` or `death` is significant. We include the interaction terms and their components in every test and we find that `lostay * charl_ind` and `lostay * age` are always significant ($p < 0.0001$).

6.5.3 Customized policy

As discussed in Section 6.4, the customized policy we propose is based on the thresholds of the Cox and competing risk analysis models that identify the groups of patients which are mostly likely affected by a decrease in length of stay. The shaded area in Figure 6.2 represents graphically the thresholds at which decreasing length of stay does not increase significantly risk of re-admission and risk of death for the Cox regression models. In order to offer a conservative estimate of when reducing length of stay, we calculate the thresholds at which length of stay does not increase the risk of re-admission and the risk of death without considering statistical significance and we find

Table 6.8: Competing risk analysis regression models for the dependent variable risk of death

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0862***	1.0861***	1.0864***	1.0863***
	(61.42)	(61.29)	(61.43)	(61.01)
`charl_ind`	1.4793***	1.5004***	1.4803***	1.4995***
	(43.56)	(40.42)	(44.23)	(40.23)
`lostay`	1.0546***	1.0583***	1.0619***	1.0618***
	(12.53)	(10.93)	(8.77)	(8.08)
`lostay` * `charl_ind`		0.9952**		0.9955*
		(-2.09)		(-1.93)
`lostay` * `age`			0.9996	0.9998
			(-1.25)	(-0.58)
N. Obs.	636,616	636,616	636,616	636,616
N. of. Hospitals	238	238	238	238
Total time at risk	753,424,721	753,424,721	753,424,721	753,424,721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

	Cox regression		*Competing risk analysis*	
charl_ind	readm	death	readm	death
0	-	-	-	-
1	89	-	-	-
2	18	-	-	-
3	0	-	-	-
4	0	90	-	-
5	0	79	-	-
6	0	69	-	-
7	0	60	46	-
8	0	51	11	-
9	0	43	0	-
10	0	34	0	-
11	0	26	0	-
12	0	17	0	-

Table 6.9: Age threshold (in years) at which increasing length of stay decreases re-admission and death rates significantly ($p < 0.1$)

that (`charl_ind` = `1` and `age` = `71`) are the thresholds of the Cox regression models and that (`charl_ind` = `5` and `age` $\leq$ `33`) are the thresholds for the competing risk analysis models. We select the thresholds of the Cox regression models because they are more stringent than the thresholds of the competing risk analysis models.

We suggest that patients with (`charl_ind` = `0`) and patients with (`charl_ind` = `1` and `age` $\leq$ `71`) should be treated as day cases since decreasing length of stay has a positive effect on their risk of re-admission/death. Since our objective is to minimize costs subject to the constraint of not increasing the risk of re-admission or death for any patient, we also propose not to modify length of stay for patients with (`charl_ind` = `1` and `age` > `71`) or with (`charl_ind` > `1`). The total costs savings of the proposed algorithm are around £354 (US$565) per elective procedure, which equates to a 19.97% reduction in the cost of the surgical procedure.

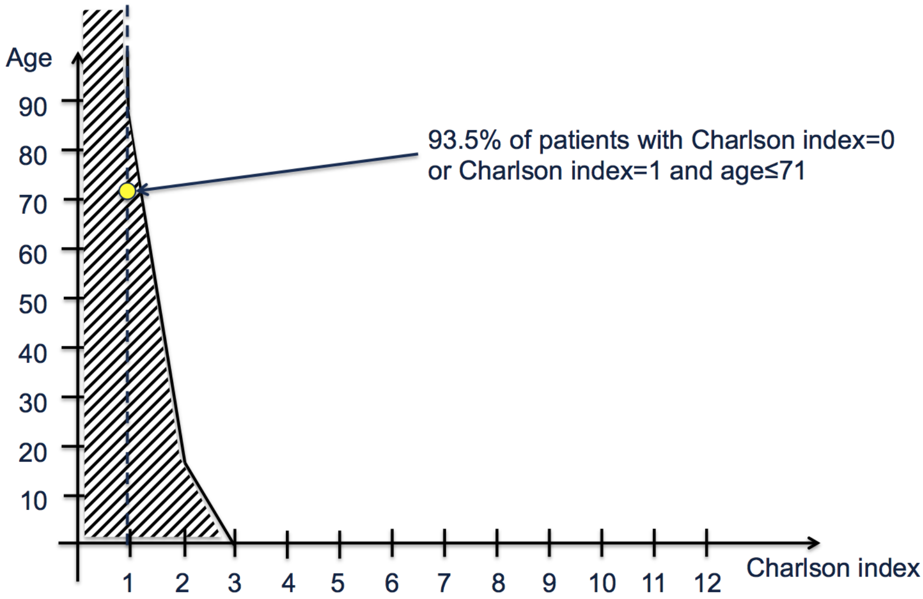


Figure 6.2: Graphical representation of the thresholds at which increasing length of stay decreases re-admission and death rates significantly ($p < 0.1$) for the Cox regression models. The shaded area represents the values of a patient's Charlson index and of a patient's age (in years) at which decreasing length of stay does not increase significantly risk of re-admission and risk of death

6.5.4 Robustness of findings

We perform several robustness tests to assess whether our results are still valid when we change our sample, the definition of our variables, and the models we use [62].

In the first test we run, we use an alternative definition of healthy/sick patient. A sick patient is a patient with a Charlson index greater than 0, while a healthy patient is a patient with no comorbidities. In order to run this test, instead of including the variable `charl_ind`, we include the dummy variable `unhealthy` that is 1 if the Charlson index of a patient is greater than 0, and 0 otherwise. We also run this test for other threshold values of the Charlson index finding results consistent with what previously reported. The results are also consistent with previous findings when we consider the competing risk analysis models[8].

[8]In this case, we have to increase the threshold value of the Charlson index: `unhealthy` is 1 if the Charlson index of a patient is greater than 3, and 0 otherwise

Table 6.10 and Table 6.11 show that the likelihood ratios are less than 0.0001 in all the models for both the outcome variable risk of re-admission and the outcome variable risk of death. In Table 6.10, we see that the odds-ratios of the variables `age`, `unhealthy`, and `lostay` are significant and greater than 1 in all the models. The values of the odds-ratios of the variables `lostay` ∗ `unhealthy` and `lostay` ∗ `age` are, instead, all significant and less than 1.

The values of the odds-ratios of the variables `age`, `unhealthy`, and `lostay` are also significant and greater than 1 in Table 6.11. The odds-ratio of the interaction term `lostay` ∗ `unhealthy` is significant in Model (2) and not significant in Model (3), but both are less than 1. Finally, the value of the odds-ratio of the interaction term `lostay` ∗ `age` is significant and less than 1.

The results reported in Table 6.10 and Table 6.11 support the first and the third hypothesis for both the outcome variables. They support the second hypothesis for the outcome variable risk of re-admission and provide some evidence to support the second hypothesis for the outcome variable risk of death.

In the second test, we increase the minimum number of patients per hospital from 5 to 10. Table 6.12 and Table 6.13 report the results for the outcome variables risk of re-admission and risk of death and show that the likelihood ratios are always less than 0.0001. We do not report the results for the Cox regression models but the findings support what we illustrated in the previous section.

In Table 6.12, we see that the values of the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are significant and greater than 1 in all the models and that the values of the odds-ratios of the interaction term `lostay` ∗ `charl_ind` are also significant but less than 1. While the value of the odds-ratio of the interaction term `lostay` ∗ `age` is less than 1 and significant in Model (3), it is less than 1 and not significant in Model (4).

Table 6.10: Cox regression models for the dependent variable risk of re-admission with alternative variable to identify unhealthy patients `unhealthy` that is 1 if the Charlson index of a patient is greater than 0, and 0 otherwise

Odds-ratio	Model (1)	Model (2)	Model (3)
`age`	1.0252***	1.0252***	1.0252***
	(82.70)	(82.41)	(82.94)
`unhealthy`	1.3534***	1.3755***	1.3739***
	(51.08)	(52.90)	(52.94)
`lostay`	1.0151***	1.0257***	1.0280***
	(6.85)	(7.93)	(8.23)
`lostay` * `unhealthy`		0.9535***	0.9602***
		(-10.07)	(-8.40)
`lostay` * `age`			0.9996***
			(-3.51)
N. Obs.	636,616	636,616	636,616
N. of. Hospitals	238	238	238
Total time at risk	853,760,626	853,760,626	853,760,626
Likelihood Ratio	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.11: Cox regression models for the dependent variable risk of death, with alternative variable to identify unhealthy patients `unhealthy` that is 1 if the Charlson index of a patient is greater than 0, and 0 otherwise

Odds-ratio	Model (1)	Model (2)	Model (3)
`age`	1.1030***	1.1029***	1.1033***
	(118.11)	(118.29)	(118.06)
`unhealthy`	1.9949***	2.0129***	2.0099***
	(72.52)	(70.15)	(69.73)
`lostay`	1.0369***	1.0449***	1.0611***
	(6.92)	(8.23)	(11.49)
`lostay` * `unhealthy`		0.9864*	0.9907
		(-1.72)	(-1.17)
`lostay` * `age`			0.9990***
			(-4.95)
N. Obs.	636,616	636,616	636,616
N. of. Hospitals	238	238	238
Total time at risk	1,270,369,583	1,270,369,583	1,270,369,583
Likelihood Ratio	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.12: Competing risk analysis regression models for the dependent variable risk of re-admission, hospitals with more than 10 patients

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0272***	1.0271***	1.0272***	1.0271***
	(81.84)	(81.59)	(82.12)	(81.71)
`charl_ind`	1.2564***	1.2699***	1.2572***	1.2696***
	(49.13)	(50.32)	(49.50)	(50.37)
`lostay`	1.0352***	1.0386***	1.0377***	1.0396***
	(11.14)	(9.49)	(10.67)	(9.60)
`lostay` * `charl_ind`		0.9911***		0.9915***
		(-4.98)		(-4.67)
`lostay` * `age`			0.9998*	0.9999
			(-1.96)	(-0.79)
N. Obs.	636,609	636,609	636,609	636,609
N. of. Hospitals	237	237	237	237
Total time at risk	753,411,728.	753,411,728	753,411,728	753,411,728
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.13 shows that the values of the coefficients of the variables `age`, `charl_ind`, and `lostay` are also significant and greater than 1 for the outcome variable risk of death. While the values of the odds-ratios of the interaction term `lostay*charl_ind` are less than 1 and significant in all the models, the values of the odds-ratios of the interaction term `lostay * age` are less than 1 but not significant.

These results provide evidence to support the first and the second hypothesis for the outcome variables risk of re-admission and risk of death. They also provide some evidence to support the third hypothesis for the outcome variable risk of re-admission.

Since pediatric hernia surgery is very different from hernia surgery on adults [359], in the third test, we remove from the sample patients that are less than 19. We report the findings of this test only for the competing risk analysis regressions but we also tested the Cox models and did not find any unexpected results. The likelihood ratios reported in Table 6.14 for the outcome variable risk of re-admission and in Table 6.15 for the outcome variable risk of death are both less than 0.0001.

In Table 6.14, we see that, while the odds-ratios of the variables `age`, `charl_ind`, `lostay` are significant and greater than 1 in all the models, the odds-ratios of the variable `lostay * charl_ind` and `lostay * age` are significant and less than 1.

Table 6.15 shows that the odds-ratios of the variables `age`, `charl_ind`, `lostay` are also significant and greater than 1 in all the models when the outcome variable is risk of death. While the odds-ratios of the variable `lostay*charl_ind` are significant and less than 1 in all the models, the odds-ratios of the variable `lostay * age` are never significant, despite being less than 1.

The results reported in Table 6.14 and Table 6.15 provide evidence to support the first and the second hypothesis for both the outcome variables. They also provide evidence to support the third hypothesis for the outcome variable risk of re-admission.

Instead of eliminating observations from patients aged less than 19, it is possible

Table 6.13: Competing risk analysis regression models for the dependent variable risk of death, hospitals with more than 10 patients

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0862***	1.0861***	1.0864***	1.0863***
	(61.42)	(61.29)	(61.43)	(61.00)
`charl_ind`	1.4793***	1.5004***	1.4803***	1.4995***
	(43.56)	(40.42)	(44.23)	(40.23)
`lostay`	1.0546***	1.0583***	1.0619***	1.0618***
	(12.53)	(10.93)	(8.77)	(8.08)
`lostay` * `charl_ind`		0.9952**		0.9955*
		(-2.09)		(-1.93)
`lostay` * `age`			0.9996	0.9998
			(-1.25)	(-0.58)
N. Obs.	636,609	636,609	636,609	636,609
N. of. Hospitals	237	237	237	237
Total time at risk	753,411,728.	753,411,728	753,411,728	753,411,728
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.14: Competing risk analysis regression models for the dependent variable risk of re-admission, patients aged 19 or more

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
age	1.0295***	1.0295***	1.0295***	1.0294***
	(118.95)	(117.67)	(118.98)	(117.99)
charl_ind	1.2524***	1.2657***	1.2541***	1.2648***
	(49.64)	(51.48)	(50.61)	(51.45)
lostay	1.0346***	1.0382***	1.0424***	1.0429***
	(11.03)	(9.31)	(8.88)	(8.48)
lostay * charl_ind		0.9912***		0.9925***
		(-4.93)		(-4.15)
lostay * age			0.9994***	0.9996*
			(-2.96)	(-1.72)
N. Obs.	619,439	619,439	619,439	619,439
N. of. Hospitals	238	238	238	238
Total time at risk	726,641,715	726,641,715	726,641,715	726,641,715
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include eme_ind, focus, foundation, imd_score, laparoscopic, male, n_beds, occupied, private, recurrence, teaching, waitlist, and week_ind.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.15: Competing risk analysis regression models for the dependent variable risk of death, patients aged 19 or more

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
age	1.0868***	1.0868***	1.0870***	1.0869***
	(63.60)	(63.54)	(63.13)	(62.78)
charl_ind	1.4792***	1.5002***	1.4802***	1.4995***
	(43.45)	(40.38)	(44.10)	(40.18)
lostay	1.0542***	1.0577***	1.0607***	1.0606***
	(12.52)	(10.93)	(8.03)	(7.87)
lostay * charl_ind		0.9953**		0.9955*
		(-2.09)		(-1.94)
lostay * age			0.9997	0.9998
			(-1.04)	(-0.45)
N. Obs.	619,439	619,439	619,439	619,439
N. of. Hospitals	238	238	238	238
Total time at risk	726,641,715	726,641,715	726,641,715	726,641,715
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include eme_ind, focus, foundation, imd_score, laparoscopic, male, n_beds, occupied, private, recurrence, teaching, waitlist, and week_ind.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

to include in the models a dummy variable indicating whether the patient is less than 19. In Table 6.16 and Table 6.17, we report the results of the competing risk analysis models for the outcome variables risk of re-admission and risk of death, where we can see that the likelihood ratios are again less than 0.0001 in all the models. We also run this test for the Cox regression models and found results consistent with what previously reported.

Table 6.16 indicates that the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are significant and greater than 1 in all the models and that the odds-ratios of the interaction term `lostay` ∗ `charl_ind` are significant and less than 1. The odds-ratio of the interaction term `lostay` ∗ `age` is neither significant in Model (3), nor in Model (4).

In Table 6.17, we also see that the values of the odds-ratios of the variables `age`, `charl_ind`, and `lostay` are significant and greater than 1 when the outcome variable is risk of death. The values of the odds-ratios of the interaction term `lostay`∗`charl_ind` are also significant but less than 1. Finally, the values of the odds-ratios of the interaction term `lostay` ∗ `age` are less than 1 but not significant neither in Model (3), nor in Model (4).

The results displayed in Table 6.16 and Table 6.17 support the first and the second hypothesis. The evidence to support the third hypothesis is limited to the coefficients of the odds-ratios being less than 1.

In the next test, we include an additional dummy variable `age65` that is 1 if the patient is more than 65, and 0 otherwise. Moreover, instead of using the interaction term `lostay`∗`age`, we use the interaction term `lostay`∗`age65`. We report the odds-ratios & z-tests for the competing risk analysis models but we also run the Cox regressions, finding consistent results for all the models but for Model (4) when the outcome variable is risk of death. In this case, we find that `lostay` ∗ `age65` is not significant. Table 6.18

Table 6.16: Competing risk analysis regression models for the dependent variable risk of re-admission using the variable `child` that is 1 if the patient is less than 19, and 0 otherwise, to control for pediatric surgery

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0291***	1.0291***	1.0291***	1.0291***
	(118.26)	(117.11)	(118.46)	(117.16)
`charl_ind`	1.2527***	1.2658***	1.2534***	1.2656***
	(49.54)	(51.10)	(49.85)	(51.20)
`lostay`	1.0344***	1.0377***	1.0358***	1.0380***
	(11.02)	(9.43)	(10.27)	(9.32)
`lostay` * `charl_ind`		0.9914***		0.9916***
		(-4.94)		(-4.70)
`lostay` * `age`			0.9998	1.0000
			(-1.37)	(-0.38)
N. Obs.	636,616	636,616	636,616	636,616
N. of. Hospitals	238	238	238	238
Total time at risk	753,424,721	753,424,721	753,424,721	753,424,721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `child`, `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.17: Competing risk analysis regression models for the dependent variable risk of death using the variable `child` that is 1 if the patient is less than 19, and 0 otherwise, to control for pediatric surgery

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age`	1.0867***	1.0866***	1.0869***	1.0867***
	(63.41)	(63.30)	(63.49)	(63.11)
`charl_ind`	1.4790***	1.5001***	1.4799***	1.4994***
	(43.48)	(40.39)	(44.06)	(40.21)
`lostay`	1.0546***	1.0582***	1.0607***	1.0612***
	(12.55)	(10.95)	(10.18)	(9.07)
`lostay` ∗ `charl_ind`		0.9952**		0.9955*
		(-2.09)		(-1.95)
`lostay` ∗ `age`			0.9997	0.9998
			(-1.38)	(-0.59)
N. Obs.	636, 616	636, 616	636, 616	636, 616
N. of. Hospitals	238	238	238	238
Total time at risk	753, 424, 721	753, 424, 721	753, 424, 721	753, 424, 721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `child`, `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

and Table 6.19 show that the likelihood ratios are less than 0.0001 in all the models.

In Table 6.18, we see that the odds-ratios of the variables `age65`, `charl_ind`, and `lostay` are significant and greater than 1 in all the models and that the odds-ratios of the interaction term `lostay` $*$ `charl_ind` are significant and less than 1. The odds-ratio of the variable `lostay` $*$ `age` is less than 1 and significant in Model (3) and less than 1 and not significant in Model (4).

Table 6.19 shows that the odds-ratios of the variables `charl_ind` and `lostay` are significant and greater than 1 in all the models and that the odds-ratios of the variable `age65` are not significant. While the odds-ratios of this dummy variable are not significant, the odds-ratios of the variable `age`, not reported in the table, are significant and greater than 1. The odds-ratios of the interaction term `lostay` $*$ `charl_ind` are significant and less than 1 in all the models but the odds-ratios of the interaction term `lostay` $*$ `age65` are not significant.

These results support the first and the second hypothesis for both the outcome variables. They also provide limited support to the third hypothesis for the outcome variable risk of re-admission. We run this test also on patients older than 80, finding additional evidence to support the third hypothesis for the outcome variable risk of re-admission.

We also perform a test to verify whether in-hospital mortality introduces a bias on the regression results for the outcome variable risk of death, censoring patients that die during the hospital stay. The results provide other evidence to support the first, the second and the third hypothesis.

Finally, we run a test in which we use conditional logistic regression on a sample representing 1% of the data since the whole dataset is too large for Stata 11.2 to find a solution. Also this test provides evidence to support the first and the second hypothesis, and evidence to support the third hypothesis limited to the coefficients of

Table 6.18: Competing risk analysis regression models for the dependent variable risk of re-admission, with alternative variable to identify old patients `age65` that is 1 if a patient is more than 65, and 0 otherwise

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age65`	1.2411***	1.2401***	1.2407***	1.2400***
	(20.90)	(20.75)	(20.83)	(20.72)
`charl_ind`	1.2518***	1.2646***	1.2527***	1.2642***
	(48.91)	(50.13)	(49.17)	(50.23)
`lostay`	1.0350***	1.0383***	1.0428***	1.0418***
	(11.09)	(9.45)	(6.87)	(6.69)
`lostay` * `charl_ind`		0.9915***		0.9920***
		(-4.81)		(-4.27)
`lostay` * `age65`			0.9892*	0.9948
			(-1.66)	(-0.71)
N. Obs.	636, 616	636, 616	636, 616	636, 616
N. of. Hospitals	238	238	238	238
Total time at risk	753, 424, 721	753, 424, 721	753, 424, 721	753, 424, 721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `age`, `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.19: Competing risk analysis regression models for the dependent variable risk of death, with alternative variable to identify old patients `age65` that is 1 if a patient is more than 65, and 0 otherwise

Odds-ratio	Model (1)	Model (2)	Model (3)	Model (4)
`age65`	1.0524 (1.22)	1.0502 (1.18)	1.0530 (1.23)	1.0501 (1.18)
`charl_ind`	1.4791*** (43.66)	1.5001*** (40.50)	1.4793*** (43.74)	1.5002*** (39.99)
`lostay`	1.0547*** (12.49)	1.0583*** (10.90)	1.0580*** (5.67)	1.0575*** (5.57)
`lostay` * `charl_ind`		0.9953** (-2.09)		0.9952** (-2.00)
`lostay` * `age65`			0.9965 (-0.32)	1.0008 (0.07)
N. Obs.	636,616	636,616	636,616	636,616
N. of. Hospitals	238	238	238	238
Total time at risk	753,424,721	753,424,721	753,424,721	753,424,721
Likelihood Ratio	<0.0001	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables include `age`, `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

the odds-ratios being less than 1.

Along with the previous robustness checks, we investigate reverse causality running a Granger causality test [116] on the monthly time-series for length of stay, re-admission, and death rates and finding that length of stay is Granger causing[9] re-admission and death rates ($p < 0.0001$). However, the test does not provide evidence to support the alternative hypothesis that re-admission and death rates are Granger causing length of stay.

As a further check of the robustness of the findings of this study to extrapolation, a bias introduced by the existence of missing data, we employ Propensity Score Matching (PSM), a tool to randomize an experiment based on the unconfoundedness assumption [122, 334]. For a binary treatment t with a binary outcome y and an array of variables $\boldsymbol{z}$, which determines whether t is 1 or 0, the unconfoundedness assumption is [122]:

$$y \perp\!\!\!\perp t|\boldsymbol{z}$$

If t is the binary variable `binary_lostay` which is 1 if the patient stays overnight, and 0 otherwise, and $\boldsymbol{y}$ is a binary variable that is 1 if the patient is re-admitted or dies, the assumption states that given the array of variables $\boldsymbol{z}$, re-admission/death does not depend on staying overnight. In other words, when we consider a homogenous subgroup in a sample, the outcome does not depend on the treatment. The variables we include in $\boldsymbol{z}$ are: `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`. We also include the variable `friday`, which is 1 if the date of admission of the patient is on Friday, and 0 otherwise. Since hospitals are more likely to discharge patients on Fridays because they want to reduce the workload during the weekend [173], we find

[9] We use the expression "to Granger cause" when the Granger test supports a causality hypothesis between two time-series [116]

that patients admitted on Friday are more likely to be discharged on the same day[10]. That said, the propensity score is a variable $p(\boldsymbol{z})$, which measures the probability of a patient to be re-admitted or die. If the unconfoundedness assumption holds then [122]:

$$y \perp\!\!\!\perp t | p(\boldsymbol{z})$$

Since, given $p(\boldsymbol{z})$, y does not depend on t, the condition for randomizing an experiment is that $p(\boldsymbol{z})$ is known. We can calculate $p(\boldsymbol{z})$ using a binary regression in which t is the dependent variable and the regressors are the variables of the array $\boldsymbol{z}$ [122]. Since the incidental parameter problem affects binary models when we include fixed-effects [185], we use tobit regression to calculate the predicted values of the treatment outcomes, computing the probability that length of stay is greater than 0.5. We still run, for comparison purposes, a logistic regression model since there is evidence that the incidental parameter problem tends to become non-relevant when the number of observations in the panel approaches the value of 4 [119]. We include the values of $p(\boldsymbol{z})$ to run the Cox regression models and assess the impact of t on y [70].

While the previous paragraphs show how to model the impact of length of stay on the outcome variable, we need to formulate a model to measure the effects of state of health and age. In order to model this interaction, we follow the recommendations by van Eeren et al. [332] and define a variable `old_sick` that is 1 if the patient is sick and old according to the thresholds defined in the first two columns of Table 6.9, and 0 otherwise. The choice to use a univariate model rather than a multivariate model is because of the multicollinearity we find in the latter model. In summary, we employ three models: Model (C1) without the propensity score and with the original control

[10] We also run the PSM models with the variable `pres_priv`, which is 1 if there are NHS patients that go to private hospitals in the same geographical area of the public hospital where the operation is performed, and 0 otherwise. We find results that are consistent with the models that include only `friday`

variables, Model (PS1.a) with the propensity score calculated using a tobit regression, and Model (PS1.b) with the propensity score calculated using a logistic regression. We report the results of the regressions in Table 6.20 for the dependent variable risk of re-admission and in Table 6.21 for the dependent variable risk of death.

In Table 6.20, we see that while the values of the odds-ratios of `old_sick` and `binary_lostay` are significant and greater than 1 in all the models, the values of the odds-ratios of `binary_lostay` $*$ `old_sick` are always significant and less than 1. The values of these variables provide evidence again to support the first, the second, and the third hypothesis and suggest that the randomization introduced by the propensity score does not affect the results we found with the other regressions. Also the likelihood ratio is < 0.0001 in all the models.

As shown in Table 6.21, the results for the dependent variable risk of death are consistent with the results for the dependent variable risk of re-admission. The odds-ratios of `old_sick` and `binary_lostay` are significant and greater than 1 in all the models and the odds-ratios of `binary_lostay` $*$ `old_sick` are significant and less than 1. The likelihood ratio is < 0.0001 in all the models and, also in this case, the use of the propensity scores does not affect our results: the outcomes of the regression provide evidence to support the first first, the second, and the third hypothesis.

6.6 Discussion

In this paper we have put the notion that reducing length of stay improves patient outcome to the empirical test. We find that, for the majority of patients, decreasing length of stay is associated with lower risk of re-admission and risk of death, a result consistent with the current recommendations of the National Institute for Clinical Excellence and of the Royal College of Surgeons for the inguinal hernia procedure [221, 275].

	Model (C1)	Model (PS1.a)	Model (PS1.b)
`old_sick`	4.2784***	4.3546***	4.3925***
	(8.34)	(8.09)	(8.26)
`binary_lostay`	1.5713***	1.5807***	1.6146***
	(55.26)	(55.16)	(58.00)
`binary_lostay*old_sick`	0.3334***	0.3397***	0.3516***
	(-6.33)	(-5.97)	(-5.86)
N. Obs.	636,616	636,616	636,616
N. of. Hospitals	238	238	238
Total time at risk	853,760,626	853,760,626	853,760,626
Likelihood Ratio	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables in Model (C1) include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`. Propensity scores in Model (PS1.a) and Model (PS1.b) are calculated using control variables and the instrumental variable `friday`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.20: Cox regression (C1) and Propensity score (PS1.a and PS1.b) models for the dependent variable risk of re-admission

Our results, however, also show that reducing length of stay may not be equally beneficial to all patient groups. Enforcing a uniform policy to reduce length of stay is likely to cause higher re-admission and death rates for some of the patients, or more specifically, for vulnerable and older patients. Our results suggest that a customized policy to deliver health care to different types of patients may lead, overall, to better outcomes. We have not found any evidence that decreasing length of stay for inguinal hernia patients, on aggregate, worsens hospital outcomes - thus confirming the recommendations of the National Institute for Clinical Excellence and of the Royal College of Surgeons [221, 275]. Secondly, we show that longer stay may expose healthy patients to the risk of infections and, based on this result, we suggest the logic of a customized

	Model (C1)	Model (PS1.a)	Model (PS1.b)
`old_sick`	42.6894***	47.2675***	47.1595***
	(23.06)	(23.31)	(23.15)
`binary_lostay`	3.4361***	3.3655***	3.5167***
	(53.10)	(51.27)	(56.10)
`binary_lostay*old_sick`	0.2393***	0.2310***	0.2603***
	(-8.29)	(-8.46)	(-7.77)
N. Obs.	636,616	636,616	636,616
N. of. Hospitals	238	238	238
Total time at risk	1,270,369,583	1,270,369,583	1,270,369,583
Likelihood Ratio	<0.0001	<0.0001	<0.0001

Notes. Standard errors are clustered at the hospital level. Asymptotic z-tests are reported in parentheses. Control variables in Model (C1) include `eme_ind`, `focus`, `foundation`, `imd_score`, `laparoscopic`, `male`, `n_beds`, `occupied`, `private`, `recurrence`, `teaching`, `waitlist`, and `week_ind`. Propensity scores in Model (PS1.a) and Model (PS1.b) are calculated using control variables and the instrumental variable `friday`.
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 6.21: Cox regression (C1) and Propensity score (PS1.a and PS1.b) models for the dependent variable risk of death

policy that would only extend the length of stay for hernia patients with a certain combination of age and vulnerability.

We validated our findings by discussing our hypotheses with three general surgeons, also asking them to outline the common reasons for not discharging hernia patients on the same day of the surgery. Their opinions were largely consistent with the results found in this research, suggesting that only vulnerable and old patients should stay longer in the hospital after the surgery to be more closely supervised than otherwise possible. Healthy patients that are not discharged on the same day of the operation are, in most cases, patients that choose to stay in the hospital after the surgery. Surgeons often do not contest these decisions because of the risk of being sued for medical malpractice. From a policy point of view, this patient group represents a major opportunity to reduce the average cost per procedure. We estimate that possible savings from reducing unnecessary stays alone to be £354 (US$565) per elective procedure, which equates to a 19.97% reduction in the average cost of the surgical procedure[11]. Extrapolated to the total number of 553, 413 inguinal hernia procedures performed, this represents a potential cost saving of £195, 908, 202 (US$312, 678, 345).

Our findings make two main contributions. Firstly, we contribute to the growing field of health care operations management, and, in particular, to the debate on adopting standard policies for health care procedures [31, 37]. It has been suggested that standard policies such as decreasing length of stay are needed to curb costs and increase the quality of health care [37], our findings qualify this argument by showing that an excessive emphasis on standard solutions can increase long-term costs. We find that standard policies - while beneficial on aggregate - are not always associated with better results and that customized solutions can decrease failure costs. We have proposed and implemented a method to identify the thresholds at which a standard policy may lead to adverse outcomes. Here, offering a differentiated policy is an effective strategy to decrease long-term failure costs. We also wonder whether the implementation of such policies is a choice in the hands of the hospital managers or becomes a 'necessity' for the whole health system in order to curb hospital costs and decrease re-admission and death rates.

Secondly, we contribute to the discourse on the impact of decreasing service time on patient outcome. Prior studies have suggested that decreasing processing time has a negative impact on hospital outcomes because doctors start to "cut corners" when they deliver care to patients [182] or they "become tired" [171]. We show that other

[11]These savings are calculated on the basis of cutting unnecessary long stay for healthy patients. These estimates are conservative because it has not been possible to estimate the additional cost of unnecessary re-admissions of vulnerable and older patients, which would further contribute to these savings

factors such as HAIs may also play a significant role in offsetting the negative impact of shorter length of stay. Empirical evidence to support this argument has also been previously provided by [34]. We extend this work by including hospital effects that so far have not been considered.

Overall our results show that - as a field - we are only beginning to understand the full implications of the implementation of standard policies. More research is needed to identify all relevant variables that determine patient outcome, the immediate cost of the respective procedure, as well as any failure cost that may result in the longer term.

Chapter 7

Conclusions

7.1 Summary of findings

The three essays of this thesis investigate health care operations management to support improved managerial decisions in the NHS. Chapter 4 showed that inguinal hernia admission rates are decreasing in the study period of this research and that, while average length of stay is decreasing, re-admission rates are increasing significantly. Moreover, women are twice more likely than men to undergo inguinal hernia surgery in emergency settings and in-hospital mortality after an emergency admission does not show any significant variation across years. This essay contributes to the knowledge on the provision of inguinal hernia care in the NHS and highlights some of the issues related to it. In Chapter 5, I showed that decreasing the focus on a surgical procedure of a department in a general hospital is correlated with an increase in health care costs for that surgical procedure. Furthermore, I found limited evidence on the benefits of spillovers and complementarities in general hospitals and I suggested that co-specialization may not be useful for hospital managers to reduce the possible negative effects of loss of focus. Finally, in Chapter 6, this research found that decreasing length of stay is related to negative long-term outcomes such as the increase of risk of re-admission and risk of death. The findings of this essay are used to suggest the logic of a customized policy that has the aim to decrease health care costs without increasing the risk of re-admission/death for NHS patients. This essay contributes to the theory on standard policies and suggests that failure costs are an aspect that needs to be taken into account when hospitals implement them.

7.2 Implications and limitations

In Chapter 1, I introduced the Shouldice Hospital that has been touted as the ideal hospital to treat hernia patients, e.g., [61, 143]. One of the reasons why the NHS is increasing the number of patients that go to small private specialty hospitals is to replicate the model of care of the Canadian hospital [225]. More in general, the objective of the British health care system is to satisfy the need for an increasing demand of health care services without additional burdens for the pockets of the taxpayers [329]. As mentioned in Section 7.1, this work suggests that if public hospitals become less focused on a surgical procedure because a part of their patients go to private hospitals, NHS costs for that procedure may increase. Further research will have to investigate the effect of loss of focus on a procedure not only on the cost to perform that procedure but also on overall hospital costs. Moreover, while there is some evidence that private hospitals are not more efficient than public hospitals [315], future studies will have to investigate whether more competition is needed to increase the efficiency of private providers.

In order to provide a solution to the current problems in the NHS, hospital managers can also follow the example of the Virginia Mason Medical Center. The Virginia Mason Medical Center has many aspects in common with NHS hospitals. It is a general hospital that was recording financial losses and that needed to implement a new model of management [33]. In order to curb costs, among the other initiatives undertaken, this hospital started the mapping of the processes that deliver value to the patients with the ambition to standardize the provision of care [31]. The implementation of standard policies to manage health care delivery, together with the adoption of a model of care based on lean, was successful and the hospital was able to return to profit [33].

While standard policies can be a successful strategy to cut costs, this dissertation suggests that customized solutions may also be required since standard solutions can have negative outcomes for some classes of patients and can increase NHS long-term costs. For this reason, the NHS may need to increase its emphasis on providing customized solutions to sick and old patients. Given these considerations, when we consider the American context, where, as discussed in [255], short term solutions to patients' current needs are more common than solutions that consider the whole cycle of care, the new regulations introduced with the "Patient Protection and Affordable Care Act" [203], such as the penalties for hospitals with high re-admission rates [173], could have a possible positive impact on hospital customization of standardized policies. More research is needed to further investigate the relationship between health care incentives and adoption of customized policies and the impact on overall costs.

The results of this work also offer a framework to discuss some of the effects of the measures contained in the "Social and Health Care Bill." Since previous literature has suggested that private hospitals have a preference to admit easy to treat patients [316], a further increase in the number of patients that go to private care may mean that public hospitals will have to manage more complex cases. If public hospitals do not decrease the number of hernia patients they treat and since more complex cases may need more days to recover, there may be a need to expand the capacity of the current hospitals or to build new hospitals. If, instead, there is a political decision not to expand the capacity of the public health care system, there may be a reduction of the volumes of patients undergoing inguinal hernia surgery.

This dissertation also introduced the concept of patient-centered care and how changing the allocation of resources in a health care system affects hospital outcomes. The debate on patient-centered care is also one of the limitations of this work since the philosophical foundations of it can be further discussed, for example, studying how to balance the need to curb costs with patients' expectations in terms of satisfaction and quality of health care delivery. At one end, when the patient is able to choose the path of care in full autonomy, one of the possible risks is that there is an increase in the provision of unnecessary services [24], for example when treatment decisions are conditioned by marketing and not by medical expertise. This reason can, to a certain extent, explain why the American system is so expensive, with average expenses per patient that were 2.5 times higher than the average expenses per patient in the British system in 2013 [324]. At the other end, when the health care system decides how to satisfy the needs of the patients with the objective to maximize the quality of care for all the patients, the risks could be ethical. Many of those who were opposing the "Patient Protection and Affordable Care Act," were claiming that it was leading to the creation of "death panels" [250] with the power to decide on the life or death of individual citizens such as people with disabilities, people with Down syndrome, or the elderly. While the risk of creating "death panels" has been debunked during the process of reform, the question on how to balance the needs of a single patient with the necessity to provide universal care remains unanswered. The definition of measures such as the QALY [96] in the British system that try to find a trade-off between these objectives are certainly a starting point to address this issue but, given the complexity of the subject, they, clearly need to be further explored and discussed.

Another problem that needs to be further investigated by future research is hospital-acquired infections (HAIs). As shown in Chapter 6, while there are international guidelines on how to decrease the rates of HAIs, the risk of acquiring a hospital infection in England is still high [22, 216] and, as discussed in Chapter 6, it is one of the possible reasons that explains why longer length of stay is associated with worse outcomes. High rates of HAIs are also common in many other OECD countries and cause thousands of avoidable deaths every year [352]. It is not clear why hospitals do not adopt sufficient measures to reduce this risk and what incentives could change these behaviors. One of the pillars of the "Health and Social Care Bill" [81], which is likely to have a positive impact in addressing this problem, is the generation of information measuring hospital performance. There are, in fact, examples of success in reducing infection rates in the NHS based on the use of information on the number of infected patients, e.g., [68, 311]. Technology has also the potential to offer solutions to address this problem, for example, with devices that increase the likelihood of hospital staff to wash their hands. PullClean© [264] is an example of this type of devices: it is a handle dispensing soap that can be mounted on hospital doors, forcing doctors and nurses to wash their hands when they enter a room to visit a new patient.

7.3 Final considerations

The need to reduce health care costs without decreasing the level of service in hospitals is both urgent and complex. It is urgent because, as discussed, there are fewer financial resources available [244] and the costs of care are increasing. Patients are becoming older, sicker, and more obese [51] and the technologies to treat them are becoming more expensive [244]. It is complex because there are no obvious solutions to it and, even when there are, hospitals are organizations incredibly resistant to change, as it is in the case of the non-application of measures to prevent HAIs.

In Chapter 2, I illustrated the research in health care operations management and I showed that there are four main areas on which researchers focus on: processes, IT, mathematical modeling, and patient-centered care. In order to satisfy the needs of the patient and to reduce costs, health care operations management is emphasizing the study of health care process design and is trying to enhance process efficiency with technology, information, and mathematical models for EBM. The study of process design begins with an understanding of the objectives to achieve and of how to achieve them. In the framework of this literature, the aim of this thesis was to contribute to the definition of the issues of health care delivery in England and to propose solutions to address them. In the same words of Dante at the conclusion of his journey through Hell, Purgatory, and Heaven, in the moment of the comprehension of everything, doing research is like being a geometer trying to square a circle. For this reason, despite contributing to the body of current knowledge, any doctoral thesis is just the starting point for future research.

Glossary

Charlson index score measuring a patient's state of health [58].

cholecystectomy surgical procedure to remove a patient's gallbladder.

colorectal resection surgical procedure to remove a part of a patient's large intestine.

complementarity joint effect of focus and co-specialization on the ability of an organization to provide a service or to manufacture a product [272].

case-mix characteristics of the patient base treated by a health care provider.

comorbidity additional condition that affects a patient's state of health.

Continuous Inpatient Spell(CIP) patient's stay in hospital from admission to discharge.

Cox regression survival model to assess the relative risk of an event [121].

curbside consultation consultation in an informal environment [62, 241].

day case patient that leaves the hospital the same day he/she entered.

Diagnosis Related Group(DRG) classification of a hospital episode adopted in the United States for cost accounting purposes.

diversification variety of businesses in which a company engages [118].

emergency admission admission to hospital for prompt treatment via the A&E department, a GP, a consultant, or the Bed Bureau [237].

ergonomics study of the design of a manufacturing/service facility to maximize its productivity [137].

explicit knowledge knowledge that can be codified formally [117].

externalization mechanisms to formalize tacit knowledge [239].

Finished Consultant Episode (FCE) a medical episode managed by a single consultant.

focus emphasis of an organization on a process, product or geographical area [201].

foundation status that grants a hospital greater financial and managerial powers [217].

Hausman test statistical test to assess whether the random-effects estimator is inconsistent [19].

hernia protusion of a viscus through the cavity that contains it [92].

general surgery abdominal surgery.

Granger causality causality relationship assessed with the test developed by C. Granger [116].

Health Related Group (HRG) classification of a hospital episode adopted in the United Kingdom for cost accounting purposes.

Index of Multiple Deprivation (IMD) score score that measures a patient's social, economic and housing issues [174].

instrument variable that has a correlation with the outcome variable of a statistical model but not with its error term [350].

Integrated Practice Unit organizational structure, proposed by M. E. Porter and E. O. Teisberg [255], centering around a patients' clinical conditions.

internal market transactions occurring inside of a system.

job shop production system that processes a large variety of products in low volumes.

laparoscopic surgery key-hole surgery.

length of stay number of days between patient's admission and discharge from hospital.

opportunity costs are what is foregone when a choice is made [47].

ordinary admission scheduled hospital admission.

Propensity Score Matching (PSM) statistical method to randomize retrospective data [122].

re-admission inpatient admission follows a previous admission to hospital.

recurrence repeated occurrence of a surgical operation.

Sargan-Hansen statistics Hausman-like test used for models that include clustered standerd errors [62, 285].

socialization mechanisms to transfer tacit knowledge from an individual to another individual [239].

spillover effect of co-specialization on the ability of an organization to provide a service or to manufacture a product [272].

tacit knowledge as defined by M. Polanyi [252], is the "knowledge that cannot be put into words."

tariff payment made to a hospital for the reimbursement of the services they provide to patients.

teaching hospital hospital that is part of a University.

throughput quantity of work that a production system processes in a unit of time.

tunnel vision exclusion of other points of view when interpreting reality.

Value-Adding Process (VAP) clinic specialized clinic, proposed by C. M. Christensen et al. [61], aimed at treating a patient after a diagnosis has already been made.

workload quantity of work that a production system needs to process in a unit of time [171].

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