Essays on Hospital Performance in England

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Abstract

This thesis contributes to the policy debate on the performance of health systems. It investigates performance dimensions such as quality and efficiency focusing on hospitals in the English National Health Service. The thesis comprises four chapters, of which the first two contribute to the limited literature on specialist hospitals. The first chapter analyses efficiency, as measured by the patient's length of stay, between specialist orthopaedic hospitals and 'trauma and orthopaedics' departments in general hospitals. The findings suggest that there are no differences in efficiency between specialist and general hospitals. The second chapter examines whether profit margins differ between specialist orthopaedic hospitals and trauma and orthopaedics departments. It finds that, under the current payment system, specialist orthopaedic hospitals have lower profit margins compared to general hospitals. This is because specialist orthopaedic hospitals admit patients that are older and more complex (i.e. more diagnoses and procedures). The third and fourth chapter contribute to the literature on hospital competition. The third chapter explores whether a hospital's quality or efficiency responds to its neighbouring rivals'. This chapter models hospital interactions within an econometric spatial framework. Although the theory suggests that hospitals might respond to their rivals' quality but not directly to efficiency, the empirical results indicate the absence of interactions across rival hospitals in both quality and efficiency. The fourth chapter studies whether the introduction of the Choice policy in 2006, which encouraged competition among hospitals, had an effect on efficiency as measured by resource management and cost indicators. The findings show that competition improves efficiency through an increase in admissions per bed and proportion of day cases, and a decrease in the proportion of wasted meals. It however reduces efficiency by increasing the number of cancelled elective operations. Competition tends to stimulate efficiency in highly competitive areas or when efficiency is low.

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Preface

Healthcare is one of the most relevant sectors in both developed and developing economies. Its growing share of gross domestic products and the increasing resource scarcity raise the question of how to best organise the delivery of healthcare services. In the last decades, the members of the Organisation for Economic Co-operation and Development (OECD) have encouraged health systems towards greater responsiveness, affordability, and efficiency in order to provide services that are accessible and of high quality (Docteur, 2004, OECD, 2017). Although all important, these goals do not necessarily move in the same direction. A responsive system accommodates patients' needs and preferences through, for example, shorter waiting times or a wider choice of providers for long-term care. Similarly, systems fostering fair access to healthcare will, for example, strengthen their workforce or extend the use of new medical technologies. Such interventions are however costly and represent a challenge for any country's budget. A more efficient delivery of healthcare services may help to deal with budget constraints but only to the extent that higher efficiency does not affect the quality of services. The way of achieving a good balance of these ambitious objectives is still the subject of a lively debate.

This thesis contributes to this policy debate by providing empirical evidence on some performance dimensions including quality and efficiency. It focuses on hospitals in the English National Health Service (NHS), which provides healthcare that is universal, tax financed, and free at the point of use. Public hospitals deliver secondary healthcare and are run by trusts, some of which are called Foundation Trusts with greater financial autonomy.[1] Some hospital trusts are teaching trusts providing research and teaching, and some are specialist trusts focusing on a limited range of conditions or client groups. Private hospitals are small and mostly focus on elective surgical procedures. Unlike public hospitals, private providers can refuse to treat highly severe

[1] Although the separation between NHS foundation trusts and NHS trusts still exists, the financial autonomy of foundation trusts has been in practice eroded in the last years up to the point where they can no longer decide how to invest their surplus (Collins, 2016).

patients (Mason et al., 2008).[2] Hospitals are mainly funded through a prospective payment system, the National Tariff Payment System, that pays a fixed tariff for each patient treated. The tariff value depends on diagnoses, procedures, and some patient characteristics as categorised by a patient classification system called the Healthcare Resource Group (HRG). In this context, hospitals compete on quality to attract patients because the latter are free to choose their preferred hospital for any elective procedure. Hospitals are also incentivised to improve efficiency in order to increase profits, which must be reinvested within the hospital.

Given such an institutional framework, the thesis is structured into two parts, with each part including two chapters. The first part investigates whether specialist orthopaedic hospitals are more efficient and financially viable compared to general hospitals. The second part relates to hospital competition and explores whether competition triggers strategic interactions across hospitals in quality and efficiency, and whether competition affects various dimensions of efficiency.

The first part of the thesis contributes to the limited literature on specialist hospitals. Specialisation is an organisational form which is supposed to generate the benefits of the 'focused factory', i.e. greater efficiency, quality, and responsiveness (Skinner, 1974, Herzlinger, 1996, Schneider et al., 2008) but not necessarily lower costs. Recent empirical findings show that specialist hospitals have similar or higher costs, are more inefficient, and apply higher charges compared to general hospitals (MedPAC, 2005, Carey et al., 2007, Kim et al., 2013, Carey et al., 2015).

More precisely, the first two chapters investigate efficiency and profit margins of specialist orthopaedic hospitals. The NHS includes more than 200 general hospitals with a T&O department

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[2] This has led to an ongoing debate because of the greater financial burden generated on public hospitals (e.g. Wallace, 2006).

and three specialist orthopaedic hospitals. Although there are few specialist orthopaedic hospitals, they play an important role. They deliver a high proportion of specialised services, commonly low-volume but high-cost treatments for patients with complex and rare conditions. Specialist orthopaedic hospitals therefore allow the achievement of a critical mass of clinical expertise to ensure patients receive specialised treatments that produces better health outcomes (NHS commissioning board, 2012). The focus is on specialist orthopaedic hospitals because trauma and orthopaedics (T&O) is one of the specialties with the highest volume of patients.

Chapter 1 investigates efficiency between specialist orthopaedic hospitals and T&O departments within general hospitals in England. It analyses a large sample of patients admitted to a T&O department in 2011/12. Efficiency is measured through the patient's length of stay (LOS). Following Laudicella et al. (2010), LOS is analysed using a two-stage regression model. In the first stage, LOS is regressed on various patient characteristics (e.g. age, gender, diagnosis) and hospital fixed effects. The estimated hospital fixed effects, which capture risk-adjusted relative performance, are regressed in the second stage to compare efficiency between specialist orthopaedic hospitals and T&O departments after accounting for some hospital characteristics (e.g. quality, size, input prices). The idea behind this approach is that LOS is likely to reflect solely hospital efficiency after allowing for patient and hospital characteristics that may be confounded with efficiency. The key finding suggests that there is no statistical difference in efficiency between specialist orthopaedic hospitals and T&O departments in general hospitals.

Chapter 2 investigates the financial viability of specialist orthopaedic hospitals relative to T&O departments in general hospitals. Its primary objective is to test whether the current prospective payment system covers the costs of specialist orthopaedic hospitals relative to T&O departments in general hospitals. In other words, the chapter tests whether costs of specialist orthopaedic hospitals are higher than T&O departments in general hospitals even after accounting for differences in revenues.

Data at HRG level are collected from the NHS reference cost database for the financial year 2013/14. Such data allow the analysis of the unit cost per patient of every inpatient HRG delivered through the T&O department of each hospital trust in the sample. The econometric strategy employs four regressions. The first regression provides raw differences in unit costs between specialist orthopaedic hospitals and T&O departments. The second regression compares unit costs after controlling for differential payments (due to different HRGs and other tariff corrections). This is the key model and provides differences in profit margins between the two types of hospital. The third regression explains any differences in profit margins as a function of possible determinants including some patient and hospital characteristics. The fourth regression examines the heterogeneity in profit margins across specialist hospitals. These models are estimated by weighted least squares, clustering standard errors within hospitals.

The findings suggest that specialist orthopaedic hospitals have on average 13% lower overall profit margins than T&O departments. The results show also that the overall profit margins in specialist orthopaedic hospitals are no longer significantly different from those in T&O departments after controlling for some patient characteristics such as patient age and severity as captured by number of diagnoses and procedures. Finally, none of the three specialist orthopaedic hospitals have profit margins significantly above the average: two of them have profit margins that are significantly below the average, while the third one has average profit margins.

The second part of the thesis mostly relates to the empirical literature on hospital competition. This literature studies the relationship between hospital competition and some dimensions of hospital performance such as quality and efficiency providing mixed results. The first studies originate from the US (e.g. Joskow, 1980, Robinson and Luft, 1985, Bamezai et al., 1999) but there exist a number of later studies focusing on European countries, especially the UK. Some of these find that competition increases efficiency (Cooper et al., 2012, Gaynor et al., 2013) while others report no association (Söderlund et al., 1997). Concerning the effects of competition on quality, some studies find negative effects (Propper et al., 2004, Propper et al., 2008) or positive effects (Cooper et al., 2011, Gaynor et al., 2013, Bloom et al., 2015), some find mixed effects based on the quality indicator (Gravelle et al., 2014a), and some find no effects (Berta et al., 2016).

Chapter 3 studies hospitals' strategic interactions on quality and efficiency. This approach is an alternative to examining the relationship between measures of competition and hospital quality and efficiency. In a competitive environment, a hospital may be expected to respond to an increase in quality by a rival hospital by also increasing quality. Similarly, a hospital may respond to an increase in efficiency by a rival hospital by also increasing efficiency (Department of Health, 2004). This chapter, therefore, investigates whether quality and efficiency are strategic complements or strategic substitutes so that higher rivals' quality (efficiency) induces a hospital to increase or reduce its quality (efficiency).

The chapter explores both clinical and non-clinical dimensions of quality. Clinical quality is measured through risk-adjusted overall mortality and readmission rate, mortality rates for hip fracture and stroke, and health gains for hip replacement. Non-clinical dimensions of patients' experience using patient satisfaction with their overall hospital experience, hospital cleanliness, and the extent to which clinicians involved the patients in the treatment decision. Hospital efficiency is captured by indicators for bed occupancy, cancelled elective operations, and cost indices for overall hospital activity, elective and non-elective activity, and for hip replacement.

Most of the quality and efficiency indicators are unconditionally spatially correlated according to the global Moran's I test. The spatial cross-sectional models are estimated by quasi-maximum likelihood controlling for observable determinants of quality and efficiency. Spatial panel models with hospital fixed or random effects are also estimated to control for unobserved time-invariant determinants of quality and efficiency. These models suggest that a hospital's quality or efficiency does not respond to its rivals' quality or efficiency, except for a hospital's overall mortality which is positively associated with that of its rivals. The results are robust to allowing for spatially correlated covariates and spatially correlated errors and to instrumenting rivals' quality and efficiency.

Finally, Chapter 4 contributes to the literature on hospital competition by investigating the effect of market structure on efficiency. It extends the existing studies on unit costs and LOS to a number of other efficiency indicators including measures of resource management and cost. The resource management indicators are admissions per bed, bed occupancy rate, number of cancelled elective operations, proportion of day, and percentage of untouched meals. The cost indicators are cleaning services costs, linen and laundry costs, and the reference cost index (RCI) for all admissions and for elective activity. The market structure is measured through the 'equivalent' number of rivals calculated as the inverse of the Herfindahl-Hirschman index (Kessler and McClellan, 2000).

The analysis focuses on a sample of public hospital trusts from the financial year 2002/03 to 2010/11. In such a context, the 'Patient Choice' reform is analysed as a natural experiment using a *quasi* difference-in-difference approach. This exploits the existence of more competitive areas with several hospitals and less competitive areas with one or few hospitals which are, respectively, more or less likely to respond to the policy. Differently from other studies, however, the *quasi* difference-in-difference regressions are estimated for nine indicators simultaneously through Seemingly Unrelated Regressions (SUR) to increase the precision of the estimates. In addition, this chapter employs an Unconditional Quantile Regression (UQR) approach to investigate whether the effect of competition varies along the efficiency indicators' distribution.

The findings suggest that competition affects efficiency in different ways. When exposed to the choice policy, one more equivalent rival increases on average the admissions per bed by 1.1% and the proportion of day cases increases by 3.8 percentage points. It decreases the proportion of untouched meals by 3.5 percentage points. In contrast, an additional equivalent rival reduces efficiency by increasing the number of cancelled elective operations by 2.6%. Instead, there are no significant effects of competition on bed occupancy rate, cleaning services costs, laundry and linen costs, and RCI for all admissions and for elective admissions. The results also suggest that SUR is a better fit than OLS. UQRs indicate that hospitals exhibiting low efficiency may be more responsive under greater competition. For instance, for hospitals with fewer admissions per bed (25^{th} quantile), one more equivalent rival increases this indicator by 2.2%.

In sum, the first part of the thesis on hospital specialisation suggests that specialist orthopaedic hospitals have lower profit margins but similar levels of efficiency compared to T&O departments in general hospitals. The findings in the second part of the thesis about hospital competition indicate that strategic interaction across rival hospitals on quality and efficiency does not necessarily occur. They show also that competition may have a different effect on efficiency depending on the indicator considered.

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Finally, I will not spend many words for the loved ones here. Probably, they will never read this thesis or, in some cases, will never be able to. But I will thank them every single moment of our everyday life together, doing my best to return them at least an infinitesimal portion of what they gave me.

Declaration

I declare that this thesis is a presentation of original work and I am the main author. More precisely, I am the sole author of Chapter 1 “Are Specialist Orthopaedic Hospitals More Efficient Than General Hospitals?”. Chapter 2 “Are costs differences between specialist and general hospitals compensated by the prospective payment system?” is co-authored with Luigi Siciliani and Andrew Street. Chapter 3 “Do Hospitals Respond to Rivals’ Quality and Efficiency? A Spatial Panel Econometric Analysis” is co-authored with Luigi Siciliani, Hugh Gravelle, and Rita Santos. Finally, Chapter 4 “Does Hospital Competition Improve Efficiency? The Effect of the Patient Choice Reform in England” is co-authored with Luigi Siciliani, Hugh Gravelle, and Giuseppe Moscelli.

For all co-authored chapters, I was the principal author. I have conducted all the empirical analyses and written the first draft, in addition to contributing to the research question, developing original aspects of the identification strategy and the empirical methods. My co-authors advised on refinement of the research question, the empirical strategy, and made comments on drafts of the chapter.

This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

Chapter 2 has been invited for a second round of revisions in the European Journal of Health Economics. Chapter 3 has been published in the special issue on “Health Economics and Policy” in Health Economics, volume 26, issue S2, September 2017, pages 38–62.

Chapter 1 – Are Specialist Orthopaedic Hospitals More Efficient Than General Hospitals?

Abstract

This study investigates whether specialist orthopaedic hospitals are more efficient than trauma and orthopaedic departments in general hospitals. To identify efficiency, we analyse the length of stay of all patients in trauma and orthopaedics allowing for patient and hospital characteristics. Using a sample of 197 English hospitals in 2011/12, we implement a two-stage regression model that includes patient-level variables in the first stage and hospital-level variables in the second stage. We find no statistical difference in efficiency between specialist orthopaedic hospitals and general hospitals.

1.1 Introduction

The efficiency of health care systems is a key goal for policy makers across Organisation for Economic Co-operation and Development (OECD) countries. It has been argued that increasing the number of specialist hospitals may enhance efficiency (Casalino et al., 2003, Shactman, 2005). Some countries are therefore moving towards a greater degree of hospital specialisation. For instance, US specialist hospitals tripled from 1991 to 2005 (Barro et al., 2006, Schneider et al., 2007). Similarly, from 2001 to 2009, China increased on average the number of specialist hospitals by 10% every year (Tang et al., 2013).

Specialist hospitals may foster better efficiency owing to a direct involvement of doctors in the management of facilities, higher patient volumes, and an improved learning-by-doing experience (Schneider et al., 2008). However, recent empirical findings show that specialist hospitals have similar or higher costs than general hospitals. In the US, orthopaedic and surgical specialist hospitals have from 20% to 30% higher costs than general hospitals (MedPAC, 2005; 2006). Carey et al. (2008) suggest that such hospitals are on average more inefficient than general hospitals.

Indeed, specialist hospitals appear to exploit economies of scale and scope less effectively (Carey et al., 2015). Although these studies cast doubts on the capability of specialist hospitals to realise their organisational advantages in practice, the activities of general hospitals are more wide-ranging and heterogeneous than specialist hospitals. Thus, some of the observed cost differences could be due to a failure to properly account for differences in the type of work performed.

To improve comparability, the present study investigates the efficiency in specialist orthopaedic hospitals and trauma and orthopaedics (T&O) departments within general hospitals. We measure efficiency through the length of stay (LOS) of a large sample of patients admitted to the T&O department of any English hospital in 2011/12. Following Laudicella et al. (2010), we analyse LOS using a two-stage regression model. In the first stage, we regress LOS on various patient characteristics (e.g. age, gender, diagnosis) and hospital fixed effects. The estimated hospital fixed effects, which capture risk-adjusted relative performance, are regressed in the second stage to compare efficiency between specialist orthopaedic hospitals and T&O departments after accounting for some hospital characteristics (e.g. quality, size, input prices). The idea behind this approach is that LOS is likely to reflect solely hospital efficiency after allowing for patient and hospital characteristics that may confound efficiency. Our key finding suggests that there is no statistical difference in efficiency between specialist orthopaedic hospitals and T&O departments in general hospitals.

In 2011/12, the English NHS includes more than 200 general hospitals with a T&O department and three specialist orthopaedic hospitals. Specialist orthopaedic hospitals are few in number but they play an important role in the English NHS. They provide high proportions of specialised services, i.e. low-volume but high-cost treatments for patients with complex and rare conditions. Specialist orthopaedic hospitals therefore facilitate the achievement of a critical mass of clinical expertise to ensure that such complex patients experience better health outcomes (NHS commissioning board, 2012). For instance, they provide 90% of bone and soft tissue sarcomas surgeries, and 50% of scoliosis treatments. They also deliver high proportions of more common, corrective procedures, such as 50% of revision knee replacements and 20% of revision hip replacements (Briggs, 2012). We focus on specialist orthopaedic hospitals because T&O is one of the hospital specialties with the highest volume of patients. In 2013, 6.7% of all NHS patients were treated in a T&O department. The efficient delivery of orthopaedic services is therefore critical for policymakers.

This study builds on the efficiency literature concerning US specialist hospitals. We propose the focus on specialist orthopaedic hospitals and T&O departments in general hospitals to improve comparability. Since LOS is measured at patient-level, our econometric model does not require assumptions on the efficiency distribution as in previous studies, such as half-normal distribution within a stochastic frontier framework (e.g. Carey et al., 2008). In addition, our research is one of the first to investigate the efficiency in T&O. Other studies analyse efficiency in general surgery, vascular, or obstetrics departments (Harper et al., 2001, Olsen and Street, 2008, Laudicella et al., 2010).

The next section (1.1.1) presents the literature review. Section 1.1.2 describes the institutional background, section 1.2 and 1.3 illustrate the method and the data, respectively. Section 1.4 discusses the results, and section 1.5 concludes.

1.1.1 Related literature

The role of specialist hospitals has been debated at length during the last decade. Herzlinger (1996) is one of the first authors to relate the hospital framework to the ‘focused factory’ model (Skinner, 1974). Specialist hospitals have the potential to supply services with higher quality and lower costs. Better quality can be guaranteed through greater volumes and stricter monitoring of patient needs. Reduced costs can be achieved owing to greater economies of scale and a more effective learning-by-doing process (Schneider et al., 2008). Opponents to the emergence of specialist hospitals, however, have raised two main concerns. First, new specialist hospitals may produce excess capacity because of the lack of sufficient competition implying higher fixed costs eventually borne by the patients (Shactman, 2005). Second, specialist hospitals may 'cherry-pick' patients jeopardising the financial viability of general hospitals (Barro et al., 2006). In particular, the second issue led the US government to impose a moratorium on referrals to specialist hospitals in 2003 (Carey et al., 2007).

A number of empirical studies test the impact of specialist hospitals on health care quality and costs. For instance, Greenwald et al. (2006) analyse 2003 Medicare claims and conduct site visits in 2004 to investigate quality across specialist and general hospitals. They observe lower mortality and greater satisfaction for patients admitted to specialist hospitals. Cram et al. (2007) find similar results for Medicare patients undergoing total hip and knee replacement between 1999 and 2003. Their findings suggest that patients are less likely to die or suffer surgical complications if treated in specialist hospitals. Barro et al. (2006) study costs in addition to quality focusing on US specialist cardiac hospitals in 1993, 1996, and 1999. They find that the entry of specialist hospitals reduces spending without a drop in quality. In our analysis, we examine whether specialist orthopaedic hospitals are more efficient than T&O departments in England.

1.1.2 Institutional background

The English National Health Service (NHS) provides health care that is universal, tax financed, and free at the point of use. The Department of Health distributes capitated funding to around 150 local authorities, called clinical commissioning groups, which use it to pay for secondary healthcare provided to NHS patients by public and private hospitals. Public hospitals deliver the great majority of healthcare and are managed by NHS trusts or NHS foundation trusts, the latter having greater financial autonomy. Some NHS hospital trusts are teaching trusts providing research and teaching, and some are specialist trusts focusing on a limited range of conditions and client groups.

Hospitals are mainly funded through a prospective payment system, the National Tariff Payment System (NTPS). This is based on Healthcare Resource Groups (HRG), a patient classification system similar to the US Diagnosis-Related Group or DRG. HRGs categorise patients into homogeneous groups depending on diagnoses, procedures, and some patient characteristics. A fixed tariff is calculated for each HRG group as its national cost averaged across providers but with adjustment for individual hospitals to reflect exogenous variations in input prices and the higher costs of specialised care (Daidone and Street, 2013, Department of Health, 2013a).

Specialist hospitals predominantly provide elective surgical care but they treat a broad range of conditions similarly to departments in public hospitals. In 2011/12, there are three trusts specialised in orthopaedic services: the Royal National Orthopaedic Hospital, the Robert Jones & Agnes Hunt Orthopaedic Hospital, and the Royal Orthopaedic Hospital. Originally, the NHS included five specialist orthopaedic trusts but, after the wave of mergers started in 1997 by the Labour Government, their number was reduced (Gaynor et al., 2012a).[3]

From 2003, moreover, the policy maker has fostered hospital specialisation through a different form of health care provider: the treatment centre. This facility provides a few surgical elective procedures such as, for instance, hip replacement and cataract surgery. The treatment centre programme was implemented under the argument that the separation of emergency and elective departments improves outcome and efficiency (House of Commons Health Committee, 2005). One of the main purposes was to reduce waiting times for the most common high-volume procedures (e.g. hip replacement). In four years, the number of treatment centres increased to

[3] The Wrightington Hospital NHS trust was merged with the Wigan and Leigh NHS Trust in April 2001, and the Nuffield Orthopaedic Centre NHS trust merged forming the Oxford University Hospitals NHS trust in November 2011.

almost 100, half of which were private (Street et al., 2010b). Treatment centres are regarded as specialist providers but they are distinct from specialist hospitals on which we focus. Treatment centres are therefore excluded from our analysis.

1.2 Methods

This study explores the variation in patient LOS across specialist orthopaedic hospitals and T&O departments in general hospitals. Following Laudicella et al. (2010), we split the analysis into two stages. In the first stage, we estimate the following linear model by OLS:

$$\ln\left(y_{ik}\right) = \mu + \boldsymbol{\beta}'\boldsymbol{x}_{ik} + \boldsymbol{\alpha}_k + \varepsilon_{ik} \tag{1.1}$$

where y_{ik} is the LOS of patient i (i=1,…,I_k) admitted to the T&O department of hospital k (k=1,…,K); μ is the intercept; $\boldsymbol{x}_{ik}$ is a vector of patient characteristics, for example, gender, age, admission type, and diagnosis; $\boldsymbol{\alpha}_k$ is a vector of hospital fixed effects (FE); and ε_{ik} is the idiosyncratic error term. We estimate clustered standard errors to account for correlations between patients within each hospital.

Estimates of the hospital FE ($\hat{\alpha}_k$) are our key focus in the first stage. FE are interpreted as deviation of hospital k's LOS from average LOS. A positive value $\hat{\alpha}_k > 0$ indicates that hospital k's LOS is above the average hospital's LOS, after controlling for patient characteristics. Hence, $\hat{\alpha}_k$ can be viewed as an indicator of relative hospital performance. With no assumptions on the correlation between $\boldsymbol{\alpha}_k$ and $\boldsymbol{x}_{ik}$, consistency of $\hat{\alpha}_k$ requires $I_k \rightarrow \infty$. This is achieved due to the high number of patients in each hospital. On the contrary, a random-effects (RE) estimator of $\boldsymbol{\alpha}_k$ is unlikely to be consistent because the assumption of no correlation between $\boldsymbol{x}_{ik}$ and $\boldsymbol{\alpha}_k$ is unlikely to hold in our case. For example, relative hospital performance may rely on the type and number of procedures provided to patients with a given condition.

In the second stage, we estimate the following regression:

$$\hat{\alpha}_k = \eta + \delta s_k + \boldsymbol{\zeta}'\boldsymbol{z}_k + \xi_k \tag{1.2}$$

where η is the intercept; s_k is a dummy variable taking value one if the hospital is specialist; $\mathbf{z}_k$ is a vector of hospital characteristics such as quality of care as measured by average health change for hip and knee replacement and emergency readmission rate in the T&O department, the number of patients in the T&O department to account for economies of scale, the market forces factor that captures exogenous variation in input prices (e.g. nurses, buildings), and a dummy indicating whether the hospital is run under a foundation trust or whether it is a teaching hospital; ξ_k is the error term.

The key coefficient is δ which compares efficiency across specialist and general hospitals because it reflects the LOS after allowing for patient and hospital characteristics that may be confounded with efficiency (e.g. patient severity, quality). $\hat{\delta} > 0$ indicates that specialist hospitals are on average less efficient than T&O departments in general hospitals. Recall that LOS is log transformed in the first stage, which implies that $\hat{\alpha}_k$ measures the percentage by which each hospital's LOS deviates from the average LOS. Hence, $\hat{\delta}$ captures the difference in the LOS deviation between specialist and general hospitals expressed in percentage points.

We bootstrap the standard errors using 100 replications because our second-stage dependent variable ($\hat{\alpha}_k$) is estimated and not observed. The inference for estimated dependent variable models may indeed be incorrect if heteroscedasticity in both sampling and random errors is neglected (Saxonhouse, 1976, Battese and Coelli, 1992, Jusko and Shively, 2005, Lewis and Linzer, 2005). Our approach is an alternative to the one proposed by Street et al. (2012). The authors model the LOS in the first stage as a Poisson process, and they use weighted least squares in the second stage estimating Efron robust standard errors.

1.3 Data

Our sample includes 842,460 patients treated across 197 hospitals in 2011/12, whose main specialty of admission is T&O. The primary source of data is HES (Hospital Episode Statistics), which includes detailed information on every single patient admitted in English hospitals (e.g. age, gender, diagnosis, procedure). We collect the market forces factor (MFF) from the reference cost database, and patient-reported outcome measures (PROMs) data on hip and knee replacement from NHS digital.

We remove duplicates, miscoded observations, and outliers from our data. To make our final sample more homogenous we also exclude patients falling under HRG codes with less than 100 observations, and hospitals treating less than 500 patients in their T&O department. Appendix A1.1 gives further details on the sample definition.

1.3.1 Variables

The dependent variable is the *logarithm of the patient's LOS* including the day of admission. The LOS is equal to one if the patient stays in hospital for less than one day. It is equal to two if the patient stays in hospital between one and two days, and so on. This allows the log transformation of the dependent variable improving the model fit. As a sensitivity check, we re-run the analysis using a square root transformation of the LOS excluding the day of admission (see section A1.3).

In the first stage, we control for patients' characteristics such as *gender* (whether the patient is male), *age*, *ethnicity* (whether the patient is white, which is the reference category, Asian, black, Chinese, mixed, or of other ethnicity), *residence* (whether the patient lives in an urban area with no less than 10,000 inhabitants), and *deprivation of the residential area* (including income, disability, living environment, and crime deprivation). Other patient-level variables capture *admission type* (whether the patient is admitted in an emergency, which is the reference category, as elective, day case, after a transfer from another hospital, or in any other way), *waiting time*, *primary diagnosis* and *procedure*, *number of secondary diagnoses* and *procedures*, and *HRG* *classification*.[4]

The second stage includes a dummy variable equal to one if the hospital is a *specialist orthopaedic hospital*, which is our key variable. To account for quality, we add the unadjusted *average health change for hip* and *knee replacement*, and the unadjusted *emergency readmissions* for patients admitted to T&O departments. We control for department size using the *number of patients in T&O*, *market forces factor*, and *teaching trusts*. Following Marini et al. (2008), we control for *foundation trusts* defining three dummies taking a value of one for, respectively, trusts that have gained the foundation status for no more than three years, foundation trusts with four to five years, and foundation trusts with more than five years.

1.3.2 Descriptive statistics

As shown in Figure 1.1, most T&O patients are discharged the same day of admission while a few patients stay in hospital for more than eight months (250 days). After taking the logarithm, the LOS distribution is less dispersed around the mean but still right-skewed.

Table 1.1 shows descriptive statistics of the patient-level regressors. 48% of patients are male, and the average patient is 53 years old. The great majority of patients are white (95.3%), 3% are Asian, 1.6% are black, and a small percentage is composed by Chinese (0.1%), mixed (0.6%), and patients of other ethnicities (1.1%). 79% of patients live in urban areas, which in most cases feature low deprivation in all dimensions (income, disability, living environment, crime) because the distribution of the deprivation indexes is always right-skewed. 28.3% of patients re admitted in an emergency, 34.7% are elective, 37% are day cases, 0.4% are transferred from another hospital, and only 0.04% is admitted through a different method. Patients wait on average 51 days between

[4] We define a dummy for each primary diagnosis and procedure to cover 81% and 80% of the sample generating 99 diagnosis and 92 procedure dummies, respectively. The remaining diagnoses and procedures flow into a residual dummy. Similarly, we define 49 HRG dummies to cover 91% of the sample, while the residual 9% is captured by a single dummy.

the decision of admission and the actual admission. Patients receive on average 2.6 diagnoses and 2.3 procedures.

As reported in Table A1.1, the three most frequent primary diagnoses are knee arthrosis (8%), hip arthrosis (5%), and derangement of meniscus (5%). In Table A1.2, the three most common procedures are knee replacement with cement (6%), endoscopic resection of semilunar cartilage (5%), and injection of therapeutic substance into joint (5%). Moreover, 12% of patients go to hospital for a test (e.g. ultrasound scan, X-rays) and, therefore, they do not undergo any procedure. As Table A1.3 shows, the three most frequent HRG codes in T&O departments are arthroscopies (10%), primary knee replacement (7%), and minor procedures to the musculoskeletal system (7%).[5]

Table 1.1 also illustrates some descriptive statistics for the second-stage regressors. The sample includes three specialist orthopaedic hospitals (1.5% of all hospitals). The average health changes after hip and knee replacement are positive, 0.419 and 0.305 respectively, suggesting that patients report on average a health gain. The T&O emergency readmission rate is on average 2%. T&O departments treat on average 5,485 patients, and the MFF is on average 1.075 varying from 1.005 to 1.298. There are 34 teaching hospitals (17.3%), and 101 foundation trusts of which 20 have acquired their status for no more than three years (10.2%), 25 from four to five years (12.7%), and 56 for more than five years (28.4%).

1.4 Results

Table 1.2 provides the first-stage estimates. Most of patient-level regressors are statistically significant at 5% level. Male patients stay 2.7% less in hospital than females, and patients younger than 20 years (-0.004/(2×0.0001)) have shorter LOS than older patients. White patients' LOS is on average 2.7% lower than Asians, 4% lower than blacks, 3.8% lower than Chinese, and 2.4%

[5] Descriptive statistics for all diagnoses, procedures, and HRG codes are reported in the Appendix 1 (section A1.2).

lower than other ethnicities. Patients from urban areas have on average 0.8% longer LOS than patients coming from rural areas. Elective patients have on average no different LOS than emergency patients, while day case patients stay in hospital 63.2% less than emergency patients. One more day of waiting for an elective procedure implies 0.002% longer LOS. One more secondary diagnosis or procedure increases LOS by 5.2% or 5.5%, respectively. The standard deviation of the FE estimates is lower than the standard deviation of the idiosyncratic error term.[6] This indicates that the regressors account for most of the variation in LOS between T&O departments. Overall, the R-squared suggests that the regressors explain 75% of the variation in LOS.

Table 1.3 presents the results of the second-stage regression, which includes hospital characteristics such as quality, size, input prices, and hospital type. Our key finding is that specialist orthopaedic hospitals are 5.6 percentage points more inefficient than T&O departments in general hospitals but this result is statistically insignificant.

In general, we observe low statistical significance across the second-stage regressors. These explain only 6% of the remaining variation in LOS (see adjusted R-squared in Table 1.3). Health gain after knee replacement and the teaching hospital dummy are instead statistically significant at 5% level. An increase in the health change after knee replacement by 0.03 units, corresponding to 10% of the mean, implies a 0.8% ($0.03 \times 0.272 \times 100$) reduction in efficiency. T&O departments in teaching hospitals are 3.6% less efficient than those in non-teaching hospitals. Instead, the estimated parameters on the average health change after hip replacement, the T&O emergency readmission rate, the number of patients in T&O, the market forces factor, and the foundation trust dummies are statistically insignificant.

As a sensitivity check we take the square root transformation of the dependent variable in the

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[6] The Hausman test suggests that the RE estimator is inconsistent.

first stage, rather than the log transformation (e.g. Ettner et al., 1998). As showed in Figure A1.1, the square root transformation has a milder normalising effect compared to the log transformation. Results for first and second stage are reported in Table A1.4 and Table A1.5, respectively. Estimates are qualitatively similar to those obtained using the log transformation.

1.5 Conclusions

This study investigates the efficiency of specialist orthopaedic hospitals in England. Specialist hospitals should benefit from a number of organisational advantages such as, for example, high volumes, focused activity, better monitoring of patients' needs (Schneider et al., 2008). In contrast, empirical studies on US specialist hospitals have not found that specialist hospitals are more efficient (Carey et al., 2008). These studies, however, compare specialist providers with general hospitals although the latter provide a more heterogeneous range of services.

We focus on specialist orthopaedic hospitals and T&O departments in general hospitals, and explore the variation in the LOS of patients admitted to a T&O department in England. The analysis controls for several factors including patient and hospital characteristics. The remaining variation in LOS is therefore assumed to reflect efficiency. Our key result indicates that there is no statistical difference in efficiency between specialist orthopaedic hospitals and T&O departments in general hospitals. This suggests that the organisational advantages of specialist orthopaedic hospitals may not necessarily translate into better efficiency as measured by LOS. Although no more efficient than T&O departments, specialist orthopaedic hospitals might provide services of higher quality.

This study has two limitations. First, we analyse only three specialist orthopaedic hospitals. Such a small number of specialist orthopaedic hospital trusts, however, is not the result of sample selection but reflects the reality that there are only three specialist orthopaedic hospital trusts in the English NHS. Second, some covariates in the first and second stage of the analysis are proxies.

In the first stage, waiting time is included as a proxy of severity but it could be correlated with efficiency (Siciliani et al., 2009). In the second stage, the average health change after hip and knee replacement and the T&O emergency readmission rate are not risk-adjusted. Further research is required before a definitive recommendation about the best way of organising T&O services.

Tables and Figures

Table 1.1 – Descriptive statistics.

Regressor	Mean	Std Dev.	Min	Max
Measured at patient level				
Male	0.477	0.499	0	1
Age	53	23	0	111
Ethnicity: white (reference)	0.953	0.237	0	1
Ethnicity: Asian	0.030	0.170	0	1
Ethnicity: black	0.016	0.127	0	1
Ethnicity: mixed	0.006	0.080	0	1
Ethnicity: Chinese	0.001	0.035	0	1
Ethnicity: Any other	0.011	0.105	0	1
Urban	0.788	0.409	0	1
Deprivation index: income	0.147	0.109	0.000	0.770
Deprivation index: disability	0.026	0.856	-3.100	3.790
Deprivation index: living environment	20.661	15.997	0.060	92.990
Deprivation index: crime	-0.035	0.815	-3.280	3.810
Admission: emergency (reference)	0.283	0.467	0	1
Admission: elective	0.347	0.453	0	1
Admission: day case	0.365	0.481	0	1
Admission: transferred from other provider	0.004	0.064	0	1
Admission: other	0.0004	0.004	0	1
Waiting time (days)	50.8	69.8	0.0	607.4
Number of secondary diagnoses	2.6	2.6	0.0	19.0
Number of secondary procedures	2.3	2.0	0.0	23.0
Measured at hospital level				
Specialist orthopaedic hospital	0.015	0.123	0	1
Average health change after hip replacement	0.419	0.064	-0.165	0.803
Average health change after knee replacement	0.305	0.049	0.169	0.632
T&O emergency readmission rate	0.019	0.008	0.004	0.062
Number of patients in orthopaedics	5,485	2,692	541	15,959
Market forces factor	1.075	0.062	1.005	1.298
Teaching hospital	0.173	0.379	0	1
Foundation trust with no more than 3 years	0.102	0.303	0	1
Foundation trust with 4 to 5 years	0.127	0.334	0	1
Foundation trust with more than 5 years	0.284	0.452	0	1
Number of patients	842,460			
Number of hospitals	197			

Table 1.2 – First-stage regression.

Regressor	Coeff	Std Err.	p-value
Male	-0.027***	0.002	0.000
Age	-0.004***	0.000	0.000
Age Squared	0.0001***	0.000	0.000
Ethnicity: Asian	0.027***	0.004	0.000
Ethnicity: black	0.040***	0.006	0.000
Ethnicity: Chinese	0.038**	0.017	0.024
Ethnicity: mixed	0.006	0.006	0.318
Ethnicity: Any other	0.024***	0.006	0.000
Urban	0.008***	0.002	0.000
Deprivation index: income	-0.0003	0.013	0.981
Deprivation index: disability	0.004**	0.002	0.040
Deprivation index: living environment	0.0002***	0.000	0.002
Deprivation index: crime	0.001	0.001	0.460
Elective	-0.0001	0.001	0.971
Day case	-0.632***	0.010	0.000
Transferred from other provider	0.007	0.009	0.404
Other admission type	0.078	0.096	0.415
Waiting time	-0.00002**	0.000	0.049
Waiting time squared	0.00000001	0.000	0.166
Number of secondary diagnoses	0.052***	0.001	0.000
Number of secondary procedures	0.055***	0.002	0.000
Constant	0.196***	0.029	0.000
Standard deviation of alpha	0.073		
Standard deviation of epsilon	0.486		
Observations	842,460		

R-square (overall) = 0.750

Test of alphas jointly equal to zero, F(196, 196) = 78.15 p-value = 0.000

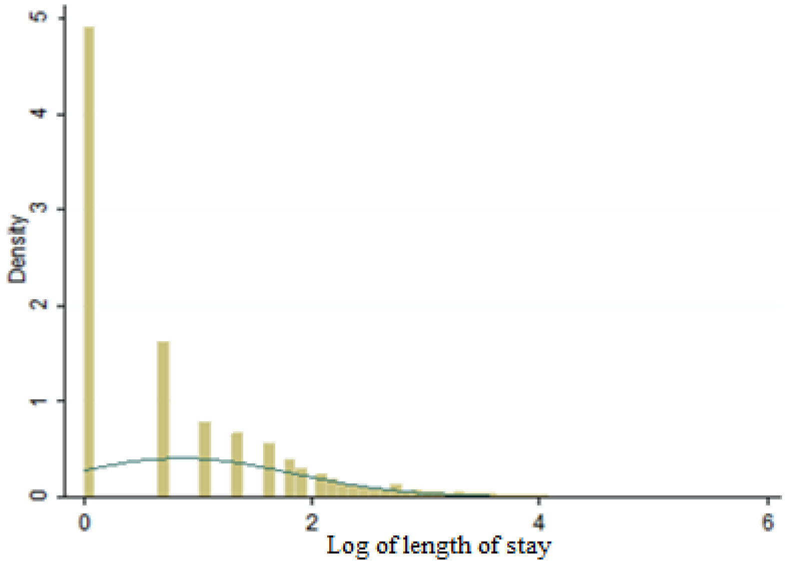
Primary diagnosis, primary procedure, HRG code, and hospital fixed effects are not reported. Standard errors are bootstrapped (100 replications).

***=p-value<0.01, **=p-value<0.05, *=p-value<0.1

Table 1.3 – Second-stage regression.

Regressor	Coeff	Std Err.	p-value
Specialist orthopaedic hospital	0.056	0.039	0.151
Average health change after hip replacement	-0.121	0.105	0.247
Average health change after knee replacement	0.272***	0.099	0.007
T&O emergency readmission rate	0.191	0.718	0.790
Number of patients in orthopaedics	-0.000001	0.000	0.717
Market forces factor	0.065	0.080	0.423
Teaching hospital	0.036**	0.014	0.013
Foundation trust with no more than 3 years	-0.016	0.021	0.456
Foundation trust with 4 to 5 years	0.018	0.015	0.207
Foundation trust with more than 5 years	-0.007	0.015	0.646
Constant	-0.116	0.118	0.328
Observations	197		
R squared = 0.11, Adjusted R squared = 0.06			
Standard errors are bootstrapped (100 replications)			

Figure 1.1 – Distribution of the logarithm of the length of stay.



Chapter 2 – Are costs differences between specialist and general hospitals compensated by the prospective payment system?

Abstract

Prospective payment systems fund hospitals based on a fixed-price regime that does not directly distinguish between specialist and general hospitals. We investigate whether current prospective payments in England compensate for differences in costs between specialist orthopaedic hospitals and trauma and orthopaedics departments in general hospitals. We employ reference cost data for a sample of hospitals providing services in the trauma and orthopaedics specialty. Our regression results suggest that specialist orthopaedic hospitals have on average 13% lower profit margins. Under the assumption of break-even for the average trauma and orthopaedics department, two of the three specialist orthopaedic hospitals appear to make a loss on their activity. The same holds true for 33% of departments in our sample. Patient age and severity are the main drivers of such differences.

2.1 Introduction

The prospective payment system (PPS) is commonly used to reimburse hospitals across Organisation for Economic Co-operation and Development (OECD) countries (Busse et al., 2006). It is built on a patient classification system that categorises patients into resource homogeneous groups, with each hospital receiving a fixed pre-determined tariff for every patient falling into a given group. This generates incentives for hospitals to contain costs.

In its purest form, a PPS reimburses hospitals only on the basis of the volume and type of patients treated, without taking organisational characteristics into account. Under the German PPS, for example, tariffs do not depend on the hospital's ownership status or membership to the national insurance programme (Klein-Hitpaß and Scheller-Kreinsen, 2015). In contrast, other PPSs do consider organisational characteristics. In the French PPS, for instance, prices differ for public and private hospitals (Busse et al., 2011). In some countries, the PPS provides greater compensation to allow for the costs of specialist care. An example is the PPS of the Lombardy region in Italy, which applies a tariff top-up to all hospitals with ‘high specialisation’ units (Ettelt et al., 2006). In England, hospitals are paid extra if their patients receive specialised care (Daidone and Street, 2013).

Some health care systems feature hospitals that specialise on a single specialty, such as cardiology, ophthalmology, or orthopaedics.[7] Specialisation is an organisational form which is supposed to generate the benefits of the ‘focused factory’, i.e. greater efficiency, quality, and responsiveness (Skinner, 1974, Herzlinger, 1996, Schneider et al., 2008) but not necessarily lower costs. In the US, the Medicare Payment Advisory Commission showed that the costs of specialist hospitals were no lower than the costs of general hospitals. While cardiac hospitals’ costs were not significantly different from general hospitals’, orthopaedic and surgical hospitals had 20 percent higher inpatient costs. Higher costs were due to more specialised and costly facilities, higher staffing levels, better quality of care, but also excess capacity and low inpatient volumes (MedPAC, 2005, MedPAC, 2006).

Such findings have stimulated empirical research on specialist hospitals’ costs. Barro et al. (2006) study the impact of specialist cardiac hospitals on overall expenditure and quality in the US between 1996 and 1999. They find that entry of specialist hospitals reduces expenditure growth without affecting outcomes. Carey et al. (2008) investigate the cost efficiency of US specialist hospitals between 1998 and 2004. They find higher levels of inefficiency in orthopaedic and surgical hospitals compared to general hospitals. Kim et al. (2013) analyse South Korean specialty orthopaedic hospitals between 2010 and 2012, which are found to apply higher patients’ charges

[7] There are specialist hospitals in Europe (Ettelt et al., 2006, Medin et al., 2011), America (Carey et al., 2009, Araújo et al., 2014), Asia (Kim et al., 2013), India (Chanda, 2002), and Africa (Castro-Leal et al., 1999).

than general hospitals. The authors suggest that such higher charges are due to greater set-up, investment, staffing and treatment costs.

The present study contributes to this small empirical literature. We investigate the financial viability of specialist orthopaedic hospitals relative to trauma and orthopaedics (T&O) departments in general hospitals in the English National Health Service (NHS). Our primary objective is to test whether costs of specialist orthopaedic hospitals are higher than T&O departments in general hospitals even after accounting for differences in revenues. In other words, we test whether the current PPS covers the costs of specialist orthopaedic hospitals relative to T&O departments in general hospitals.

In England, the majority of hospitals are funded through the national tariff payment system (NTPS).[8] The NTPS is characterised by two key elements: the healthcare resource groups (HRGs), which classify patients into homogeneous categories based on diagnoses, procedures and some patients characteristics (Busse et al., 2011); and the tariffs, which vary by HRG and admission type (elective or non-elective) and reflect the national cost for an HRG averaged across all hospitals (Department of Health, 2013b). An additional payment for excess bed days is made for patients whose length of stay is beyond a threshold, called the trim point, which also varies by HRG and admission type.[9] Both the base and excess bed day tariffs are adjusted by the market forces factor (MFF) index to account for exogenous geographical differences in input prices (Department of Health, 2013a). Tariffs are inflated if the patient receives specialised services under specific HRGs (Daidone and Street, 2013).[10] With such a payment system, specialist

[8] More than 60% of hospital income comes from the NTPS. The remaining part is agreed in the NHS standard contract on the basis of actual activity (Department of Health, 2012c).

[9] The trim point is the maximum expected length of stay for a patient falling under a specific HRG. It is defined by the Department of Health in order to identify unusually long lengths of stay and statistical outliers (Department of Health, 2013a).

[10] At the time of our study, top-ups were paid for Children’s, orthopaedic, spinal, and neurosciences specialised services. While all hospitals can obtain the top-up for specialised orthopaedic services, top-ups for the other specialised services are paid to a restricted number of eligible providers.

hospitals are likely to obtain higher revenues owing to the greater proportion of patients within an HRG who receive a specialised service.

We collect data at HRG level from the NHS reference cost (RC) database for the financial year 2013/14. Such data allow us to analyse the unit cost per patient of every inpatient HRG delivered through the T&O department of each hospital trust (hospital from now on) in the sample.[11] Our econometric strategy employs four regressions. The first regression provides raw differences in unit costs between specialist orthopaedic hospitals and T&O departments. In a second regression, we compare unit costs after controlling for differential payments (due to different HRGs and other tariff corrections). This is our key model and provides differences in profit margins between the two types of hospital: given that HRG tariffs are fixed, any differences in unit costs after controlling for differences in payment will be reflected in the profit margin. In the third regression, we explain any differences in profit margins (i.e. in costs after controlling for payment) as a function of possible determinants including patient characteristics such as proportion of males, age, socio-economic status, number of diagnoses and procedures, and hospital characteristics such as the salary of doctors, hospital type, scale economies, quality, and geographical location. Our fourth regression examines the heterogeneity in profit margins across specialist hospitals. We estimate these models by weighted least squares (WLS), clustering standard errors within hospitals.

The English NHS includes 141 general hospitals with a T&O department and three specialist orthopaedic hospitals. Although there are few specialist orthopaedic hospitals, they play an important role in the English NHS. They deliver high proportions of specialised services, commonly low-volume but high-cost treatments for patients with complex and rare conditions.

[11] In the English NHS, a hospital trust or acute trust is an authority that provides secondary health care services through one or more acute hospitals.

Specialist orthopaedic hospitals therefore allow the achievement of a critical mass of clinical expertise to ensure patients receive specialised treatments that produces better health outcomes (NHS commissioning board, 2012). For instance, they provide 90% of bone and soft tissue sarcomas surgeries, and 50% of scoliosis treatments. They also perform high proportions of more common, corrective procedures, such as 50% of revision knee replacements and 20% of revision hip replacements (Briggs, 2012). We focus on specialist orthopaedic hospitals because T&O is the specialty with the fourth highest volume of patients, after general medicine, general surgery, and paediatrics. In 2013, 6.7% of all NHS patients were treated in a T&O department.

To the best of our knowledge, this is one of the first attempts to study differences in profit margins between specialist hospitals and departments within general hospitals undertaking similar activities. Previous work focuses on either costs (e.g. MedPAC, 2006) or revenues (e.g. Kim et al., 2013). Our analysis is at HRG level, rather than patient level, making use of cost data that all English hospitals are required to report annually to the Department of Health (DH). This is a natural choice since payment is also at HRG level and our focus is on controlling for differences in payment across hospital types. As cost data are available only at HRG-level in most countries, our methodological approach can easily be employed and replicated in future studies, either to compare specialist and general hospitals, or to make other types of comparison, such as between teaching and non-teaching hospitals.

The paper is structured as follows. Section 2.2 provides the economic framework. Section 2.3 describes the econometric strategy. Section 2.4 describes the data and shows descriptive statistics. Section 2.5 presents the results. Section 2.6 discusses and concludes.

2.2 Economic framework

Under a PPS, hospitals are funded according to the number and type of patients treated. In the English payment system, the total revenue of hospital $k=1,\dots,K$ for providing HRG $j=1,\dots,J$

amounts to:

$$R_{jk} = R_{jk}^{IN} + R_{jk}^{EB} = p_{jk}^{IN}\left(1+te_{jk}\right)y_{jk} + p_{jk}^{EB}\left(1+te_{jk}\right)q_{jk}\,, \tag{2.1}$$

where R_{jk}^{IN} is the total *inlier* revenue of hospital k for treating patients who have a normal length of stay for their HRG j; R_{jk}^{EB} is the total *excess bed day* revenue of hospital k earned for each additional day that patients stay beyond their specific HRG j's trim point; p_{jk}^{IN} is the HRG *inlier* price received by hospital k for treating a patient falling under HRG j; p_{jk}^{EB} is the *per diem* price received by hospital k for a single excess bed day produced under HRG j; t is the tariff top-up on specialised orthopaedic services, which is a constant proportion across HRGs and hospitals; e_{jk} is the proportion of patients in hospital k falling under HRG j receiving a specialised orthopaedic treatment; y_{jk} is the number of patients admitted in hospital k under HRG j;[12] and q_{jk} is the number of excess bed days produced in hospital k under HRG j.

The HRG prices p_{jk}^{IN} and p_{jk}^{EB} can be written more explicitly as:

$$p_{jk}^{IN} = \left(\alpha_{j}^{IN} + b\right)m_{k}\,, \tag{2.2}$$

$$p_{jk}^{EB} = \left(\alpha_{j}^{EB} + b\right)m_{k}\,, \tag{2.3}$$

where α_{jk}^{IN} is the *inlier* tariff for treating a patient falling under HRG j; α_{jk}^{EB} is the *excess bed day* tariff of each excess bed day under HRG j. These do not vary by hospital. In contrast, m_k is a MFF index capturing exogenous geographical differences in the prices of hospital inputs (staff, land, and buildings) that vary depending on the hospital's location. Finally, b is a fixed tariff adjustment common across hospitals, such as pay and price inflation or the national efficiency adjustment.

The total cost of hospital k for providing HRG j is:

$$C_{jk} = C_{jk}^{IN} + C_{jk}^{EB} = c_{jk}^{IN}y_{jk} + c_{jk}^{EB}q_{jk}\,, \tag{2.4}$$

where C_{jk}^{IN} is the total *inlier* cost of hospital k for treating patients under HRG j (up to the trim

[12] The number of patients is expressed by the number of finished consultant episodes (FCEs). A FCE is a hospital episode for a patient under the care of an individual consultant.

point); C_{jk}^{EB} is the total *excess bed day* cost of hospital k for the excess bed days produced under HRG j; c_{jk}^{IN} is the *inlier* unit cost of hospital k for HRG j, and c_{jk}^{EB} is the *per diem* unit cost of hospital k for each excess bed day falling under HRG j. Since the national tariffs are set equal to the national average cost, we can write them more explicitly as:

$$\alpha_j^{IN} = \frac{\sum_k c_{jk}^{IN} y_{jk}}{\sum_k y_{jk}} \quad \text{and} \quad \alpha_j^{EB} = \frac{\sum_k c_{jk}^{EB} q_{jk}}{\sum_k q_{jk}}. \tag{2.5}$$

Therefore, the total profit function of hospital k for providing HRG j is:

$$\pi_{jk} = R_{jk}^{IN} - C_{jk}^{IN} + R_{jk}^{EB} - C_{jk}^{EB} = \left[p_{jk}^{IN} \left(1+te_{jk}\right) - c_{jk}^{IN} \right] y_{jk} + \left[p_{jk}^{EB} \left(1+te_{jk}\right) - c_{jk}^{EB} \right] q_{jk}. \tag{2.6}$$

The profit margin, i.e. the profit per patient allocated to HRG j in hospital k, can be written as:

$$\tilde{\pi}_{jk} = \frac{\pi_{jk}}{y_{jk}} = p_{jk}^{IN} \left(1+te_{jk}\right) - c_{jk}^{IN} + \left[p_{jk}^{EB} \left(1+te_{jk}\right) - c_{jk}^{EB} \right] \frac{q_{jk}}{y_{jk}}, \tag{2.7}$$

where $p_{jk}^{IN} \left(1+te_{jk}\right) - c_{jk}^{IN}$ is the *inlier* profit margin of hospital k for HRG j, and $p_{jk}^{EB} \left(1+te_{jk}\right) - c_{jk}^{EB}$ is the *per diem* profit margin of hospital k for each excess bed day produced under HRG j. As prices are fixed, this simply demonstrates that profitability will vary according to differences in costs that are not accounted for in the payment arrangement.[13]

Several factors driving hospital unit costs may also explain differences between specialist and general hospitals. Following Bradford et al. (2001), we summarise these in the following function:

$$c_{jk} = c\left(\boldsymbol{x}_{jk}, \boldsymbol{z}_k\right), \tag{2.8}$$

where $\boldsymbol{x}_{jk}$ is a vector of patient characteristics not captured by the HRG classification system; and $\boldsymbol{z}_k$ is a vector of hospital characteristics, such as input prices that are not captured fully by the market forces adjustment, teaching activity, or economies of scale. For instance, specialist

[13] To illustrate this point, suppose that a specialist orthopaedic hospital s and a T&O department in general hospital g have the same volume of patients and excess bed days (y_s=y_g, q_s=q_g), the same location (m_s=m_g), and the same proportion of top-up tariffs (e_s=e_g). Then, differences in profits will be equal to $\pi_g - \pi_s = (c_s^{IN} - c_g^{IN}) y_g + (c_s^{EB} - c_g^{EB}) q_g$. For instance, $\pi_g - \pi_s > 0$ implies that the specialist orthopaedic hospital has lower profit margins than the T&O department in a general hospital. Such a difference will reflect factors not allowed for in the payment mechanism.

hospitals are likely to employ surgeons with advanced expertise that are paid higher salaries, and to use more costly high tech equipment. A high level of specialisation is likely to produce high quality of care and, perhaps, higher costs. Specialist hospitals might attract higher volumes of patients, which may allow them to exploit economies of scale but could translate into larger proportions of complex patients requiring a more intensive use of resources. Below, in our empirical analysis, we are able to control for a number of such explanatory factors.

2.3 Econometric specification

We focus on four key specifications. The dependent variable is the log of the *inlier* unit cost (c_{jk}^{IN}) or the *per diem* unit cost (c_{jk}^{EB}).[14] All models are estimated by WLS in order to take into account, respectively, the number of patients (y_{jk}) or excess bed days (q_{jk}) of every HRG within each hospital. Moreover, we cluster standard errors within hospitals in order to allow for any form of serial correlation of errors across HRGs.

In the first regression, model I, we test whether unit costs are on average higher in specialist orthopaedic hospitals before accounting for any differences in payments across hospitals:

$$\ln\left(c_{jk}\right) = \mu + \beta s_k + \varepsilon_{jk} , \tag{2.9}$$

where c_{jk} is the *inlier* or *per diem* unit cost of HRG j in hospital k, μ is the intercept, s_k is a dummy equals one if hospital k is a specialist orthopaedic hospital, and ε_{jk} is the error term.

The estimated coefficient $\hat{\beta}$ translates into $\tilde{\beta} = \exp\left(\hat{\beta}\right) - 1$ (Halvorsen and Palmquist, 1980, Bamezai et al., 1999 p. 240). This expresses the percentage difference in unit costs between specialist orthopaedic hospitals and T&O departments in general hospitals, i.e. $\tilde{\beta} = \left(\bar{c}_s - \bar{c}_g\right) / \bar{c}_g$ with $\bar{c}_s$ and $\bar{c}_g$ being respectively the specialist orthopaedic hospitals and the T&O departments' unit cost averaged across HRGs and hospitals. Suppose that $\tilde{\beta} > 0$, which implies higher unit costs

[14] We take the logarithm to improve model fit, since unit costs are left-skewed. All estimated coefficients are therefore interpreted as semi-elasticities.

in specialist orthopaedic hospitals. This, however, does not necessarily imply that specialist orthopaedic hospitals have lower profit margins because no account is taken of hospital revenue. Specialist orthopaedic hospitals may provide more expensive treatments that are fully compensated by a higher HRG tariff.

Our second and main econometric specification, model II, accounts for differences in payments across specialist orthopaedic hospitals and T&O departments:

$$\ln\left(c_{jk}\right)=\mu+\beta s_k+\gamma m_k+\delta e_{jk}+\alpha_j+\varepsilon_{jk}\,, \tag{2.10}$$

where m_k is the MFF index, e_{jk} is the proportion of specialised services, and α_j indicates a set of HRG fixed effects which controls for differences in average cost for each HRG; in turn, this controls for the fixed prices at HRG level which are based on the average cost within each HRG.

This specification compares unit costs across specialist orthopaedic hospitals and T&O departments, after differences in the MFF and specialist top-up payments are taken into account. The tariffs are subtracted through the HRG fixed effects, i.e. a dummy variable for each HRG *j*. The estimated coefficient of every HRG dummy captures the average unit cost of the corresponding HRG category. Suppose again that $\tilde{\beta}>0$ (computed using the estimated $\hat{\beta}$ in Model II). This result now implies that specialist orthopaedic hospitals exhibit lower profit margins compared with T&O departments.

If we find that specialist orthopaedic hospitals are less financially viable, the finding could be due to a number of competing reasons which we account for in our model III. Following common practice (e.g. Street et al., 2010a, Gutacker et al., 2013), this model controls for patient and hospital characteristics that may explain differences in unit costs in addition to differences in payments and, therefore, profitability:

$$\ln\left(c_{jk}\right)=\mu+\beta s_k+\gamma m_k+\delta e_{jk}+\boldsymbol{\rho}'\boldsymbol{x}_{jk}+\boldsymbol{\theta}'\boldsymbol{z}_k+\alpha_j+\varepsilon_{jk}\,, \tag{2.11}$$

where $\boldsymbol{x}_{jk}$ is a vector of patient characteristics measured at HRG level namely the proportion of males, average age, average socio-economic status, average number of diagnoses and procedures; and $\boldsymbol{z}_k$ is a vector of hospital characteristics such as doctor salaries, a dummy indicating whether the hospital is teaching hospital or a foundation trust, size dummies calculated using the number of T&O beds to capture potential economies of scale, the average patient outcomes for hip and knee replacement as measure of quality, and regional dummies to allow for residual geographical differences not captured by other adjustments.

The estimated coefficient $\hat{\beta}$ in model II provides an average effect across specialist orthopaedic hospitals. There may be heterogeneity in terms of their financial position, with some exhibiting lower deficits and others higher surpluses. To explore such heterogeneity, as a sensitivity analysis, we estimate the following model IV which includes hospital fixed effects and directly standardises unit costs (c_{jk}) by the MFF index (m_k):

$$\ln\left(c_{jk}/m_k\right) = \mu + \boldsymbol{\beta}'\boldsymbol{h}_k + \delta e_{jk} + \alpha_j + \varepsilon_{jk} \; . \qquad (2.12)$$

In this specification, the specialist orthopaedic hospital dummy (s_k) used in model I, II, or III is replaced with a vector of hospital dummies ($\boldsymbol{h}_k$). Also $\boldsymbol{\beta}$ is now a vector including k coefficients, one for each hospital dummy: for instance, if $\hat{\beta}_k > 0$ then the provision of trauma and orthopaedic services in hospital k implies lower profit margins relative to the average hospital. We directly standardise unit costs (c_{jk}) because the MFF index (m_k) would be perfectly collinear with hospital dummies ($\boldsymbol{h}_k$) if added as an additional control variable.

All regression models are estimated separately for *inlier* and *per diem* unit costs because the HRG price is computed separately for *inlier* and *excess bed day* activity. For each model, we obtain the *inlier* and *per diem* estimates of β, which are then used to compute an *overall* measure of cost (for model I) or profitability (for models II, III, and IV). For instance, consider our key model II in equation (2.10), which estimates the percentage difference in *inlier* or *per diem* profit margins between specialist orthopaedic hospitals and T&O departments. The percentage difference in *overall* profit margin per patient treated between specialist orthopaedics hospitals and T&O departments, after allowing for differences in unit costs of excess bed days, can be written as:

$$\frac{\bar{\pi}_g - \bar{\pi}_s}{\bar{C}_g} = \frac{\left(\bar{c}_s^{IN} - \bar{c}_g^{IN}\right)\bar{y} + \left(\bar{c}_s^{EB} - \bar{c}_g^{EB}\right)\bar{q}}{\bar{c}_g^{IN}\bar{y} + \bar{c}_g^{EB}\bar{q}}, \qquad (2.13)$$

where $\bar{\pi}_g - \bar{\pi}_s$ is the difference in profit averaged across HRGs and hospitals between T&O departments and specialist orthopaedic hospitals, expressed as a percentage of the T&O departments' total cost averaged across HRGs and hospitals, $\bar{C}_g$ (to be consistent with the interpretation of profitability of the *inlier* activity, $\tilde{\beta}^{IN}$, and *excess bed day* activity, $\tilde{\beta}^{EB}$); $\bar{c}_s^{IN} - \bar{c}_g^{IN} = \tilde{\beta}^{IN}\bar{c}_g^{IN}$ and $\bar{c}_s^{EB} - \bar{c}_g^{EB} = \tilde{\beta}^{EB}\bar{c}_g^{EB}$ are the difference in *inlier* and *per diem* unit costs averaged across HRGs and hospitals, respectively; $\bar{y}$ and $\bar{q}$ are the average volume of patients and the average number of excess bed days, respectively.[15] Standard errors of the *overall* estimates are bootstrapped using 1,000 replications.

2.4 Data

Our primary source of data is the RC database for the financial year 2013/14. For every admission type of every single inpatient HRG, each hospital annually reports information on *inlier* unit costs, *per diem* unit costs, number of patients, and excess bed days.

Hospitals follow a standard process in calculating unit costs by applying the rules set out in the NHS costing manual, which establishes three basic principles (Department of Health, 2012a): first, costs capture the full cost of the services delivered, so that they can be reconciled back to the original aggregated costs in the accounts; second, costs are preferably allocated through direct

[15] The computation of the *overall* profitability for model IV in equation (2.12) differs from the computation described in equation (2.13). It becomes $\left(\bar{\pi}_k - \bar{\pi}\right)/\bar{C} = \left[\left(\bar{c}_k^{IN} - \bar{c}^{IN}\right)\bar{y} + \left(\bar{c}_k^{EB} - \bar{c}^{EB}\right)\bar{q}\right]/\left(\bar{c}^{IN}\bar{y} + c^{EB}\bar{q}\right)$, where $\bar{\pi}_k$ and $\bar{c}_k$ are the hospital *k*'s total profit and unit cost respectively averaged across HRGs and hospitals, $\bar{\pi}$ and $\bar{c}$ are the total profit and unit cost respectively averaged across HRGs and hospitals, $\bar{C}$ is the total cost averaged across HRGs and hospitals, $\left(\bar{c}_k^{IN} - \bar{c}^{IN}\right) = \tilde{\beta}^{IN}\bar{c}^{IN}$ and $\left(\bar{c}_k^{EB} - \bar{c}^{EB}\right) = \tilde{\beta}^{EB}\bar{c}^{EB}$. Also in this case, the standard errors of the *overall* estimates are bootstrapped using 1,000 repetitions.

imputation rather than through apportionment; and third, costs rigorously match the services generating them. The costing process consists of a top-down approach that, in the first instance, groups total costs into: costs that are directly attributable to patients (e.g. doctors, nurses, drugs); costs that are only indirectly linked to patients and that are identified on an activity basis (e.g. linen, catering); and overhead costs that are not related to patients (e.g. senior managers, administrative employees). Such costs are then attributed to macro-areas of treatment and support services (e.g. pharmacy, building maintenance), to hospital specialties (e.g. general surgery, orthopaedics), to wards, and finally to HRGs. Costs are further split by admission type such as non-elective (short or long), elective, and day case.[16] Cost data are audited and must comply with validation rules to assure their accuracy, which is fundamental for the calculation of the national tariffs (Department of Health, 2014).

Our sample for the analysis of *inlier* unit costs consists of 79,096 observations across 1,284 HRGs and 134 hospitals.[17] Of these observations, 14,181 refer to day case treatment, 18,170 to elective care, 19,532 are short-stay non-elective care, and 27,186 are long-stay non-elective care. The sample for the analysis of *per diem* unit costs comprises 16,098 observations, of which 4,087 are elective and 12,011 are non-elective.

For every HRG in each hospital, we calculate the proportion of patients who receive specialised orthopaedic services, the proportion of male patients, average patient age, average socio-economic status, average number of diagnoses and procedures using data summarised from patient-level information in the HES (Bojke et al., 2015).[18] We collect several variables measured at hospital

[16] Unlike elective and day case patients, the admission of non-elective patients is unplanned. Day case and short non-elective patients do not have an overnight stay in hospital, while elective and long non-elective patients have at least one overnight stay.

[17] Ten T&O departments in general hospitals did not report data on PROMs for hip or knee replacement and they are, therefore, dropped from the sample.

[18] We count specialised services following the rules defined in the Prescribed Specialised Services (PPS), and not the criteria specified in the Specialised Services National Definition Sets (SSNDS). We use the overall Index of Multiple Deprivation (IMD) as a measure of socio-economic status. This index is constructed through the combination of seven

level, most of which are from the Health and Social Care Information Centre (HSCIC; since renamed NHS Digital): a dummy variable for specialist orthopaedic hospitals, teaching hospitals, and foundation trusts; the average salary of doctors employed in the T&O specialty;[19] and regional dummies. The HSCIC also provides Patient Reported Outcome Measures (PROMs) including, for each hospital, the average health change of patients undergoing hip and knee replacement (Appleby and Devlin, 2004, Gomes et al., 2015). PROMs measure the patients' quality of life through the EQ-5D health-status questionnaire before and six months after their surgery. Hence, the health change is the difference between the post and pre-surgery EQ-5D scores, and it is estimated through a risk-adjustment methodology that takes account of patient characteristics and factors beyond hospitals' control (Department of Health, 2012b).[20] Using data from the NHS statistics, we construct dummies related to the size of the T&O department (small, medium, large, and very large), which are defined on the quartiles of the T&O beds distribution of all hospitals. Finally, the RC database reports the MFF index.

2.4.1 Descriptive statistics

Figure 2.1 illustrates that the distribution of *inlier* and *per diem* unit costs substantially departs from normality when in natural units, while it is approximately normal after taking the log. Table 2.1 contains descriptive statistics of the variables measured at HRG level for the sample with observations of all admission types.[21] Our sample includes the three specialist orthopaedic

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IMD domains such as income, employment, health deprivation and disability, education, skills and training, barriers to housing and services, crime, and living environment. A value of one indicates extreme deprivation while 32,482 indicates no deprivation.

[19] The salary of a doctor employed in the T&O specialty is estimated through an s-shape function of age, minimum and maximum salary. Further details are provided in section A2.1 of the Appendix 2.

[20] More precisely, the risk-adjustment methodology comprises three steps. The first step consists of estimating a Generalised Least Square fixed effects model in which the dependent variable is the post-surgery EQ-5D score of each patient, the covariates are pre-surgery EQ-5D score, patient characteristics (e.g. gender, age, ethnicity), economic deprivation, comorbidity, procedure and post-operative length of stay. This regression also controls for unobserved hospital heterogeneity through fixed effects. In the second step, the model is used to estimate predictions. The third step aggregates such predictions to obtain the adjusted average post-surgery EQ-5D score for each provider, from which the national average pre-surgery EQ-5D score is subtracted for the calculation of the adjusted average health gain.

[21] Table A2.1 and Table A2.2 in section A2.2 of the Appendix 2 show descriptive statistics of the variables measured

hospitals and 131 T&O departments in general hospitals. Specialist orthopaedic hospitals have on average higher *inlier* unit costs than T&O departments (£5,196 vs £2,987) and a higher number of patients per HRG (20 vs 12). The proportion of patients receiving specialised services is higher in specialist orthopaedic hospitals (1.1%) than T&O departments (0.1%). 49% of patients are male in both specialist orthopaedic hospitals and T&O departments, while patients in specialist orthopaedic hospitals are on average eight years younger (47 vs 55) and better-off (deprivation index greater by 2%). Specialist orthopaedic hospitals record about the same number of diagnoses (5) for their average patient but provide one more procedure (4 vs 3) than T&O departments.

The lower part of Table 2.1 also provides descriptive statistics for excess bed days. *Per diem* unit costs are on average higher in specialist orthopaedic hospitals (£465) than in T&O departments (£301). There are on average 22 excess bed days per HRG, but many more in the specialist orthopaedic hospitals (45) than in T&O departments (22). The proportion of patients receiving specialised services with a *per diem* unit cost is also higher in specialist orthopaedic hospitals (2.7% vs 0.1%). Similarly, the proportion of male patients with a long length of stay in specialist hospitals is slightly greater than in T&O departments (47.5% vs 46.8%). Long-stay patients are nine years younger (49 vs 58), better-off (deprivation index greater by 3%), and have the same number of diagnoses (5) but one more procedure (4 vs 3) in specialist orthopaedic hospitals compared to T&O departments.

Table 2.2 illustrates descriptive statistics of the variables measured at hospital level. 24 (17.9%) trusts are teaching hospitals, and 80 (59.7%) hospitals have foundation status. Two of the specialist orthopaedic hospitals are foundation trusts but none is a teaching hospital. 15 hospitals are in the London region, one of which is specialised. The remaining two specialist orthopaedic

at HRG level for the sample with day case and elective observations, and short non-elective and long-non elective observations, respectively.

hospitals are located in the West Midlands region, which includes 14 other general hospitals. The regions with the largest and smallest number of hospitals are, respectively, the North West including 22 hospitals, and the East Midlands and the North East with 8 hospitals. On the basis of the quartile division, a T&O department is categorised as small if it has less than 46 specialty beds, medium if between 46 and 61 beds, large if between 62 and 79 beds, and very large if it has more than 79 beds. The three specialist orthopaedic hospitals fall into the very large group. The MFF index is on average greater in specialist orthopaedic hospitals compared to T&O departments (1.085 vs 1.075). A doctor working in T&O earns on average approximately £86,000. Doctors in specialist orthopaedic hospitals are paid 5.6% more, on average, than doctors in T&O departments.

Of all NHS patients treated in the T&O specialty, 9.5% receive a hip replacement and 6.7% undergo a knee replacement. Specialist orthopaedic hospitals have a higher average health gain for hip (0.442 vs 0.425) and knee (0.317 vs 0.315) replacement.

2.5 Results

Table 2.3 provides the estimation results of models I, II and III for *inlier* and *per diem* unit costs when all admission types are included in the sample. Recall that unit costs are in logs. The specialist orthopaedic hospital dummy's estimated coefficient is positive and statistically significant at 5% level in model I and II but it is insignificant in model III for the *inlier* unit costs. It is always negative but statistically insignificant in the regressions for the *per diem* unit costs. Specialist orthopaedic hospitals and T&O departments in general hospitals have therefore statistically different costs for the *inlier* activity but statistically similar costs for the *excess bed day* activity. The first column of Table 2.3 shows the estimates of model I in equation (2.9), indicating raw differences in unit costs between specialist orthopaedic hospitals and T&O departments. Specialist orthopaedic hospitals have on average (exp(0.149)−1=)[22] 16.1% higher

[22] The exponential transformation is applied to all the figures reported in the text in this section. This explains the

inlier unit costs. In contrast, they have on average 14.4% lower *per diem* unit costs but this result is not statistically significant.

Model II in equation (2.10) provides estimates of differences in unit costs after accounting for differences in revenue by subtracting tariffs (HRG fixed effects) and by accounting for tariff adjustments (MFF and specialised services top-ups). The specialist orthopaedic hospital dummy's estimated coefficient therefore can be interpreted as the difference in profit margins between specialist orthopaedic hospitals and T&O departments.[23] Specialist orthopaedic hospitals have on average 20.3% lower *inlier* profit margins. A percentage point increase in the proportion of specialised services raises *inlier* unit costs by 1.2%. A standard deviation increase in the MFF (0.064) is associated with an increase in *inlier* unit costs of 5.6%.

With model III in equation (2.11), we investigate whether differences in profit margins can be explained by patient and hospital characteristics. The differences in *inlier* and *per diem* unit costs ($\hat{\beta}$) are both statistically insignificant, as are the variables capturing hospital characteristics. Instead, patient characteristics measuring age and number of diagnoses and procedures are significant at 1% level in explaining the differences in *inlier* (but not *per diem*) profit margins between specialist orthopaedic hospital and T&O departments.[24] Age and *inlier* unit costs have a quadratic relationship so that unit costs decrease up to 75 years (-0.015/(2×0.0001)) and increase above that. At the sample mean of 54.7 years, one more year decreases inlier unit costs by 0.4%

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differences with the coefficients reported in Table 2.3.

[23] Recall that the unit cost is the dependent variable in model II (III or IV) while tariffs are on the right-hand-side of the equation. Under such a regression design, β reflects the difference between unit costs and tariffs instead of the definition of profit margins, i.e. difference between tariffs and unit costs. To abide by the correct definition of profit margins, the interpretation of β must be reversed so that, for example, a positive estimate indicates lower profit margins in specialist orthopaedic hospitals relative to T&O departments in general hospitals.

[24] To reinforce this finding, we provide the results of a stepwise regression in Table A2.3 in section A2.3 of the Appendix 2. These results show that age, number of diagnoses and procedures together drive the differences in *inlier* unit costs between specialist orthopaedic hospitals and T&O departments in general hospitals, with there being a seeming difference between the hospital types if any of these patient characteristics is omitted. Table A2.4 shows that differences between hospital types in *per diem* unit costs are always statistically insignificant whether or not patient characteristics are accounted for.

(-0.015+2×0.0001×54.7). An additional diagnosis or procedure raises *inlier* unit costs by 3.8% or 2.4%, respectively. We extend model III by adding interactions between all control variables. We find that differences in both *inlier* and *per diem* profit margins between specialist orthopaedic hospitals and T&O departments remain statistically insignificant (see Table A2.5 in section A2.3 of the Appendix 2).[25]

So far, we have presented our findings on specialist orthopaedic hospitals for *inlier* and *excess bed day* hospital activity, separately. Table 2.4 reports the *overall* percentage change in unit costs ($\tilde{\beta}$) between specialist orthopaedic hospitals and T&O departments for each admission type.[26] The *overall* percentage change is calculated as the sum of *inlier* and *per diem* percentage changes in unit cost or profit margins. The first column shows the percentage changes derived from model I. The *overall* unit costs are not statistically different between specialist orthopaedic hospitals and T&O departments. In model II, when hospital revenues are taken into account, specialist orthopaedic hospitals have on average 13% lower *overall* profit margins than T&O departments at 1% of statistical significance (see footnote 23 for details on the interpretation). Model III shows that the *overall* profit margins in specialist orthopaedic hospitals are no longer significantly different from those in T&O departments after controlling for some key determinants including patient characteristics such as proportion of males, age, socio-economic status, number of diagnoses and procedures, and hospital characteristics such as salary of doctors, hospital type, specialty size, quality, and other regional differences.

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[25] As a further robustness check, we estimate model V which is akin to model III but also includes hospital random effects. Unlike the hospital fixed-effects model, the hospital random-effects model can be estimated when the specialist orthopaedic hospital dummy is included although this requires the additional assumption that the covariates are uncorrelated with the time-invariant unobserved hospital heterogeneity. Table A2.6 in section A2.3 of the Appendix 2 shows that the results for model V are very similar to those for model III.

[26] Recall that the percentage change ($\tilde{\beta}$) is obtained through the exponential transformation of the estimated coefficient ($\hat{\beta}$).

2.5.1 Sensitivity analysis

As a sensitivity analysis, we estimate the same three models for each admission type. The lower panel of Table 2.4 (second column) shows that statistically significant lower *overall* profit margins in specialist orthopaedic hospitals are found for elective (22.6%) and long non-elective activity (38.9%), but not for short non-elective and day case activity.

Finally, estimation of model IV including hospital fixed effects in equation (2.12) suggests wide variation in *overall* (*inlier*) profit margins across hospitals in our sample, from 37.5% (38.6%) below the average to 38% (40.6%) above the average. Figure 2.1 indicates that 45 hospitals, i.e. about a third, have significantly lower *overall* profit margins compared to the average profit margins, and 42 have significantly higher *overall* profit margins.[27] None of the three specialist orthopaedic hospitals have *overall* or *inlier* profit margins significantly above the average. In particular, as shown in Table 2.5, the *overall* profit margins of the Robert Jones and Agnes Hunt orthopaedic hospital (minus 19.9%) and the Royal orthopaedic hospital (minus 35.2%) are significantly below the average.[28] The Royal National orthopaedic hospital has instead average *overall* profit margins. The latter finding is driven by higher profit margins on day case activity (40.6%).

2.6 Discussion and conclusion

The English NTPS is used to reimburse hospitals according to the amount and mix of activity that they undertake. Like most PPSs, there is a recognition that HRGs imperfectly account for all patient or exogenous hospital characteristics that might influence costs (Busse, 2012, Monteith,

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[27] We count only hospitals for which confidence intervals do not overlap the dashed horizontal line at zero, i.e. hospitals for which the deviation of profit margins from the mean is statistically different from zero.

[28] Recall that β_k in model IV captures the deviation of hospital k's profit margins from the mean profit margins: a positive β_k means that hospital k's profit margins are lower than the mean, while a negative β_k suggests that hospital k's profit margins are higher than the mean (see also footnote 23 for details on the interpretation). For ease of interpretation, we multiply the estimate of β_k by minus one and, therefore, the negative sign now indicates profit margins that are lower than the mean. All coefficients in Table 2.5 indicate the percentage change ($\tilde{\beta}_k$) obtained through the exponential transformation of $\hat{\beta}_k$.

2013). As such, payment adjustments include top-ups to the tariff if patients received particular specialised care and payment corrections allow for differential costs of labour and capital across the country. These refinements help ensure a fair reimbursement system that rewards hospitals according to the care that they provide, not the advantageous circumstances in which they might operate (Daidone and Street, 2013, Grašič et al., 2015).

Given these payment adjustments, hospitals that provide care at a cost below tariff should be more profitable. Arguably specialist hospitals should be in a strong position to benefit financially from these arrangements. By focussing on a limited set of services they should be able to better exploit informational or organisational advantages associated with specialisation. Such advantages derive from concentrating on a specific, defined caseload that enhances learning-by-doing and attracts staff with particular expertise and more easily allows efficient practice in care delivery to be identified and operationalised (Schneider et al., 2008).

If these advantages obtain we would expect specialist hospitals to earn higher profits than general hospitals that undertake similar activities. The evidence provided in this study does not support this claim. We have analysed the costs and revenues associated with delivery of trauma and orthopaedic services in all three specialist orthopaedic hospitals and 131 T&O departments in general hospitals in England. We find that, compared to the national average, profit margins are 13% lower in the three specialist orthopaedic hospitals. Profits are statistically significantly lower across all patients that have at least one overnight stay, either elective or non-elective.

These lower profits are not due simply to patients in specialist hospitals requiring long lengths of stay or specialist care. Payment arrangements allow for this possibility through *excess bed day* payments and tariff top-ups for specialised treatments, and we account for these revenue adjustments in our analysis. Nor does it appear that differences can be explained by the characteristics of the hospitals such as their teaching and foundation status or geographical location, nor by the number of the T&O patients treated, nor by variation in doctors' salaries, nor by the quality of care as captured by PROMs for two high-volume orthopaedic procedures such as hip and knee replacement. Lower profits are observed even after these potential explanatory factors are taken into account.

Instead, we find that lower profit margins in specialist orthopaedic hospitals are explained by patient characteristics such as age and severity as captured by the number of diagnoses and procedures. This means that, although hospital payments are based on a detailed patient classification system (HRG) and on adjustments for the higher cost of specialised care, providers that generally attract more complex patients such as specialist orthopaedic hospitals may be financially disadvantaged. That said, being part of a general hospital does not guarantee better financial performance with 33% of the T&O departments also making a loss.

Our study has three main limitations. First, our sample includes only three specialist orthopaedic hospitals. Such a small number of specialist orthopaedic hospital trusts, however, is not the result of sample selection but reflects the reality that there are only three specialist orthopaedic hospital trusts in the English NHS. Specialist hospitals are few and far between in many countries. Hence, we believe that our analysis is appropriate and generally applicable. Moreover, although we are limited by the actual number of hospitals, we analyse hundreds of HRGs for each specialist hospital and we investigate heterogeneity across the three hospitals in model IV using hospital fixed effects. This model shows that two of the three specialist hospitals make a loss and none of them makes a profit, which confirms that specialist orthopaedic hospitals are in a relatively weak financial position.

Second, our estimated tariffs may not be identical to current tariffs, i.e. the actual tariffs that hospitals receive in 2013/14. We compute tariffs by including in our models (II, III, or IV) the HRG fixed effects, which capture the unit cost of each HRG averaged across hospitals. This reflects the methodology used to compute current tariffs but, in practice, current tariffs are based on cost data lagged by three years in order to ensure data accuracy and stakeholder engagement in their calculation (Department of Health, 2013a). To account for the time lag, the current tariffs' methodology adjusts for inflation and efficiency trends. We therefore argue that tariffs estimated through our methods are a reasonable approximation to current tariffs.

Finally, PROMs are currently available only for two orthopaedic procedures such as hip and knee replacements. These procedures are however the most common in T&O departments: of all NHS patients treated in the T&O specialty, 9.5% receive a hip replacement and 6.7% undergo a knee replacement. We therefore argue that hip and knee replacements are indicative of departmental performance.

Future research may be required before a definitive recommendation about whether profit margins differ in trauma and orthopaedic services across general and specialised hospitals. But we have set out a methodology that can be applied to other types of hospital service and in other settings, to investigate the extent to which differences in costs between groups of hospitals are adequately covered by prospective payment systems.

Tables and Figures

Table 2.1 – Descriptive statistics of variables measured at HRG level.

	Variable at HRG level	All hospitals				Specialist hospitals				General hospitals			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Inlier	Inlier unit cost	3,031	3,484	22	129,419	5,196	8,555	173	129,419	2,987	3,287	22	78,447
	Number of patients (FCEs)	12.2	37.4	1	1,622	20.3	57.7	1	644	12.1	36.9	1	1,622
	Number of specialised services	0.05	0.73	0	55	0.66	4.23	0	55	0.04	0.42	0	26
	Proportion of specialised services (%)	0.1	1.7	0.0	100.0	1.1	6.1	0.0	69.2	0.1	1.5	0.0	100.0
	Proportion of males (%)	49.1	19.6	0.0	100.0	49.2	24.3	0.0	100.0	49.1	19.5	0.0	100.0
	Age	54.7	18.9	0.0	97.0	47.4	17.4	1.0	90.0	54.8	18.9	0.0	97.0
	Deprivation index	15,969	4,889	12	32,474	16,296	4,365	194	32,417	15,963	4,899	12	32,474
	Number of diagnoses	4.969	2.655	1	20	4.733	2.511	1	13	4.974	2.657	1	20
	Number of procedures	3.079	2.108	0	24	4.118	2.158	0	12	3.058	2.102	0	24
	Number of HRGs	1,284				415				1,272			
	Observations	79,069				1,564				77,505			
Excess bed day	Per diem unit cost	305	474	20	54,422	465	2,867	65	54,422	301	188	20	9,499
	Number of excess bed days	22.2	35.5	1	715	44.8	81.8	1	715	21.7	33.4	1	538
	Number of specialised services	0.11	1.31	0	55	1.95	7.56	0	55	0.07	0.56	0	26
	Proportion of specialised services (%)	0.2	2.0	0.0	69.2	2.7	9.6	0.0	69.2	0.1	1.3	0.0	45.6
	Proportion of males (%)	46.8	16.2	0.0	100.0	47.5	18.1	0.0	100.0	46.8	16.2	0.0	100.0
	Age	57.8	15.7	0.1	97.0	49.2	16.2	7.9	90.0	58.0	15.6	0.1	97.0
	Deprivation index	16,047	4,564	201	32,268	16,499	3,636	1,428	31,664	16,036	4,583	201	32,268
	Number of diagnoses	5.096	2.535	1	20	4.906	2.501	2	13	5.100	2.536	1	20
	Number of procedures	3.160	2.096	0	24	4.378	2.265	0	12	3.131	2.084	0	24
	Number of HRGs	675				183				662			
	Observations	16,098				373				15,725			

Table 2.2 – Descriptive statistics of variables measured at hospital trust level.

Variable at hospital trust level	All hospitals				Specialist hospitals				General hospitals			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Specialist orthopaedic hospital	0.022	0.148	0	1	1.000	0.000	1	1	0.000	0.000	0	0
Market forces factor	1.076	0.064	1.003	1.298	1.085	0.082	1.032	1.180	1.075	0.063	1.003	1.298
Salary of doctors (£10,000)	8.664	0.744	6.596	10.060	9.134	0.293	8.797	9.324	8.653	0.749	6.596	10.060
Teaching hospital	0.179	0.385	0	1	0.000	0.000	0	0	0.183	0.388	0	1
Foundation hospital	0.597	0.492	0	1	0.667	0.577	0	1	0.595	0.493	0	1
Small department	0.201	0.403	0	1	0.000	0.000	0	0	0.206	0.406	0	1
Medium department	0.284	0.452	0	1	0.000	0.000	0	0	0.290	0.456	0	1
Large department	0.254	0.437	0	1	0.000	0.000	0	0	0.260	0.440	0	1
Very large department	0.261	0.441	0	1	1.000	0.000	1	1	0.244	0.431	0	1
Average health change after hip replacement	0.425	0.028	0.311	0.476	0.442	0.033	0.410	0.476	0.425	0.028	0.311	0.474
Average health change after knee replacement	0.315	0.028	0.215	0.396	0.317	0.025	0.288	0.332	0.315	0.028	0.215	0.396
London	0.112	0.316	0	1	0.333	0.577	0	1	0.107	0.310	0	1
East Midlands	0.060	0.238	0	1	0.000	0.000	0	0	0.061	0.240	0	1
East of England	0.127	0.334	0	1	0.000	0.000	0	0	0.130	0.337	0	1
North East	0.060	0.238	0	1	0.000	0.000	0	0	0.061	0.240	0	1
North West	0.164	0.372	0	1	0.000	0.000	0	0	0.168	0.375	0	1
South East	0.149	0.358	0	1	0.000	0.000	0	0	0.153	0.361	0	1
South West	0.112	0.316	0	1	0.000	0.000	0	0	0.115	0.320	0	1
West Midlands	0.119	0.325	0	1	0.667	0.577	0	1	0.107	0.310	0	1
Yorkshire and The Humber	0.097	0.297	0	1	0.000	0.000	0	0	0.099	0.300	0	1
Number of trusts	134				3				131			

Table 2.3 – Estimation results when all admission types are included.

Regressor	Inlier			Per diem		
	Model I	Model II	Model III	Model I	Model II	Model III
Specialist orthopaedic hospital	0.149**	0.185**	0.149	-0.156	-0.276	-0.140
	(0.059)	(0.076)	(0.097)	(0.187)	(0.196)	(0.204)
Market forces factor		0.845***	0.928**		0.353	0.485
		(0.213)	(0.460)		(0.381)	(1.228)
Proportion of specialised services		0.012**	0.010*		0.003	0.003
		(0.005)	(0.006)		(0.003)	(0.003)
Proportion of males			-0.00009			-0.0004
			(0.000)			(0.001)
Age			-0.015***			-0.006
			(0.004)			(0.006)
Age (squared)			0.0001***			0.0001*
			(0.000)			(0.000)
Deprivation index			-0.000003			-0.000007
			(0.000)			(0.000)
Number of diagnoses			0.037***			-0.031*
			(0.010)			(0.018)
Number of procedures			0.024***			-0.017
			(0.007)			(0.012)
Salary of doctors			0.003			-0.041
			(0.021)			(0.040)
Teaching trust			0.057*			0.097
			(0.034)			(0.076)
Foundation trust			-0.049*			0.011
			(0.026)			(0.059)
Medium department			-0.019			-0.068
			(0.035)			(0.081)
Large department			-0.021			0.002
			(0.032)			(0.083)
Very large department			0.022			-0.117
			(0.034)			(0.077)
Average health change after hip replacement			0.952*			-1.896*
			(0.523)			(1.081)
Average health change after knee replacement			-0.414			0.468
			(0.465)			(1.177)
Constant			6.625***			6.429***
			(0.608)			(1.607)
HRG fixed effects	NO	YES	YES	NO	YES	YES
Regional fixed effects	NO	NO	YES	NO	NO	YES
Observations	79,069	79,069	79,069	16,098	16,098	16,098
Adjusted R-squared	0.001	0.797	0.805	0.005	0.074	0.157

Standard errors are clustered at hospital trust level and are reported in parentheses

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 2.4 – Differences in unit costs between specialist orthopaedic hospitals and T&O departments in general hospitals.

	Inpatient activity	Model I	Model II	Model III
All admission types	Overall[1]	0.114	0.135***	0.116
		(0.157)	(0.000)	(0.466)
	Inlier	0.161**	0.203**	0.161
		(0.013)	(0.016)	(0.125)
	Per diem	-0.144	-0.241	-0.131
		(0.408)	(0.161)	(0.494)
Elective	Overall[1]	0.254***	0.226***	0.204**
		(0.000)	(0.000)	(0.026)
	Inlier	0.311***	0.282***	0.249***
		(0.000)	(0.000)	(0.000)
	Per diem	-0.225	-0.248	-0.176
		(0.195)	(0.175)	(0.243)
Long non-elective	Overall[1]	0.601***	0.389***	0.403*
		(0.000)	(0.000)	(0.076)
	Inlier	0.741*	0.499***	0.486***
		(0.064)	(0.004)	(0.003)
	Per diem	-0.140	-0.192	-0.033
		(0.395)	(0.196)	(0.864)
Short non-elective		0.293	0.320	0.369*
		(0.101)	(0.147)	(0.099)
Day case		-0.071	0.029	-0.018
		(0.731)	(0.887)	(0.924)

[1] Standard errors are bootstrapped using 1,000 replications.

p-value in parentheses; *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 2.5 – Specialist orthopaedic hospitals' *overall* profit margins.

Specialist orthopaedic hospital	All admission types	Day case	Elective	Short non-elective	Long non-elective
Royal National Orthopaedic Hospital NHS Trust	0.0%	40.6%*	-30.5%*	-79.4*	-80.5%*
Robert Jones And Agnes Hunt Orthopaedic Hospital NHS Foundation Trust	-19.9%*	-21.5%*	-18.0%*	4.2%	-4.8%
Royal Orthopaedic Hospital NHS Foundation Trust	-35.2%*	-29.5%*	-29.0%*	-69.0%*	-30.6%*

* significantly different from the average hospital at 5%

Figure 2.1 – Distribution of *inlier* and *per diem* unit costs in natural units and logs.

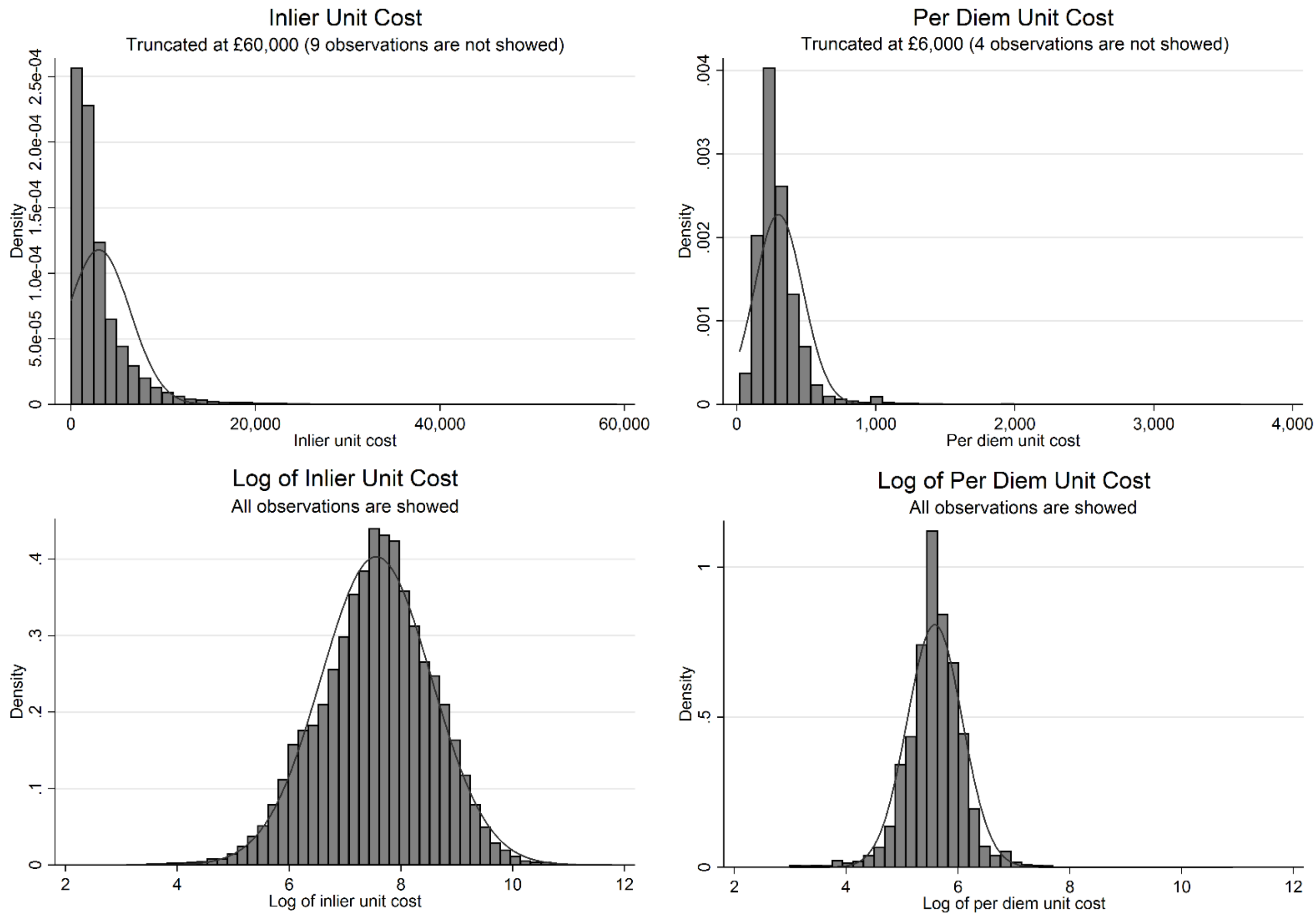
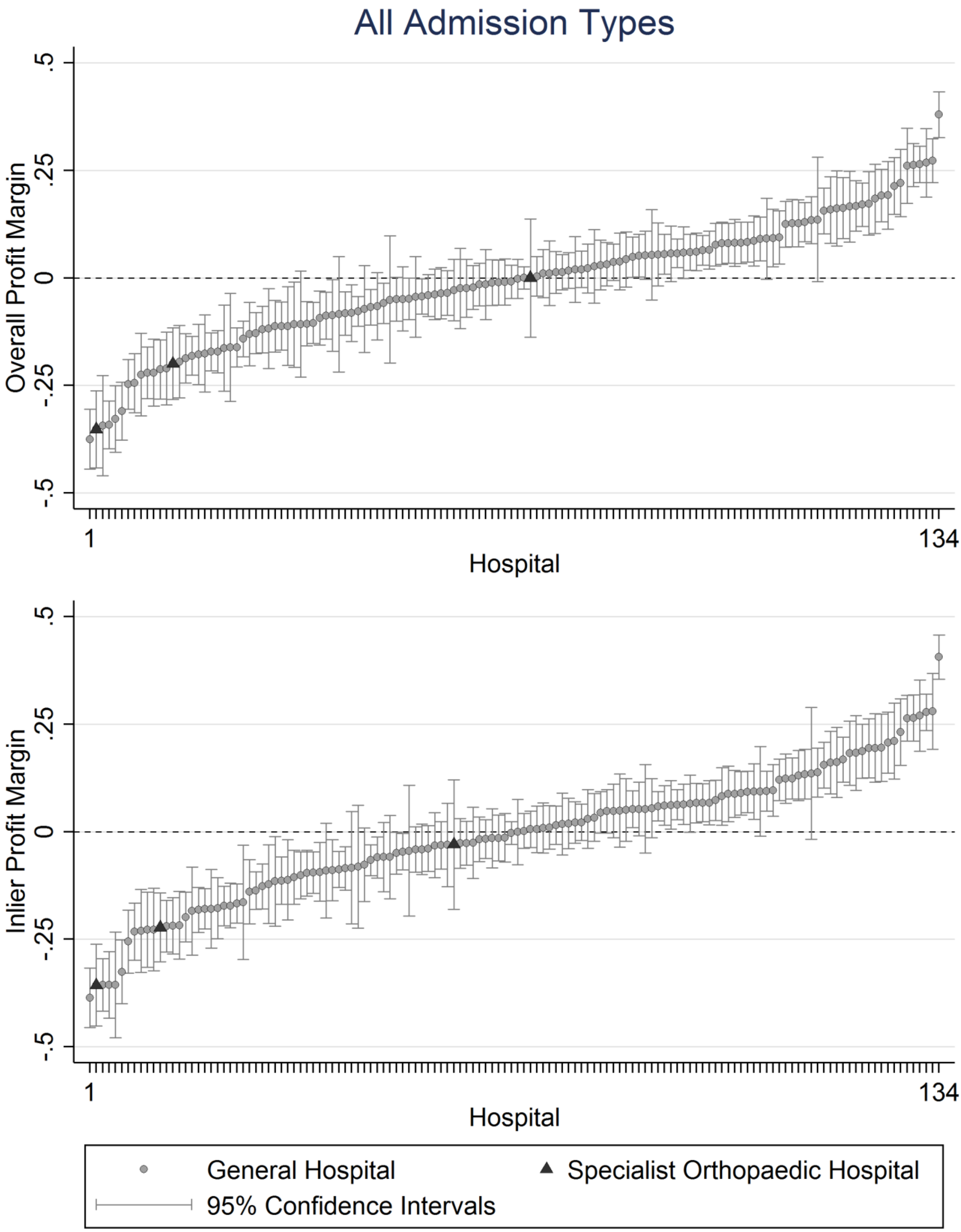


Figure 2.2 – Distribution of *overall* and *inlier* profit margins.



Chapter 3 – Do Hospitals Respond to Rivals' Quality and Efficiency? A Spatial Panel Econometric Analysis

Abstract

We investigate whether hospitals in the English National Health Service change their quality or efficiency in response to changes in quality or efficiency of neighbouring hospitals. We first provide a theoretical model which predicts that a hospital will not respond to changes in the efficiency of its rivals but may change its quality or efficiency in response to changes in the quality of rivals, though the direction of the response is ambiguous. We use data on eight quality measures (including mortality, emergency readmissions, patient reported outcome, and patient satisfaction) and six efficiency measures (including bed occupancy, cancelled operations, and costs) for public hospitals between 2010/11 and 2013/14 to estimate both spatial cross-sectional and spatial fixed and random effects panel data models. We find that although quality and efficiency measures are unconditionally spatially correlated, the spatial regression models suggest that a hospital's quality or efficiency does not respond to its rivals' quality or efficiency, except for a hospital's overall mortality which is positively associated with that of its rivals. The results are robust to allowing for spatially correlated covariates and spatial correlated errors and to instrumenting rivals' quality and efficiency.

3.1 Introduction

Quality and efficiency are fundamental goals for policymakers in the hospital sector. In the presence of fixed prices, policymakers have argued that competition may induce hospitals to compete on quality to attract patients and to enhance their efficiency (Gaynor, 2007). Investigations of the effect of competition on quality and efficiency in the US, the United Kingdom, and other OECD countries have produced mixed results (section 3.1.1).

In this study, rather than examining the relationship between measures of competition and hospital quality and efficiency, we use an alternative approach by examining hospitals' strategic interactions. For example, in a competitive environment we may expect a hospital to respond to an increase in quality by a rival hospital by also increasing quality: in industrial economics terms qualities are *strategic* complements. We present a simple theory model (Section 2) which shows that this intuition can be correct if treatment costs are increasing in quality. The reduction in demand which follows from an increase in rival's quality reduces total treatment cost of providing quality and at the margin incentivises the hospital to increase quality. There is however an offsetting effect: the reduction in demand also reduces incentives to contain cost which reduces the profit margin on additional patients. We therefore investigate empirically whether quality and efficiency are strategic complements or strategic substitutes so that higher rivals' quality (efficiency) induces a hospital to increase or reduce its quality (efficiency).

We consider both clinical and non-clinical dimensions of quality. We measure clinical quality through risk-adjusted overall mortality and readmission rate, and mortality rates for high-volume conditions such as hip fracture and stroke. Since the vast majority of patients do not die or have an emergency readmission we also measure health gains for a common elective procedure (hip replacement) using patients-reported outcomes (PROMs). We capture non-clinical dimensions of patients' experience using patient satisfaction with their overall hospital experience, hospital cleanliness, and the extent to which clinicians involved the patients in the treatment decision. We measure hospital efficiency through indicators for bed occupancy, cancelled elective operations, and cost indices for overall hospital activity, elective and non-elective activity, and for hip replacement. All these measures are in the public domain so that hospital managers and senior physicians are in principle able to compare themselves with their rivals.

The global Moran's I test suggests that most of the quality and efficiency indicators are unconditionally spatially correlated. We estimate spatial cross-sectional models by quasi-maximum likelihood (ML) controlling for observable determinants of quality and efficiency. To control for unobserved time-invariant determinants of quality and efficiency, we also estimate spatial panel models with hospital fixed or random effects. These models suggest that a hospital's quality or efficiency does not respond to its rivals' quality or efficiency, except for a hospital's overall mortality which is positively associated with that of its rivals. The results are robust to allowing for spatially correlated covariates and spatially correlated errors and to instrumenting rivals' quality and efficiency.

Sections 3.1.1 and 3.1.2 review the literature and the institutional background. Section 3.2 provides a simple theoretical model. Section 3.3 outlines the empirical strategy. Section 3.4 describes the data. Section 3.5 discusses the results, and Section 3.6 concludes.

3.1.1 Related literature

Our study contributes to the literature on hospital competition and, more broadly, to spatial econometrics applications in health economics. Early studies focus on the relationship between hospital competition and efficiency in the US. They show that non-price competition combined with a cost-based reimbursement system may lead to overprovision of hospital services (e.g. Joskow, 1980, Robinson and Luft, 1985). Later studies find a beneficial effect of price competition on costs (e.g. Zwanziger and Melnick, 1988, Bamezai et al., 1999). Studies on the impact of hospital competition on clinical quality, measured usually by mortality, have mixed results. Some find that competition improves quality (Kessler and McClellan, 2000, Kessler and Geppert, 2005), others that competition reduces quality (Gowrisankaran and Town, 2003) or has no effect (Mukamel et al., 2001).

UK studies also have mixed results. While some find that competition increases efficiency (Cooper et al., 2012, Gaynor et al., 2013) others report no association (Söderlund et al., 1997). Some studies find negative effects of competition on quality when prices are not fixed and negotiated with the purchaser (Propper et al., 2004, Propper et al., 2008); some later studies find positive effects where prices were fixed within a DRG type system (Cooper et al., 2011, Gaynor et al., 2013, Bloom et al., 2015), and some find mixed effects based on the quality indicator (Gravelle et al., 2014a).

A smaller number of studies take a different approach: rather than examining the quasi-reduced form relationship between market structure and quality or price, they use spatial econometric methods to investigate strategic interactions amongst hospitals by examining whether a hospital's quality or price depends on the quality or price of its rivals. Mobley (2003) and Mobley et al. (2009) examine strategic complementarity in prices within the US context where hospital prices are not fixed. Similarly, Choné et al. (2014) study strategic complementarity of GPs' prices in France using an instrumental variables (IV) approach. Gravelle et al. (2014b) use a cross section of English data and find that four out of sixteen clinical and patient-reported hospital quality measures are strategic complements.

We contribute to this literature in a number of ways. First, we complement the theory model in Brekke et al. (2012), which shows that competition can influence efficiency through its effect on quality, and the finding in Cooper et al. (2012), which suggest that market structure affects efficiency, by examining strategic interactions amongst hospitals with respect to efficiency. Second, we employ panel data to control for unobserved time-invariant heterogeneity. Third, previous studies on strategic interactions amongst hospitals have been cross-sectional and so may be biased when estimated by ML because of unobserved factors generating spatial correlations amongst hospitals. We therefore address potential endogeneity in cross-sectional models by using an IV approach.

More generally, our study contributes to the small but growing literature on spatial econometrics applications in health economics. As well as hospital competition, this literature discusses alternative sources of spatial dependence across healthcare authorities. Following

Manski (1993), Moscone and Knapp (2005) propose a classification of spatial effects for mental health expenditure in England. More recently, Atella et al. (2014) investigate spillovers in healthcare expenditure amongst Italian local health authorities and Guccio and Lisi (2016) look at interactions amongst hospitals' caesarean section rates. Another strand of this literature focuses on healthcare expenditure and its determinants. Some studies investigate whether spatial interactions affect expenditure (Moscone et al., 2007a, Moscone et al., 2007b). Other studies allow for spatial dependence to identify the effect of other factors, such as income, on healthcare expenditure (Costa-i-Font and Pons-Novell, 2007, Baltagi and Moscone, 2010, Moscone and Tosetti, 2010, Baltagi et al., 2016). Other studies show that it is necessary to allow for spatial correlations when examining the determinants on health outcomes, such as mortality (Lorant et al., 2001), avoidable emergency admissions (Mobley et al., 2006, Weeks et al., 2016), admission, discharge and treatment indicators (Bech and Lauridsen, 2008, Baltagi and Yen, 2014, Gaughan et al., 2015), and HIV prevalence rate (Docquier et al., 2014).

The present study extends the analysis by Gravelle et al. (2014b) on strategic interactions amongst English hospitals in several directions. In terms of research question, we focus on strategic interactions in efficiency in addition to quality. Gravelle et al. (2014b) use cross-sectional data from the financial year 2009/10 while our study covers the more recent and longer period from 2010/11 to 2013/14, which gives us the opportunity to exploit panel data methods. We also analyse quality indicators not included by Gravelle et al. (2014b), i.e. the PROMs for two high-volume orthopaedic procedures (hip and knee replacement). Most importantly, we employ a ML panel spatial lag model and a cross-sectional IV approach. We also use a richer set of demand and supply shifters to better account for potential factors generating spatial correlations. Our results are different but compatible with those obtained by Gravelle et al. (2014b) as discussed in greater detail in Section 5.3.

3.1.2 Institutional background

The English National Health Service (NHS) provides healthcare which is universal, tax financed, and free at the point of use. The Department of Health distributes capitated funding to around 150 local health authorities which use it to pay for secondary healthcare provided to NHS patients by public and private hospitals. Public hospitals are run by NHS Trusts or NHS Foundation Trusts, the latter having greater financial autonomy. Some NHS hospital trusts are teaching trusts providing research and teaching, and some are specialist trusts focusing on a limited range of conditions or client groups.

Hospitals are mainly funded through a prospective payment system, the National Tariff Payment System. This is based on Healthcare Resource Groups (HRGs), a patient classification system similar to the American Diagnosis-Related Group or DRG. The HRGs categorise patients into homogeneous groups depending on diagnoses, procedures, and some patient characteristics. A fixed tariff is calculated for each HRG group as its national cost averaged across providers but with adjustments for individual hospitals to reflect exogenous variations in input prices and the higher costs of specialised care (Department of Health, 2013a).

Hospital competition has been encouraged by relaxing restrictions on patients' choice of hospital for elective care. Since 2008 patients have been allowed to choose any qualified provider (Department of Health, 2009). Choice is facilitated through the website 'NHS Choices', which provides information on hospital performance (e.g. mortality, waiting times).

3.2 Theoretical model

We sketch a simple two-provider model of quality competition and cost reducing effort. Hospital i has demand function $D_i(q_i,q_j)$ which is increasing in own quality q_i and decreasing in the quality of hospital j. The objective function of hospital i is:

$$U_i = \left[p - c_i\left(q_i, e_i; \theta_i\right)\right] D_i\left(q_i, q_j; \theta_i\right) - G_i\left(q_i, e_i; \theta_i\right) \quad (3.1)$$

where p is the fixed price per treatment that the hospital receives from a third-party payer. $c_i(q_i,e_i)$ are variable treatment costs, which are increasing in quality and decreasing in cost-containment effort or efficiency e_i. $G_i(q_i,e_i)$ are monetary and non-monetary fixed costs which are increasing in both quality and cost-containment (managerial) effort. We assume that quality and cost-containment effort are substitutes, i.e. $G_{iq_ie_i}(q_i,e_i)>0$, since both are types of managerial effort. To keep computations simple, we assume that quality and efficiency are instead independent in variable costs, i.e. $c_{iq_ie_i}(q_i,e_i)=0$. θ_i is a vector of shift parameters (such as local input prices, population demographics, and morbidity).

Hospital i chooses quality and efficiency to satisfy:

$$U_{iq_i}=\left[p-c_i(q_i,e_i;\theta_i)\right]D_{iq_i}(q_i,q_j;\theta_i)-c_{iq_i}(q_i,e_i;\theta_i)D_i(q_i,q_j;\theta_i)-G_{iq_i}(q_i,e_i;\theta_i)=0 \quad (3.2)$$

$$U_{ie_i}=-c_{ie_i}(q_i,e_i;\theta_i)D_i(q_i,q_j;\theta_i)-G_{ie_i}(q_i,e_i;\theta_i)=0 \quad (3.3)$$

where $D_{iq_i}>0$, $c_{iq_i}>0$, and $G_{iq_i}>0$, and denote partial derivatives with respect to quality. With strictly concave utility functions these optimality conditions are also sufficient. Note that the price must exceed the marginal cost of treating additional patients if the hospital is to be induced to provide positive quality. The optimal quality is determined such that the marginal profit from higher additional demand is equal to the marginal cost of quality. The optimal level of efficiency (cost-containment effort) is such that the marginal benefit from lower costs and higher profits are equal to the marginal disutility from efficiency.

The first order conditions (3.2) and (3.3) define the reaction functions for hospital i's quality and efficiency as functions of the choice of quality by hospital j:

$$q_i=q_i^R(q_j;\theta_i) \quad (3.4)$$

$$e_i=e_i^R(q_j;\theta_i)\,. \quad (3.5)$$

Since neither of the first order conditions depends on the efficiency of hospital j, it is apparent that quality and efficiency of hospital i are strategically independent of the efficiency of hospital *j*.

Totally differentiating the first order conditions we obtain:

$$\frac{\partial q_i^R}{\partial q_j} = \left\{ -U_{iq_iq_j} U_{ie_ie_i} + U_{ie_iq_j} U_{iq_ie_i} \right\} \Delta^{-1} =$$

$$= \left\{ -[\underbrace{(p - c_i)}_{+} \underset{?}{D_{iq_iq_j}} - \underset{+}{c_{iq_i}} \underset{-}{D_{iq_j}}] \underset{-}{U_{ie_ie_i}} - \underset{-}{c_{ie_i}} \underset{-}{D_{iq_j}} \underset{+}{U_{iq_ie_i}} \right\} \Delta^{-1} \tag{3.6}$$

where $\Delta = U_{iq_iq_i} U_{ie_ie_i} - U_{iq_ie_i}{}^2 > 0$ by the concavity of the objective function. The term in square brackets in (3.6) is the direct effect of the rival's quality on the marginal profit from higher quality. It is not obvious whether an increase in rival's quality reduces or increases the marginal gain in patient numbers from higher quality. Suppose for simplicity that $D_{iq_iq_j}$ is zero. The second part of the square bracketed term is the reduction in the variable cost because the increase in rival's quality reduces demand and so the marginal cost of output of hospital *i*, which then responds by increasing quality. However, the second term in the curly bracket shows that the lower demand also reduces incentives to contain costs (indirect effect) and so variable cost may increase, making increases in quality to attract additional patients less profitable.

3.3 Methods

We investigate whether hospitals' quality or efficiency responds to the quality or efficiency of their rivals estimating cross-sectional linear versions of the reaction functions by ML:

$$y_i = \rho \sum_j w_{ij} y_j + \beta' X_i + \varepsilon_i \tag{3.7}$$

where y_i is the quality or efficiency of hospital *i* ($i = 1,\ldots,I$); y_j is the quality or efficiency of hospital *i*'s rival *j* ($j \neq i$); w_{ij} are spatial weights, X_i is a vector of covariates including demand shifters (e.g. population density, proportion of elderly individuals), supply shifters (e.g. number of managers, proportion of consultants), hospital type (e.g. foundation trusts, teaching hospitals) and a constant; and ε_i is the error term. In matrix form we estimate:

$$Y = \rho WY + X\beta + \varepsilon \tag{3.8}$$

where W is the spatial weight matrix composed of the elements w_{ij}. The spatial weights are generated from the inverse distance function:

$$w_{ij} = \begin{cases} 0 & \text{if} \quad i = j \\ d_{ij}^{-1} & \text{if} \quad d_{ij} \leq 30 \text{ km and } i \neq j \\ 0 & \text{if} \quad d_{ij} > 30 \text{ km and } i \neq j \end{cases} \tag{3.9}$$

where d_{ij} is the straight line distance between hospital i and j. We assume, as in recent literature, that 30 km is the radius within which hospitals compete (Gaynor et al., 2012a, Bloom et al., 2015). Hospitals that are further away within a 30 km radius have a lower weight, and hospitals that are further than 30 km have a zero weight. The weight matrix W is row standardised, i.e. the elements of each row sum to one. WY is therefore a weighted average of the rivals' quality or efficiency.

The key coefficient is ρ. If $\rho > 0$ then quality (efficiency) increases in response to an increase in rivals' quality (efficiency). But there are two other potential reasons for spatial correlation in outcomes. First, a hospital's quality may vary with characteristics of rival hospitals, such as proportion of foundation trusts amongst rivals. Second, unobserved characteristics common across rival hospitals may affect quality in a given area. For instance, rival hospitals with appealing neighbourhoods are more likely to attract and employ skilled doctors and managers, and provide similar quality. If we fail to account for these factors, spatial correlation will be spurious.

There is an analogy between our spatial approach and the peer-effects literature where the identification issue is known as the "*reflection problem*" (Manski, 1993). Strategic interactions amongst hospitals, as captured by the rivals' quality or efficiency (WY), are the *endogenous effects* of the peer-effects literature. Observed characteristics of rival hospitals (WX) are the *contextual effects* and unobserved hospital characteristics similar across rivals are *correlated effects* contained in the error term ε.

To control for time-invariant unobserved factors, we estimate spatial panel models using the fixed (FE) or random-effects (RE) ML estimator:[29]

$$y_{it} = \rho \sum_j w_{ij} y_{jt} + \beta' X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{3.10}$$

where γ_t is a year indicator. The hospital effect α_i captures unobserved time-invariant hospital heterogeneity and will therefore potentially reduce time-invariant bias from contextual and correlated effects. Estimates, however, might still be biased in the presence of unobserved time-varying factors affecting the patient case-mix. For instance, patient comorbidities and severity not captured by the risk adjustment may lead to higher hospital mortality rates. Risk-adjustment methodologies generally use routine patient data that reflect the information collected through DRG-type patient classification systems. Although such systems provide a large number of patient categories, there is recognition that they can only imperfectly capture patient complexity (e.g. Mason et al., 2011, Gutacker et al., 2013). Since patient comorbidities and severity vary over time, we cannot rule them out as a potential source of endogeneity.

We test the robustness of our results in a number of ways. First, we estimate the spatial Durbin model (SDM) adding all the spatially lagged covariates (*WX*) to the cross-sectional and panel models. This will reduce potential bias due to contextual effects. Second, we allow for correlated effects which lead to spatially correlated errors by estimating spatial autocorrelation (SAC) models with spatially lagged errors: $\varepsilon_{it} = \lambda \sum_j w_{ij} \varepsilon_{jt} + \xi_{it}$. Third, following the theory in section 3.2, we test whether a hospital's quality (efficiency) responds to rivals' efficiency (quality) by adding a spatially lagged efficiency (quality) measure to the main regressions. We also examine whether results are sensitive to extending the radius within which hospitals compete to 60 km or 90 km.

Finally, in cross-sectional models, to further address potential bias from contextual and correlated effects we use two-stage least squares (2SLS) instrumenting WY_t with its two or three

[29] We use the Stata user-written command `spreg` to estimate cross-sectional models (Drukker et al., 2015), and `xsmle` to estimate panel models (Belotti et al., 2014).

year lagged value (WY_{t-2} or WY_{t-3}). An instrument is valid (Stock and Watson, 2003, p.423) if it is exogenous (not a regressor in the second stage regression and uncorrelated with unobserved factors captured by the error term) and relevant (correlated with the instrumented endogenous variable). We argue that, whilst current outcomes are potentially influenced by rival's current outcomes (or possibly last period outcomes), adjustment is sufficiently rapid that current outcomes are not affected by what rivals were doing two or three years previously. Some studies on the English NHS (Gaynor et al., 2012b, Sivey, 2012, Gutacker et al., 2016) show that patients choose hospitals with higher quality and lower waiting times. For example, Gutacker et al. (2016) find that the demand of a hospital decreases by 0.63% if a rival located within 10 km increases its PROMs quality by 1%. Hospitals are therefore unlikely to delay their reaction to changes in rivals' performance by two or three years in order to avoid reductions in the volume of patients treated and, hence, revenue. On the other hand, WY_{t-2} (or WY_{t-3}) is likely to be relevant because hospital quality is unlikely to change rapidly over time so that WY_{t-2} (or WY_{t-3}) will be a good predictor of WY_t. We can also test for relevance in the first stage model.

3.4 Data

We have eight quality indicators and six efficiency indicators measured at hospital trust level and have four years of data (from 2010/11 to 2013/14, except for the readmission rate where we use data for 2008/09 to 2011/12).[30] Such indicators are issued annually or quarterly in the public domain, with the most recent collection released in 2010 (patient reported outcome measures).[31] They are therefore available to providers.[32]

[30] Detailed definitions of the quality and efficiency indicators are included in the Appendix 3 (Table A3.1 and Table A3.2). The publication of the emergency readmission rate has been suspended because of a revision of the methodology.

[31] The SHMI was published annually until 2011 and quarterly afterwards. Bed occupancy data were released annually up to 2009/10 and quarterly afterwards. Cancelled elective operations have been issued quarterly since their first publication in 1996/97. All other indicators have annual frequency.

[32] The SHMI is only available for general hospitals but not for specialist hospitals. The reference cost index for hip replacement is not directly available as the other reference cost indexes. Its calculation, however, follows the same

3.4.1 Quality indicators

The risk-adjusted Summary Hospital-level Mortality Indicator (SHMI) is the ratio of the actual number of deaths from all causes in hospital or within 30 days of discharge to the number of deaths expected given the characteristics of patients. The expected deaths are estimated through a logistic regression controlling for differences in patient case-mix. We also use risk-adjusted mortality rates for two emergency conditions (hip fracture and stroke), and risk-adjusted emergency readmissions for all conditions. These three indicators are calculated through an indirect standardisation methodology that multiplies the ratio between observed and expected events (deaths or readmissions) by the national rate of patients. The expected events are in this case the product between the number of patients for a provider and the national rate of patients for each risk-adjustment category (e.g. gender-age combination) summed over all categories.

We use risk-adjusted average health change for elective hip replacement patients derived from PROMs (patient reported outcome measures) data. On the basis of the EQ-5D questionnaire (Brooks, 1996, Brooks et al., 2005), the change in a patient's health is calculated as difference between the self-assessed health status of elective patients before and six months after their surgery. Clinical quality indicators and PROMs are available from the health and social care information centre (HSCIC).[33]

We use three patient satisfaction indicators for overall experience, hospital cleanliness, and involvement in treatment decisions. Patients were asked to rate their hospital experience on a scale between 0 and 100, whereas 0 indicates extreme dissatisfaction and 100 complete satisfaction. The indicators are obtained by averaging the patient rates across hospitals and they are risk-adjusted

transparent methodology (Department of Health, 2014) and uses public data firstly released in January 2011.

[33] The SHMI is adjusted for gender, age, admission method, year index, Charlson comorbidity index, and diagnosis. Hip fracture and stroke mortality are adjusted for gender and age. The emergency readmission rate is adjusted for gender, age, admission method, diagnosis, and procedure. The health change after hip replacement is adjusted for patient characteristics (e.g. gender, age, ethnics), initial health status, self-assessed health status, economic deprivation, comorbidity, procedure, and post-operative length of stay.

using patients' gender, age, ethnic group, and admission method (elective or emergency). They are available from the annual NHS Inpatient Surveys conducted for the Care Quality Commission.

3.4.2 Efficiency indicators

The bed occupancy rate is the ratio of occupied to available hospital beds (e.g. Zuckerman et al., 1994). We measure the rate of cancelled elective operations as the ratio of the number of cancelled elective operations for non-clinical reasons to the number of elective admissions (Rumbold et al., 2015). The reference cost index (RCI) compares a hospital's total costs with the national average total costs for the same HRG groups. A RCI greater than 100 indicates higher than average costs. We also use the RCI for elective and non-elective activity, and for hip replacement.

3.4.3 Control variables

Our control variables include demand and supply shifters. Demand shifters comprise: demographic variables such as *population density* and *proportion of individuals aged 65 and over*, which we calculate using annual mid-year population estimates; socioeconomic measures: *proportion of individuals employed or looking for a job*, *proportion of individuals with a degree*, and *proportion of owner occupier households*; and a measure of population health: *proportion of individuals in good or very good health*. Socioeconomic and health measures are computed using 2011 Census data for all small areas within a 15 km radius.[34]

Supply shifters include: the *number of managers, junior doctors in training as a proportion of total clinical staff*, *consultants as a proportion of total clinical staff*, and the *number of beds*.[35] Junior doctors in training are qualified doctors under postgraduate training at the start of their medical career. Consultants lead teams of lower grade doctors and are primarily responsible for patients. Increasing the proportion of experienced doctors is likely to improve patient outcomes

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[34] These areas (Lower Layer Super Output Areas) have on average 1,500 inhabitants and a minimum of 1,000.

[35] The total clinical staff is the total number of doctors, nurses, and allied professionals (e.g. therapists, healthcare scientists, technicians).

and possibly efficiency.[36] Information on hospital staff is collected from the HSCIC, whilst NHS statistics provide the number of beds.[37] Finally, we control for type of hospital**:** *foundation trust*, *teaching hospital*, and *specialist hospital*.

3.4.4 Descriptive statistics

Table 3.1 has descriptive statistics. The number of hospital trusts varies between 106 (for hip fracture mortality rate) and 142 (for emergency readmission rate) across indicators. The sample size for each indicator is determined by the number of hospitals with at least one rival, and is constant over time because we use a balanced panel. Hospitals with no providers within a radius of 30 km (i.e. monopolists) are dropped because, by construction, they do not compete. In the case of the sample for overall patient satisfaction, 13% of hospitals are monopolists, 23% are exposed to low competition with one or two rivals, 38% are located in areas with three to nine rivals, and 26% have more than nine rivals (up to a maximum of 25 rivals).

The SHMI and the RCIs are on average 100 by construction. On average, patients undergoing hip replacement have an average health gain of 0.413 HRQoL and 79% of all patients report high overall satisfaction.

The summary statistics for the explanatory variables are for the overall patient satisfaction hospital sample. Amongst the demand shifters, for example, 15.7% of individuals are over 65 years old. 83 hospitals (62.9%) are foundation trusts, 24 (18.4%) are teaching, and 14 (10.6%) are specialist.

Since hospital catchment areas overlap by construction for hospitals with at least one rival, a hospital's demand shifters are always strongly (above 80%) correlated with its rivals'. In contrast,

[36] Siciliani and Martin (2007) show that more consultants are associated with lower waiting times for elective care.

[37] Data on hospital staff are available from 2010/11 onwards. The number of managers, the proportion of junior doctors in training, and the proportion of consultants are therefore omitted in the regressions for the emergency readmission rate to allow comparability between cross-sectional and panel models.

supply shifters have more variations across rivals.

3.5 Results

Table 3.2 has the results of the global Moran's I test for overall spatial correlation of the quality and efficiency indicators.[38] Spatial correlation is significant (at 5% level) and positive for two clinical indicators (SHMI and emergency readmissions) and two patient-reported indicators (patient satisfaction on overall experience and hospital cleanliness). Its magnitude varies between moderate (0.150 for overall patient satisfaction in 2012/13) and high (0.528 for SHMI in 2012/13). All four cost indicators have a significant and positive spatial correlation ranging between 0.150 (for RCI for hip replacement in 2011/12) and 0.483 (for RCI in 2013/14).[39]

3.5.1 Regression results

Table 3.3 reports the estimated spatial lag coefficient ($\hat{\rho}$) from the ML models for each quality and efficiency indicator after controlling for demand shifters, supply shifters, and type of hospital (full results with coefficients on the covariates are in Appendix Table A3.3 and Table A3.4). In the cross-sectional models, SHMI has positive and statistically significant spatial lag for two years. 10% lower SHMI (higher quality) in rival hospitals increases the hospital's SHMI by 2.9% in 2010/11 and 2% in 2011/12. For other quality and efficiency indicators, we obtain a statistically insignificant or weakly significant (at 10% level) estimated spatial lag with a few exceptions (stroke mortality rate in 2013/14 and non-elective RCI in 2010/11).[40] Overall, there is weak statistical evidence of spatial correlation in cross-sectional models.

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[38] The global Moran's I test calculates the overall degree of spatial association between observations (Anselin, 2013). It differs from the local Moran's I test, which provides a measure of spatial clustering for each observation (Anselin, 1995).

[39] The local Moran's I test on quality and efficiency indicators in 2010/11 (available upon request) has some evidence of spatial correlations for London hospitals. Other hospitals not located in London, however, also exhibit a positive and significant local spatial correlation. The majority of hospitals show an insignificant local spatial correlation.

[40] We also test the robustness of our results for bed occupancy rate and the RCI to risk-adjustment by controlling for proportion of male patients, patient age, and proportion of emergency admissions in equation (3.7) and (3.10). The results (available upon request) remain similar to those reported in Table 3.3.

Unlike supply shifters and hospital type dummies, demand shifters play a major role in generating cross-sectional spatial correlation. Rival hospitals are indeed close neighbours sharing similar population characteristics.

Table 3.3 also has estimates of the spatial lag coefficient after controlling for unobserved time-invariant heterogeneity with FE and RE panel data models. There is a positive statistically significant spatial lag for two of the quality measures (0.172 for SHMI and 0.110 for overall patient satisfaction) and none of the efficiency models have statistically significant spatial lags.[41] In sum, the cross-sectional and panel ML estimates do not suggest that hospital quality or efficiency generally depends on rivals' quality or efficiency.

3.5.2 Robustness and sensitivity analysis

We also estimate the effect of the spatial lag WY in SDM models with spatially lagged covariates and SAC models which allow for spatial correlation in the error term. The SDM results in Table 3.4 are broadly similar to those in Table 3.3. Once we allow for possible contextual effects with spatially lagged covariates the only hospital outcome variable which is correlated with rival outcomes is SHMI. When we instead allow possible correlated effects with the SAC specification (Table 3.5) we again find that SHMI is the only quality indicator spatially correlated with rivals. However, two of the six efficiency measures (cancelled elective procedures, elective reference cost index) are negatively correlated with those of rivals.

Likelihood ratio tests (reported in the Appendix Table A3.5) suggest that adding the spatial lags of covariates (the SDM specification) only improves model fit for overall patient satisfaction and the rate of cancelled elective operations. The SAC model only improves the fit in the case of cancelled elective operations. Thus, overall, allowing for contextual or correlated effects with

[41] Results for cross-sectional and panel models also mirror the global Moran's I test on the residuals. Residuals are obtained from a linear regression, estimated by OLS, including all controls except the spatial lag of the dependent variable. Results are available on request.

SDM or SAC models does not change the results from the simpler specification.[42]

We also test whether a hospital's quality (efficiency) responds to rivals' efficiency (quality) by adding spatial lags of efficiency (quality) to the baseline model.[43] Results in Table 3.6 are similar to those in Table 3.3 in respect of the effect of rivals' quality (efficiency) on hospital quality (efficiency). In addition, and in line with our theoretical predictions, we do not generally observe an effect of rivals' efficiency on a hospital's quality (Appendix Table A3.6). Our theory model does however imply that rivals' quality could affect hospital efficiency and we find some weak evidence for this (Appendix Table A3.7). For instance, higher rivals' quality, as measured by the SHMI, is significantly associated with better efficiency, as measured by the non-elective RCI, in 2010/11, 2011/12, and 2012/13. However, this association is only weakly significant (at 10% level) in 2013/14 and disappears in the panel model.

3.5.3 IV results

Table 3.7 has the results from 2SLS cross-sectional models instrumenting the spatial lags of quality or efficiency with their temporal spatial lags $WY_{t\text{-}2}$ or $WY_{t\text{-}3}$. The instruments appear relevant in that they have first stage F statistics greater than 10 (Staiger and Stock, 1997). The IV estimates also suggest little evidence of strategic interactions across hospitals in quality or efficiency: the spatial lag is significant at 5% level for only the SHMI in 2012-13 and the emergency readmissions in 2013-14.

The results in our study are compatible with those reported in Gravelle et al. (2014b), who analyse sixteen quality indicators for English hospitals in 2009/10 through a spatial lag model estimated by ML. The two studies have five indicators in common: three mortality indicators

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[42] We also find that expanding the catchment areas to 60 km or 90 km from 30 km does not change the results of the baseline models reported in Table 3.3. Results are available on request.

[43] We use rivals' bed occupancy rate and reference cost index as measures of rivals' efficiency, and rivals' SHMI and overall patient satisfaction as measures of rivals' quality.

(overall mortality, hip fracture and stroke mortality) and two patient satisfaction indicators (satisfaction with hospital cleanliness and decision involvement).[44] Table 3.8 provides a direct comparison of the results. If we compare results from Gravelle et al. (2014b) in 2009/10 with ours in 2010/11 and 2011/12 (the two closest years), the spatial lag is significant for overall mortality and it is insignificant for hip fracture mortality in both studies. The stroke mortality spatial lag is weakly significant in Gravelle et al. (2014b) and insignificant in our study. The results for the patient satisfaction indicators differ. They are significant or weakly significant in Gravelle et al. (2014b) but insignificant in our model. The differences may be due to the different sample years and, in the case of satisfaction with decision involvement, to the inclusion of additional demand shifters.[45]

3.6 Conclusions

We investigated whether a hospital's quality or efficiency responds to an increase in quality or efficiency of its rivals. We test for unconditional spatial correlation using the global Moran's I test and find strong evidence of positive spatial correlation for four of the eight quality and four of the six efficiency indicators. But when we estimate ML spatial cross-sectional models that include covariates potentially affecting hospital demand and costs, we no longer observe statistically significant spatial dependence for most indicators. Only for overall hospital mortality there is significant correlation with rivals' quality. Similarly, we observe little evidence of spatial dependence, except for overall mortality, after controlling for unobserved time-invariant hospital heterogeneity in ML spatial panel models. Finally, after instrumenting the spatial lags of quality

[44] Gravelle et al. (2014b) explore the spatial dependence for other indicators not included in this study. Amongst these, they find a positive and significant spatial correlation for hip replacement readmissions and patient satisfaction on trust in the doctors. No (or weak) spatial dependence is instead observed for mortality from high and low risk conditions, deaths after surgery, hip replacement and stroke readmissions, hip and knee revisions, operations within two days from hip fracture, and redo rates for prostate resection.

[45] The additional demand shifters are: proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion owner occupier households, and proportion of individuals in good or very good health.

and efficiency by their temporal lags, we again find little evidence of spatial dependence. Hospital quality (efficiency), therefore, does not appear to respond to the quality (efficiency) of neighbouring hospitals.

In conclusion, our empirical analysis suggests the absence of hospital spillovers in quality and efficiency. The results are in line with our theoretical model, which shows that efficiencies are strategic independent. The model also implies that whether qualities are strategic complements or substitutes is in principle indeterminate. A hospital whose rivals have higher quality will, ceteris paribus, have lower demand and this may both reduce the marginal cost of providing quality but also weaken incentives to contain costs therefore reducing the price mark-up and the incentive to provide quality. These two effects may cancel out leaving quality unaffected by rivals' quality.

The lack of hospital strategic interaction on quality is not incompatible with the recent empirical literature (reviewed in section 3.1.1) which shows that areas with less concentrated hospital market structure (more competition) increases quality in England (Cooper et al., 2011, Gaynor et al., 2013, Bloom et al., 2015). For example, our model suggests that if the marginal cost of treatment is constant, then qualities are strategic independent. But in this scenario it is still the case that a market structure with a larger number of rivals increases the demand responsiveness and therefore the marginal revenue from an increase in quality (so that equilibrium quality increases in the number of providers).

These findings have policy implications. They suggest that policy interventions incentivising quality or efficiency at local level will not generate positive (or negative) spillovers to other hospitals. A local policy intervention, e.g. a Care Commissioning Group which introduces a pay for performance scheme in a hospital will change quality in that hospital but will not increase the quality in other nearby hospitals. Similarly, the adoption of a new technology which increases quality in one hospital will not necessarily spread out to other hospitals. In turn, this implies that there may be scope for policymakers to develop policies which encourage cooperation across hospitals. For example, in France a new policy tool was introduced in 2016 (*Groupement Hospitalier de Territoire*) to foster cooperation of public hospitals under which each hospital has to join a group associated with a teaching hospital, and can share activity, equipment, medical teams and a joint information system (Choné, 2017, Siciliani et al., 2017).

The results have also implications for antitrust policies. Brekke et al. (2016) for example suggest that if two hospitals merge they will reduce quality and costs, and non-merging rival hospitals might also reduce quality if quality is a strategic complements. Our study suggests that hospital mergers will not induce other non-merging hospitals also to reduce quality or costs. Policy makers can therefore concentrate on evaluating just the immediate effects of a potential merger on the merging hospitals.

Tables and Figures

Table 3.1 – Descriptive statistics.

Variable	Obs	Trusts	Monop	Mean	Std. dev.			Min	Max
					Ov	Betw	With		
Quality indicator									
Clinical									
Summary Hospital-level Mortality Indicator	476	119	20	99.9	10.0	9.5	3.5	53.9	124.8
Hip fracture mortality rate (%)	424	106	19	7.2	1.9	1.4	1.3	2.4	14.6
Stroke mortality rate (%)	444	111	20	17.4	3.2	2.4	2.2	9.8	32.7
Emergency readmission rate (%)	568	142	20	11.1	1.4	1.3	0.6	5.1	17.2
Patient reported									
Average health change after hip replacement	428	107	19	0.413	0.033	0.022	0.025	0.264	0.538
Overall patient satisfaction	528	132	19	78.8	3.9	3.5	1.8	67.3	90.4
Patient satisfaction on hospital cleanliness	528	132	19	88.1	3.3	3.0	1.3	77.3	96.8
Patient satisfaction on decision involvement	528	132	19	72.0	3.9	3.4	2.0	61.8	85.4
Efficiency indicator									
Bed occupancy rate (%)	536	134	18	87.0	6.5	5.7	3.0	58.3	98.7
Rate of cancelled elective operation (%)	536	134	17	0.81	0.37	0.31	0.19	0.02	2.41
Reference cost index	560	140	18	100.6	10.8	10.2	3.5	81.1	148.2
Elective reference cost index	560	140	18	100.8	15.5	13.6	7.4	62.7	167.7
Non-elective reference cost index	560	140	18	102.4	17.9	16.0	8.1	70.4	213.1
Reference cost index for hip replacement	508	127	18	99.6	24.6	20.4	13.9	37.8	237.1
Control variable									
Demand shifter									
Population density (1,000 indv/km^2)				1.808	2.032	2.037	0.041	0.124	7.859
Proportion of individuals aged 65 and over (%)				15.7	3.1	3.1	0.6	9.2	25.2
Proportion of individuals employed or looking for a job (%)				70.0	2.9	2.9	0.0	63.9	76.7
Proportion of individuals with a degree (%)				18.4	7.9	7.9	0.0	7.4	35.9
Proportion of owner occupier households (%)				61.6	8.9	9.0	0.0	40.0	77.6
Proportion of individuals in good or very good health (%)				81.5	2.9	2.9	0.0	75.2	86.8
Supply shifter									
Number of managers (100)				0.66	0.44	0.43	0.11	0.04	3.59
Proportion of junior doctors in training (%)				2.6	1.1	1.1	0.3	0.0	6.7
Proportion of consultants (%)				6.3	1.1	1.0	0.4	2.2	11.7
Number of beds (1,000)				0.631	0.342	0.340	0.042	0.014	2.025
Hospital type									
Foundation trust				0.629	0.484	0.477	0.087	0	1
Teaching hospital				0.184	0.388	0.387	0.038	0	1
Specialist hospital				0.106	0.308	0.387	0.038	0	1

Obs=total number of observations, Trusts=number of non-monopolist hospital trusts, Monop=number of monopolists, Ov=overall, Betw=between, With=within

Descriptive statistics refer to the sample of providers with at least one rival.

Descriptive statistics on control variables are calculated on the overall patient satisfaction's sample.

Table 3.2 – Global Moran's I test for spatial correlation.

Indicator	2010/11	2011/12	2012/13	2013/14	All years
<u>*Quality*</u>					
Clinical					
Summary Hospital-level Mortality Indicator	0.516 (0.000)***	0.460 (0.000)***	0.528 (0.000)***	0.507 (0.000)***	0.487 (0.000)***
Hip fracture mortality rate	0.160 (0.040)**	0.134 (0.081)*	-0.013 (0.968)	0.090 (0.230)	0.081 (0.000)***
Stroke mortality rate	-0.155 (0.067)*	0.126 (0.079)*	-0.073 (0.421)	-0.078 (0.387)	-0.040 (0.060)*
Emergency readmission rate	0.163 (0.009)***	0.235 (0.000)***			0.165 (0.000)***
Patient reported					
Average health change after hip replacement	0.053 (0.438)	0.089 (0.228)	0.037 (0.568)	-0.030 (0.806)	0.041 (0.035)**
Overall patient satisfaction	0.210 (0.002)***	0.202 (0.003)***	0.150 (0.026)**	0.116 (0.080)*	0.158 (0.000)***
Patient satisfaction on hospital cleanliness	0.154 (0.022)**	0.128 (0.056)*	0.160 (0.018)**	0.208 (0.002)***	0.164 (0.000)***
Patient satisfaction on decision involvement	0.093 (0.156)	0.105 (0.113)	0.031 (0.587)	0.116 (0.080)*	0.083 (0.000)***
<u>*Efficiency*</u>					
Bed occupancy rate	0.069 (0.277)	0.040 (0.502)	-0.098 (0.195)	0.009 (0.813)	0.004 (0.720)
Rate of cancelled elective operations	0.155 (0.019)**	-0.050 (0.546)	0.088 (0.172)	0.046 (0.444)	0.053 (0.002)***
Reference cost index	0.440 (0.000)***	0.425 (0.000)***	0.426 (0.000)***	0.483 (0.000)***	0.439 (0.000)***
Elective reference cost index	0.226 (0.001)***	0.230 (0.000)***	0.293 (0.000)***	0.337 (0.000)***	0.272 (0.000)***
Non-elective reference cost index	0.272 (0.000)***	0.341 (0.000)***	0.273 (0.000)***	0.209 (0.001)***	0.281 (0.000)***
Reference cost index for hip replacement	0.189 (0.006)***	0.150 (0.025)**	0.196 (0.005)***	0.260 (0.000)***	0.201 (0.000)***

Correlations computed with an inverse distance weight matrix of 30 km catchment area. Data on the emergency readmission rate are currently available up to 2011/12. The statistic in year 2012/13 and 2013/14 is therefore omitted. The statistic for all years is obtained using data from 2008/09 to 2011/12.

p-values (in parentheses) are calculated assuming a normal distribution of the indicator

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.3 – Spatial lag coefficient.

Indicator	Cross-Section				Panel	
	2010/11	2011/12	2012/13	2013/14	FE	RE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	0.285	0.203	0.108	0.145	0.172	0.184
	(0.002)***	(0.044)**	(0.278)	(0.194)	(0.001)***	(0.000)***
Hip fracture mortality rate	-0.025	0.119	-0.179	-0.156	-0.007	0.002[C]
	(0.831)	(0.297)	(0.116)	(0.184)	(0.896)	(0.976)
Stroke mortality rate	-0.172	-0.171	-0.174	-0.272	-0.056	-0.059
	(0.117)	(0.136)	(0.130)	(0.025)**	(0.307)	(0.299)
Emergency readmission rate	0.070	0.137			0.100	0.130
	(0.483)	(0.140)			(0.055)*	(0.010)**
Patient reported						
Average health change after hip replacement	0.048	-0.029	-0.199	-0.163	-0.044	-0.024[C]
	(0.685)	(0.810)	(0.097)*	(0.124)	(0.456)	(0.682)
Overall patient satisfaction	0.100	0.095	0.048	0.105	0.110	0.122
	(0.178)	(0.190)	(0.534)	(0.185)	(0.034)**	(0.005)***
Patient satisfaction on hospital cleanliness	-0.012	0.000	-0.061	0.086	-0.063	-0.023
	(0.898)	(0.998)	(0.497)	(0.313)	(0.261)	(0.647)
Patient satisfaction on decision involvement	0.024	0.048	-0.073	0.055	-0.023	0.016
	(0.778)	(0.561)	(0.398)	(0.543)	(0.668)	(0.740)
Efficiency						
Bed occupancy rate	-0.008	-0.015	-0.173	-0.079	-0.031	-0.023[C]
	(0.932)	(0.887)	(0.073)*	(0.442)	(0.559)	(0.655)
Rate of cancelled elective operations	0.068	-0.157	0.032	-0.008	0.053	0.044[C]
	(0.476)	(0.151)	(0.749)	(0.934)	(0.289)	(0.380)
Reference cost index	-0.087	-0.079	-0.067	0.003	0.007	0.018
	(0.378)	(0.412)	(0.513)	(0.980)	(0.900)	(0.732)
Elective reference cost index	-0.003	-0.094	-0.051	-0.030	-0.039	-0.039[C]
	(0.973)	(0.323)	(0.612)	(0.776)	(0.447)	(0.437)
Non-elective reference cost index	-0.211	-0.108	-0.168	-0.121	-0.072	-0.060
	(0.037)**	(0.248)	(0.092)*	(0.287)	(0.185)	(0.251)
Reference cost index for hip replacement	-0.054	-0.117	0.067	0.085	-0.041	-0.021
	(0.626)	(0.332)	(0.532)	(0.448)	(0.474)	(0.707)

ML estimation. Each cross-sectional regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. Cross-sectional estimates in year 2012/13 and 2013/14 are therefore omitted. Panel estimates are obtained using data from 2008/09 to 2011/12. In addition, data on hospital staff are available from 2010/11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.4 – Spatial lag coefficient with Spatial Durbin Model.

Indicator	Cross-Section				Panel	
	2010/11	2011/12	2012/13	2013/14	FE	RE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	0.201	0.139	0.053	0.143	0.152	0.172
	(0.063)*	(0.237)	(0.641)	(0.247)	(0.004)***	(0.001)***
Hip fracture mortality rate	-0.073	0.045	-0.249	-0.197	-0.010	-0.009[C]
	(0.544)	(0.707)	(0.027)**	(0.103)	(0.860)	(0.878)
Stroke mortality rate	-0.210	-0.181	-0.242	-0.246	-0.078	-0.056[C]
	(0.074)*	(0.127)	(0.035)**	(0.058)*	(0.170)	(0.326)
Emergency readmission rate	-0.026	0.030			0.095	0.118
	(0.835)	(0.781)			(0.070)*	(0.025)**
Patient reported						
Average health change after hip replacement	0.056	-0.062	-0.233	-0.264	-0.048	-0.031[C]
	(0.639)	(0.633)	(0.076)*	(0.024)**	(0.422)	(0.599)
Overall patient satisfaction	-0.137	-0.122	-0.096	0.012	0.073	0.085
	(0.171)	(0.265)	(0.380)	(0.914)	(0.160)	(0.102)
Patient satisfaction on hospital cleanliness	-0.076	-0.088	-0.137	-0.014	-0.060	-0.050[C]
	(0.507)	(0.438)	(0.240)	(0.906)	(0.293)	(0.371)
Patient satisfaction on decision involvement	-0.005	-0.052	-0.204	-0.084	-0.039	-0.019
	(0.959)	(0.629)	(0.061)*	(0.454)	(0.473)	(0.725)
Efficiency						
Bed occupancy rate	-0.058	-0.050	-0.115	-0.123	-0.036	-0.023[C]
	(0.600)	(0.674)	(0.300)	(0.265)	(0.508)	(0.679)
Rate of cancelled elective operations	0.052	-0.209	-0.130	-0.076	0.030	0.041
	(0.596)	(0.061)*	(0.246)	(0.487)	(0.553)	(0.415)
Reference cost index	-0.174	-0.153	-0.104	-0.091	-0.004	0.002
	(0.118)	(0.182)	(0.358)	(0.434)	(0.934)	(0.968)
Elective reference cost index	0.018	-0.105	-0.095	-0.161	-0.038	-0.040[C]
	(0.870)	(0.314)	(0.396)	(0.171)	(0.450)	(0.447)
Non-elective reference cost index	-0.283	-0.218	-0.268	-0.194	-0.076	-0.089
	(0.009)***	(0.050)*	(0.012)**	(0.101)	(0.160)	(0.104)
Reference cost index for hip replacement	-0.199	-0.191	0.056	0.014	-0.058	-0.048
	(0.092)*	(0.110)	(0.636)	(0.909)	(0.288)	(0.388)

ML estimation. Each cross-sectional regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The Spatial Durbin Model includes the spatial lag of all regressors. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. Cross-sectional estimates in year 2012/13 and 2013/14 are therefore omitted. Panel estimates are obtained using data from 2008/09 to 2011/12. In addition, data on hospital staff are available from 2010/11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.5 – Spatial lag coefficient with spatially correlated disturbances (SAC model).

Indicator	Spatial lag	Cross-Section				Panel
		2010/11	2011/12	2012/13	2013/14	FE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	ρ	0.331**	0.108	0.240	0.085	0.345***
	λ	-0.080	0.154	-0.198	0.105	-0.204
Hip fracture mortality rate	ρ	0.133	0.045	0.193	0.239	-0.298*
	λ	-0.215	0.095	-0.450**	-0.429**	0.275*
Stroke mortality rate	ρ	0.099	-0.063	-0.293	-0.243	-0.009
	λ	-0.341	-0.132	0.145	-0.047	-0.051
Emergency readmission rate	ρ	0.160	0.360***			0.051
	λ	-0.152	-0.348**			0.052
Patient reported						
Average health change after hip replacement	ρ	-0.104	-0.001	-0.135	-0.017	0.012
	λ	0.193	-0.044	-0.093	-0.208	-0.063
Overall patient satisfaction	ρ	0.224***	0.117	0.097	0.033	0.199
	λ	-0.342**	-0.082	-0.107	0.142	-0.100
Patient satisfaction on hospital cleanliness	ρ	-0.016	0.051	0.005	0.140	-0.027
	λ	0.007	-0.093	-0.124	-0.095	-0.039
Patient satisfaction on decision involvement	ρ	-0.089	0.025	0.056	0.102	-0.093
	λ	0.189	0.043	-0.202	-0.080	0.071
Efficiency						
Bed occupancy rate	ρ	0.348**	0.006	-0.410***	-0.076	0.059
	λ	-0.417**	-0.030	0.295*	-0.004	-0.099
Rate of cancelled elective operations	ρ	0.549***	-0.013	0.418***	0.389***	-0.474***
	λ	-0.570***	-0.170	-0.510***	-0.507***	0.491***
Reference cost index	ρ	0.043	0.042	0.012	0.101	0.017
	λ	-0.219	-0.225	-0.124	-0.166	-0.012
Elective reference cost index	ρ	-0.215	0.086	0.083	0.107	-0.374***
	λ	0.261	-0.221	-0.192	-0.223	0.336***
Non-elective reference cost index	ρ	0.002	0.093	0.055	-0.013	-0.171
	λ	-0.304*	-0.341**	-0.315*	-0.175	0.114
Reference cost index for hip replacement	ρ	0.122	-0.032	0.048	0.150	-0.066
	λ	-0.267	-0.117	0.038	-0.085	-0.001

ML estimation. Each cross-sectional regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The panel model also includes year dummies.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. Cross-sectional estimates in year 2012/13 and 2013/14 are therefore omitted. Panel estimates are obtained using data from 2008/09 to 2011/12. In addition, data on hospital staff are available from 2010/11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

The p-value is omitted. *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.6 – Spatial lag coefficient with additional spatial lags of quality or efficiency.

Indicator	Cross-Section				Panel	
	2010/11	2011/12	2012/13	2013/14	FE	RE
Quality						
Clinical						
Summary Hospital-level Mortality Indicator	0.212	0.159	0.098	0.156	0.170	0.181
	(0.043)**	(0.130)	(0.328)	(0.164)	(0.001)***	(0.000)***
Hip fracture mortality rate	0.016	0.094	-0.199	-0.205	-0.040	-0.021[C]
	(0.891)	(0.403)	(0.085)*	(0.083)*	(0.468)	(0.710)
Stroke mortality rate	-0.156	-0.176	-0.189	-0.305	-0.060	-0.057[C]
	(0.156)	(0.132)	(0.097)*	(0.013)**	(0.279)	(0.316)
Emergency readmission rate	0.091	0.092			0.065	0.114
	(0.327)	(0.351)			(0.233)	(0.028)**
Patient reported						
Average health change after hip replacement	-0.006	-0.064	-0.157	-0.195	-0.039	-0.035[C]
	(0.958)	(0.606)	(0.207)	(0.082)*	(0.505)	(0.557)
Overall patient satisfaction	0.047	0.061	0.003	0.084	0.084	0.092
	(0.568)	(0.460)	(0.971)	(0.349)	(0.113)	(0.052)*
Patient satisfaction on hospital cleanliness	-0.016	-0.054	-0.082	0.044	-0.069	-0.045
	(0.873)	(0.565)	(0.371)	(0.624)	(0.218)	(0.382)
Patient satisfaction on decision involvement	0.035	0.075	-0.130	0.029	-0.032	-0.001
	(0.719)	(0.405)	(0.163)	(0.761)	(0.552)	(0.986)
Efficiency						
Bed occupancy rate	-0.054	-0.114	-0.097	0.049	-0.090	-0.053[C]
	(0.619)	(0.333)	(0.401)	(0.641)	(0.136)	(0.367)
Rate of cancelled elective operations	0.084	-0.024	0.125	0.040	0.018	0.050
	(0.424)	(0.839)	(0.246)	(0.713)	(0.736)	(0.353)
Reference cost index	0.016	0.034	0.030	-0.049	0.046	0.059
	(0.886)	(0.757)	(0.787)	(0.682)	(0.430)	(0.297)
Elective reference cost index	0.016	0.034	0.030	-0.049	0.046	0.059
	(0.886)	(0.757)	(0.787)	(0.682)	(0.430)	(0.297)
Non-elective reference cost index	-0.064	-0.081	-0.145	-0.018	-0.076	0.025
	(0.572)	(0.468)	(0.189)	(0.884)	(0.179)	(0.647)
Reference cost index for hip replacement	-0.122	-0.187	-0.012	0.068	-0.107	-0.070
	(0.287)	(0.092)*	(0.919)	(0.555)	(0.058)*	(0.212)

ML estimation. Each cross-sectional regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals in good or very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. The efficiency indicators added to the regressions for the quality indicators are bed occupancy rate and RCI. The quality indicators added to the regressions for the efficiency indicators are SHMI and overall patient satisfaction. The panel model also includes year dummies.

In the regressions including SHMI, hip fracture and stroke mortality as dependent or independent variable, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. Cross-sectional estimates in year 2012/13 and 2013/14 are therefore omitted. Panel estimates are obtained using data from 2008/09 to 2011/12. In addition, data on hospital staff are available from 2010/11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

C = the RE estimator passes the Hausman test at 5% level, and it is therefore consistent and efficient.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.7 – Spatial lag coefficient. IV estimates.

Indicator	WY_{t-2}		WY_{t-3}
	2012/13	2013/14	2013/14
Quality			
Clinical			
Summary Hospital-level Mortality Indicator	0.421	0.419	0.519
	(0.026)**	(0.069)*	(0.090)*
Hip fracture mortality rate	-0.092	0.389	-0.035
	(0.820)	(0.189)	(0.939)
Emergency readmission rate	0.321	0.313	0.307
	(0.065)*	(0.048)**	(0.087)*
Patient reported			
Overall patient satisfaction	0.123	0.097	0.089
	(0.281)	(0.385)	(0.467)
Patient satisfaction on hospital cleanliness	0.034	0.126	0.155
	(0.799)	(0.276)	(0.218)
Patient satisfaction on decision involvement	0.068	0.196	0.266
	(0.654)	(0.162)	(0.081)*
Efficiency			
Bed occupancy rate	-0.042	0.095	0.0003
	(0.807)	(0.568)	(0.999)
Rate of cancelled elective operations	0.315	-0.226	-0.074
	(0.286)	(0.231)	(0.792)
Reference cost index	-0.124	-0.056	-0.110
	(0.526)	(0.727)	(0.518)
Elective reference cost index	0.116	0.069	0.027
	(0.758)	(0.771)	(0.920)
Non-elective reference cost index	-0.057	-0.175	-0.339
	(0.780)	(0.530)	(0.272)
Reference cost index for hip replacement	0.524	0.660	0.625
	(0.074)*	(0.168)	(0.109)

IV estimation. The first-stage F statistic for each specification and outcome indicator is reported in parenthesis following the same order of the table (WY_{t-2} in 2012/13; WY_{t-2} in 2013/14; WY_{t-3} in 2013/14): SHMI (94.49; 95.69; 39.70), hip fracture mortality rate (16.58; 52.46; 14.30), emergency readmission rate (140.68; 168.39; 101.60), overall patient satisfaction (175.89; 261.03; 159.30), patient satisfaction on hospital cleanliness (282.66; 467.54; 234.30), patient satisfaction on decision involvement (100.42; 216.06; 145.80), bed occupancy rate (85.14; 135.99; 103.92), rate of cancelled elective operations (30.46; 105.08; 35.54), reference cost index (87.65; 206.49; 164.61), elective reference cost index (16.29; 56.77; 50.91), non-elective reference cost index (60.16; 59.51; 42.62), reference cost index for hip replacement (44.49; 13.39; 31.14).

Each regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed or looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals in good/very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. The estimate refers to the latest available years (2010/11 or 2011/12) and not to 2012/13 or 2013/14.

For stroke mortality and average health change after hip replacement, estimates are omitted because of the absence of a relevant instrument.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 3.8 – Comparison with results in Gravelle et al. (2014b).

Indicator		GSS (2014)	Our study			
		2009/10	2010/11	2011/12	2012/13	2013/14
Overall mortality	(1)	0.276	0.377	0.260	0.162	0.241
		(0.004)***	(0.000)***	(0.008)***	(0.106)	(0.027)**
	(2)	0.234	0.314	0.214	0.105	0.173
		(0.019)**	(0.001)***	(0.036)**	(0.304)	(0.119)
Hip fracture mortality rate	(1)	0.028	0.118	0.103	-0.121	-0.105
		(0.807)	(0.286)	(0.374)	(0.283)	(0.370)
	(2)	-0.066	-0.019	0.093	-0.218	-0.203
		(0.580)	(0.868)	(0.422)	(0.054)*	(0.087)*
Stroke mortality rate	(1)	0.179	-0.037	-0.172	-0.123	-0.291
		(0.100)*	(0.748)	(0.143)	(0.284)	(0.015)**
	(2)	0.147	-0.127	-0.203	-0.163	-0.316
		(0.189)	(0.265)	(0.083)*	(0.162)	(0.009)***
Patient satisfaction on hospital cleanliness	(1)	0.179	-0.003	-0.015	-0.060	0.045
		(0.070)*	(0.976)	(0.869)	(0.538)	(0.622)
	(2)	0.171	-0.045	-0.030	-0.111	0.009
		(0.077)*	(0.633)	(0.740)	(0.248)	(0.918)
Patient satisfaction on decision involvement	(1)	0.245	0.092	0.068	-0.022	0.060
		(0.012)**	(0.272)	(0.407)	(0.792)	(0.504)
	(2)	0.167	0.005	-0.038	-0.087	-0.031
		(0.102)	(0.953)	(0.649)	(0.317)	(0.736)

GSS (2014) = Gravelle at al. (2014b). Both GSS (2014) and our study's estimates are obtained by ML. While GGS (2014) use an inverse distance weight matrix with a 30 min travel distance threshold, we use a 30 km straight line distance threshold.

Specification (1) controls for: number of rivals, teaching trusts, foundation trusts, specialist hospitals, number of patients, market forces factor, population density, London trusts.

Specification (2) controls for all covariates in (1) and for: proportion of individuals aged 65 and over, proportion of individuals employed and looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals with a degree, proportion of individuals in good and very good health.

The specialist dummy is omitted if the quality indicator's sample does not include specialist hospitals, i.e. for all indicators included in Gravelle, Santos, and Siciliani (2014) and for SHMI, hip fracture and stroke mortality rate.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Chapter 4 – Does Hospital Competition Improve Efficiency? The Effect of the Patient Choice Reform in England

Abstract

We use the 2006 relaxation of constraints on patient choice of hospital in the English NHS to investigate the effect of hospital competition on dimensions of efficiency including indicators of resource management (admissions per bed, bed occupancy rate, proportion of day cases, cancelled elective operations, proportion of untouched meals) and costs (cleaning services costs, laundry and linen costs, reference cost index for overall and elective activity). We employ a *quasi* difference-in-difference approach and estimate seemingly unrelated regressions and unconditional quantile regressions with data on hospital trusts from 2002/03 to 2010/11. Our findings suggest that increased competition had mixed effects on efficiency. An additional equivalent rival increased admissions per bed and the proportion of day cases by 1.1 and 3.8 percentage points, and reduced the proportion of untouched meals by 3.5 percentage points, but it also increased the number of cancelled elective operations by 2.6%. Unconditional quantile regression results indicate that hospitals with low efficiency, as measured by fewer admissions per bed and a smaller proportion of day cases, are more responsive to competition.

4.1 Introduction

The efficiency of health care systems is a key goal for policy makers across OECD countries. Some of these, such as Australia, England, and the Nordic countries, pursue greater efficiency by stimulating hospital competition through policies that give individuals the right to choose among hospitals (Cookson and Dawson, 2012, Propper, 2012, Palangkaraya and Yong, 2013).

In this paper, we use the 2006 English NHS relaxation of constraints on patient choice of hospital to investigate whether there was any effect of the exposure to greater competition on hospital efficiency. The aim of the reform was to induce hospitals to compete on quality and to enhance efficiency. The theory suggests that, under a DRG-type payment system, patient choice may affect efficiency in different ways through its interaction with quality. Higher quality implies greater volumes of patients and, in turn, larger incentives to improve efficiency by containing costs to increase the profit margin on each extra patient (Ma, 1994). But making an additional effort to increase quality may reduce the cost-containment effort (Brekke et al., 2012).

The previous empirical literature (reviewed briefly in section 1.2) focuses on unit costs and length of stay (e.g Cooper et al., 2012, Gaynor et al., 2013) measured at the aggregate level or for a specific procedure (hip and knee replacement). We provide a richer analysis by examining a wider range of efficiency dimensions. Hospitals may increase efficiency by treating more patients for a given number of beds. We therefore examine admissions per bed, bed occupancy, cancelled elective operations, and the proportion of day cases. Hospitals may also become more efficient via better management of amenities. We therefore examine the percentage of untouched meals, cleaning services costs and linen and laundry costs. Hospitals may also reduce unit costs which we measure through the reference cost index (RCI), which compares a hospital's total costs with the national average total costs for the same mix of services and is used by the policy maker to assess hospital efficiency (Department of Health, 2014).

We analyse samples of public hospital trusts from the financial year 2002/03 to 2010/11. As with studies such as Cooper et al. (2012) and Gaynor et al. (2013), we use the 'Patient Choice' reform as a natural experiment and use a *quasi* difference-in-difference approach. This empirical strategy exploits the variation in market structure facing different hospitals, under the plausible argument that hospitals in more competitive areas are more likely to change their behaviour after the relaxation of constraints on patient choice of provider. Unlike previous studies, we estimate the *quasi* difference-in-difference regressions for our nine efficiency indicators simultaneously through Seemingly Unrelated Regressions (SUR; Zellner, 1962, 1963). SUR is supposed to improve the precision of the estimates, since we have a wide range of hospital efficiency outcomes, which are potentially correlated. We also use the Unconditional Quantile Regression (UQR) approach suggested by Firpo et al. (2009) to investigate whether the effect of competition varies for more or less efficient hospitals. Competition is measured through the 'equivalent' number of rivals (Kessler and McClellan, 2000), which is calculated as the inverse of the predicted Herfindahl-Hirschman index (HHI).

Our findings suggest that competition has mixed effects on efficiency. Post Choice policy, one more equivalent rival increases efficiency as measured by admissions per bed by 1.1% and the proportion of day cases increases by 3.8 percentage points and decreases the proportion of untouched meals by 3.5 percentage points. But the number of cancelled elective operations increases by 2.6%.[46] There are no statistically significant effects on the other five efficiency indicators (bed occupancy, cleaning services costs, laundry and linen costs, and RCI for all admissions and for elective admissions). We also find that SUR has generally better explanatory power than OLS and standard errors are smaller in most cases. The UQR results indicate that hospitals exhibiting low efficiency and facing greater competition may be more responsive to the Choice reform. For instance, one more equivalent rival increases admissions per bed by 2.2% for hospitals with fewer admissions per bed (25th quantile), but there is no statistically significant effect for hospitals with more admissions per bed (e.g. 50th or 75th quantile).

The next two sections briefly describe the related literature and the institutional background in the English NHS. Section 4.2 explains the econometric strategy. Section 4.3 describes the data, and Section 4.4 provides the results. Section 4.5 concludes.

4.1.1 Related studies

A number of empirical studies investigate the effect of competition on efficiency in the US

[46] We analyse the log of admissions per bed and cancelled elective operations. The effect of market structure on these indicators is therefore expressed as a percentage change. Instead, proportion of day cases and untouched meals are studied in their natural units and the effect of market structure is interpreted in percentage points.

(Gaynor and Town, 2011). Early studies suggest that hospital competition leads to an inefficient use of resources under a retrospective payment system (e.g. Joskow, 1980, Robinson and Luft, 1985).[47] Later studies find evidence of lower hospital costs in more competitive areas after the introduction of prospective payment system and managed care (Zwanziger and Melnick, 1988, Bamezai et al., 1999).[48] For example, Kessler and McClellan (2000) and Kessler and Geppert (2005), find that hospital competition has a welfare-enhancing effect by reducing costs and increasing quality for patients who had a heart attack.

For the UK, Söderlund et al. (1997) find no association between competition and unit cost after the introduction of the NHS internal market.[49] Gaynor et al. (2013) focus on a more recent reform that aimed at stimulating competition among hospitals through Patient Choice (see section 1.2 for details on the reform). The authors implement a *quasi* difference-in-difference estimator and find that competition reduced length of stay but did not change expenditure per admission.[50] Cooper et al. (2012) also exploit the Patient Choice reform and find that it reduced the pre-surgery length of stay of elective procedures such as hip and knee replacement, hernia repair, and arthroscopy more in competitive areas. By contrast, Bloom et al. (2015) use an IV strategy on a cross-section of hospitals in 2006 and find that competition increases average length of stay.[51]

Our study contributes to this literature in three ways. First, we extend the analysis of length of stay and unit costs to a wider set of efficiency indicators. We include measures of resource

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[47] A retrospective payment system reimburses hospitals for the actual costs incurred for each patient.

[48] In 1982, hospitals in California were paid a fixed price for each patient treated, and new pro-competition laws allowed insurance companies to offer patients health care plans after negotiating the price with providers.

[49] The NHS internal market reform was introduced in 1991 and it stimulated competition by separating the roles of financier and supplier of health care services. Suppliers (hospitals trusts) had to compete to secure contracts, and therefore income, offered by the purchaser. The internal market was abolished some years later in 1997.

[50] Gaynor et al. (2013) study other aspect of hospital performance such as total number of admissions, total number and share of elective admissions, and total expenditure. They also investigate the effect of competition on quality as measured by heart attack and overall mortality.

[51] Most of the investigations on hospital competition focus on the US and the UK but recent studies explore hospital competition also in other countries. For example, Berta et al. (2016) examines the effect of hospital competition on quality in Italy and find no association using indicators such as mortality and readmission rates.

management such as admissions per bed, bed occupancy rate, cancelled operations, proportion of day cases and untouched meals, and cost indicators such as cleaning services costs and laundry and linen costs, and the RCI as an alternative indicator to unit costs. Second, we estimate simultaneously the regressions for our indicators by SUR to account for correlations across the error terms. Third, we test whether the effect of competition on efficiency varies at different quantiles of the efficiency distribution using the UQR estimator of Firpo et al. (2009).

4.1.2 Institutional background

The English National Health Service (NHS) provides healthcare which is universal, tax financed, and free at the point of use. The Department of Health distributes capitated funding to around 150 local health authorities, which use it to pay for secondary health care provided to NHS patients by public and private hospitals. Public hospitals are run by NHS Trusts or NHS Foundation Trusts, the latter having greater financial autonomy. Some NHS hospital trusts are teaching trusts providing research and teaching, and some are specialist trusts focusing on a limited range of conditions or client groups. Private hospitals are small, with no more than 50 beds, and overall provide about 6.5% of hospital beds (Boyle, 2011). They mostly focus on elective surgical procedures and, unlike public hospitals, they can refuse to treat highly severe patients (Mason et al., 2008).

Hospitals are mainly funded through a prospective payment system, the National Tariff Payment System. This is based on Healthcare Resource Groups (HRGs), a patient classification system similar to the American Diagnosis-Related Group. HRGs are groups of patients who are homogeneous with respect to diagnoses, procedures, and some patient characteristics. A fixed tariff is calculated for each HRG group as its national cost averaged across providers, but with adjustments for individual hospitals to reflect exogenous variations in input prices and the higher costs of specialised care (Department of Health, 2013a).

Hospital competition has been encouraged by relaxing restrictions on patients' choice of hospital for elective care. Before 2006, elective patients were mainly restricted to the set of hospitals in contract with their local health authority. In 2006, patients were given the right to be offered a choice of at least four hospitals for elective care. Since 2008, patients have been allowed to choose any qualified provider (Department of Health, 2009). Choice is facilitated through the website 'NHS Choices', which provides information on some aspects of hospital performance (e.g. mortality, waiting times).

4.2 Methods

To assess the impact of the Patient Choice reform on efficiency, we employ the following baseline model (Model I):

$$y_{kt} = \mu + \beta \bar{M}_k d_{t \geq 2006\text{-}07} + X_{kt}\theta + \lambda_t + \alpha_k + \varepsilon_{kt} \tag{4.1}$$

where y_{kt} is an efficiency indicator for hospital $k=1,\ldots,K$ in year t=2002/03,…,2010/11; μ is the intercept; $\bar{M}_k = \left(1/T_k^{pre}\right)\sum_{t=2002\text{-}03}^{2005\text{-}06} M_{kt}$ measures the average pre-reform market structure of hospital k, with M_{kt} being the market structure of hospital k in year t and T_k^{pre} the number of pre-reform years for hospital k; $d_{t\geq 2006/07}$ is a dummy equal to one from year 2006/07 onwards, when the policy was introduced; X_{kt} is a vector of hospital-level control variables (e.g. percentage of male patients, patient age); λ_t and α_k are respectively year dummies to account for time trend (e.g. of technical progress) and hospital fixed effects to allow for time-invariant unobserved factors and ε_{kt} is an idiosyncratic error term. We use $\bar{M}_k$ instead of M_{kt} in equation (4.1) to avoid potential endogeneity due to, for example, low quality and efficiency of some hospitals affecting entry by rivals after the reform.

Model I is a *quasi* difference-in-difference regression because it uses a variable with differing *treatment intensity* rather than a treatment or control group (Angrist and Pischke, 2008, p. 175). The idea is that the Patient Choice policy affects to a greater extent areas with more providers (i.e.

more competitive areas) than areas with fewer providers (i.e. less competitive areas). The English NHS fits this empirical strategy because of the high geographical variation in the English hospital market structure.[52]

The coefficient β in Model I is our difference-in-difference estimator. It indicates whether the effect of competition on efficiency changed after the reform. For example, $\beta>0$ implies that after the choice reform hospitals in more competitive areas experience a greater increase in the efficiency indicator compared to hospitals in less competitive areas. β is identified under the common trend assumption (i.e. efficiency in both more competitive and less competitive areas follow the same trend in the absence of the reform).

We estimate Model I for nine efficiency indicators. These outcomes are likely to be influenced by common unobservable factors (e.g. unmeasured patient characteristics) and to respond to exogenous shocks (e.g. introduction of a new medical technology). As a result, the error terms across the nine regressions may be correlated. The single-equation OLS estimator neglects such correlations which, if accounted for, may allow more precise estimates. We, therefore, estimate Model I jointly for all the efficiency indicators via a SUR model.

SUR and OLS are equivalent if there is no correlation between error terms (Zellner, 1962). Even when errors are correlated, SUR and OLS are equivalent if the covariates exhibit greater collinearity across regressions than within regressions. If covariate collinearity within regressions is greater than across regressions, SUR will still provide more efficient estimates (Baltagi, 2011, p. 245). This latter condition is likely to be met in our study because, although using mostly the same covariates across regressions, the inclusion of hospital dummies (i.e. the hospital fixed effects) may induce some collinearity within regressors, and also because of the heterogeneity of

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[52] For instance, hospitals in London generally compete with more than ten rivals within a radius of 30 km but some hospitals in the North East of England do not face any rival within the same radius.

the different efficiency indicators we use.[53] We estimate SUR by maximum likelihood and we cluster standard errors within hospitals to allow for the serial correlation of errors over time. We test the validity of SUR against OLS using a Breusch-Pagan (1979) test on the stacked error terms to verify the hypothesis of independent equations (i.e. no correlation between error terms).

As in Kessler and McClellan (2000), we test whether the effect of the market structure on efficiency is non-linear using Model II:

$$y_{kt} = \mu + Q_k d_{t \geq 2006\text{-}07} \beta' + X_{kt}\theta + \lambda_t + \alpha_k + \varepsilon_{kt}\,, \tag{4.2}$$

where Q_k is a vector of three dummies constructed on the quartile of the pre-reform market structure ($\bar{M}_k$) distribution: a dummy equal to one for the second quartile (hospitals subject to low competition), one for the third quartile (high competition), and another for the fourth quartile (very high competition). The omitted dummy for the first quartile (hospitals subject to the lowest competition) is the reference category.

We also estimate Model III that, differently from the previous models, controls for time-varying market structure:

$$y_{kt} = \mu + \beta M_{kt} d_{t \geq 2006\text{-}07} + \delta M_{kt} + X_{kt}\theta + \lambda_t + \alpha_k + \varepsilon_{kt}\,. \tag{4.3}$$

The coefficient β in equation (4.3) has the same interpretation as in Model I, while δ captures the effect of competition in the pre-reform period.

As an additional robustness check, we implement Model IV, a more flexible version of Model III, which allows β to vary in each period as follows:

$$y_{kt} = \mu + P_t M_{kt} \beta' + \rho M_{kt} + X_{kt}\theta + \lambda_t + \alpha_k + \varepsilon_{kt}\,, \tag{4.4}$$

where P_t is a vector of year dummies, excluding year 2005/06. This model provides information on the evolution of the effect of competition on efficiency in each pre- and post-reform year. We

[53] Intuitively, by using a lot of different efficiency indicators, the conditional mean function of each indicator is likely to be affected differently by covariates, choice policy and hospital fixed-effects, thus reducing the potential of collinearity across regression on different outcomes.

expect a significant effect of competition on efficiency in the post-reform years and no effect in the pre-reform years.

All the above models focus on the effect of competition on *average* efficiency. It may be argued that there is more scope for competition to affect efficiency when efficiency is low. In general, the effect of market structure on efficiency might vary (non-linearly) depending on the levels of the efficiency indicators. To investigate this, we implement in Model V the UQR approach suggested by Firpo et al. (2009) as follows:

$$R_\tau\left(y_{kt}\right) = \mu_\tau + \beta_\tau \bar{M}_k d_{t\geq 2006\text{-}07} + X_{kt}\theta_\tau + \lambda_t + \alpha_k + \varepsilon_{kt}\,, \qquad (4.5)$$

where $R_\tau(y_{kt})$ captures the τ^{th} unconditional quantile of the efficiency indicator distribution.[54] Estimates from this approach have an interpretation similar to model I: $\beta_\tau>0$ indicates that, as a result of the choice policy, hospitals in the τ^{th} *unconditional* quantile of the efficiency indicator distribution and located in more competitive areas experience a greater increase in the efficiency indicator compared to similar hospitals located in less competitive areas.[55] We focus on the 10th, 25th, 50th, 75th, and 90th unconditional quantiles and we bootstrap clustered standard errors using 1,000 replications.[56]

[54]More formally, $R_\tau(y_{kt})$ is the Recentered Influence Function (RIF) calculated as $RIF(y_{kt};q_\tau)=q_\tau+(\tau\text{-}1[y_{kt}\leq q_\tau])/f_y(q_\tau)$, where q_τ is the τ^{th} quantile of y_{kt}, $1[y_{kt}\leq q_\tau]$ is a dummy equal to one when y_{kt} is below q_τ, and $f_y(q_\tau)$ is the estimated density function at q_τ. The density function is estimated assuming a Gaussian kernel and using the optimal bandwidth that minimises the mean integrated squared error.

[55] Using UQRs to evaluate the effect of a change in policy provides several advantages compared to the alternative approach of conditional quantile regressions (CQR) introduced by Koenker and Bassett (1978). In CQRs, the covariates have the effect of redefining the quantiles of the dependent variable distribution (Borah and Basu, 2013): a hospital in the top of the efficiency indicator distribution may end up in the bottom of the conditional distribution. Hence, we cannot conclude whether explanatory variables have bigger or smaller effects on hospitals in particular quantiles. A further limitation of the conditional quantile approach concerns fixed effects, which must be treated as pure location shifters that remain constant across quantiles (e.g. Canay, 2011). This might be a strong assumption in empirical applications. In our case, for example, fixed effects are likely to capture unobserved case-mix, which needs to yield the same effect on the outcome for all hospitals, regardless of their *conditional* efficiency.

[56] We perform all estimations in Stata. We fit SUR through the command `gsem`. The unconditional quantile regression is implemented using `xtrifreg` (Borgen, 2016).

4.3 Data

4.3.1 Efficiency indicators

We have nine efficiency indicators from 2002/03 to 2010/11.[57] As a measure of resource management, we use the number of *admissions per bed* calculated with data on admissions from NHS Digital and on beds from the NHS statistics. Other indicators of resource management are *bed occupancy rate* and number of *cancelled elective operations* for non-clinical reasons from the NHS statistics, and *proportion of day cases* and *proportion of untouched meals* from the NHS Digital. We also use cost indicators including *cleaning services costs* and *laundry and linen costs* from the NHS Digital, and *RCI* and *elective RCI* which are available from the reference cost database.[58]

4.3.2 Measure of hospital market structure

We capture the market structure through the '*equivalent*' *number of rival hospitals*, including both public and private providers. This is calculated as the inverse of the Herfindahl-Hirschman Index (HHI) based on hospitals' predicted patient flows.[59] Following Kessler and McClellan (2000), we calculate the HHI for hospital *k* as follows:

$$HHI_k = \sum_o S_{ko} HHI_o = \sum_o S_{ko} \sum_k \left(S_{ok}\right)^2 \quad (4.6)$$

where S_{ko} is the predicted market share of hospital *k*'s patients living in neighbourhood *o* within 30 km; and HHI_o indicates the concentration of patients across neighbourhoods, which is calculated through the predicted share of patients living in neighbourhood *o* admitted to hospital *k*

57 Table A4.4 has the link to the website where each variable was collected.

58 Cleaning services costs include all pay (e.g. salaries) and non-pay (e.g. equipment) costs for both in-house or contracted out cleaning services. Laundry and linen costs are defined in a similar way.

59 To predict the patient flows, we estimate the following Poisson choice model for each year: $E\left(I_{ko} \mid distance_{ko}, \boldsymbol{z}_k, L_o\right) = \exp\left(\phi_1 distance_{ko} + \phi_2 distance_{ko}^2 + \boldsymbol{\phi}_3' \boldsymbol{z}_k + \boldsymbol{\chi}' \boldsymbol{L}_o\right)$, where I_{ko} is the number of hospital *k*'s patients living in neighbourhood *o*, $distance_{ko}$ is the distance between neighbourhood *o*'s centroid and hospital *k* located within 30 km, z_k is a vector of hospital type dummies to control for public hospitals, foundation trusts, and teaching hospitals, and L_o is a vector of LSOA dummies.

(S_{ok}).[60] The hospital HHI (HHI_k) can be interpreted as a weighted average of the neighbourhood HHI (HHI_o), which helps to identify each hospital's market.[61] The inverse of hospital HHI (HHI_k^{-1}) represents therefore the number of rivals that would exist if patients were uniformly distributed across hospitals. The equivalent number of rivals is constructed using data from Hospital Episode Statistics (Gravelle et al., 2014a).

4.3.3 Other control variables

We include a number of control variables: the *percentage of male patients*, *percentage of patients between 15 and 59*, *60 and 74*, and *older than 74 years* (the reference category is the age range between 0 and 14), and *percentage of emergency admissions*. We also use a dummy for *Foundation Trusts*. Information for these variables comes from the NHS Digital. In addition, we control for exogenous variation in input prices (e.g. nurses, buildings) through the *market forces factor* (*MFF*) *index* collected from the reference cost database. We also add the *number of beds* to the regressions for cancelled elective operations, cleaning services costs, and laundry and linen costs.

4.3.4 Descriptive statistics

Table 4.1 provides descriptive statistics. The sample includes between 143 (laundry and linen costs) and 173 (RCI) hospitals observed on average for a period of almost 9 years. In each year, there are on average 110 admissions per bed. The bed occupancy rate is 86%. 30.7% of patients are on average admitted as day cases, and hospitals cancel on average 359 elective operations in a year. On average, 7.6% of meals served to patients remain untouched, the cleaning services and the laundry and linen costs are respectively £2,842 thousands and £807 thousands. The reference

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[60] The patient share S_{ok} is the ratio between the number of hospital k's patients living in neighbourhood o (I_{ko}) and the number of patients living in neighbourhood o (I_o), while S_{ko} is computed dividing I_{ko} by the number of hospital k's patients (I_k).

[61] The neighbourhood is a small geographical area called LSOA (Lower Super Output Area), which includes on average 1,500 inhabitants but no less than 1,000.

cost indexes are 100 by construction: a RCI greater than 100 indicates that a hospital's total costs are greater than the national average total costs for the same HRG groups.[62]

Although all indicators are used to capture efficiency, we expect admissions per bed, bed occupancy rate, and proportion of day cases to be positively correlated with efficiency, while the others to be negatively correlated. Table A4.1 of the Appendix 4 shows simple pairwise correlations. For example, admissions per bed is positively correlated with bed occupancy rate and negatively correlated with the RCIs. Similarly, the bed occupancy rate is negatively correlated with the RCIs, and the proportion of day cases is negatively correlated with the laundry and linen costs. Correlations are generally low and mostly below 30%.

Figure 4.1 illustrates the trend in some efficiency indicators from 2002/03 to 2010/11.[63] Over the whole period, we note a positive time trend in admissions per bed, cleaning services costs, and laundry and linen costs. A negative trend is instead observed for the percentage of untouched meals. Bed occupancy rate, rate of day cases, and cancelled elective operations have a positive trend only from or after 2006/07. Cancelled elective operations, however, decrease from 2009/10 to 2010/11.

Table 4.1 also shows descriptive statistics on covariates. There are on average 3.7 equivalent rivals. 44.1% of patients are male, 13.5% are between 0 and 14 years old, 44.4% are between 15 and 59, 21% are between 60 and 74, and 20.8% are older than 74 years. 35.2% of patients are admitted in an emergency. Hospitals have on average 686 beds. 28.3% of trusts are Foundation Trusts, and the MFF is on average one by construction.

4.4 Results

Table 4.2 shows the results for Model I. The key coefficient indicates whether the effect of

[62] Table A4.2 provides the unconditional quantiles of the efficiency indicators.

[63] We omit the trend of the RCIs because their annual average equals 100 by construction.

competition on efficiency changed after the policy. It is statistically significant at 5% level in the regression for admissions per bed, proportion of day cases, cancelled elective operations, and proportion of untouched meals. One more equivalent rival increases on average admissions per bed by 1.1%. Table A4.3 in the Appendix 4 suggests that this is due to competition reducing beds but having no effect on admissions.[64]

Competition increases efficiency when measured by the proportion of day cases and untouched meals. An additional equivalent rival increases the proportion of day cases by 0.38 percentage points and reduces the proportion of untouched meals by 0.35 percentage points. In contrast, competition reduces efficiency when measured as cancelled elective operations: one more equivalent rival increases cancelled elective operations by 2.6%.

Table 4.2 also displays the coefficients on control variables. For instance, the proportion of male patients is associated with a higher proportion of day cases (0.323). A one percentage point increase in patients between 60 and 74 years old is associated with more admissions per bed by 1.2%. A higher proportion of emergency patients is associated with a lower proportion of day cases (-0.646). Foundation trusts are associated with greater inefficiency having on average fewer admissions per bed by 3% and a lower bed occupancy by one percentage point. The bottom of Table 4.2 reports the p-value for the Breusch-Pagan test, which indicates the presence of correlation among the error terms across regressions. This suggests that SUR may have better explanatory power than OLS thanks to its higher precision of the estimates (i.e. lower standard errors).[65]

Table 4.3 has the key results for Model II, in which the policy break dummy is interacted with

[64] Evidence on beds is weak in model I and III but stronger in model IV (Table A4.3). In Model I, an additional equivalent rival reduces beds by 0.5%, but this estimate is only significant at 10 % level. We observe higher statistical significance in model IV: an additional equivalent rival significantly reduces beds by 0.6% in 2007/08, 0.8% in 2008/09, and 1.3% in 2010/11.

[65] The Breusch-Pagan test suggests that SUR is favoured also for Model II, III, and IV.

three dummies indicating whether a hospital is subject to low competition, high competition or very high competition, respectively. The reference category indicates hospitals subject to very low competition. The estimates suggest that the choice policy has a greater effect on efficiency for hospitals exposed to high or very high competition compared to hospitals exposed to very low competition. Admissions per bed decrease by 5.2% and the proportion of untouched meals reduces by 2.18 percentage points for hospitals exposed to very high competition. The proportion of day cases goes up by 1.09 and 2.1 percentage points for hospitals facing high competition and very high competition, while the RCI falls by 2.7 points for hospitals facing high competition.

Table 4.4 illustrates the key results for Model III and IV. Model III controls for market structure varying over time. Compared to Model I, the key coefficient is unchanged for admissions per bed and proportion of day cases, but it is no longer significant at 5% level for cancelled elective operations and proportion of untouched meals. The association between competition and efficiency before the reform (δ) is never statistically significant at 5% level. The association between competition and efficiency after the reform ($\beta+\delta$) is significant only for the admissions per bed: an additional equivalent rival increases admissions per bed by 1.5% (0.9%+0.6%) after the reform.

Model IV analyses how the effect of competition on efficiency changes in every year before and after the policy implementation. Considering the proportion of day cases, for example, the estimated coefficient on the interaction term is negative and insignificant in the pre-reform periods, and increasingly positive and significant in the post-reform periods. Such estimates clearly indicate a persistent effect of the reform on efficiency as captured by the proportion of day cases.

Table 4.5 illustrates UQR results. They suggest that less efficient hospitals tend to respond more to competition. This is the case of efficiency outcomes as the admissions per bed, the percentage of day cases and, to a lesser extent, the percentage of untouched meals. For hospitals with fewer admissions per bed (25th quantile), an additional equivalent rival increases admissions per bed by 2.2%. Similarly, for hospitals with lower proportions of day cases (10th or 25th quantile), an additional equivalent rival increases such proportions by 0.91 or 0.4 percentage points. If hospitals have a high proportion of untouched meals (75th quantile), an additional equivalent rival decreases untouched meals by 0.43 percentage points, even though this result is only significant at 10% level. Finally, when hospitals have fewer cancelled elective operations (10th quantile), an additional equivalent rival leads to an increase in this indicator by 7.2%.

4.5 Discussion and conclusion

This study has investigated whether competition improves some dimensions of hospital efficiency in England using the exogenous variation generated by the Patient Choice reform and the geographical variation in the market structure. We find that greater competition induces hospitals to increase their efficiency by increasing admissions per bed and proportion of day cases, and by reducing the proportion of untouched meals. In contrast, hospitals appear less efficient in terms of cancelled elective operations. The effect of the choice reform is larger for hospitals facing more rivals. We also observe that less efficient hospitals generally respond more to competition.

After the introduction of Patient Choice, hospitals may have varied their efficiency levels by spreading their fixed costs on a larger share of patients through an increase in admissions per bed and proportion of day cases. Our findings on admissions per bed are in line with the recent concerns about the reduction of beds in NHS hospitals (Hosken, 2016). Also the result on the proportion of day cases is largely coherent with the reduction in pre-surgery and overall length of stay on specific elective procedures found by Cooper et al. (2012). The authors highlight that "by 2010, patients were 41.7% more likely to receive surgery on the day that they were admitted to the hospital than they were in 2002" (Cooper et al., 2012, p.17-18). Similarly, hospitals might have reduced their variable costs by, for example, reducing the proportion of untouched meals.

The improvements in such efficiency dimensions, however, may have brought hospitals close or over their full capacity levels, especially in the presence of understaffing of nurses and doctors (Bates, 2005). The increases in admissions per bed and proportion of day cases may have therefore caused a rise in the number of cancelled elective operations. Since public hospitals cannot refuse treatments for emergency patients, cancelling elective operations is the most likely mechanism that hospitals have to release pressure due to excess demand of overall hospital services (i.e. the sum of emergency and elective admissions). In addition, hospitals can increase waiting times in order to reduce excess demand. But such an alternative mechanism was not available to managers and doctors in the years following the Choice policy (i.e. 2006-2011) due to the waiting time reforms, which implied heavy penalties for hospitals with long waiting times (Propper et al., 2008).

Cancelled elective operations may have increased also because of some distortions in the payment arrangements. Cookson et al. (2017b) show that providers were more likely to cancel elective operations until 2009/10 (our last but one analysed financial year). Hospitals could cancel operations and still receive a tariff until 2009/10 and, therefore, the authors suggest that this produced an incentive to cancel operations to increase revenues. Such behaviour may have been exacerbated once competition had been introduced in 2006.

Tables and figures

Table 4.1 – Descriptive statistics.

Variable	Def	Obs	Trust	Year	Mean	SD			Min	Max
						Overall	Between	Within		
Efficiency indicator										
Admissions per bed	E	1,498	171	8.76	110	31	25	18	38	319
Bed occupancy rate (%)	E	1,503	172	8.74	86.0	6.3	5.3	3.5	50.5	99.2
Proportion of day cases (%)	E	1,477	169	8.74	30.8	8.6	7.9	3.5	4.6	90.5
Cancelled elective operations	I	1,477	170	8.69	360	288	250	142	6	2426
Proportion of untouched meals (%)	I	1,382	160	8.64	7.6	5.4	3.7	4.0	0.0	49.0
Cleaning services costs (£1,000)	I	1,381	159	8.69	2,842	1,823	1,580	901	69	12,941
Laundry and linen costs (£1,000)	I	1,215	143	8.5	807	488	459	160	40	2,864
Reference cost index	I	1,516	173	8.76	100.8	12.9	11.5	5.8	66.0	195.8
Elective reference cost index	I	1,498	171	8.76	100.2	16.5	13.6	9.3	60.5	197.3
Measure of market structure										
Equivalent number of rivals (HHI^{-1})					3.7	2.5	2.4	0.7	1.0	13.6
Control variable										
Percentage of male patients (%)					44.1	4.8	4.7	0.9	14.8	65.3
Percentage of patients between 0 and 14 years (%)					13.5	13.1	12.9	1.2	0.0	94.2
Percentage of patients between 15 and 59 years (%)					44.4	8.0	7.8	1.6	5.8	74.3
Percentage of patients between 60 and 74 years (%)					21.0	5.9	5.7	1.1	0.0	47.0
Percentage of patients older than 74 years (%)					20.8	6.2	6.1	1.3	0.0	42.8
Percentage of emergency admissions (%)					35.2	9.6	9.1	2.7	0.2	61.8
Number of beds					686	382	374	65	31	2,523
Foundation trust					0.287	0.453	0.301	0.339	0	1
Market forces factor					1.003	0.074	0.074	0.014	0.886	1.323

E=positive indicator of efficiency, I=negative indicator of efficiency.

Descriptive statistics for competition measure and control variables are calculated on the admissions per bed's sample.

Table 4.2 – Competition and efficiency: Model I.

Regressor	Log of admissions per bed	Bed occupancy rate	Proportion of day cases	Log of cancelled operations	Proportion of untouched meals	Log of cleaning services costs	Log of laundry and linen costs	Reference cost index	Elective reference cost index
Policy break 2006/07*Pre-reform HHI^{-1}	0.011	0.053	0.381	0.026	-0.347	0.0004	-0.005	-0.306	-0.516
	(0.004)**	(0.120)	(0.118)***	(0.013)**	(0.172)**	(0.007)	(0.008)	(0.275)	(0.391)
Proportion of male patients	-0.001	-0.036	0.323	-0.033	-0.008	-0.001	-0.002	-0.053	0.108
	(0.004)	(0.152)	(0.147)**	(0.017)*	(0.242)	(0.009)	(0.009)	(0.257)	(0.417)
Proportion of patients between 15 and 59	0.018	-0.043	0.019	-0.017	-0.178	0.018	0.005	-0.509	-0.447
	(0.004)***	(0.143)	(0.120)	(0.014)	(0.171)	(0.010)*	(0.007)	(0.283)*	(0.420)
Proportion of patients between 60 and 74	0.012	-0.185	1.085	0.011	-0.273	0.010	-0.003	-0.424	-0.855
	(0.006)**	(0.205)	(0.172)***	(0.021)	(0.238)	(0.011)	(0.012)	(0.361)	(0.637)
Proportion of patients beyond 74	-0.002	0.120	-0.303	0.014	-0.098	0.006	0.021	-0.200	0.267
	(0.005)	(0.172)	(0.143)**	(0.019)	(0.244)	(0.012)	(0.010)**	(0.309)	(0.568)
Proportion of emergency patients	-0.007	-0.035	-0.646	-0.020	-0.106	0.004	0.000	0.006	0.336
	(0.002)***	(0.055)	(0.056)***	(0.006)***	(0.069)	(0.003)	(0.003)	(0.119)	(0.178)*
Log of beds				-0.013		0.088	0.318		
				(0.248)		(0.101)	(0.080)***		
Foundation trust	-0.030	-1.021	-0.505	0.079	-0.283	0.015	0.116	0.309	1.143
	(0.012)**	(0.441)**	(0.328)	(0.054)	(0.541)	(0.024)	(0.539)	(0.801)	(1.439)
Market forces factor	0.348	7.295	-16.257	-0.120	-27.029	-0.347	0.028	-1.691	-29.030
	(0.280)	(8.839)	(9.187)*	(1.053)	(12.636)**	(0.568)	(0.029)	(20.431)	(27.186)
Constant	3.694	86.790	42.691	8.049	52.485	6.388	3.568	137.249	142.996
	(0.474)***	(15.379)***	(13.890)***	(2.257)***	(17.983)***	(1.291)***	(1.000)***	(29.858)***	(47.614)***

SUR estimation. All regressions control for hospital and year fixed effects. Policy break 2006/07 is an indicator for years 2006/07 to 2010/11.

Breusch-Pagan test for diagonal variance-covariance matrix: p-value<0.001.

Clustered standard errors in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 4.3 – Competition quartiles and efficiency: Model II.

Efficiency indicator	2nd quartile	3rd quartile	4th quartile
Log of admissions per bed	0.011	0.026	0.052
	(0.022)	(0.022)	(0.023)**
Bed occupancy rate	0.549	1.285	0.951
	(0.661)	(0.691)*	(0.815)
Proportion of day cases	0.809	1.085	2.104
	(0.626)	(0.497)**	(0.744)***
Log of cancelled elective operations	-0.025	0.084	0.119
	(0.079)	(0.081)	(0.084)
Proportion of untouched meals	-1.342	-1.805	-2.175
	(0.908)	(0.948)*	(1.043)**
Log of cleaning services costs	-0.036	-0.054	-0.021
	(0.038)	(0.048)	(0.045)
Log of laundry and linen costs	0.055	-0.009	0.020
	(0.054)	(0.046)	(0.046)
Reference cost index	-0.369	-2.702	-1.892
	(1.147)	(0.998)***	(1.497)
Elective reference cost index	2.473	-2.331	-3.301
	(1.939)	(1.986)	(1.973)*

SUR estimation. In addition to hospital and year fixed effects, all regressions control for gender, age categories, emergency admissions, foundation trusts, and market forces factor. The regressions for cancelled elective operations, cleaning services costs, and laundry and linen costs also control for beds.

Quartile dummies are constructed on the pre-reform HHI^{-1}: 2nd quartile=low-competition market, 3rd quartile=high-competition market, 4th quartile=very high-competition market; 1st quartile=very low-competition market (reference category).

Breusch-Pagan test for diagonal variance-covariance matrix: p-value<0.001

Clustered standard errors in parentheses.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 4.4 – Competition and efficiency: with time varying competition.

Regressor	Log of admissions per bed	Bed occupancy rate	Proportion of day cases	Log of cancelled operations	Proportion of untouched meals	Log of cleaning services costs	Log of laundry and linen costs	Reference cost index	Elective reference cost index
				Model III					
Policy break*HHI^{-1}	0.009 (0.004)**	0.051 (0.110)	0.329 (0.105)***	0.022 (0.011)*	-0.256 (0.156)	0.002 (0.006)	0.00002 (0.007)	-0.186 (0.220)	-0.422 (0.338)
HHI^{-1}	0.006 (0.007)	0.020 (0.208)	-0.277 (0.170)	-0.003 (0.027)	-0.156 (0.306)	-0.019 (0.010)*	-0.013 (0.015)	-0.556 (0.370)	-0.387 (0.710)
				Model IV					
Dummy 2002/03*HHI^{-1}	-0.004 (0.006)	-0.007 (0.214)	-0.246 (0.179)	-0.016 (0.034)	0.567 (0.317)*	0.024 (0.015)*	0.012 (0.012)	0.122 (0.460)	-0.533 (0.713)
Dummy 2003/04*HHI^{-1}	-0.004 (0.004)	-0.036 (0.144)	-0.134 (0.137)	-0.018 (0.020)	0.178 (0.225)	-0.007 (0.018)	0.018 (0.010)*	-0.129 (0.269)	-0.268 (0.489)
Dummy 2004/05*HHI^{-1}	-0.002 (0.003)	-0.042 (0.105)	-0.035 (0.086)	-0.024 (0.013)*	0.347 (0.192)*	0.004 (0.007)	-0.007 (0.009)	-0.094 (0.190)	0.204 (0.383)
Dummy 2006/07*HHI^{-1}	0.003 (0.004)	-0.221 (0.099)**	0.161 (0.087)*	0.010 (0.009)	0.118 (0.114)	0.008 (0.006)	0.002 (0.006)	0.014 (0.258)	-0.197 (0.353)
Dummy 2007/08*HHI^{-1}	0.008 (0.004)*	0.195 (0.171)	0.239 (0.138)*	0.025 (0.013)*	0.070 (0.153)	-0.005 (0.010)	0.001 (0.009)	-0.603 (0.255)**	-0.542 (0.382)
Dummy 2008/09*HHI^{-1}	0.006 (0.005)	0.205 (0.205)	0.292 (0.113)***	0.024 (0.015)	-0.015 (0.253)	0.006 (0.006)	0.001 (0.009)	-0.204 (0.250)	-0.531 (0.446)
Dummy 2009/10*HHI^{-1}	0.008 (0.005)	-0.001 (0.161)	0.350 (0.126)***	-0.002 (0.019)	-0.374 (0.200)*	0.003 (0.006)	0.002 (0.009)	-0.189 (0.253)	-0.546 (0.480)
Dummy 2010/11*HHI^{-1}	0.013 (0.005)**	0.153 (0.174)	0.423 (0.155)***	-0.016 (0.018)	-0.353 (0.193)*	0.005 (0.007)	0.007 (0.009)	-0.356 (0.279)	-0.691 (0.489)
HHI^{-1}	0.004 (0.008)	0.044 (0.228)	-0.359 (0.186)*	0.014 (0.028)	-0.096 (0.335)	-0.016 (0.013)	-0.009 (0.016)	-0.504 (0.401)	-0.555 (0.735)

SUR estimation. In addition to hospital and year fixed effects, all regressions control for gender, age categories, emergency admissions, number of beds, foundation trusts, and market forces factor. The regressions for cancelled elective operations, cleaning services costs, and laundry and linen costs also control for beds.
Post-reform effect of market structure (p-value) in Model III ($\beta+\delta$). Log of admission per bed: 0.015 (0.014); bed occupancy rate: 0.071 (0.745); proportion of day cases: 0.052 (0.753); log of cancelled operations: 0.019 (0.469); proportion of untouched meals: -0.412 (0.155); log of cleaning services costs: -0.017 (0.114); log of laundry and linen costs: -0.013 (0.360); reference cost index: -0.742 (0.101); elective reference cost index: -0.809 (0.214).
Breusch-Pagan test for diagonal variance-covariance matrix: p-value=0.000. Clustered standard errors in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table 4.5 – Effects of competition at different efficiency quantiles: Model V.

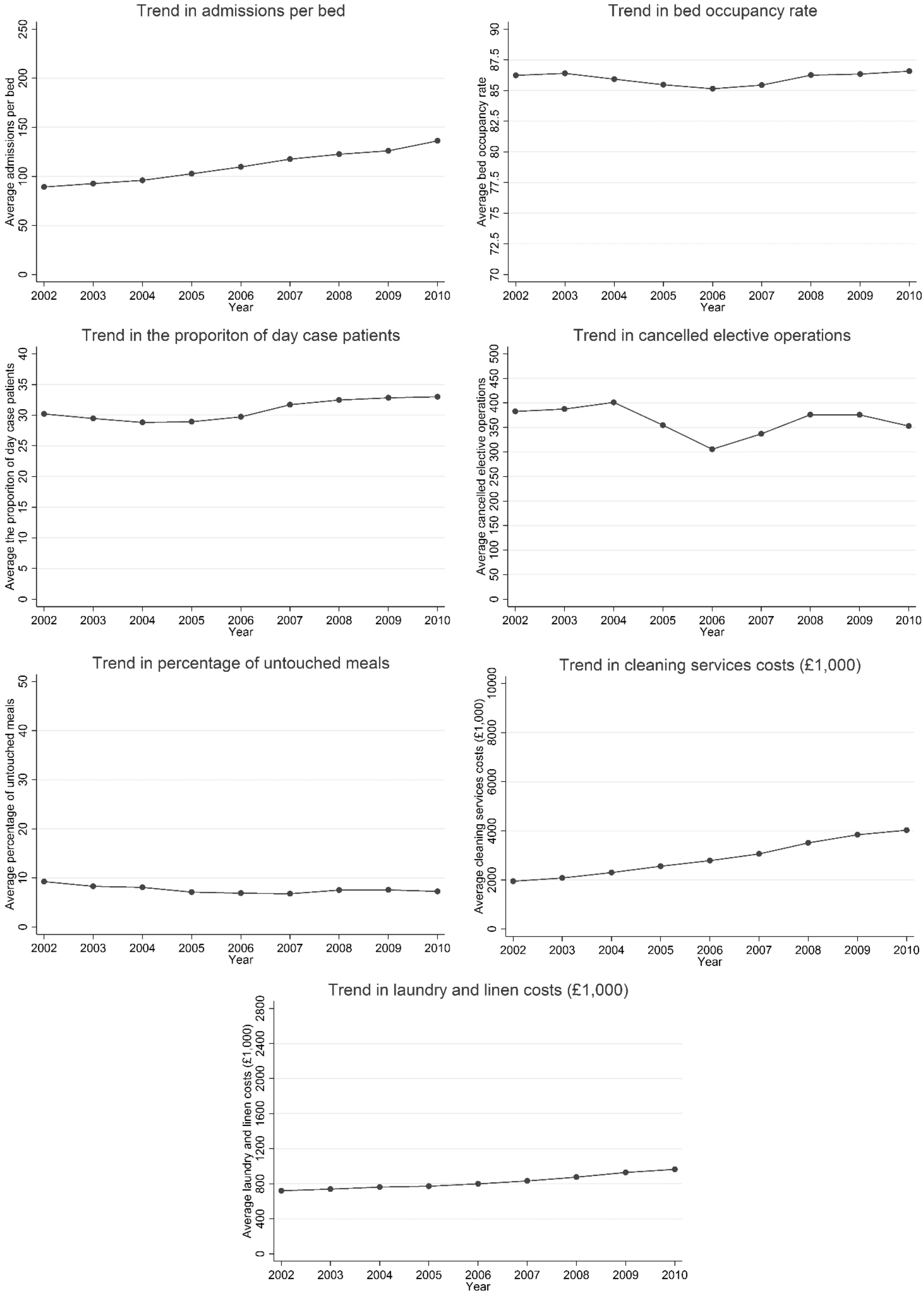
Efficiency indicator	10th	25th	50th	75th	90th
Log of admissions per bed	0.019	0.022	0.002	-0.010	-0.009
	(0.015)	(0.011)**	(0.008)	(0.008)	(0.010)
Bed occupancy rate	0.461	0.147	-0.079	-0.183	-0.211
	(0.408)	(0.190)	(0.148)	(0.191)	(0.252)
Proportion of day cases	0.914	0.396	0.220	0.101	0.277
	(0.372)**	(0.201)**	(0.202)	(0.255)	(0.377)
Log of cancelled elective operations	0.072	0.035	0.011	0.017	0.041
	(0.037)**	(0.023)	(0.022)	(0.022)	(0.026)
Proportion of untouched meals	-0.076	-0.196	-0.168	-0.429	-0.627
	(0.160)	(0.128)	(0.144)	(0.245)*	(0.469)
Log of cleaning services costs	0.018	-0.037	-0.031	-0.007	0.053
	(0.036)	(0.023)	(0.022)	(0.020)	(0.035)
Log of laundry and linen costs	-0.075	-0.021	0.010	-0.018	0.016
	(0.046)	(0.020)	(0.018)	(0.015)	(0.032)
Reference cost index	-0.419	-0.319	-0.233	-0.532	0.062
	(0.281)	(0.248)	(0.250)	(0.424)	(1.068)
Elective reference cost index	0.295	-0.316	-0.395	-0.390	-1.934
	(0.501)	(0.386)	(0.487)	(0.742)	(1.592)

Unconditional quantile regression. In addition to hospital and year fixed effects, all regressions control for gender, age categories, emergency admissions, number of beds, foundation trusts, and market forces factor. The regressions for cancelled elective operations, cleaning services costs, and laundry and linen costs also control for beds.

Bootstrapped clustered standard errors (using 1,000 replications) in parenthesis.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Figure 4.1 – Trend in the efficiency indicators from 2002/3 to 2010/11.



Conclusions

This thesis has investigated two topics. The first two chapters focus on specialisation in the hospital sector with a focus on specialist orthopaedic hospitals. Chapter 1 studies the efficiency of specialist orthopaedic hospitals compared to trauma & orthopaedics (T&O) departments in general hospitals. The key finding suggests that there is no statistical difference in efficiency, as measured by length of stay (LOS), between specialist orthopaedic hospitals and T&O departments. Chapter 2 examines the financial viability of specialist orthopaedic hospitals by testing whether their costs are higher than T&O departments in general hospitals after accounting for differences in revenues. The findings suggest that specialist orthopaedic hospitals have on average 13% lower overall profit margins than T&O departments. Such lower profit margins are due to some patient characteristics such as patient age and severity as captured by number of diagnoses and procedures.

Specialisation is an organisational form which is supposed to generate a number of benefits such as greater efficiency, quality, and responsiveness (Skinner, 1974, Herzlinger, 1996, Schneider et al., 2008). On this basis, we would expect specialist hospitals to exhibit better financial performance compared to general hospitals that undertake similar activities. The evidence provided in this thesis does not support this claim and it may therefore have important policy implications.

Since specialist hospitals may not be as efficient as advocates proclaim, at least for T&O services that we consider, it may be better financially to manage and operate services as part of a larger organisational entity. This might allow T&O departments to benefit from economies of scope, including access to a larger pool of staff and shared facilities such as operating theatres and pharmacy. On the other hand, other variables that we have not thoroughly explored may justify such a difference in the financial performance. For example, specialist hospitals may provide services of higher quality compared to T&O departments, which will therefore have relatively lower costs and, in turn, higher profits. Moreover, being part of a general hospital does not necessarily translate into better financial performance. Further investigations are needed to clarify which factors determine higher profit margins in some T&O departments compared to specialist orthopaedic hospitals. The resulting best practices could be then applied to the least performing hospitals to produce savings.

Another important implication of this thesis relates to the prospective payment system. It has been long recognised that the English Healthcare Resource Group (HRG) classification can only imperfectly account for patient complexity (Mason et al., 2008, Gutacker et al., 2013). The capacity of a prospective payment system to reimburse hospitals for their actual activity might be insufficient especially for providers with a more complex patient case-mix such as specialist hospitals. Adjustments that take account of the specific nature of specialist hospitals may help to reduce the relative unbalance of their financial performance. Similar solutions have already been implemented in other countries. The French prospective payment system, for instance, differentiates prices for public and private hospitals (Busse et al., 2011). The reimbursement system of the Lombardy region in Italy applies a tariff top-up to all hospitals with 'high specialisation' units (Ettelt et al., 2006). In England, hospitals are paid extra if their patients receive specialised care (Daidone and Street, 2013).

This first part of the thesis has some limitations. The main limitation is that results are based on a sample including only three specialist orthopaedic hospitals. The small number of specialist orthopaedic hospital trusts, however, reflects the reality that there are only three specialist orthopaedic hospital trusts in the English NHS. Although the hospital sector is moving towards a greater degree of specialisation (e.g. Barro et al., 2006, Tang et al., 2013), there are still a few specialist hospitals in many countries. Hence, the analysis proposed in this thesis is appropriate and generally applicable. A second limitation is that the patient's LOS is only a proxy to measure efficiency. Cost data provide a more comprehensive measure of efficiency by capturing, for example, the inputs' productivity through the salary of doctors and nurses. The analysis of costs may therefore yield a different efficiency ranking compared to the analysis of LOS (e.g. Gaughan et al., 2012). Finally, to disentangle efficiency from quality and to test whether quality drives profit margins in specialist hospitals, we use the health gains for hip and knee replacement. Although we take into account the outcome of only two procedures, we argue that these surgeries are indicative of departmental performance being the most common in T&O departments. Future research may focus also on the evaluation of differences in quality between specialist and general hospitals as better quality indicators (e.g. patient self-reported outcome measures on other procedures) become more widespread.

The remaining two chapters in the second part of the thesis investigate different aspects of hospital competition. Chapter 3 analyses whether hospitals that strategically interact with neighbouring hospitals improve their quality or efficiency. The results indicate that a hospital's quality or efficiency does not respond to its rivals' quality or efficiency, except for a hospital's overall mortality which is positively associated with that of its rivals. Chapter 4 evaluates the effect of market structure on a number of efficiency measures. The findings suggest that competition may affect efficiency in different ways. Competition increases efficiency as measured by admissions per bed, proportion of day cases, and untouched meals. Competition, however, reduce efficiency by increasing the number of cancelled elective operations. In addition, hospitals exhibiting low efficiency may be more responsive under greater competition.

The primary objective of the Choice policy introduced in 2006 was to stimulate hospital quality and reduce waiting times giving elective patients the freedom to choose where to be admitted. This policy is supposed to have affected the system of incentives in the hospital sector implying a number of other indirect effects that are relevant to the policy maker. A potential consequence is that hospital mergers may have an effect on the quality and efficiency of non-merging neighbouring hospitals. Another possible effect is that policy interventions incentivising quality or efficiency at local level (e.g. adoption of a new technology) may generate spillovers to other hospitals. This thesis however suggests that such indirect implications do not occur because a hospital will not respond to its nearer hospitals although these can potentially absorb volumes of patients and, in turn, revenues. This finding implies that there may be scope for the policy maker to develop policies which encourage cooperation across hospitals. In France, for instance, hospitals can be associated in groups which share activity, equipment, medical teams and a joint information system (Choné, 2017, Siciliani et al., 2017).

An additional implication is the extent to which the Choice policy can affect efficiency along with quality and waiting time. A hospital that, after the policy, provides services of higher quality will face an increase in demand. Such an increase can be dealt with only through changes of the hospital supply. Higher admissions per bed, greater proportions of day cases, and smaller proportions of untouched meals imply that hospitals tend to increase their efficiency in addition to quality. But the effect of the policy does not necessarily move in the direction of greater efficiency. It may also generate negative incentives for hospitals which, for example, may cancel more elective operations if this produces higher revenues (Cookson et al., 2017a). Further research is required to identify and better monitor other potential side effects of the reform.

Moreover, since 2008, competition is extended to all qualified providers including private hospitals which are generally smaller and more profit-oriented and thus less altruistic than public hospitals. Healthcare systems with both public and private hospitals are common among some European and low- and middle-income countries (Basu et al., 2012, Siciliani et al., 2017) but evidence on strategic interactions between these two hospital types is scarce. Future research may therefore yield a more complete picture also on this subject.

Finally, the recent emergence of new healthcare paradigms such as the integration models poses new challenges for the research agenda. Greater integration between healthcare sectors implies that services will be delivered through a system that puts primary, community, mental health, and hospital care together with the aim of improving quality. This may generate forms of competition based on selective contracting mechanisms where a commissioner negotiates a contract with a group of providers in order to encourage collaborative networks (Siciliani et al., 2017). Future investigations may evaluate whether such new healthcare models produce better outcomes compared to the current models where care is mostly fragmented and competition occurs between providers.

Appendix 1

A1.1 Sample definition

We extract data from HES, which includes information at patient level. We select patients whose main specialty is T&O. Then, we eliminate duplicates, observations with misreported HRG, and missing values. We also eliminate outliers by applying the rule:

$$LOS_{ik} > CV^{upper} = Q_{90\%}^{LOS} + \left[\left(Q_{90\%}^{LOS} - Q_{10\%}^{LOS}\right) \times 5\right] \neq 0 \qquad \text{(A1.1)}$$

Where LOS_{ik} is the LOS of patient *i* in hospital *k* excluding the day of admission, CV^{upper} is the upper critical value, $Q_{10\%}^{LOS}$ and $Q_{90\%}^{LOS}$ indicate the 10th and 90th percentile of the LOS distribution, respectively. The rule does not apply if *CV* is equal to zero. The lower critical value is neglected since LOS cannot be lower than zero. The rule in (A1.1) can be viewed as a conservative version of the more standard interquartile range rule. The idea is to remove all observations that are far apart from the 90th percentile.

We drop all hospitals not reporting PROMs data. Finally, we eliminate departments with less than 500 patients, and HRGs with less than 100 observations to improve comparability across hospitals. In total, we remove approximately 120,000 observations.

A1.2 Diagnoses, procedures, and HRG codes

Table A1.1 – Diagnosis dummies' descriptive statistics and estimates.

No	Diagnosis dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
1)	M179	Gonarthrosis, unspecified	0.076	7.6%	0.040	0.029	0.167
2)	M232	Derangement of meniscus due to old tear or injury	0.047	12.3%	0.110	0.029	0.000
3)	M169	Coxarthrosis, unspecified	0.051	17.4%	0.023	0.028	0.403
4)	S720	Fracture of neck of femur	0.040	21.4%	0.629	0.032	0.000
5)	G560	Carpal tunnel syndrome	0.036	25.0%	0.103	0.032	0.001
6)	M255	Pain in joint	0.025	27.4%	0.081	0.028	0.001
7)	S525	Fracture of lower end of radius	0.023	29.7%	0.025	0.028	0.377
8)	S470	Follow-up care involving removal of fracture plate and other internal	0.022	31.9%	0.106	0.030	0.033
9)	M201	Hallux valgus (acquired)	0.017	33.6%	-0.052	0.030	0.083
10)	M199	Arthrosis, unspecified	0.019	35.5%	0.042	0.028	0.132
11)	T840	Mechanical complication of internal joint prosthesis	0.018	37.3%	0.125	0.028	0.000
12)	S721	Pertrochanteric fracture	0.015	38.7%	0.732	0.032	0.000
13)	M511	Lumbar and other intervertebral disc disorders with radiculopathy	0.015	40.3%	0.052	0.030	0.085
14)	M754	Impingement syndrome of shoulder	0.012	41.5%	0.035	0.029	0.224
15)	S828	Fractures of other parts of lower leg	0.012	42.7%	0.444	0.030	0.000
16)	M720	Palmar fascia fibromatosis (Dupuytren)	0.012	43.9%	-0.004	0.032	0.889
17)	M233	Other meniscus derangements	0.011	45.0%	0.064	0.029	0.026
18)	M171	Other primary gonarthrosis	0.013	46.4%	0.024	0.034	0.493
19)	M545	Low back pain	0.010	47.4%	0.037	0.031	0.236
20)	M751	Rotator cuff syndrome	0.011	48.5%	-0.017	0.028	0.549
21)	T848	Other complications of internal orthopaedic prosthetic devices	0.011	49.7%	0.036	0.029	0.203
22)	M238	Other internal derangements of knee	0.010	50.6%	0.107	0.028	0.000
23)	M480	Spinal stenosis	0.009	51.6%	0.062	0.031	0.046
24)	M161	Other primary coxarthrosis	0.010	52.6%	-0.002	0.030	0.953
25)	M674	Ganglion	0.008	53.4%	0.104	0.028	0.003
26)	M159	Polyarthritis, unspecified	0.010	54.3%	-0.008	0.030	0.799
27)	S526	Fracture of lower end of both ulna and radios	0.006	55.2%	0.103	0.029	0.030
28)	M553	Trigger finger	0.007	55.9%	0.051	0.032	0.111
29)	M512	Other specified intervertebral disc displacement	0.007	56.6%	0.106	0.031	0.001
30)	S422	Fracture of upper end of humerus	0.007	57.3%	0.345	0.030	0.030
31)	M841	Nonunion of fracture (pseudarthrosis)	0.007	58.0%	0.099	0.028	0.000
32)	T845	Infection and inflammatory reaction due to internal joint prosthesis	0.006	58.6%	0.453	0.029	0.000
33)	S424	Fracture of lower end of humerus	0.006	59.2%	0.268	0.028	0.000
34)	S623	Fracture of lower end of tibia	0.006	59.9%	0.598	0.034	0.000
35)	M750	Adhesive capsulitis of shoulder	0.006	60.5%	0.056	0.029	0.057
36)	M139	Arthritis, unspecified	0.006	60.9%	0.050	0.029	0.087
37)	G562	Lesion of ulnar nerve	0.006	61.5%	0.031	0.030	0.984
38)	S626	Fracture of other finger	0.006	62.1%	-0.036	0.029	0.211
39)	S326	Fracture of lateral malleolus	0.005	62.6%	0.049	0.036	0.178
40)	S322	Fracture of shaft of tibia	0.005	63.0%	0.478	0.031	0.000
41)	S821	Fracture of upper end of tibia	0.005	63,5%	0.607	0.031	0.000

No	Diagnosis dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
42)	T814	Infection following a procedure, not elsewhere classified	0.005	64.0%	0.016	0.032	0.624
43)	M241	Other articular cartilage disorders	0.005	64.4%	0.175	0.029	0.003
44)	S520	Fracture of upper end of ulna	0.005	64.9%	0.531	0.035	0.000
45)	L031	Cellulitis of other parts of limb	0.005	65.4%	0.473	0.030	0.000
46)	M513	Other specified intervertebral disc degeneration	0.005	65.9%	0.253	0.029	0.000
47)	M796	Pain in limb	0.005	66.3%	0.054	0.029	0.068
48)	T841	Mechanical complication of internal fixation device of bones of limb	0.005	66.8%	0.148	0.030	0.000
49)	L024	Cutaneous abscess, furuncle and carbuncle of limb	0.004	67.2%	0.248	0.0.31	0.000
50)	S420	Fracture of clavicle	0.004	67.6%	0.087	0.030	0.004
51)	M254	Effusion of joint	0.004	68.0%	0.845	0.034	0.000
52)	S723	Fracture of shaft of femur	0.004	68.3%	0.223	0.028	0.000
53)	M205	Other deformities of toe(s) (acquired)	0.003	68.7%	-0.016	0.030	0.597
54)	M189	Arthrosis of first carpometacarpal joint, unspecified	0.004	69.0%	0.014	0.030	0.650
55)	S623	Fracture of other metacarpal bone	0.004	69.4%	0.035	0.030	0.236
56)	S524	Fracture of shafts of both ulna and radius	0.004	69.8%	0.044	0.031	0.158
57)	M758	Other shoulder lesions	0.004	70.1%	0.030	0.028	0.293
58)	S724	Fracture of lower end of femur	0.003	70.4%	0.784	0.035	0.000
59)	M202	Hallux rigidus	0.003	70.7%	0.014	0.030	0.633
60)	G576	Lesion of plantar nerve	0.003	71.0%	0.093	0.033	0.005
61)	M549	Dorsalgia, unspecified	0.003	71.3%	0.051	0.031	0.093
62)	M244	Recurrent dislocation and subluxation of joint	0.003	71.7%	0.010	0.033	0.767
63)	M478	Other spondylosis	0.003	72.0%	-0.009	0.043	0.835
64)	M170	Primary gonarthrosis, bilateral	0.004	72.3%	0.036	0.032	0.259
65)	C795	Secondary malignant neoplasm of bone and bone marrow	0.003	72.6%	0.504	0.037	0.000
66)	M204	Other hammer toe(s) (acquired)	0.003	72.9%	0.060	0.030	0.043
67)	M659	Synovitis and tenosynovitis, unspecified	0.003	73.2%	0.031	0.029	0.280
68)	M431	Spondylolisthesis	0.003	73.5%	0.118	0.036	0.001
69)	Z478	Other specified orthopaedic follow-up care	0.003	73.7%	0.035	0.087	0.686
70)	M706	Trochanteric bursitis	0.003	74.0%	0.028	0.031	0.367
71)	M190	Primary arthrosis of other joints	0.003	74.3%	0.043	0.028	0.131
72)	M069	Rheumatoid arthritis, unspecified	0.003	74.6%	0.068	0.030	0.023
73)	S610	Open wound of finger(s) without damage to nail	0.003	74.8%	-0.079	0.039	0.046
74)	S825	Fracture of medial malleolus	0.003	75.1%	0.258	0.032	0.000
75)	M257	Osteophyte	0.002	75.3%	0.019	0.029	0.516
76)	L600	Ingrowing nail	0.002	75.5%	0.044	0.032	0.178
77)	S324	Fracture of fibula alone	0.002	75.8%	0.780	0.038	0.000
78)	S860	Injury of Achilles' tendon	0.003	76.0%	0.195	0.033	0.000
79)	M543	Sciatica	0.002	76.2%	0.047	0.034	0.175
80)	S320	Fracture of lumbar vertebra	0.002	76.5%	0.582	0.037	0.000
81)	M771	Lateral epicondylitis	0.002	76.7%	0.111	0.029	0.000
82)	M253	Other instability of joint	0.003	76.9%	0.117	0.045	0.011
83)	S520	Fracture of patella	0.002	77.2%	0.444	0.031	0.000
84)	S920	Fracture of calcaneus	0.002	77.4%	0.336	0.033	0.000

No	Diagnosis dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
85)	S423	Fracture of shaft of humerus	0.002	77.6%	0.566	0.036	0.000
86)	S325	Fracture of pubis	0.002	77.8%	0.249	0.030	0.000
87)	M191	Post-traumatic arthrosis of other joints	0.002	78.0%	0.111	0.030	0.000
88)	S722	Subtrochanteric fracture	0.002	78.3%	0.384	0.033	0.000
89)	M840	Malunion of fracture	0.002	78.5%	0.900	0.033	0.006
90)	M234	Loose body in knee	0.002	78.7%	0.090	0.030	0.003
91)	M160	Primary coxarthrosis, bilateral	0.002	78.9%	0.150	0.030	0.625
92)	M258	Other specified joint disorders	0.002	79.1%	0.050	0.032	0.121
93)	S099	Unspecified injury of head	0.002	79.3%	0.575	0.042	0.000
94)	M242	Disorder of ligament	0.002	79.5%	0.055	0.030	0.064
95)	T846	Infection and inflammatory reaction due to internal fixation device	0.002	79.7%	0.090	0.340	0.008
96)	M150	Primary generalized (osteo)arthrosis	0.002	79.9%	0.040	0.370	0.274
97)	M899	Disorder of bone, unspecified	0.002	80.1%	0.051	0.330	0.127
98)	M235	Chronic instability of knee	0.002	80.3%	-0.345	0.035	0.000
99)	M248	Other specific joint derangements, not elsewhere classified	0.002	80.6%	0.133	0.031	0.000
100)	-	Any other diagnoses	0.195	100.0%	0.159	0.028	0.000

Table A1.2 – Procedure dummies' descriptive statistics and estimates.

No	Procedure dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
1)	-	No procedure performed	0.124	11.2%	0.371	0.016	0.000
2)	W822	Endoscopic resection of semilunar cartilage	0.054	17.3%	0.551	0.020	0.000
3)	W401	Primary total prosthetic replacement of knee joint using cement	0.061	22.6%	1.026	0.032	0.000
4)	W903	Injection of therapeutic substance into joint	0.046	27.2%	0.757	0.021	0.000
5)	A651	Carpal tunnel release	0.035	30.7%	0.520	0.025	0.000
6)	W283	Removal of internal fixation from bone	0.030	33.7%	0.551	0.029	0.000
7)	W371	Primary total prosthetic replacement of hip joint using cement	0.027	36.3%	0.651	0.017	0.000
8)	W201	Primary open reduction of fracture of long bane and extramedullary fixation using plate	0.026	38.8%	0.647	0.020	0.000
9)	W381	Primary total prosthetic replacement of hip joint not using cement	0.024	41.2%	0.777	0.032	0.000
10)	O291	Subacromial decompression	0.020	43.1%	0.356	0.020	0.000
11)	W242	Closed reduction of fracture of long bone and rigid internal fixation	0.017	44.8%	0.622	0.021	0.000
12)	W262	Manipulation of fracture of bone	0.016	46.4%	0.400	0.016	0.000
13)	W461	Primary prosthetic replacement of head of femur using cement	0.016	47.9%	0.710	0.024	0.000
14)	A522	Therapeutic sacral epidural injection	0.013	49.2%	0.530	0.052	0.000
15)	W742	Reconstruction of intraarticular ligament	0.012	50.4%	0.381	0.020	0.000
16)	W901	Aspiration of joint	0.011	51.5%	0.660	0.019	0.000
17)	A577	Injection of therapeutic substance around spinal nerve root	0.010	52.5%	0.470	0.046	0.000
18)	W241	Close reduction of intracapsular fracture of neck of femur and fixation using nail or screw	0.009	53.4%	0.407	0.045	0.000
19)	T723	Release of constriction of sheath of tendon	0.008	54.3%	0.554	0.023	0.000
20)	V544	Injection around spinal facet of spine	0.009	55.1%	0.691	0.025	0.000
21)	W879	Unspecified diagnostic endoscopic examination of knee joint	0.008	55.9%	0.639	0.021	0.000
22)	W531	Primary resurfacing arthroplasty of joint	0.008	56.6%	0.768	0.030	0.000
23)	W791	Soft tissue correction of hallux valgus	0.006	0.6%	0.586	0.022	0.000
24)	W941	Primary hybrid prosthetic replacement of hip joint using cemented femoral component	0.007	58.0%	0.639	0.024	0.000
25)	W471	Primary prosthetic replacement of head of femur not using cement	0.006	58.5%	0.688	0.026	0.000
26)	T676	Primary simple repair of tendon	0.006	59.1%	0.763	0.028	0.000
27)	W243	Closed reduction of fracture of long bone and flexible internal fixation	0.006	60.2%	0.648	0.021	0.000
28)	WI91	Primary open reduction of fracture of neck of femur and open fixation using pin and plate	0.006	60.8%	0.677	0.020	0.000
29)	W192	Primary open reduction of fracture of long bone and fixation using rigid nail	0.006	59.6%	0.477	0.030	0.000
30)	T521	Palmar fasciectomy	0.006	61.3%	0.528	0.018	0.000
31)	S571	Debridement of skin	0.005	61.9%	0.538	0.021	0.000
32)	X481	Application of plaster cast	0.005	62.4%	0.299	0.022	0.000
33)	W205	Primary open reduction of fracture of ankle and extramedullary fixation	0.006	63.4%	0.696	0.033	0.000
34)	U212	Computerised tomography	0.005	62.9%	0.537	0.025	0.000
35)	S069	Unspecified other excision of lesion of skin	0.005	63.9%	0.811	0.022	0.000
36)	S472	Drainage of lesion of skin	0.005	64.9%	0.563	0.024	0.000

No	Procedure dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
37)	W198	Other specified primary open reduction of fracture of bone and intramedullary fixation	0.005	65.4%	0.610	0.034	0.000
38)	W802	Open debridement of joint	0.005	64.4%	0.445	0.020	0.000
39)	U211	Magnetic resonance imaging	0.005	65.8%	0.584	0.019	0.000
40)	W232	Secondary open reduction of fracture of bone and extramedullary fixation	0.005	66.3%	0.611	0.018	0.000
41)	U051	Computed tomography of head	0.004	67.1%	0.596	0.031	0.000
42)	W593	Fusion of first metatarsophalangeal joint	0.004	66.7%	0.439	0.026	0.000
43)	W852	Endoscopic irrigation of knee joint	0.003	67.5%	0.611	0.046	0.000
44)	W396	Closed reduction of dislocated total prosthetic replacement of hip joint	0.004	67.9%	0.546	0.024	0.000
45)	W621	Primary arthrodesis and internal fixation of joint	0.004	68.3%	0.617	0.023	0.000
46)	S421	Primary suture of skin	0.004	68.6%	0.605	0.023	0.000
47)	W891	Endoscopic chondroplasty	0.003	69.0%	0.543	0.022	0.000
48)	W068	Other specified total excision of bone	0.004	69.4%	0.593	0.021	0.000
49)	U136	Computed tomography of bone	0.004	69.7%	0.537	0.020	0.000
50)	T791	Plastic repair of rotator cuff of shoulder	0.004	70.1%	0.561	0.021	0.000
51)	A671	Cubital tunnel release	0.004	70.7%	-0.044	0.028	0.115
52)	V255	Primary posterior decompression of lumbar spinal cord	0.003	70.4%	1.061	0.039	0.000
53)	W833	Endoscopic shaving of articular cartilage	0.004	71.1%	0.381	0.022	0.000
54)	A521	Therapeutic lumbar epidural injection	0.003	71.4%	0.693	0.022	0.000
55)	W411	Primary total prosthetic replacement of knee joint not using cement	0.003	72.1%	0.439	0.041	0.000
56)	W595	Fusion of interphalangeal joint of toe	0.003	71.7%	0.551	0.021	0.000
57)	T625	Injection into bursa	0.003	72.4%	0.609	0.025	0.000
58)	T525	Digital fasciectomy	0.003	72.7%	0.529	0.023	0.000
59)	A611	Excision of lesion of peripheral nerve	0.003	73.0%	0.476	0.023	0.000
60)	W919	Unspecified other manipulation of joint	0.003	73.3%	0.658	0.028	0.000
61)	W248	Other specified closed reduction of fracture of bone and internal fixation	0.003	73.6%	0.706	0.023	0.000
62)	U055	Magnetic resonance imaging of spine	0.003	73.9%	0.457	0.020	0.000
63)	W164	Osteotomy and internal fixation	0.002	74.4%	1.045	0.045	0.000
64)	W373	Revision of total prosthetic replacement of hip joint using cement	0.002	74.2%	0.614	0.047	0.000
65)	T591	Excision of ganglion of wrist	0.003	74.7%	0.749	0.023	0.000
66)	W391	Primary total prosthetic replacement of hip joint	0.002	75.0%	0.476	0.021	0.000
67)	W712	Open excision of intraarticular osteophyte	0.003	75.7%	0.472	0.022	0.000
68)	T962	Excision of lesion of soft tissue	0.002	75.4%	0.614	0.024	0.000
69)	W421	Primary total prosthetic replacement of knee joint	0.002	75.2%	0.530	0.024	0.000
70)	W208	Other specified primary open reduction of fracture of bone and extramedullary fixation	0.002	76.1%	0.583	0.094	0.000
71)	W403	Revision of total prosthetic replacement of knee joint using cement	0.003	76.6%	0.749	0.024	0.000
72)	W153	Osteotomy of first metatarsal bone	0.002	75.9%	0.627	0.024	0.000
73)	W202	Primary open reduction of fracture of long bone and extramedullary fixation using cerclage	0.002	76.4%	0.665	0.021	0.000
74)	W083	Excision of excrescence of bone	0.002	77.0%	0.334	0.022	0.000
75)	U054	Computed tomography of spine	0.002	75.8%	0.565	0.026	0.000

No	Procedure dummy		Mean	Cumulative	Estimate	Std Err.	p-value
	Code	Label					
76)	W195	Primary open reduction of fragment of bone and fixation using screw	0.002	77.2%	0.467	0.023	0.000
77)	T392	Excision of ganglion of hand	0.002	77.8%	0.558	0.023	0.000
78)	W771	Repair of capsule of joint for stabilisation of joint	0.002	77,6%	0.564	0.020	0.000
79)	W085	Partial excision of bone	0.002	77.4%	0.500	0.024	0.000
80)	W851	Endoscopic removal of loose body from knee joint	0.002	78.4%	0.388	0.023	0.000
81)	T691	Primary tenolysis	0.002	78.8%	0.529	0.022	0.000
82)	W781	Release of contracture of shoulder joint	0.002	78.2%	0.527	0.020	0.000
83)	W889	Unspecified diagnostic endoscopic examination of other joint	0.002	79.0%	0.575	0.021	0.000
84)	W845	Endoscopic drilling of epiphysis for repair of articular cartilage	0.002	78.6%	0.684	0.030	0.000
85)	W303	Removal of external fixation from bone	0.002	78.0%	0.505	0.025	0.000
86)	W669	Unspecified primary closed reduction of traumatic dislocation of joint	0.002	79.3%	0.689	0.028	0.000
87)	W664	Primary open reduction of fracture dislocation of joint and internal fixation	0.001	79.2%	0.748	0.022	0.000
88)	W572	Primary excision arthroplasty of joint	0.001	79.5%	0.022	0.039	0.569
89)	T702	Tenotomy	0.002	80.2%	0.584	0.028	0.000
90)	V337	Primary microdiscectomy of lumbar intervertebral disc	0.002	79.7%	0.471	0.046	0.000
91)	V254	Primary posterior laminectomy decompression of lumbar spinal cord	0.002	79.9%	0.441	0.042	0.000
92)	W194	Primary open reduction of fracture of small bone and fixation using screw	0.002	80.0%	0.541	0.049	0.000
93)	-	Any other procedures	0.175	100.0%	0.585	0.019	0.000

Table A1.3 – HRG dummies' descriptive statistics and estimates.

No	HRG dummy Code	Label	Mean	Cumulative	Estimate	Std Err.	p-value
1)	H10	Arthroscopies	0.100	10.0%	-0.370	0.024	0.000
2)	H04	Primary knee replacement	0.072	17.1%	0.194	0.032	0.000
3)	H22	Minor procedures to the musculoskeletal system	0.067	23.8%	-0.635	0.026	0.000
4)	H13	Hand procedures - category 1	0.043	28.2%	-0.326	0.030	0.000
5)	H17	Soft tissue or other bone procedures - category 1 <70 w/o cc	0.042	32.4%	-0.313	0.024	0.000
6)	A07	Intermediate pain procedures	0.036	36.0%	-0.364	0.049	0.000
7)	H80	Primary hip replacement cemented	0.037	39.5%	0.614	0.025	0.000
8)	H19	Soft tissue or other bone procedures - category 2 <70 w/o cc	0.035	43.0%	-0.272	0.021	0.000
9)	H37	Closed pelvis or lower limb fractures <70 w/o cc	0.031	46.1%	-0.046	0.020	0.024
10)	S22	Planned procedures not carried out	0.029	48.9%	0.334	0.023	0.000
11)	H40	Closed upper limb fractures or dislocations <70 w/0 cc	0.027	51.8%	-0.311	0.021	0.000
12)	H99	Complex elderly with a musculoskeletal system primary diagnosis	0.029	54.5%	-0.408	0.023	0.000
13)	P15	Accidental injury without brain injury	0.025	57.0%	-0.335	0.020	0.000
14)	H52	Removal of fixation device <70 wlo cc	0.025	59.5%	-0.374	0.032	0.000
15)	H81	Primary hip replacement uncemented	0.023	61.9%	0.432	0.035	0.000
16)	H21	Muscle, tendon or ligament procedures - category 2	0.022	64.1%	-0.255	0.024	0.000
17)	H12	Foot procedures - category 2	0.020	66.1%	-0.358	0.024	0.000
18)	H36	Closed pelvis or lower limb fractures >69 or w cc	0.016	67.7%	0.409	0.022	0.000
19)	H20	Muscle, tendon or ligament procedures - category 1	0.014	69.2%	-0.381	0.025	0.000
20)	H39	Closed upper limb fractures or dislocations >69 or w cc	0.016	70.7%	-0.050	0.022	0.025
21)	H71	Revisional procedures to hips	0.015	72.2%	-0.261	0.026	0.000
22)	H16	Soft tissue or other bone procedures - category 1 >69 or w cc	0.015	73.6%	0.735	0.025	0.00)
23)	H18	Soft tissue or other bone procedures - category 2 >69 or w cc	0.013	74.9%	-0.123	0.023	0.000
24)	J37	Minor skin procedures - category i w/o cc	0.013	76.2%	-0.442	0.025	0.000
25)	R03	Decompression and effusion for degenerative spinal disorders	0.012	77.3%	0.231	0.034	0.000
26)	H14	Hand procedures - category 2	0.010	78.4%	-0.455	0.025	0.000
27)	H50	Multiple injury <70	0.009	79.3%	0.177	0.026	0.000
28)	H45	Minor fractures or dislocations	0.010	80.3%	-0.435	0.021	0.000
29)	H11	Foot procedures - category 1	0.007	81.0%	-0.349	0.024	0.000
30)	H86	Neck of femur fracture with hip replacement w cc	0.008	81.7%	0.286	0.022	0.000
31)	H42	Sprains, strains, or minor open wounds <70 w/o cc	0.008	82.4%	-0.310	0.022	0.000
32)	R16	Thoracic or lumbar spinal disorders <70 w/o cv	0.007	83.1%	0.189	0.025	0.000
33)	S19	Complications of procedures	0.007	83.8%	0.083	0.034	0.017
34)	R15	Thoracic or lumbar spinal disorders >69 or w cc	0.006	84.4%	-0.361	0.025	0.000
35)	J35	Minor skin procedures category 2 w/o cc	0.006	85.0%	0.182	0.022	0.000
36)	H49	Multiple injury >69	0.006	86.2%	0.172	0.027	0.000
37)	H27	Non-inflammatory bone or joint disorders >69 or w cc	0.006	85.6%	0.452	0.025	0.000
38)	H72	Revisional procedures to knees	0.007	86.7%	0.536	0.028	0.000

No	HRG dummy Code	HRG dummy Label	Mean	Cumulative	Estimate	Std Err.	p-value
39)	H51	Removal of fixation device >69 or w cc	0.036	87.2%	0.195	0.037	0.000
40)	R02	Surgery for prolapsed inter vertebral disc	0.006	87.7%	-0.342	0.032	0.000
41)	H41	Sprains, strains, or minor open wounds >69 or w cc	0.005	88.2%	0.049	0.033	0.140
42)	H07	Primary or revisional shoulder, elbow, or ankle replacements	0.005	89.1%	-0.018	0.026	0.491
43)	H88	Other neck of femur fracture w cc	0.004	88.7%	-0.367	0.066	0.000
44)	J36	Minor skin procedures - category 1 w cc	0.004	89.5%	-0.315	0.026	0.000
45)	H84	Intracapsular neck of femur fracture with fixation w cc	0.004	90.0%	-0.006	0.027	0.827
46)	H87	Neck of femur fracture with hip replacement w/o cc	0.004	90.4%	0.265	0.022	0.000
47)	C57	Major mouth or throat procedures	0.005	91.2%	0.125	0.025	0.000
48)	H24	Soft tissue disorders <70 w/o cc	0.004	90.8%	0.329	0.022	0.000
49)	J34	Minor skin procedures - category 2 w cc	0.004	91.5%	-0.029	0.029	0.310
50)	-	Any other HRG category	0.088	100.0%	0.113	0.020	0.000

A1.3 Square root transformation of the dependent variable

Table A1.4 – First-stage estimates using a square root transformation.

Regressor	Coeff	Std Err.	p-value
Male	-0.037***	0.002	0.000
Age	-0.008***	0.001	0.000
Age Squared	0.0001***	0.000	0.000
Ethnicity: Asian	0.035***	0.006	0.000
Ethnicity: black	0.057***	0.009	0.000
Ethnicity: Chinese	0.056**	0.024	0.019
Ethnicity: mixed	0.005	0.008	0.565
Ethnicity: Any other	0.037***	0.010	0.000
Urban	0.014***	0.003	0.000
Deprivation index: income	-0.003	0.018	0.876
Deprivation index: disability	0.006*	0.003	0.066
Deprivation index: living environment	0.0003***	0.000	0.001
Deprivation index: crime	0.002	0.002	0.342
Elective	0.132	0.150	0.382
Day case	-0.849***	0.013	0.000
Transferred from other provider	0.210	0.183	0.253
Other admission type	0.016	0.014	0.262
Waiting time	-0.00003**	0.000	0.039
Waiting time squared	0.000	0.000	0.180
Number of secondary diagnoses	0.086***	0.003	0.000
Number of secondary procedures	0.090***	0.003	0.000
Constant	-0.203***	0.059	0.001
Standard deviation of alpha	0.110		
Standard deviation of epsilon	0.755		

842,460 observations, 197 hospital trusts

R-square (overall) = 0.700

Test of alphas jointly equal to zero, F(196, 196) = 77.05 p-value = 0.000

Primary diagnosis, primary procedure, HRG code, and hospital fixed effects are included but not reported

Standard errors are bootstrapped (100 replications)

Table A1.5 – Second-stage estimates using a square root transformation.

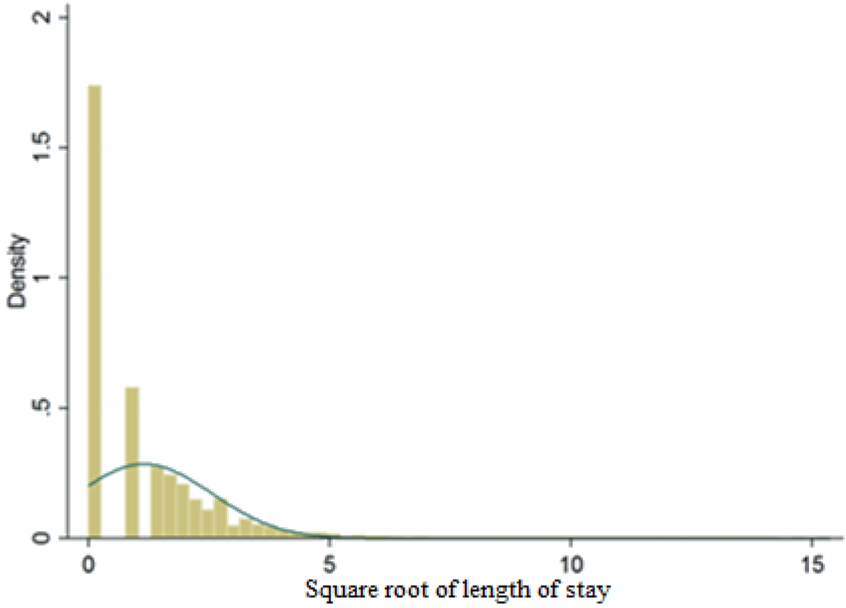
Regressor	Coeff	Std Err.	p-value
Specialist orthopaedic hospital	0.065	0.058	0.261
Average health change after hip replacement	-0.143	0.160	0.372
Average health change after knee replacement	0.397***	0.151	0.009
T&O emergency readmission rate	0.219	1.082	0.840
Number of patients in orthopaedics	-0.000002	0.000	0.579
Market forces factor	0.101	0.121	0.405
Teaching hospital	0.054**	0.021	0.011
Foundation trust with no more than 3 years	-0.019	0.032	0.561
Foundation trust with 4 to 5 years	0.031	0.022	0.164
Foundation trust with more than 5 years	-0.013	0.023	0.589
Constant	-0.188	0.180	0.300

197 observations

R squared = 0.09, Adjusted R squared = 0.04

Standard errors are bootstrapped (100 replications)

Figure A1.1– Distribution of the square root of the length of stay.



Appendix 2

A2.1 Estimation of the salary of doctors

We assume that the salary of doctors follows an s-shape function depending on age, minimum and maximum salary. This means that salary rises with increasing returns in the first half of the working life, and it goes up with decreasing returns during the second half. In symbols, we estimate the salary as follows:

$$w_{nk} = f_{nk} \cdot W\left(w^{\min}, w^{\max}, A_{age}\right) \tag{A2.1}$$

where w_{nk} is the salary of doctor $n=1,\ldots,N$ in hospital k, f_{nk} is the full time equivalent ratio,[66] W is the s-shape salary function, w^{min} and w^{max} are the minimum and maximum salaries associated to the doctor's grade, and A_{age} is a coefficient varying depending on the doctor's age. The salary function W can be represented as follows:

$$W\left(w^{\min}, w^{\max}, A_{age}\right) = \begin{cases} w^{\min} & \text{if} \quad age < 30 \\ w^{\min} + \dfrac{w^{\max} - w^{\min}}{A_{age}} & \text{if} \quad 30 \le age < 50 \\ w^{\max} - \dfrac{w^{\max} - w^{\min}}{A_{age}} & \text{if} \quad 50 \le age < 70 \\ w^{\max} & \text{if} \quad age \ge 70 \end{cases} \tag{A2.2}$$

where,

$$A_{age} = \begin{cases} 20 & \text{if} \quad 30 \le age \le 34 \quad \text{or} \quad 65 \le age \le 69 \\ 10 & \text{if} \quad 35 \le age \le 39 \quad \text{or} \quad 60 \le age \le 64 \\ 5.5 & \text{if} \quad 40 \le age \le 44 \quad \text{or} \quad 55 \le age \le 59 \\ 3.2 & \text{if} \quad 45 \le age \le 54 \end{cases} \tag{A2.3}$$

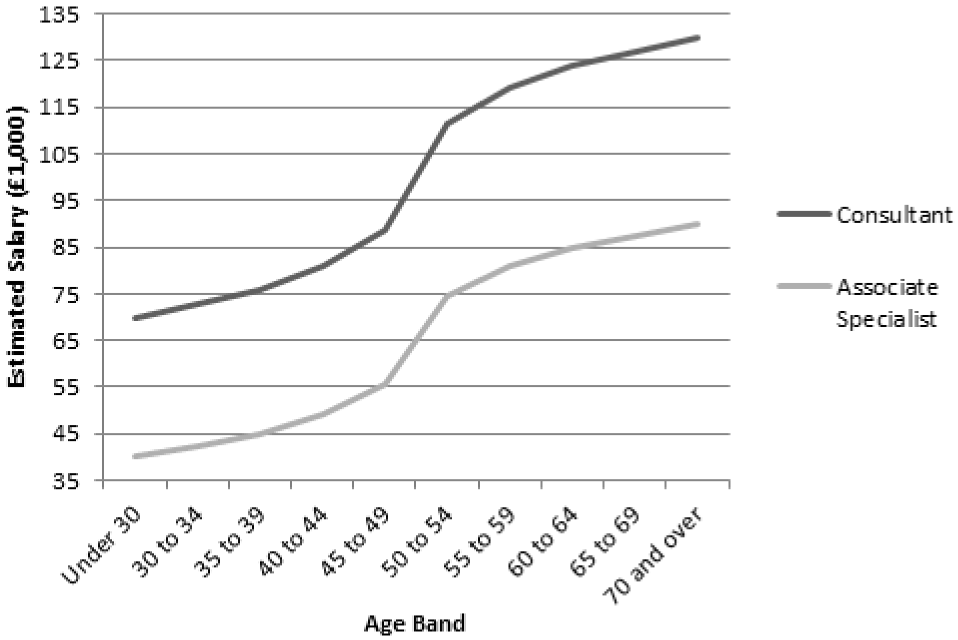
In Figure A2.1, we illustrate the salary function $W(\cdot)$ or consultant and associate specialist doctors.

The average salary of doctors in hospital k (w_k) is therefore calculated as follows:

66 The full time equivalent ratio is the proportion of the total number of paid hours during a period over the number of working hours in that period.

$$w_k = \frac{\sum_n w_{nk}}{N_k}. \tag{A2.4}$$

Figure A2.1 – Estimated salary function for consultants and associate specialists



A2.2 Descriptive statistics by admission type

Table A2.1 – Descriptive statistics for day case and elective activity.

	Variable at HRG level	All hospitals		Specialist hospitals		General hospitals	
		Mean	SD	Mean	SD	Mean	SD
	Day case						
	Inlier unit cost	1,408	876	1,492	973	1,406	872
	Number of patients (FCEs)	26	67	33	77	25	66
	Number of specialised services	0.07	0.75	0.43	3.10	0.06	0.52
	Proportion of specialised services (%)	0.2	1.8	0.6	4.2	0.2	1.6
	Proportion of males (%)	49.8	19.5	48.6	22.5	49.8	19.4
	Age	49.6	17.2	44.2	17.3	49.8	17.1
	Deprivation index	16,039	4,769	16,140	3,868	16,036	4,795
	Number of diagnoses	3.718	1.704	3.983	1.926	3.709	1.695
	Number of procedures	3.449	1.630	4.041	1.729	3.430	1.623
	Number of HRGs	509		239		490	
	Observations	14,181		441		13,740	
	Elective						
Inlier	Inlier unit cost	3,680	3,620	5,978	8,808	3,586	3,200
Inlier	Number of patients (FCEs)	16	42	23	58	15	41
Inlier	Number of specialised services	0.07	0.94	0.61	4.06	0.05	0.47
Inlier	Proportion of specialised services (%)	0.2	2.3	1.2	6.3	0.2	1.9
Inlier	Proportion of males (%)	48.9	19.5	49.4	26.3	48.9	19.2
Inlier	Age	54.6	16.9	47.6	17.9	54.8	16.8
Inlier	Deprivation index	16,080	4,807	16,368	4,648	16,068	4,813
Inlier	Number of diagnoses	4.644	2.369	4.908	2.640	4.633	2.357
Inlier	Number of procedures	3.516	1.901	4.195	2.288	3.488	1.879
Inlier	Number of HRGs	730		350		696	
Inlier	Observations	18,179		716		17,463	
Excess bed day	Per diem unit cost	358	897	563	3,450	344	245
Excess bed day	Number of excess bed days	19	34	49	92	17	25
Excess bed day	Number of specialised services	0.24	1.91	1.65	6.66	0.14	0.88
Excess bed day	Proportion of specialised services (%)	0.4	2.9	2.5	9.0	0.3	1.8
Excess bed day	Proportion of males (%)	46.7	14.4	46.6	18.1	46.7	14.1
Excess bed day	Age	56.2	13.3	48.9	16.3	56.7	12.9
Excess bed day	Deprivation index	16,235	4,350	16,557	3,762	16,213	4,386
Excess bed day	Number of diagnoses	4.343	2.076	4.807	2.494	4.312	2.041
Excess bed day	Number of procedures	3.656	1.838	4.416	2.263	3.605	1.795
Excess bed day	Number of HRGs	313		151		282	
Excess bed day	Observations	4,087		257		3,830	

Table A2.2 – Descriptive statistics for short non-elective and long non-elective activity.

	Variable at HRG level	All hospitals		Specialist hospitals		General hospitals	
		Mean	SD	Mean	SD	Mean	SD
	Short non-elective						
	Inlier unit cost	1,253	1,381	2,154	3,412	1,248	1,358
	Number of patients (FCEs)	6	12	2	1	6	12
	Number of specialised services	0.03	0.39	0.20	1.93	0.03	0.36
	Proportion of specialised services (%)	0.1	0.9	0.4	3.8	0.1	0.8
	Proportion of males (%)	49.5	18.6	50.0	21.9	49.5	18.6
	Age	52.7	20.8	47.8	16.8	52.7	20.8
	Deprivation index	15,908	4,843	15,869	4,634	15,908	4,845
	Number of diagnoses	4.840	2.562	4.490	2.196	4.842	2.564
	Number of procedures	2.466	1.907	3.656	2.115	2.459	1.903
	Number of HRGs	839		97		836	
	Observations	19,523		119		19,404	
	Long non-elective						
Inlier	Inlier unit cost	4,720	4,241	10,181	12,150	4,661	4,035
Inlier	Number of patients (FCEs)	8	17	3	3	8	18
Inlier	Number of specialised services	0.04	0.76	1.31	6.28	0.03	0.37
Inlier	Proportion of specialised services (%)	0.1	1.7	1.9	8.4	0.1	1.4
Inlier	Proportion of males (%)	48.6	20.5	49.4	22.6	48.5	20.4
Inlier	Age	58.9	18.7	51.4	15.7	59.0	18.7
Inlier	Deprivation index	15,902	5,035	16,529	4,240	15,895	5,043
Inlier	Number of diagnoses	5.933	2.947	5.547	2.770	5.937	2.949
Inlier	Number of procedures	3.035	2.458	4.235	2.403	3.022	2.456
Inlier	Number of HRGs	1,022		175		1,020	
Inlier	Observations	27,186		288		26,898	
Excess bed day	Per diem unit cost	286	162	247	148	287	162
Excess bed day	Number of excess bed days	23	36	35	53	23	36
Excess bed day	Number of specialised services	0.07	1.02	2.61	9.25	0.04	0.40
Excess bed day	Proportion of specialised services (%)	0.1	1.6	3.2	10.8	0.1	1.1
Excess bed day	Proportion of males (%)	46.9	16.8	49.6	18.1	46.8	16.8
Excess bed day	Age	58.4	16.4	49.8	15.9	58.5	16.4
Excess bed day	Deprivation index	15,983	4,633	16,370	3,353	15,979	4,643
Excess bed day	Number of diagnoses	5.352	2.625	5.126	2.512	5.354	2.626
Excess bed day	Number of procedures	2.992	2.151	4.296	2.276	2.979	2.146
Excess bed day	Number of HRGs	647		86		643	
Excess bed day	Observations	12,011		116		11,895	

A2.3 Additional sensitivity analysis

Table A2.3 – Stepwise regression analysis in model III for *inlier* unit costs.

Regressor	Inlier							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Specialist orthopaedic hospital	0.147	0.199**	0.200**	0.178**	0.181**	0.159*	0.165*	0.170*
	(0.099)	(0.085)	(0.085)	(0.089)	(0.083)	(0.095)	(0.086)	(0.091)
Market forces factor	0.810*	0.947**	0.945**	0.875**	1.043**	0.927**	1.027**	1.036**
	(0.450)	(0.441)	(0.441)	(0.435)	(0.469)	(0.459)	(0.468)	(0.463)
Proportion of specialised services	0.010*	0.011**	0.011**	0.010*	0.010*	0.010*	0.010*	0.011**
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)
Proportion of males	0.00005		0.0004	-0.0001	-0.0001	-0.00004	-0.0002	0.0004
	(0.000)		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age	-0.015***			-0.013***	-0.013***	-0.014***	-0.014***	
	(0.004)			(0.004)	(0.004)	(0.004)	(0.004)	
Age (squared)	0.00008**			0.00007*	0.00008*	0.00009**	0.0001**	
	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)	
Deprivation index	-0.000003				-0.000004	-0.000003	-0.000004	-0.000004
	(0.000)				(0.000)	(0.000)	(0.000)	(0.000)
Number of diagnoses	0.041***					0.042***		0.033***
	(0.011)					(0.010)		(0.010)
Number of procedures	0.028***						0.032***	0.027***
	(0.007)						(0.008)	(0.007)
Salary of doctors		-0.001	-0.001	-0.001	-0.0006	0.003	-0.0007	0.003
		(0.021)	(0.021)	(0.020)	(0.020)	(0.021)	(0.020)	(0.021)
Teaching trust		0.081**	0.081**	0.070**	0.066*	0.058*	0.063*	0.066*
		(0.036)	(0.037)	(0.036)	(0.035)	(0.034)	(0.035)	(0.035)
Foundation trust		-0.063**	-0.063**	-0.060**	-0.058**	-0.050*	-0.055**	-0.052**
		(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Medium department		-0.007	-0.007	-0.013	-0.021	-0.017	-0.022	-0.015
		(0.035)	(0.035)	(0.035)	(0.036)	(0.035)	(0.036)	(0.035)
Large department		-0.013	-0.013	-0.018	-0.021	-0.021	-0.021	-0.018
		(0.034)	(0.034)	(0.033)	(0.033)	(0.032)	(0.033)	(0.033)
Very large department		0.026	0.026	0.022	0.02	0.023	0.019	0.024
		(0.034)	(0.034)	(0.034)	(0.035)	(0.034)	(0.034)	(0.034)
Average health change after hip replacement		0.825	0.825	0.847	0.89	0.952*	0.900*	0.936*
		(0.554)	(0.553)	(0.546)	(0.546)	(0.524)	(0.540)	(0.531)
Average health change after knee replacement		-0.519	-0.515	-0.485	-0.373	-0.453	-0.332	-0.402
		(0.474)	(0.474)	(0.477)	(0.476)	(0.467)	(0.473)	(0.466)
Constant	7.100***	6.372***	6.356***	6.913***	6.697***	6.681***	6.618***	5.979***
	(0.553)	(0.589)	(0.592)	(0.589)	(0.607)	(0.603)	(0.611)	(0.612)
HRG fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors are clustered at hospital trust level and are reported in parentheses

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A2.4 – Stepwise regression analysis in model III for *per diem* unit costs.

Regressor	Per diem							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Specialist orthopaedic hospital	-0.131	-0.107	-0.131	-0.123	-0.102	-0.101	-0.096	-0.112
	(0.304)	(0.295)	(0.304)	(0.306)	(0.278)	(0.282)	(0.278)	(0.278)
Market forces factor	0.490	0.910	0.497	0.529	1.239	1.246	1.234	1.133
	(1.274)	(1.144)	(1.271)	(1.244)	(1.357)	(1.334)	(1.356)	(1.371)
Proportion of specialised services	0.000	0.001	0.000	0.000	0.001	0.001	0.001	0.000
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Proportion of males		-0.0007	-0.0009	-0.0006	-0.0005	-0.0005	-0.0005	-0.001
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Age		-0.011		-0.010	-0.011	-0.011	-0.010	
		(0.013)		(0.014)	(0.014)	(0.013)	(0.014)	
Age (squared)		0.000		0.000	0.000	0.000	0.000	
		(0.000)		(0.000)	(0.000)	(0.000)	(0.000)	
Deprivation index		-0.000010			-0.00002*	-0.00002*	-0.00002*	-0.00002
		(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
Number of diagnoses		0.006				-0.002		0.002
		(0.029)				(0.029)		(0.029)
Number of procedures		-0.022					-0.012	-0.018
		(0.021)					(0.021)	(0.020)
Salary of doctors	-0.068		-0.068	-0.068	-0.065	-0.065	-0.065	-0.065
	(0.049)		(0.049)	(0.049)	(0.047)	(0.047)	(0.047)	(0.047)
Teaching trust	0.014		0.015	0.020	0.006	0.006	0.007	-0.001
	(0.087)		(0.087)	(0.089)	(0.089)	(0.091)	(0.090)	(0.090)
Foundation trust	0.045		0.045	0.045	0.052	0.051	0.050	0.050
	(0.071)		(0.071)	(0.070)	(0.070)	(0.068)	(0.070)	(0.069)
Medium department	-0.065		-0.064	-0.061	-0.095	-0.095	-0.095	-0.098
	(0.088)		(0.088)	(0.089)	(0.096)	(0.096)	(0.096)	(0.096)
Large department	0.069		0.07	0.073	0.057	0.057	0.057	0.052
	(0.094)		(0.094)	(0.097)	(0.099)	(0.099)	(0.099)	(0.098)
Very large department	-0.036		-0.036	-0.032	-0.043	-0.043	-0.043	-0.048
	(0.092)		(0.092)	(0.092)	(0.090)	(0.091)	(0.090)	(0.092)
Average health change after hip replacement	-0.225		-0.222	-0.228	-0.031	-0.036	-0.028	-0.020
	(1.275)		(1.274)	(1.276)	(1.282)	(1.283)	(1.280)	(1.283)
Average health change after knee replacement	0.936		0.924	0.895	1.392	1.397	1.375	1.382
	(1.211)		(1.215)	(1.222)	(1.255)	(1.267)	(1.255)	(1.275)
Constant	5.539***	4.979***	5.568***	5.732***	4.810***	4.810***	4.863***	4.854**
	(1.744)	(1.350)	(1.752)	(1.647)	(1.753)	(1.754)	(1.759)	(1.922)
HRG fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors are clustered at hospital trust level and are reported in parentheses

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A2.5 – Analysis of interactions between covariates in model III.

Regressor		Inlier		Per diem
Specialist orthopaedic hospital		0.083		-0.146
(1) Market forces factor		-6.022		-1.440
(2) Proportion of specialised services		-0.198*		-0.054
(3) Proportion of males		-0.005		-0.012
(4) Age		0.044		-0.004
(5) Age (squared)		-0.001***		0.000
(6) Deprivation index		0.000		0.000
(7) Number of diagnoses		0.116		0.064
(8) Number of procedures		-0.123		0.022
(9) Salary of doctors		-0.614		-1.054
(10) Teaching trust		-1.071		-1.821
(11) Foundation trust		-0.712		-2.798***
(12) Medium department		0.100		4.843***
(13) Large department		1.150		2.900
(14) Very large department		1.099		4.579**
(15) Average health change after hip repl.		0.656		13.009
(16) Average health change after knee repl.		-0.082		-27.838
	(1) x (2)	0.150**	(4) x (10)	0.010**
	(3) x (2)	0.0002**	(6) x (2)	0.000002***
	(3) x (9)	-0.001**	(6) x (13)	-0.00002**
	(5) x (11)	0.0001**	(6) x (14)	-0.00005***
	(5) x (4)	0.00001***	(6) x (15)	0.001***
	(7) x (2)	-0.003**	(7) x (2)	0.002**
	(7) x (3)	-0.0004**	(7) x (5)	-0.00004**
	(8) x (11)	0.026**	(8) x (11)	0.029***
Interactions	(8) x (4)	-0.003***	(11) x (9)	-0.167**
	(8) x (5)	0.00003***	(12) x (1)	-3.635***
	(13) x (11)	-0.184***	(13) x (11)	0.398***
	(14) x (2)	0.028***	(14) x (1)	-3.815***
	(15) x (2)	-0.18**	(15) x (12)	-5.829**
	(15) x (11)	2.199**	(16) x (9)	3.314***
	(15) x (12)	-2.634**	(16) x (11)	8.573***
	(15) x (14)	3.088**	(16) x (12)	5.422**
	(16) x (14)	-3.108**		
Constant		13.516**		12.454
HRG fixed effects		YES		YES
Regional fixed effects		YES		YES
Adjusted R-squared		0.814		0.307

Interactions not significant at 1% or 5% level are not reported.

Standard errors are clustered at hospital trust level.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A2.6 – Results for model V that includes hospital random effects.

Regressor	Inlier	Per diem
Specialist orthopaedic hospital	0.122	-0.201
	(0.342)	(0.288)
Market forces factor	0.428	0.049
	(0.651)	(1.488)
Proportion of specialised services	0.014*	0.002
	(0.008)	(0.003)
Proportion of males	-0.0006	-0.0003
	(0.000)	(0.001)
Age	-0.018***	-0.006
	(0.004)	(0.006)
Age (squared)	0.0001***	0.00008
	(0.000)	(0.000)
Deprivation index	-0.000001	-0.000003
	(0.000)	(0.000)
Number of diagnoses	0.040***	-0.016
	(0.012)	(0.012)
Number of procedures	0.013	-0.015*
	(0.009)	(0.008)
Salary of doctors	0.008	-0.044
	(0.030)	(0.048)
Teaching trust	0.076	0.108
	(0.051)	(0.086)
Foundation trust	-0.052	0.03
	(0.037)	(0.071)
Medium department	0.006	-0.063
	(0.051)	(0.090)
Large department	-0.015	0.041
	(0.047)	(0.098)
Very large department	0.008	-0.121
	(0.049)	(0.088)
Average health change after hip replacement	1.345*	-2.202
	(0.768)	(1.361)
Average health change after knee replacement	-0.137	0.003
	(0.691)	(1.389)
Constant	-0.050***	-0.024
	(0.018)	(0.031)
Hospital random effects	YES	YES
HRG fixed effects	YES	YES
Regional fixed effects	YES	YES

Maximum likelihood estimation. For ease of computation, we control for the HRG fixed effects using the Frisch-Waugh-Lovell transformation.

Clustered standard errors are bootstrapped with 1,000 repetitions and are reported in parentheses.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Appendix 3

Table A3.1 – Definition for the quality indicators.

Quality indicators
The Summary Hospital-level Mortality Indicator (SHMI) is a ratio of the observed number of deaths to the expected number of deaths for a trust (provider). The observed number of deaths is the total number of finished provider spells for the trust which resulted in a death either in-hospital or within 30 days (inclusive) of discharge from the trust. The expected deaths are estimated through a logistic regression controlling for age, gender, admission method, year index, Charlson Comorbidity Index and diagnosis grouping. A three year dataset is used to create the risk-adjusted models.
The hip fracture mortality rate captures deaths within 30 days (from 0 to 29 days inclusive) of an emergency admission to hospital with a primary diagnosis of fractured proximal femur (ICD-10 codes S720, S721, S722). It is indirectly standardised by age and sex.
The stroke mortality rate captures deaths within 30 days (from 0 to 29 days inclusive) of an emergency admission to hospital with a primary diagnosis of stroke (all ICD-10 codes from I61 to I64). It is indirectly standardised by age and sex.
The emergency readmission rate captures the percentage of emergency admission to any hospital in England occurring within 28 days of the last discharge from hospital after admission. The rate is calculated considering all patients aged between 16 and 74. It is indirectly standardised by age, sex, method of admission of discharge spell, diagnosis within medical specialties, and procedure within surgical specialties.
Source: Health and Social Care Information Centre, NHS Digital Indicator Portal *Link*: https://indicators.hscic.gov.uk/webview/
The average health change after hip replacement is extracted from PROMs data. PROMs comprise a pair of questionnaires completed by the patient, one before and one after surgery (at least six months after for hip replacements). All patients, irrespective of their condition, are asked to complete a common set of questions about their health status. This includes sections about the patient's circumstances, pre-existing conditions and the EQ-5D health questionnaire consisting of a five-dimensional descriptive system and a visual analogue scale (EQ-VAS). Post-operative questionnaires also contain additional questions about the surgery, such as how the patient perceives the results of the operation and whether there were any post-operative complications, such as bleeding or wound problems. Patients undergoing hip replacement surgery are also asked to complete a condition-specific section. The collected data are risk-adjusted for patient characteristics (e.g. gender, age, ethnics), initial health status, self-assessed health status, economic deprivation, comorbidity, procedure, and post-operative length of stay.
Source: Health and Social Care Information Centre *Link*: http://content.digital.nhs.uk/proms
Patient satisfaction indicators are derived from the NHS Inpatient Surveys for the Care Quality Commission which is administered to a random sample of patients in all acute trusts. The variables relate to three questions to patients: 1) From 0 to 100, "Overall, how would you rate the care you received?" (Overall patient satisfaction); 2) From 0 to 100, "In your opinion, how clean was the hospital room or ward that you were in?" (Satisfaction on hospital cleanliness); 3) From 0 to 100, "Were you involved as much as you wanted to be in decisions about your care and treatment?" (Satisfaction on decision involvement). The data has been standardised to adjust for these differences in patient-mix using the respondent's age, gender, ethnic group and method of admission (emergency or elective).
Source: NHS patient surveys *Links*: http://www.nhssurveys.org/surveys , https://www.kingsfund.org.uk/publications/patients-experience-using-hospital-services

Table A3.2 – Definition for the efficiency indicators.

Efficiency indicators
The bed occupancy rate is the ratio of the overnight occupied beds to the overnight available beds. For wards open overnight, an occupied bed day is defined as one which is occupied at midnight on the day in question. The number of occupied beds excludes any bed days of occupation by well babies. The number of available beds only includes beds in units managed by the provider, not beds commissioned from other providers. It excludes any beds designated solely for the use of well babies. Such data are available quarterly.
The rate of cancelled elective operations is the ratio of the number of last minute cancellations by the hospital for non-clinical reasons to the number of elective patients. Last minute means on the day the patient was due to arrive, after the patient has arrived in hospital, or on the day of the operation or surgery. Elective cancelled operations are provided in each quarter. The number of elective patients is calculated as the sum of planned and waiting list admissions, where the admission is a finished admission episode, i.e. the first period of inpatient care under one consultant within one healthcare provider. The number of elective patients is published annually.
Source: NHS statistics *Link*: https://www.england.nhs.uk/statistics/statistical-work-areas/
The reference cost index shows the actual cost of an organisation's case-mix compared with the same case-mix delivered at national average cost. Each organisation's reference cost index is calculated by dividing its total costs (unit costs × activity) by the expected costs (national average mean unit cost × activity). The reference cost index is computed separately also for elective and non-elective activity. Elective activity refers to patients whose admission to hospital is planned, including day case patients. Non-elective activity refers to patients whose admission is not planned, including emergency admissions and admissions for maternity, births, and non-emergency patient transfers, and requires staying in hospital for more than one day. The reference cost index for hip replacement is calculated selecting the HRG codes: HB11A, HB11B, HB11C, HB12A, HB12B, and HB12C.
Source: Reference costs data *Link*: https://www.gov.uk/government/collections/nhs-reference-costs

Table A3.3 – ML estimates for the quality indicators in 2013/14.

	Regressor	SHMI	Hip fract. mortality	Stroke mortality	Emerg. readm.	Health change hip repl.	Overall satisf.	Satisf. on cleanlin.	Satisf. on involvem.
	Spatial lag of the dependent variable	0.145	-0.156	-0.272**	0.137	-0.163	0.105	0.086	0.055
Demand shifter	Population density	-0.903	0.032	0.240	-0.052	0.009**	0.156	0.246	-0.058
	Proportion of individuals aged 65 and over	-0.037	-0.268**	0.089	-0.216**	0.004***	0.330**	0.322**	0.624***
	Proportion of ind. employed or looking for a job	0.237	0.148	-0.109	-0.037	-0.001	0.044	0.058	0.080
	Proportion of individuals with a degree	-0.397	0.052	0.060	0.031	-0.002*	-0.069	-0.157*	-0.073
	Proportion of owner occupier households	0.019	0.103*	0.041	0.002	0.0000	-0.086	-0.081	-0.196*
	Proportion of ind. in good/very good health	-0.603	-0.541***	-0.164	-0.200	0.008**	0.147	0.043	0.279
Cost shifter	Number of managers	-1.797	-0.315	-1.606**		-0.004	0.435	-0.888	0.293
	Proportion of junior doctors in training	0.917	-0.016	0.637		-0.016***	-0.664**	-0.587**	-0.827**
	Proportion of consultants	-0.605	-0.160	0.404		0.002	0.090	0.117	0.049
	Number of beds	2.667	-0.165	-0.767	0.362	0.010	0.578	1.357	1.272
Type	Foundation trust	0.432	-0.224	-0.480	-0.049	-0.002	1.44***	0.523	1.434**
	Teaching hospital	-2.005	0.698	0.149	-0.160	-0.010	0.838	1.172	0.693
	Specialist hospital				-1.257***	-0.024	5.434***	4.620***	5.795***
	Constant	126.827***	39.683***	34.329*	31.199***	-0.067	56.281***	75.031***	43.391**
Variance		42.184	2.058***	8.212***	1.422***	0.001***	4.094***	5.156***	8.019***
Observations		119	106	111	142	107	132	132	132

ML estimation. Only cross-sectional results for 2013/14 are reported. Results for the emergency readmission rate refer to the most recent available financial year (2011/12).

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Estimates for the emergency readmission rate refer to 2011/12. Data on this variable are currently available up to 2011/12. Data on hospital staff are available from 2010/11 onwards. Hence, all regressions for the emergency readmission rate do not include the number of managers, the proportion of junior doctors in training, and the proportion of consultants.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.4 – ML estimates for the efficiency indicators in 2013/14.

	Regressor	Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	RCI for hip repl.
	Spatial lag of the dependent variable	-0.079	-0.008	0.003	-0.030	-0.121	0.096
Demand shifter	Population density	1.529**	0.043	2.06**	2.813**	1.754	0.590
	Proportion of individuals aged 65 and over	0.018	-0.010	-0.942**	-0.831	-0.821	-0.140
	Proportion of ind. employed or looking for a job	-0.215	0.016	1.341**	0.824	2.832**	2.623*
	Proportion of individuals with a degree	-0.421**	-0.027**	0.519**	-0.234	1.045**	0.635
	Proportion of owner occupier households	0.143	0.007	0.526**	0.036	0.482	-0.723
	Proportion of ind. in good/very good health	1.194*	0.028	-1.474*	0.141	-3.247*	-2.512
Cost shifter	Number of managers	0.364	0.048	2.602	0.147	3.677	-3.900
	Proportion of junior doctors in training	-0.051	-0.037	-0.398	1.164	0.205	1.974
	Proportion of consultants	-0.237	0.028	0.489	0.406	0.839	-1.076
	Number of beds	1.123	0.010	-0.018	-4.200	3.977	11.189
Type	Foundation trust	-2.458**	-0.145**	-1.342	-2.186	-1.717	4.757
	Teaching hospital	-1.148	0.170	0.614	2.456	0.087	-5.376
	Specialist hospital	-5.618*	-0.048	9.426***	11.789**	21.428***	25.155
	Constant	11.159	-2.494	91.661**	41.426	129.643	135.915
Variance		28.800***	0.118***	41.994***	110.523***	193.989***	298.786***
Observations		134	134	140	140	140	127

ML estimation. Only cross-sectional results for 2013/14 are reported

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.5 – Likelihood Ratio test: spatial lag vs SDM or SAC model.

Indicator	Model	Cross-Section				Panel	
		2010/11	2011/12	2012/13	2013/14	FE	RE
<u>*Quality*</u>							
Clinical							
Summary Hospital-level Mortality Indicator	SDM	(0.254)	(0.047)**	(0.298)	(0.674)	(0.090)*	(0.539)
	SAC	(0.687)	(0.560)	(0.419)	(0.556)	(0.363)	
Hip fracture mortality rate	SDM	(0.246)	(0.024)**	(0.011)**	(0.638)	(0.812)	(0.149)
	SAC	(0.348)	(0.779)	(0.078)*	(0.189)	(0.333)	
Stroke mortality rate	SDM	(0.589)	(0.824)	(0.098)*	(0.492)	(0.198)	(0.459)
	SAC	(0.201)	(0.570)	(0.524)	(0.795)	(0.766)	
Emergency readmission rate	SDM	(0.656)	(0.092)*			(0.871)	(0.884)
	SAC	(0.659)	(0.087)*			(0.816)	
Patient reported							
Average health change after hip replacement	SDM	(0.010)***	(0.467)	(0.792)	(0.188)	(0.679)	(0.332)
	SAC	(0.491)	(0.831)	(0.671)	(0.408)	(0.643)	
Overall patient satisfaction	SDM	(0.000)***	(0.002)**	(0.173)	(0.090)*	(0.004)***	(0.013)**
	SAC	(0.045)**	(0.550)	(0.509)	(0.397)	(0.726)	
Patient satisfaction on hospital cleanliness	SDM	(0.194)	(0.386)	(0.819)	(0.909)	(0.741)	(0.797)
	SAC	(0.968)	(0.580)	(0.431)	(0.586)	(0.793)	
Patient satisfaction on decision involvement	SDM	(0.001)***	(0.012)**	(0.398)	(0.103)	(0.080)*	(0.012)**
	SAC	(0.453)	(0.790)	(0.353)	(0.705)	(0.815)	
<u>*Efficiency*</u>							
Bed occupancy rate	SDM	(0.711)	(0.655)	(0.768)	(0.081)*	(0.605)	(0.687)
	SAC	(0.200)	(0.895)	(0.184)	(0.989)	(0.616)	
Rate of cancelled elective operations	SDM	(0.940)	(0.209)	(0.020)**	(0.005)***	(0.016)**	(0.698)
	SAC	(0.015)**	(0.705)	(0.035)**	(0.075)*	(0.001)***	
Reference cost index	SDM	(0.295)	(0.530)	(0.966)	(0.613)	(0.013)**	(0.415)
	SAC	(0.201)	(0.151)	(0.428)	(0.338)	(0.928)	
Elective reference cost index	SDM	(0.537)	(0.270)	(0.315)	(0.142)	(0.000)***	(0.072)*
	SAC	(0.241)	(0.504)	(0.337)	(0.231)	(0.020)**	
Non-elective reference cost index	SDM	(0.058)*	(0.256)	(0.372)	(0.222)	(0.001)***	(0.170)
	SAC	(0.121)	(0.033)**	(0.075)*	(0.313)	(0.324)	
Reference cost index for hip replacement	SDM	(0.128)	(0.560)	(0.885)	(0.391)	(0.246)	(0.783)
	SAC	(0.180)	(0.632)	(0.850)	(0.675)	(0.995)	

Null hypothesis: the spatial lag model is nested in the SDM or SAC model
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.6 – Spatial lag model for the quality indicators allowing for spatially lagged efficiency.

Variable		Quality indicators							
		SHMI	Hip fract. mortality	Stroke mortality	Readm.	Health change hip repl.	Overall satisf.	Satisf. on cleanliness	Satisf. on involvem.
Spatial lag	2010/11	0.212	0.016	-0.156	0.203	-0.006	0.047	-0.016	0.035
		(0.043)**	(0.891)	(0.156)	(0.047)**	(0.958)	(0.568)	(0.873)	(0.719)
Spatially lagged bed occupancy rate		0.281	-0.044	0.161	0.022	-0.001	-0.078	-0.004	0.006
		(0.142)	(0.372)	(0.014)**	(0.411)	(0.341)	(0.102)	(0.923)	(0.902)
Spatially lagged reference cost index		-0.154	0.014	0.002	0.033	-0.001	0.015	-0.067	0.031
		(0.420)	(0.775)	(0.972)	(0.132)	(0.060)*	(0.745)	(0.116)	(0.502)
Spatial lag	2011/12	0.159	0.094	-0.176	0.117	-0.064	0.061	-0.054	0.075
		(0.130)	(0.403)	(0.132)	(0.254)	(0.606)	(0.460)	(0.565)	(0.405)
Spatially lagged bed occupancy rate		0.495	0.026	0.038	0.051	-0.001	-0.069	-0.079	-0.051
		(0.019)**	(0.632)	(0.698)	(0.005)***	(0.133)	(0.171)	(0.071)*	(0.323)
Spatially lagged reference cost index		-0.070	-0.067	0.017	0.017	-0.001	-0.037	-0.080	-0.090
		(0.723)	(0.196)	(0.846)	(0.438)	(0.383)	(0.444)	(0.058)*	(0.070)*
Spatial lag	2012/13	0.098	-0.199	-0.189	0.091	-0.157	0.003	-0.082	-0.130
		(0.328)	(0.085)*	(0.097)*	(0.327)	(0.207)	(0.971)	(0.371)	(0.163)
Spatially lagged bed occupancy rate		0.551	0.0004	-0.057	0.018	0.000001	-0.063	-0.048	-0.102
		(0.004)***	(0.995)	(0.521)	(0.351)	(0.999)	(0.064)*	(0.222)	(0.028)**
Spatially lagged reference cost index		0.040	-0.023	-0.137	0.008	-0.0004	-0.060	-0.089	-0.134
		(0.812)	(0.682)	(0.080)*	(0.625)	(0.482)	(0.142)	(0.065)*	(0.015)**
Spatial lag	20113/14	0.156	-0.205	-0.305	0.092	-0.195	0.084	0.044	0.029
		(0.164)	(0.083)*	(0.013)**	(0.351)	(0.082)*	(0.349)	(0.624)	(0.761)
Spatially lagged bed occupancy rate		0.180	0.024	0.106	0.021	-0.001	-0.039	-0.072	-0.095
		(0.352)	(0.590)	(0.212)	(0.362)	(0.371)	(0.312)	(0.080)*	(0.064)*
Spatially lagged reference cost index		0.160	-0.040	0.059	-0.036	-0.0005	-0.026	-0.081	-0.061
		(0.378)	(0.346)	(0.465)	(0.092)*	(0.367)	(0.550)	(0.084)*	(0.296)
Spatial lag	FE	0.170	-0.040	-0.060	0.065	-0.039	0.084	-0.069	-0.032
		(0.001)***	(0.468)	(0.279)	(0.233)	(0.505)	(0.113)	(0.218)	(0.552)
Spatially lagged bed occupancy rate		-0.051	0.004	-0.047	0.014	-0.001	-0.060	-0.027	-0.071
		(0.626)	(0.924)	(0.456)	(0.082)*	(0.225)	(0.109)	(0.347)	(0.089)*
Spatially lagged reference cost index		0.049	-0.008	-0.116	0.009	0.0003	-0.006	-0.020	0.021
		(0.563)	(0.816)	(0.028)**	(0.463)	(0.515)	(0.856)	(0.431)	(0.562)
Spatial lag	RE	0.181	-0.021	-0.057	0.114	-0.035	0.092	-0.045	-0.001
		(0.000)***	(0.710)	(0.316)	(0.028)**	(0.557)	(0.052)*	(0.382)	(0.986)
Spatially lagged bed occupancy rate		0.091	0.015	0.004	0.018	-0.001	-0.060	-0.043	-0.067
		(0.374)	(0.622)	(0.933)	(0.044)**	(0.093)*	(0.025)**	(0.083)*	(0.031)**
Spatially lagged reference cost index		0.051	-0.007	-0.070	0.004	-0.001	-0.032	-0.044	-0.035
		(0.544)	(0.791)	(0.116)	(0.713)	(0.092)*	(0.223)	(0.064)*	(0.251)

ML estimation. Control variables are identical to those in the main regression

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.7 – Spatial lag model for the efficiency indicators allowing for spatially lagged quality.

Variable		Efficiency indicators					
		Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	Unit cost of hip repl.
Spatial lag	2010/11	-0.054	0.084	-0.029	0.016	-0.064	-0.122
		(0.619)	(0.424)	(0.806)	(0.886)	(0.572)	(0.292)
Spatially lagged SHMI		-0.021	-0.002	-0.256	-0.494	-0.615	0.00002
		(0.817)	(0.773)	(0.030)**	(0.032)**	(0.004)***	(0.548)
Spatially lagged overall patient satisfaction		-0.639	0.006	-0.573	-0.966	-1.582	0.0001
		(0.026)**	(0.785)	(0.090)*	(0.172)	(0.014)**	(0.221)
Spatial lag	2011/12	-0.114	-0.024	-0.038	0.034	-0.081	-0.230
		(0.333)	(0.839)	(0.742)	(0.757)	(0.468)	(0.039)**
Spatially lagged SHMI		-0.113	-0.005	-0.157	-0.540	-0.415	0.00003
		(0.248)	(0.415)	(0.169)	(0.006)***	(0.037)**	(0.239)
Spatially lagged overall patient satisfaction		-1.083	0.003	-0.185	-0.627	-0.512	0.00009
		(0.000)***	(0.866)	(0.566)	(0.261)	(0.357)	(0.215)
Spatial lag	2012/13	-0.097	0.125	-0.124	0.030	-0.145	-0.011
		(0.401)	(0.246)	(0.286)	(0.787)	(0.189)	(0.925)
Spatially lagged SHMI		0.037	-0.004	-0.088	-0.257	-0.367	0.00003
		(0.705)	(0.574)	(0.478)	(0.183)	(0.047)**	(0.199)
Spatially lagged overall patient satisfaction		-0.427	0.041	-0.259	-1.094	-0.714	-0.00010
		(0.242)	(0.120)	(0.579)	(0.131)	(0.308)	(0.325)
Spatial lag	20113/14	0.049	0.040	0.060	-0.049	-0.018	0.060
		(0.641)	(0.713)	(0.609)	(0.682)	(0.884)	(0.613)
Spatially lagged SHMI		-0.203	-0.009	-0.053	-0.274	-0.395	-0.00001
		(0.049)**	(0.209)	(0.717)	(0.248)	(0.075)*	(0.691)
Spatially lagged overall patient satisfaction		-0.290	-0.026	0.035	-0.112	-0.299	0.00004
		(0.331)	(0.199)	(0.933)	(0.872)	(0.635)	(0.591)
Spatial lag	FE	-0.090	0.018	0.029	0.046	-0.076	-0.095
		(0.136)	(0.736)	(0.607)	(0.430)	(0.179)	(0.091)*
Spatially lagged SHMI		0.003	0.010	0.077	-0.051	0.077	0.00003
		(0.954)	(0.017)**	(0.233)	(0.685)	(0.537)	(0.115)
Spatially lagged overall patient satisfaction		-0.280	-0.006	0.050	0.403	0.434	0.00003
		(0.064)*	(0.560)	(0.758)	(0.214)	(0.168)	(0.552)
Spatial lag	RE	-0.053	0.050	0.090	0.059	0.025	-0.069
		(0.367)	(0.353)	(0.103)	(0.297)	(0.647)	(0.220)
Spatially lagged SHMI		-0.031	0.003	0.024	-0.183	-0.171	0.00002
		(0.561)	(0.485)	(0.713)	(0.116)	(0.150)	(0.203)
Spatially lagged overall patient satisfaction		-0.512	-0.001	-0.144	-0.025	-0.364	0.00003
		(0.001)***	(0.929)	(0.403)	(0.937)	(0.257)	(0.522)

ML estimation. Control variables are identical to those in the main regression
p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.8 – First-stage estimates on the instrument and F statistic using quality indicators.

IV	Estimate		SHMI	Hip fract. mortality	Emerg. readm.	Overall satisf.	Satisf. on cleanliness	Satisf. on involvem.
W_{t-2}	I stage coefficient on the instrument	2012/13	0.610	0.499	0.778	0.587	0.830	0.707
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		94.49	16.58	140.68	175.89	282.66	282.66
	I stage coefficient on the instrument	2013/14	0.560	0.489	0.875	0.621	0.940	0.794
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		95.69	52.46	168.39	261.03	467.54	467.54
W_{t-3}	I stage coefficient on the instrument	2013/14	0.393	0.320	0.796	0.600	0.880	0.784
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		39.70	14.30	101.60	159.30	234.30	145.80

Stock-Yogo 10% maximal IV size critical value = 16.38; Stock-Yogo 15% maximal IV size critical value = 8.96; Stock-Yogo 20% maximal IV size critical value = 6.66; Stock-Yogo 25% maximal IV size critical value = 5.53

Each regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed and looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals with a degree, proportion of individuals in good and very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. Control variables are included in the first stage of the 2SLS estimator.

In the regressions for SHMI, hip fracture, and stroke mortality, the specialist dummy is omitted because of the absence of specialist hospitals in these samples.

Data on the emergency readmission rate are currently available up to 2011/12. The estimate refers to the most recent available years (2010/11 and 2011/12).

For stroke mortality and average health change after hip replacement, estimates are omitted because of the absence of relevant instruments.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A3.9 – First-stage estimates on the instrument and F statistic using efficiency indicators.

IV	Estimate		Bed occupancy	Cancelled operations	RCI	Elective RCI	Non-elect. RCI	RCI for hip repl.
W_{t-2}	I stage coefficient on the instrument	2012/13	0.641	0.484	0.594	0.271	0.525	0.437
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		85.14	30.46	87.65	16.29	60.16	44.49
	I stage coefficient on the instrument	2013/14	0.775	0.897	0.734	0.419	0.461	0.236
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		135.99	105.08	206.49	56.77	59.51	13.39
W_{t-3}	I stage coefficient on the instrument	2013/14	0.616	0.480	0.704	0.380	0.483	0.291
			(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
	I stage F (Cragg-Donald) statistic		113.70	35.60	177.60	53.30	51.30	23.45

Stock-Yogo 10% maximal IV size critical value = 16.38; Stock-Yogo 15% maximal IV size critical value = 8.96; Stock-Yogo 20% maximal IV size critical value = 6.66; Stock-Yogo 25% maximal IV size critical value = 5.53

Each regression controls for: population density, proportion of individuals aged 65 and over, proportion of individuals employed and looking for a job, proportion of individuals with a degree, proportion of owner occupier households, proportion of individuals with a degree, proportion of individuals in good and very good health, number of managers, proportion of junior doctors in training, proportion of consultants, number of beds, foundation trust, teaching hospital, specialist hospital. Control variables are included in the first stage of the 2SLS estimator.

p-value in parentheses, *** p-value<0.01, ** p-value<0.05, * p-value<0.1

Appendix 4

Table A4.1 – Pairwise correlations across efficiency indicators.

Efficiency indicator	Def	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Log of admissions per bed	E	1.0000								
(2) Bed occupancy rate	E	0.2018*	1.0000							
(3) Proportion of day cases	E	0.1028*	-0.1041*	1.0000						
(4) Log of cancelled elective operations	I	-0.0181	0.1674*	0.0551	1.0000					
(5) Proportion of untouched meals	I	0.0405	0.0159	-0.0199	0.0134	1.0000				
(6) Log of cleaning services costs	I	0.2821*	0.2116*	-0.1088*	0.5955*	-0.002	1.0000			
(7) Log of laundry and linen costs	I	0.1926*	0.3147*	-0.2760*	0.6670*	0.0185	0.8133*	1.0000		
(8) Reference cost index	I	-0.2197*	-0.1566*	0.0982*	-0.1022*	-0.0121	-0.0550	-0.1696*	1.0000	
(9) Elective reference cost index	I	-0.2575*	-0.1590*	-0.045	-0.1227*	-0.0267	-0.0904*	-0.1776*	0.7412*	1.0000

E=positive indicator of efficiency, I=negative indicator of efficiency

* = statistically significant at 5% level after Bonferroni adjustment

Table A4.2 – Unconditional quantiles of the efficiency indicators.

Efficiency indicator	10th	25th	50th	75th	90th
Admissions per bed	75	91	109	126	142
Bed occupancy rate	78.2	82.8	86.6	90.2	93.3
Proportion of day cases	22.1	26.4	30.0	34.6	39.1
Cancelled elective operations	86	154	284	475	763
Proportion of untouched meals	2.4	4.2	6.4	9.6	14.5
Cleaning services costs	987	1,547	2,440	3,676	5,207
Laundry and linen costs	280	465	709	1,052	1,430
Reference cost index	88.2	92.6	98.0	106.3	116.2
Elective reference cost index	82.2	88.9	97.2	108.6	122.6

Table A4.3 – Competition, admissions, and beds.

Regressor	Model	Log of admissions	Log of beds
Policy break 2006/07*Pre-reform HHI^{-1}	I	0.006	-0.005
		(0.004)	(0.003)*
Policy break 2006/07*HHI^{-1}	III	0.004	-0.005
		(0.003)	(0.003)
HHI^{-1}		-0.001	-0.007
		(0.005)	(0.004)*
Dummy 2002/03*HHI^{-1}	IV	-0.008	-0.005
		(0.005)*	(0.004)
Dummy 2003/04*HHI^{-1}		-0.004	-0.001
		(0.004)	(0.003)
Dummy 2004/05*HHI^{-1}		-0.003	-0.003
		(0.003)	(0.002)
Dummy 2006/07*HHI^{-1}		0.003	-0.001
		(0.003)	(0.002)
Dummy 2007/08*HHI^{-1}		0.004	-0.006
		(0.003)	(0.003)**
Dummy 2008/09*HHI^{-1}		-0.002	-0.008
		(0.004)	(0.003)**
Dummy 2009/10*HHI^{-1}		0.001	-0.007
		(0.004)	(0.004)*
Dummy 2010/11*HHI^{-1}		0.003	-0.013
		(0.004)	(0.004)***
HHI^{-1}		-0.002	-0.005
		(0.006)	(0.005)
Observations		1,516	1,507
Number of trusts		173	172
Average		73,232	682

OLS estimation. In addition to hospital and year fixed effects, all regressions control for gender, age categories, emergency admissions, foundation trusts, and market forces factor.

Clustered standard errors in parentheses.

*** p-value<0.01, ** p-value<0.05, * p-value<0.1

Table A4.4 – Data sources.

Variable	Link
Efficiency indicator	
Admissions Day cases	http://content.digital.nhs.uk/article/2021/Website-Search?q=title%3A%22Hospital+Episode+Statistics%2C+Admitted+patient+care+-+England%22+or+title%3A%22Hospital+Admitted+Patient+Care+Activity%22&go=Go&area=both
Beds Bed occupancy rate	https://www.england.nhs.uk/statistics/statistical-work-areas/bed-availability-and-occupancy/bed-data-overnight/
Cancelled elective operations	https://www.england.nhs.uk/statistics/statistical-work-areas/cancelled-elective-operations/cancelled-ops-data/
Proportion of untouched meals Cleaning services costs Laundry and linen costs	http://hefs.hscic.gov.uk/DataFiles.asp
Reference cost index	http://webarchive.nationalarchives.gov.uk/+/http://www.dh.gov.uk/en/Managingyourorganisation/NHScostingmanual/DH_129310?PageOperation=email https://www.gov.uk/government/collections/nhs-reference-costs
Covariate	
Patient gender Patient age Emergency admissions	http://content.digital.nhs.uk/article/2021/Website-Search?q=title%3A%22Hospital+Episode+Statistics%2C+Admitted+patient+care+-+England%22+or+title%3A%22Hospital+Admitted+Patient+Care+Activity%22&go=Go&area=both
Foundation trusts	http://hefs.hscic.gov.uk/DataFiles.asp
Market forces factor	http://webarchive.nationalarchives.gov.uk/+/http://www.dh.gov.uk/en/Managingyourorganisation/NHScostingmanual/DH_129310?PageOperation=email https://www.gov.uk/government/collections/nhs-reference-costs

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