Article:

Gravelle, Hugh Stanley Emrys orcid.org/0000-0002-7753-4233, Siciliani, Luigi orcid.org/0000-0003-1739-7289 and Moscelli, Guiseppe (Accepted: 2020) Hospital competition and quality for non-emergency patients in the English NHS. RAND JOURNAL OF ECONOMICS. ISSN 0741-6261 (In Press)

Hospital competition and quality for non-emergency patients in the English NHS

Giuseppe Moscelli[a, b] Hugh Gravelle[a] Luigi Siciliani[a,c]

16 October 2020

Abstract

We investigate the effect on the quality of three high-volume non-emergency treatments of a reform that relaxed restrictions on patient choice of hospital. We employ a quasi difference-in-difference strategy and use control functions to allow for time-varying patient selection into providers correlated with unobserved morbidity. After the reform, public hospitals facing more rivals reduced quality, increased waiting times, and reduced length of stay for hip and knee replacements. This is likely due to regulated prices implying larger losses on these treatments compared to coronary artery bypass grafts where no effects were found. Our findings are robust to estimation methods, competition measures, and allowing for entry of private providers.

JEL Nos: C26, I11, I18, L22, L33.
Keywords: competition, quality, hospital, choice, difference-in-difference, control function.

[a] Economics of Social and Health Care Research Unit, Centre for Health Economics, University of York, YO10 5DD, York, UK.
[b] School of Economics, University of Surrey, GU2 7XH, Guildford, UK. Corresponding author: g.moscelli@surrey.ac.uk
[c] Department of Economics and Related Studies, University of York, YO10 5DD, York, UK.

1 Introduction

In OECD economies health spending accounts for around 9% of GDP (OECD, 2019). Reforms in several countries have attempted to increase competition amongst healthcare providers to reduce costs and improve quality (EXPH, 2015; OECD, 2012; Siciliani, *et al.*, 2017). In systems with low or zero patient co-payments, hospitals facing regulated prices can attract patients only by improving quality. It is argued that increasing competition amongst hospitals will lead to higher quality. One way to increase competitive pressures is to enhance the ability of patients to choose their hospital (Blöchliger, 2008; Le Grand, 2003).

Theory models predict that greater competition increases quality when hospitals maximise profit, face regulated prices, have constant marginal costs, and the price exceeds the cost of the marginal patient (Gaynor, 2006). But predictions are ambiguous when additional features of the hospital sector and the institutional context are taken into account (Katz, 2013). Hospitals in publicly-funded systems may face constraints on capacity resulting in an increasing marginal cost of treatment. Demand for elective (non-emergency) care is rationed by waiting time (Lindsay and Feigenbaum, 1984) and patients can wait a long time for treatment (Siciliani *et al.*, 2013). This will affect the response of quality and supply to greater competition and imply that evaluation of competition policy should also take account of its effect on waiting time. Public and non-profit hospitals may have altruistic motives and a limited ability to appropriate profits. These may lead them to treat patients whose marginal cost exceeds the regulated price and thus to respond to competition policies, which make demand more responsive to quality, by reducing quality (Brekke *et al.*, 2011, 2014).

We use a natural experiment to investigate the effect of greater patient choice on the quality of three high volume non-emergency treatments: hip replacement, knee replacement, and coronary artery bypass. Prior to 2006 patients in the English National Health Service (NHS) had their choice of hospital limited to those with which their local health authority had a contract. In 2006 patients were given the right to be offered a choice of at least four hospitals and this was later extended to any qualified provider. We use a quasi difference in differences strategy to investigate whether the relaxation of constraints on patient choice led to larger changes in quality for hospitals with more rivals. We measure hospital quality by whether patients have an emergency hospital readmission within 28 days of discharge after their index elective treatment, or whether they die anywhere within 30 days of admission for coronary bypass surgery.

We make five main contributions. First, we examine whether the 2006 patient choice reform had greater effects on quality of *elective* (non-emergency) surgical treatments for hospitals with more rivals (and also consider the effects on waiting times and patient length of stay.) The bulk of previous literature, reviewed in Section 2.3, is concerned with the effect of competition on the quality of *emergency* treatment, mainly for acute myocardial infarction (AMI). We examine elective treatments because hospitals compete for elective, rather than emergency, patients. Moreover, the correlation between emergency and elective quality patients across hospitals is low (as we show in Section 5) and we find that the reform had different effects on emergency and elective quality.

Second, we consider three high-volume elective treatments: hip replacement, knee replacement, and coronary artery bypass grafts (CABG). These are procedures whose patients' health outcomes have been used by the English NHS as indicators of the performance of NHS-funded secondary healthcare providers.[1] Hip and knee procedures are in a different speciality (musculoskeletal) from CABG (circulatory), which has fewer providers, all in the public sector. There are also low correlations in quality across the procedures, even for hip and knee replacements. Using these three procedures allows us to examine the heterogeneity of the effects of the choice reform across specialities, within specialities, and across market structures.

Patients' choice of hospital is affected, inter alia, by their beliefs about its quality and patients with different levels of morbidity may vary in the relative importance they attach to quality compared to other attributes, such as distance. The choice reform widened patient choice sets and its effect on choice of hospital could have varied with patient morbidity. Concerns about choice of providers of different quality being differently affected by unobserved patient morbidity led the earlier literature to concentrate on the effect of competition on the quality of emergency rather than elective conditions. Our third contribution is to test for and control for this selection bias using control functions (Terza *et al.*, 2008; Wooldridge, 2015).

Fourth, we develop a new theory model to guide our analysis and interpretation of results. Previous theory models have examined how hospitals in fixed price regimes compete in quality (Gaynor, 2006; Brekke *et al.*, 2014) or in waiting times (Brekke *et al.*, 2008; Sa *et al.*, 2019) but not in both. We provide a theory model where the hospital *simultaneously* chooses quality and waiting times.

Finally, we examine some possible mechanisms underlying the effects of the choice reform on quality. First, longer waiting times could affect emergency readmissions because patient health

[1] See https://digital.nhs.uk/data-and-information/publications/clinical-indicators/compendium-of-population-health-indicators/compendium-hospital-care/.

could deteriorate whilst waiting for treatment. Second, changes in length of stay could have affected our elective quality measure (emergency readmissions after elective treatment) if patients were discharged 'quicker but sicker'.[2] Third, hospitals with better emergency quality could have worse elective quality within the same speciality because physicians must choose how to allocate their efforts between them. We therefore test whether the choice reform also affected waiting times and length of stay for our three elective procedures and the mortality rates for emergency acute myocardial infarction (AMI) and emergency hip replacement.

We find that for the two musculoskeletal treatments – hip and knee replacements – the choice reform led to reduced quality for providers facing more rivals pre-reform relative to those facing fewer rivals. We estimate that, relative to a provider with no rivals, the choice reform increased emergency readmissions after hip replacement by 0.57% for a provider facing the average number of rivals, compared to the mean pre-reform risk of 5.72%. For knee replacement, the reduction was 0.30%, compared to the baseline risk of 1.9%. There was no effect of the choice reform on quality (whether measured by emergency readmission or mortality) for CABG patients. We find evidence of endogenous time-varying patient selection into hospitals. Allowing for unobserved patient selection increases the magnitude of the estimated effect of the choice reforms by a fifth for hip replacement, but doubles it for knee replacement.

Our results are robust to the use of alternative competition measures based on different definitions of the relevant market. They are also robust to different control function methods, to the inclusion of indicators of rurality and population density, to allowing the effects of covariates to differ pre- and post-choice reform, to allowing for potential sample selection bias from focussing on NHS patients treated in NHS hospitals, to allowing for cream-skimming by new private entrants, and to survivorship bias arising because only patients who do not die are counted in our emergency readmission measure.

We find that providers facing more rivals pre-reform had greater increases in waiting times and reductions in length of stay for hip and knee replacements, thereby possibly increasing readmission rates. Effort diversion is suggested by our finding that the choice reform reduced mortality for emergency hip fracture patients (in the same speciality as elective hip and knee replacements) and for emergency AMI patients (in the same speciality as elective CABG patients).

Theory models suggest that a key factor influencing the effect of competition on quality is whether the hospital makes a profit on the patients who would be attracted by an increase in quality. Thus, the apparently counter-intuitive negative effect of the choice reforms on hip and knee replacement quality may be explained by our back of the envelope calculations, which suggest that hospitals were making a larger loss on hip and knee replacements, where we find a reduction in quality, than on CABG treatments, where we find no effect on quality.

In the next Section we describe the institutional settings of the English NHS and summarise previous literature. In Section 3, we sketch a theoretical model to guide the interpretation of our results. In Sections 4 and 5 we explain the methods used in the empirical analysis and describe the data. Section 6 presents the results. Section 7 concludes with a discussion of the results and their relationship with those from other studies of hospital competition and quality.

2 Background

2.1 English National Health Service

NHS hospital treatment is tax funded and there are no charges to patients. Patients can only access elective hospital care by a referral from their family doctor (general practitioner; henceforth, GP). Most hospital care for NHS patients is provided by public hospitals (NHS Trusts), which are public bodies subject to financial and regulatory control and expected to break even.

A series of changes in the market for NHS-funded hospital care were introduced during our study period (2002/3-2011/12[3]) with the intention of stimulating competition to improve quality (Department of Health, 2000; 2002) and reduce waiting times. During the study period, local health authorities (Primary Care Trusts – PCTs) held budgets from the Department of Health to purchase hospital care for their populations. Before 2003/4, PCTs mainly placed block contracts with local healthcare providers to treat all patients referred to the hospital. GPs could in principle refer to any NHS provider, with an out-of-area tariff being charged if the provider was not in contract with the PCT in which the patient was resident.

Between 2003/4 and 2008/9 prospective payment per patient treated was progressively rolled out. The payment system was based on Healthcare Resource Groups (HRGs): groupings of hospital services of similar costs and type, akin to Diagnosis Related Groups. The tariff for a procedure was the average of relevant HRG costs over all hospitals in the two previous years, with an allowance for geographic variation in input prices (Monitor, 2013; Grašič *et al.*, 2015).[4]

[3] Our data are for financial years (1 April to 31st May).
[4] Financial penalties for emergency readmissions following elective procedures were introduced in 2011 (Kristensen, 2017) but will not have affected provider incentives in our study period (2002/3 to 2010/11).

Until 2003/4 very few NHS-funded patients were treated in private sector hospitals. From 2003/4 privately owned Independent Sector Treatment Centres (ISTCs) specialising in the provision of a limited set of elective treatments, including hip and knee replacement but not CABG, were encouraged to locate in areas where NHS patients were experiencing long waiting times (Department of Health, 2004; Department of Health, 2006). They received favourable five year contracts with revenue that did not vary with the number of patients treated (Naylor and Gregory, 2009). From 2008/9 onwards other private providers were allowed to provide most types of non-emergency treatment to NHS-funded patients. These non-ISTC private providers were paid the same HRG based tariff per patient as NHS providers. As initial ISTC contracts expired, ISTCs were also paid the HRG tariff from 2009/10 onwards.

Before 2006, the amount of choice for elective care varied across PCTs and general practices, depending on the set of hospitals with which the PCT had placed block contracts and GPs' willingness to refer outside this set. From 2006/7, elective patients had to be offered a choice of at least four hospitals by their GPs and from 2008/9 they could choose any qualified provider, whether NHS or private.

The numbers of NHS patients treated in the private sector increased rapidly from 2008/9 (Arora *et al.*, 2013). By 2010/11, the private sector treated around 4% of all NHS elective patients (Hawkes, 2012).

To complement the choice reform, an electronic booking service for outpatient appointments was rolled out from 2005 (Dusheiko and Gravelle, 2018). This made it easier for patients and their GPs to book outpatient appointments during a consultation and provided information on waiting times for appointments. In 2007 the NHS Choices website was established to provide public information on all providers of NHS services. The website enabled users to search for providers within specified distances and is likely to have improved patient information about what was available locally.

Patient choices of hospital are guided by their GPs (Beckert, 2018) who are repeat players (on average a general practice will have around 6 patients per year who have a hip replacement) and GPs from different practices can exchange information at local medical committees and other meetings of local GPs. There is considerable evidence that choice of hospital is affected by quality (Brekke *et al.*, 2014). Moscelli *et al.* (2016) found that elective hip replacement patients were less likely to choose hospitals with higher emergency readmission rates after hip replacement, and Gaynor *et al.* (2016) that elective CABG patients less likely to choose hospital with higher CABG mortality rates. Both studies found that responsiveness of demand to these quality measures increased after the choice reform

2.2 Elective hip and knee replacement and coronary artery bypass markets

Elective hip and knee replacement are musculoskeletal treatments, usually for osteoarthritis health problems, whilst CABG is a cardiovascular procedure used for some circulatory system diseases (e.g. clogged arteries). In the English NHS, all three are publicly-funded high-volume elective procedures (**Figure 1**), with a yearly average of about 10,000 first time CABG treatments and over 45,000 each for primary hip and knee replacement.

The supply sides of the markets for these treatments differ. In the period covered by our sample, NHS-funded hip (knee) replacement surgery was offered in 232 (238) NHS sites and 47 (52) private hospital sites. Between 2005/6 and 2010/11 the percentage of NHS-funded patients treated in private providers increased from 1.3% to 13.6% for hip replacements and 1.2% to

13.7% for knee replacements (**Appendix Table A1**). NHS-funded elective CABG surgery was performed almost exclusively in 47 NHS hospital sites.

Privately funded elective CABG patients treated in private hospitals accounted for 4.87% of all CABG patients in England (NICOR, 2012). In 2010/11, 11% of elective hip and knee replacements were privately funded (Arora *et al.*, 2013).

2.3 Previous literature

The empirical literature on hospital competition and quality has mainly focused on quality for emergency conditions, in particular acute myocardial infarction (AMI). This approach reduces possible bias from selection of hospitals by patients with different unobserved morbidity as emergency patients are unlikely to be choosing their hospital. But it relies on the assumption that quality for emergency patients is strongly correlated with quality, and therefore demand, from elective patients (Bloom *et al.*, 2015). Results are mixed, with some studies finding that increased competition increases quality (Kessler and McClellan, 2000; Kessler and Geppert, 2005; Cooper *et al.*, 2011; Gaynor *et al.*, 2013; Colla *et al.*, 2016; Bloom *et al.*, 2015) and others that it has no effect (Mukamel *et al.*, 2001) or reduces quality (Shen, 2003; Propper *et al.*, 2004; Propper *et al.*, 2008), or has effects which vary across the type of emergency condition (Moscelli *et al.*, 2018b).

There are fewer studies of competition for elective care. Colla *et al.* (2016), using cross-sectional data and relying on observables to allow for case-mix differences across hospitals, finds that competition had no effect on 30-day emergency readmission rates for Medicare hip and knee replacement patients and reduced quality for dementia patients. Wilson (2016) uses a control function with distance as an instrumental variable to control for unobserved selection amongst haemodialysis patients in Atlanta. Quality at a provider was lower the greater the proportion of local providers who were affiliated with the provider. In a one year cross-section study of English hip replacement patients, Feng *et al.* (2015) measures quality using very detailed data on patient reported outcomes and finds that competition had a positive but statistically insignificant association with quality. Cooper *et al.* (2018) find that the opening of a private hospital near an NHS hospital led to a reduction in its pre-operative length of stay for hip and knee replacement patients, and left the NHS providers to treat sicker patients who had longer post-operative length of stay. Using data from 2009 to 2012, Skellern (2018) finds that competition had a *negative* effect on patient reported outcomes for NHS hip and knee replacement, groin hernia, and varicose veins, though the effect is statistically insignificant once hospital fixed effects are allowed for.

Our analysis combines features from these studies: patient level outcomes; focus on elective treatments; longitudinal variation in a country-wide setting (all admissions in England); using a control function to allow for patient unobservable self-selection; inclusion of hospital site fixed effects to allow for unobservable time-invariant supply-side differences; and analysis of the effects of the competition on quality, waiting times and length of stay.

3 Theoretical framework: competition, waiting time and quality

The hospital faces a demand function $D(q, w, \theta)$ which is increasing in quality ($D_q > 0$) and decreasing in waiting time ($D_w < 0$). θ is a parameter which increases the responsiveness of demand to quality and waiting time ($D_{q\theta} > 0$, $D_{w\theta} < 0$) and can be interpreted as an exogenous measure promoting competition, such as a policy increasing patient choice, or improving information about quality. The policy may increase or reduce demand.[5]

The hospital chooses w and q and meets the resulting demand. Its cost function $C(D(q,w;\theta),q)$ is increasing and convex in output and quality. Its objective function is

$$v(w,q;\theta)=\pi(w,q,\theta)+B(w,q)=pD(w,q;\theta)-C(D(w,q;\theta),q)+B(w,q) \tag{1}$$

where p is the fixed price per patient treated and $B(w,q)$ captures additional motivations to provide quality, $B_q > 0$, and to reduce waiting times, $B_w < 0$ that go beyond current profits. Public hospitals will care about profit because they are expected to break even. Managers and staff in all types of hospital will care directly about quality and waiting times because of intrinsic motivation (Bénabou and Tirole, 2006) or altruistic concerns towards the patients (McGuire, 2000). $B(w,q)$ may also capture future effects on demand. Lower quality may risk unfavourable media coverage, audits by regulators, and possible worse future job prospects for hospital managers. A concern with waiting time could reflect penalties for breaching waiting times targets (Propper *et al.*, 2010). We assume that $v(\cdot)$ is well behaved: strictly concave in w and q with continuous second order partial derivatives.

First order conditions at an interior solution ($w > 0$, $q > 0$) are

$$v_w(w,q;\theta)=[p-C_D(D(w,q;\theta)]D_w(w,q;\theta)+B_w(w,q)=0 \tag{2}$$

$$v_q(w,q;\theta)=[p-C_D(D(w,q;\theta)]D_q(w,q;\theta)-C_q(D(w,q;\theta)+B_q(w,q)=0 \tag{3}$$

For a hospital which has motivation that goes beyond profit, equation (2) implies, since $B_w < 0$ and $D_w < 0$, that the hospital will make a loss on marginal patients: $p - C_D < 0$.

[5] Subscripts denote derivatives. Note that relaxing constraints on patient choice of hospital could increase demand ($D_\theta > 0$) for providers near to patients whose restricted choice set did not include them or reduce it ($D_\theta < 0$) for providers far from patients whose restricted choice set included them.

Notice that because demand is rationed by waiting time, a hospital which cares only about profit ($B_w = 0$, $B_q = 0$) will, from (2), equate its marginal cost to the regulated price ($p = C_D$) and, from (3), set quality to its minimum level since $v_q = -C_q < 0$. Such a hospital will also not respond to shifts in demand when policy or market conditions (θ) change: it will just let waiting time adjust to clear the market.[6]

The model can also be applied to private providers treating publicly funded patients at a fixed price. Although these providers may have a stronger emphasis on profits relative to other motivations, they will typically have lower waiting times than NHS providers because they treat fewer patients and have a lower marginal cost. A recent study covering a wide range of elective treatments, including hip and knee replacements, found that private and public providers do not differ in quality for NHS-funded patients, as measured by emergency readmission rates (Moscelli *et al.*, 2018c).[7] As mentioned above, we interpret the parameter θ as the effects on public hospitals of the relaxation of constraints on choice of provider. It could also be interpreted more broadly as an increase in competitiveness due to entry of private providers.

Our focus is on the effects of changing market conditions (captured by θ) on w and q. These are ambiguous in general since they depend on the derivatives of both $v_w(w,q;\theta)$ and $v_q(w,q;\theta)$ with respect to w, q, and θ and thus on fine details of the cost, demand, and intrinsic motivation

[6] With a high enough regulated price the provider will choose positive quality and a zero waiting time. Only models with stochastic waiting times, as in Gravelle and Schroyan (2020), can yield solutions in which a profit maximizing provider facing a regulated price will have positive quality *and* positive (expected) waiting time.
[7] An earlier theoretical study (Brekke et *al*., 2012) shows that the effect of being a private versus a public hospital on quality is theoretically ambiguous. On one hand, private providers have a stronger incentive to attract demand and compete on quality. On the other hand, they have stronger incentives to skimp on quality to increase profits..

functions. We can obtain some intuition by making strong simplifying assumptions about the hospital's non-profit motivation $B(w,q)$: $B_{wq} = 0$; the demand function $D(w,q;\theta)$: $D_{ww} = 0$, $D_{qq} = 0$, $D_{wq} = 0$; and that the marginal costs of output and quality are constant with respect to output: $C_{DD} = 0$, $C_{qD} = 0$). With these assumptions (see Appendix C)

$$\operatorname{sgn} \partial q / \partial \theta = \operatorname{sgn}\left[v_{w\theta} v_{wq} - v_{q\theta} v_{ww} \right] = \operatorname{sgn} v_{q\theta} = \operatorname{sgn} \underbrace{\left(p - c_D \right)}_{-} \underset{+}{D_{q\theta}} \tag{4}$$

$$\operatorname{sgn} \partial w / \partial \theta = \operatorname{sgn}\left[v_{q\theta} v_{wq} - v_{w\theta} v_{qq} \right] = \operatorname{sgn} v_{w\theta} = \operatorname{sgn} \underbrace{\left(p - C_D \right)}_{-} \underset{-}{D_{w\theta}} \tag{5}$$

A direct concern with waiting time ($B_w < 0$) leads the provider to increase output beyond the profit maximising point and to operate where marginal cost exceeds the price: $p < C_D$. Since an increase in competition makes demand more responsive to quality ($D_{q\theta} > 0$) it will increase the marginal loss from increase in quality and so the hospital will reduce quality. Similarly, the increased marginal loss from increasing volume to reduce waiting time will lead the hospital to increase waiting time.

Relaxing the strong assumptions made above means that the hospital may not increase waiting time and reduce quality when competition increases. But a provider which cares directly about quality and waiting time will find that its marginal losses from increasing quality and reducing waiting time will increase when greater competition makes demand more responsive to quality and waiting time and this will explain why it might reduce quality and increase waiting time.

4 Methods

4.1 Model specification

We measure quality as a patient having an emergency readmission within 28 days of discharge from hospital after their elective procedure. For CABG patients we also measure quality as the patient dying in or outside hospital within 30 days of admission for a CABG procedure (Section 5.1). We estimate linear probability models (LPM)

$$q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\psi}_2 + \mu_h + \varepsilon_{it} + \varepsilon_{ht} \tag{6}$$

where q_{iht} is equal to 1 if patient i treated in NHS site h in year t (t = 2002/3,…,2010/11) had an emergency readmission within 28 days of hospital admission and zero otherwise; β_t is a year effect and $\mathbf{x}_{iht}$ is a vector of patient covariates; $\bar{M}_h$ is market structure, measured as the equivalent number of rivals (Section 5.2), facing site h averaged across the years 2002/3 to 2005/6 *before* the relaxation of constraints on patient choice; A_t is the choice policy indicator, being equal to 0 in the four pre-choice reform years (2002/3 to 2005/6) and to 1 in the five post-reform years (2006/7 to 2010/11); $\mathbf{x}_{ht}$ is a vector of hospital site time-varying covariates. μ_h is a time-invariant hospital site effect; ε_{it} is the effect of unobserved patient characteristics and ε_{ht} is the effect of unobserved time-varying hospital characteristics.

Equation (6) describes a *quasi* difference-in-difference strategy (Card, 1992). The parameter of interest, γ, is identified through differences in treatment *intensity*, rather than through the assignment to a defined treatment or control group (Angrist and Pischke, 2009). The treatment is the choice reform and its effect varies across providers exposed to different market structures. The effect of the 2006 choice reform on quality for a provider with $\bar{M}_h$ rivals compared with a provider with no rivals is $\gamma \bar{M}_h$: the policy reform pivots the quality function about its intercept on the quality axis in (q, $\bar{M}_h$) space. We estimate Equation (6) with hospital site fixed effects μ_h to control for unobserved time-invariant provider heterogeneity. Year dummies control for time-varying factors, including other policy changes, such as the phased introduction of prospective pricing, and technical progress. We use a rich set of patient characteristics to control for severity (Section 5.3).[8]

Like the bulk of the hospital competition literature our outcome model is linear. Estimating LPMs has several advantages in our context. First, we can interpret the estimated coefficients as marginal effects because LPMs approximate conditional expectation functions, whether linear or non-linear (Angrist, 2001; Angrist and Pischke, 2009). Second, LPMs with hospital fixed effects are not subject to the incidental parameters problem that afflicts non-linear estimators for limited dependent variables (Lancaster, 2000; Greene, 2004). Third, unlike probit or logit estimators, LPMs are not biased if there is measurement error in the dependent variable (Hausman, 2001). Fourth, we use two control function strategies to allow for endogenous patient choice of hospital (Section 4.3). A linear outcome model permits comparison between them which would not be possible with logit or probit outcome models.[9]

4.2 Endogenous market structure

There are two main threats to identification of the change in the effects of market structure after the choice reform of 2006. The first is endogeneity of market structure. Our preferred measure of market structure is based on the Herfindahl Hirschman Index (HHI): the sum of the square of provider market shares. Because observed market shares may depend on provider quality, we follow the standard practice (Kessler and McClellan, 2000) of computing the HHI using predicted market shares from a model in which patient choice of provider depends on distance

[8] This baseline quasi-DiD strategy with hospital fixed effects is similar to those used by Cooper *et al.* (2011), Gaynor *et al.* (2013) in their analyses of the effect of the reform on AMI mortality and Moscelli *et al.* (2018b) for hip fracture mortality, both emergency conditions. We show in **Table 9** that we get similar results to these articles when we use our specification to examine the effect of the choice reform on AMI and hip fracture mortality using measures of speciality (circulatory, musculoskeletal) market competition.

[9] We also estimated logit outcome models with hospital fixed effects and a control function derived from a conditional logit first stage choice model and obtained very similar marginal effects (**Appendix Table A8**).

and other covariates but does not depend on quality (Appendix B). But using predicted HHI does not eliminate another source of potential endogeneity of market structure: new providers may choose to locate near poor quality incumbents. Hence, we follow Gaynor *et al.* (2013) and use a measure of pre-choice time-invariant market structure (i.e. $\bar{M}_h$ the average of the market structure measures over the pre-policy period) that is not affected by endogenous entry and exit decisions.

There were two main sources of changes in market structure over the period 2002/3 to 2010/11. From 2003/4, new private providers specialising in a small number of treatments, including hip and knee and replacements, were encouraged to enter and locate in areas where NHS patients were experiencing long waiting times (Department of Health, 2004; Department of Health, 2006). Cooper *et al.* (2018) found that, whilst this entry was more likely where existing NHS providers had longer waiting times, it was not associated with changes in length of stay or quality. We include these new providers in our measure $\bar{M}_h$ of pre-choice reform competition facing NHS providers.

From 2008/9, there was entry by existing private hospitals which had previously only treated private patients. If pressure on management to improve quality is driven by overall elective competition, as in Bloom *et al.* (2015), then the fact that private providers accounted for only 4% of all elective NHS-funded treatments (Hawkes, 2012) even at the end of our period also suggests that endogeneity may not be an important problem when market structure is measured at the level of all elective admissions, as it is in one of our specifications. We also add a time-varying measure of the number of local private providers to our baseline specification and find that our results are unchanged.

4.3 Endogenous patient selection of hospital

The second potential identification problem is that unobservable patient morbidity ε_{it}, which will affect the probability of readmission or mortality q_{iht}, may also affect patient choice of provider and bias the estimates of effects of market structure on hospital quality (Gowrisankaran and Town, 1999; Geweke *et al.*, 2003).

The direction of the bias arising from the effect of unobserved morbidity on choice of hospital is not obvious *a priori*. A patient's choice of hospital will depend on their beliefs about its quality. The effect of hospital quality may vary with the morbidity of the patient. Morbidity may affect the importance that patients' attach to quality relative to other attributes such as distance to hospitals. The choice reform widened patient choice sets and this could have changed the effect of morbidity on choice of provider.

If the effect of unobserved morbidity on patient choice of hospital is time-invariant, then the estimates of γ will be unbiased, thanks to the inclusion of hospital fixed effects μ_h in our baseline quality model (Equation (6)). But, otherwise, we need to control for selection. We use a rich set of patient characteristics, including comorbidities and past emergency hospital admissions, to control for selection on observables and, to the extent that observable and unobservable morbidity are correlated, to reduce selection on unobservable morbidity.

We also use two control function strategies (Terza *et al.*, 2008; Wooldridge, 2015) to tackle any remaining selection on unobservables. In these two stage residual inclusion (2SRI) strategies the first stage is a model for the probability that that a patient chooses a provider, with explanatories, such as patient distance to provider, which are uncorrelated with provider quality. In the second stage we add the residuals from the choice model to the model (Equation (6)) for patient outcomes.

In the first strategy we estimate H separate linear probability models (one for each provider) for the choice of provider h by patient i in year t:

$$C_{it}^{h} = \sum_{t'=2002/3}^{2010/11} D_{t'} \left[\alpha_{0t}^{h} + \alpha_{1t}^{h} d_{ih} + \alpha_{2t}^{h} d_{ih}^{2} + \alpha_{3t}^{h} d_{ih}^{3} + \alpha_{4t}^{h} nearest_{ih} + e_{it}^{h} \right] \tag{7}$$

where C_{it}^{h} = 1 if patient i chooses hospital h in year t and zero otherwise, D_t is a dummy for year t, d_{ih} is the distance from provider h to the centroid of patient i's small area of residence (Lower Super Output Area – LSOA),[10] $nearest_{ih}$ is an indicator for h being the nearest provider to patient i, and e_{it}^{h} is the error term.[11] We then estimate the linear second stage outcome model as

$$q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\psi}_2 + \hat{\mathbf{r}}_{it}^{LPM\prime}\boldsymbol{\psi}_3 + \mu_h + \varepsilon_{iht} \tag{8}$$

where $\hat{\mathbf{r}}_{it}^{LPM} = [\hat{r}_{i1t}^{LPM}, \hat{r}_{i2t}^{LPM}, ..., \hat{r}_{iHt}^{LPM}]$ and $\hat{r}_{iht}^{LPM} = C_{iht} - \hat{C}_{iht}$ are the residuals from the linear first stage Equation (7).

With linear first and second stage models, 2SRI will produce the same results as two stage least squares (2SLS). A joint test on the significance of the residuals can also be used as a simple Durbin-Wu-Hausman test for endogeneity of choice of provider (Terza *et al.*, 2008; Wooldridge, 2015). In a robustness check for the LPM outcome specification we use a non-linear (logit) outcome model. With such a non-linear second stage a control function strategy (2SRI) will yield consistent estimates (Terza, *et al.*, 2008).

[10] In the period 2002 to 2010 there were 32,482 LSOAs with an average population of 1500.
[11] Gowrisankaran and Town (1999) use a similar specification.

In the second control function strategy, we estimate a first stage *conditional logit* model for patient choice of hospital in which the utility obtained by patient *i* from provider *h* in year *t* is

$$U_{iht} = V_{iht} + \xi_{iht} = \lambda_{1t} d_{ih} + \lambda_{2t} d_{ih}^2 + \lambda_{3t} d_{ih}^3 + \lambda_{4t} T_{ht} + \lambda_{5t} F_{ht} + \lambda_{6t} PO_{ht} + \lambda_{7t} nearest_{ht} + \xi_{iht} \tag{9}$$

where T_{ht}, F_{ht} and PO_{ht} are indicators for teaching, foundation trust and privately-owned status, and ξ_{iht} are random terms with i.i.d extreme value distributions. The probability that patient *i* chooses provider *h* in year *t* is (McFadden, 1974)

$$P_{iht} = \exp\left(V_{iht}\right)\left[\sum\nolimits_{h' \in S_i} \exp(V_{ih't})\right]^{-1}. \tag{10}$$

where the patient choice set S_i is the closest 50 providers (accounting for over 99% of choices in each year).[12]

Estimation of the conditional logit model across all hospitals in each year yields residuals $\hat{r}_{iht}^{CLM} = C_{iht} - \hat{P}_{iht}$, which we then include in the LPM second stage outcome regression, as in Equation (8).[13] Compared to linear 2SRI, identification requires slightly stronger assumptions (Blundell and Powell, 2003, 2004).[14]

In both control function strategies inclusion of the residuals from the first stage choice model in the second stage quality model control for endogenous patient selection of hospital. The strategies are complements. Linear 2SRI is simpler and more robust. CL 2SRI requires stronger

[12] Wilson (2016) also uses a conditional logit choice model as the first stage choice model.
[13] For hospitals not in the nearest 50 we set the residual to 1 unless the patient chose a hospital not in the nearest 50 (1% of patients), in which case we set the residual to 0 for the hospital chosen and to 1 for all other hospitals outside the nearest 50.
[14] The key assumption is that $E(\varepsilon \mid \mathbf{x}, g(\xi)) = E\left[\varepsilon \mid g(\xi)\right] = E(\varepsilon \mid \hat{r}^{CLM}) = \psi_3 \hat{r}^{CLM}$ where $g(.)$ is a function of the error terms ξ_{iht} from the first stage choice utility function in Eq. (9), and ψ_3 is a correlation coefficients between the error terms ε and $g(\xi)$. The conditional logit model does not have explicit error terms so the identification of the model relies on the correlation between the errors terms ε from the outcome regression and a function, $g(\xi_{iht}) = C_{iht} - \hat{P}_{iht} = \hat{r}_{iht}^{CLM}$, of the latent errors ξ_{iht} which are not directly observable.

assumptions but has a more plausible first stage specification which should predict hospital choice more accurately (and cannot yield choice probabilities outside (0,1)) and so should produce more efficient estimates of γ (Newey and McFadden, 1994). Hence, if the two CF strategies produce similar parameter estimates of γ, this is reassuring and we can trust the estimates produced by the more efficient CL 2SRI estimator.[15]

Our control function strategies use distances from patient's residence to hospitals as instrumental variables (IVs) in first stage models of choice of provider. Distance IVs have been common in the healthcare literature since McClellan *et al.* (1994) and Newhouse and McClellan (1998). Many studies show that distance is a good predictor of choice of hospital (for examples for England, see Gaynor *et al.*, 2016; Gutacker *et al.*, 2016; Moscelli *et al.*, 2016). Distance also satisfies the exogeneity requirement for an IV: as Gowrisankaran and Town (1999) note, whilst distance to the *chosen* hospital may be correlated with morbidity, the distances from patient's residence to hospitals in the choice set is not.[16]

4.4 Sample selection

Our sample is NHS-funded patients treated in NHS hospitals. We exclude NHS-funded patients treated in the specialist private providers who entered the market from 2003/4 onwards. Until

[15] We also estimated a three-step model in which the first step is a choice model, the second regresses patient outcomes on patient covariates, year by provider effects, and the choice residuals to obtain a hospital by year estimate of quality, and the third step regresses this on year effects, hospital covariates, hospital fixed effects and interaction $A_t\bar{M}_h$. Results (**Appendix Table A9**) are similar to those from our baseline two step model.

[16] There is no evidence of residential sorting for elective hospital care in England. It is possible that patients in need of repeated treatments, like haemodialysis or chemotherapy, may locate closer to hospitals to minimize travel. But patients are less likely to change their residence for one-off treatments like CABG or hip and knee replacement, especially after the reduction of hospital waits for elective treatments in England from 2005 onwards. The baseline model contains measures of direct patient level morbidity. It also includes claims for benefits for incapacity and invalidity benefits and measures of deprivation in the small area in which the patient lives, plus the distance from the patient to the nearest Type 1 Accident and Emergency Department (located only in large NHS hospitals). This further increases the plausibility of the assumption that the distance IVs are, conditional on the variables included in the outcome model, uncorrelated with the outcome.

2009, these providers were not paid per patient treated (Naylor and Gregory, 2009) and were only moved onto HRG pricing per patient treated as their long term contracts expired. Hence, they had little incentive to compete on quality for most of our period and including them could bias the estimate of γ towards zero. Nor do we include NHS patients treated in the other, non-specialist, private providers who started treating NHS-funded patients from 2008 onwards since we cannot compute a pre-reform time-invariant market structure measure for them. Hence we estimate the effect of the choice reforms only for NHS patients treated in NHS hospitals. But we know that NHS patients treated in NHS providers were observedly and unobservedly more morbid than NHS patients treated in the private sector (Mason *et al.*, 2010; Moscelli *et al.*, 2018c) so that there is a risk of sample selection bias, in addition to unobserved selection of patients into individual NHS hospitals.

To test for possible sample selection bias we also estimate an augmented outcome model, adding the Heckman selection correction term (inverse Mills ratio) from an additional first stage probit model for choice of NHS rather than private hospital (Heckman, 1979). We specify latent utility from treatment in an NHS provider as

$$NHS_{it}^{*} = \rho_{0t} + \rho_{1t}(d_{itNHS} - d_{itISP}) + \mathbf{x}_{it}'\boldsymbol{\rho}_{2t} + u_{it} \tag{11}$$

with the patient choosing an NHS provider if and only if $NHS_{it}^{*} \geq 0$. d_{itNHS} and d_{itISP} are the distances from the centroid of the patient's LSOA to the closest NHS hospital site and to the closest private provider hospital site. We assume, plausibly, that *differential* distance $d_{itNHS} - d_{itISP}$ satisfies the exclusion restriction.

In all outcome models the standard errors are bootstrapped (1,000 replications) to account for the sampling error resulting from the inclusion of the estimated residuals (Murphy and Topel, 1985). We report *t*-statistics based on robust standard errors clustered at hospital site level (Cameron and Miller, 2015; Moulton, 1990).

5 Data

Our main dataset is Hospital Episodes Statistics (HES) which has information on all admissions to NHS providers and all NHS-funded hospital admissions to private providers. We use data on NHS-funded elective hip replacement, knee replacement and CABG patients aged 35 and over (**Appendix B1** has detailed procedure codes).[17]

5.1 Outcomes

We measure quality for elective hip and knee replacement, and CABG by whether the patient had an emergency admission within 28 days of discharge after their initial elective procedure. Emergency readmissions are one of the performance indicators in the NHS Outcomes Framework[18] and are a widely used in health economics and clinical studies (Ashton *et al.*, 1997; Weissman *et al.*, 1999; Balla *et al.*, 2008; Billings *et al.*, 2012; Blunt *et al*, 2015). As elective CABG treatment has a mortality risk of 1.1%, around four times larger than for hip and knee replacement, we also measure CABG quality by whether the patient died in *any* location (inside or outside the hospital) within 30 days of their index admission.[19] Waiting time is the number of days from a patient being placed on the waiting list to being admitted to hospital. Length of stay is the number of days from admission to discharge from hospital.

[17] As in Kessler and McClellan (2000), Gaynor *et al.* (2013) and Cooper *et al.* (2011), we include hospital sites only in years in which they had at least a threshold number of admissions (100 for hip replacement, 100 for knee replacement, 20 for CABG).

[18] We use the official definition of an emergency readmission (HSCIC 2016) https://files.digital.nhs.uk/C4/E99638/Spec_03K_520ISR7G.pdf. Emergency readmissions are attributed to the hospital where the index elective care was performed, not to the hospital that provided the emergency care.

[19] We cannot use quality measures based on patient reported outcomes as these were not available for hip and knee replacements before 2009, and were never collected for CABG.

5.2 Market Structure

We construct measures of market structure facing NHS hospital sites providing hip replacements (232), knee replacements (238), and CABG (47) between 2002/3 and 2010/11. Our main measures are based on the Herfindhal-Hirshmann Index (HHI): the sum of the squared market shares of the providers in the market, whether NHS or private. We measure market structure as the *reciprocal* of the HHI, i.e. the *equivalent number of* rivals – the number of equal sized firms that would yield the same HHI. This make results easier to interpret since a larger equivalent number of rivals means that competition is greater. It also facilitates comparison when we use a simple count of actual rivals as a robustness check. HHIs are computed from predicted patient flows (Section 4.2, and **Appendix B2**). It is possible that quality for a procedure depends on competition in the market for that procedure (hip replacement, knee replacement, CABG), in the market for the speciality (musculoskeletal, circulatory), or in the market for all elective admissions. We therefore compute the equivalent number of rivals using predicted HHIs for each of these three markets. As a robustness check, we also use a count of the actual number of rival hospital sites within 30 kilometres.[20]

5.3 Patients' and hospitals characteristics

To control for patient characteristics we use gender, age in 10 year bands, the number of co-morbidities based on ICD10 codes, the Charlson index based on morbidities predictive of future mortality (Charlson *et al.*, 1987), and the number of emergency hospitalizations in the previous year as a measure of patient severity. We also attribute IMD[21] income deprivation, IMD living environment deprivation, incapacity benefit claims rate and disability claims rate by patient LSOA of residence. Hospital characteristics are captured by indicators for

[20] All our market structure measures, whether HHIs or count of rivals, are based on hospital sites with a minimum of at least 100 elective admissions of any type per year.

[21] Index of Multiple Deprivation. See http://geoconvert.mimas.ac.uk/help/imd-2007-manual.pdf.

Foundation Trust status which gives greater financial flexibility (Marini *et al.*, 2008), and for teaching hospital status. In robustness checks we also use an indicator for the rurality of the hospital site and measures of population density.

5.4 Summary statistics

Table 1 reports descriptive statistics on NHS patients treated in NHS providers. Post-reform the mean risk of an emergency readmission fell slightly for hip replacements but increased for knee replacements and CABGs. Mortality risk, length of stay, and waiting time fell for all three procedures. Mean ages for hip and knee replacement are 68 and 70 years, respectively, and 65 for CABG. The proportion of female patients is much higher for hip and knee replacement (60% and 58%) than for CABG (19%). Hip and knee replacement patients have an average of three co-morbidities whilst CABG patients have more than five, and also have fewer emergency admissions in the year prior to treatment.[22]

Table 2 reports correlations among risk-adjusted NHS hospital site quality measures for our three elective procedures. They are generally small. The highest correlation (0.28) is between knee and hip replacement emergency readmission rates, which is to be expected given that they may be carried out by the same surgical teams. CABG readmission and mortality rates are also significantly positively correlated (0.17). The correlations between the CABG and the hip and knee replacement quality measures are weak. Given that the literature on hospital competition has focused on mortality rates for emergency admissions for conditions such as AMI we also

[22] Hip and knee replacement procedures provided by NHS hospitals increased and then fell slightly between 2002/3-2010/11 (**Appendix Figure A1**). CABGs declined over the entire period. Risk-adjusted elective care hospital quality declined (28-day standardized emergency readmissions increased) over the period (**Appendix Figure A2**), reflecting either a secular decline in provider quality or an increase in unobserved morbidity of admitted patients, possibly due to changes in GP referral and hospital admission thresholds.

report, in italics, the correlations between our elective care quality measures with the mortality of two high volume emergency conditions (AMI and hip fracture) in the same specialities as CABG and hip and knee replacement. The emergency mortality rates are weakly associated with the elective care quality measures and the only significant correlations are negative.[23] These correlations suggest that mortality for an emergency conditions is not necessarily indicative of hospital quality for elective procedures, even within the same speciality.

Table 3 has summary statistics for market structure. Most of the competition measures relating to hip and knee replacements increased over the period by between 15% and 23%, but CABG market structure was substantially unchanged as no private providers entered this market. The percentage increase in the actual number of NHS and private elective care providers within 30 km was very similar (24%) to that for the equivalent number (23%).[24,]

Figure 2 compares the percentages of patients who chose their nth nearest provider before and after the relaxation of constraints on choice. For both hip and knee replacements the percentage of patients choosing their nearest provider fell from just under 70% in 2002/03 to just over 46% in 2010/11. By contrast there was a small increase in CABG patients choosing the nearest provider. **Figure 3** compares patient volumes in the pre and post-choice periods for hospitals above and below median quality. Higher quality providers have larger volumes than low quality providers in both periods, but the volume difference is larger after 2006 when constraints on choice were relaxed. This suggests a '*flight to quality*', with patient choice

[23] Gravelle et al. (2014) used a larger set of measures for 2009/10 and also found find little evidence for a positive correlation between elective and emergency care hospital quality.

[24] The correlations for the equivalent number of rival sites for all elective admissions with the equivalent numbers of rivals for the two specialties are at least 0.97 and for the three procedures are at least 0.85. The correlation with the actual numbers of rivals for all elective admissions is 0.78 (**Appendix Table A2**). **Figure A3** plots the trends in the competition measures.

becoming more responsive to quality after the choice reform, as confirmed in Gaynor *et al.* (2016) for CABG and Moscelli *et al.* (2016) for hip replacement.

We estimated DID models for observed morbidity which shows that for the hip and knee replacement the post-reform increase in some types of morbidity was greater for hospitals facing more pre-choice competition (**Appendix Table A3, Panel B**). This suggests that it is possible that unobserved morbidity changed differentially for hospitals facing more or less competition. [25]

6 Estimation results

In this section we report results from our quasi-difference in difference models which investigate whether, and how, relaxation of constraints on choice led to greater changes in outcomes for providers facing more competition.

6.1 Baseline specifications

Table 4 reports the coefficient (γ) on the interaction between pre-2006 speciality market structure and the post-2006 choice reform indicator. Column (1) has results from models with only hospital and time fixed effects; column (2) adds covariates. Columns (3) and (4) are from models which also contain the residuals from first stage linear and conditional logit choice models.

[25] **Appendix Table A3, Panel A** reports the differences in pre-reform patient outcomes and characteristics (aggregated to hospital site level) for providers facing below and above mean pre-reform competition. Providers facing above average competition had lower emergency readmission rates, shorter waiting times, and higher length of stay. Differences in patient health (past emergency readmissions, number of diagnosis and Charlson Index) were statistically insignificant. Hip replacement and CABG providers facing more competition treated slightly younger patients.

Panel a has results for hip replacement. In all four specifications the positive coefficient γ on the *Post-Choice Policy*Market structure* interaction implies that relaxation of constraints on choice had a larger positive effect on readmissions (a larger reduction in quality) for providers facing more pre-2006 competition. Adding covariates (column (2) vs column (1)) reduces γ slightly and adding the first stage residuals increases it, though it is not statistically significant for the linear 2SRI model (column (3)). The first stage choice model residuals are jointly statistically significant for both the CL and linear specifications, indicating that there was endogenous selection. Allowing for endogenous selection has a relatively modest effect on the estimates of γ, increasing them by about a fifth and the confidence intervals from the models with and without residuals overlap.[26, 27]

Panel b is for knee replacement and again all four specifications suggest that the relaxation of constraints on choice increased emergency readmissions. The effect is statistically significant in all cases and is doubled with the CL 2SRI and Linear 2SRI models compared to the model (column (2)) which does not allow for endogenous selection.

Panels *c* and *d* for CABG report small, generally negative, and statistically insignificant effects on emergency readmissions and on mortality for all four specifications, whether or not we control for endogenous selection of hospitals.[28]

---

[26] The 1st stage F-statistics for the linear 2SRI models are very large (**Appendix Table A4**). For the CL 2SRI, in the absence of a formal test for instrument strength, we find (**Appendix Table A5)** that the first stage conditional logit choice models have a very high goodness of fit. For example, Cragg and Uhler's R-Squared is over 0.989 in all years.

[27] The Oster (2019) test for coefficient stability (**Appendix Table A6**), obtained using the *psacalc* Stata function, suggests that the bias in the coefficient on $A_t\bar{M}_h$ due to unobservables is in the same direction as the bias due to the omission of observable confounders.

[28] **Appendix Table A7** has the full estimation results for the outcome for the CL 2SRI strategy in column (4) of Table 4. In **Appendix Table A8** we report the marginal effects from the logit outcome second stage using the residuals from the conditional logit first stage choice model. Results are very similar to those in Table 4. In **Appendix Table A9** we report the results from the three-step model mentioned in the Methods section (footnote 12), which are very similar to those from our two-step approach in Table 4.

Given a pre-reform average equivalent number of rivals of 2.71, measured at musculoskeletal specialty level, the choice reform increased emergency readmissions by 0.57% ($\gamma \bar{M}_h$) after hip replacement for a hospital with the average number of rivals pre-reform compared to a hospital with no rivals. The mean pre-reform hip replacement readmission risk was 5.74%. For knee replacement the increased readmission risk was 0.30% compared to the mean pre-reform risk of 1.69%.

6.2 Robustness Checks

6.2.1 Measure of market structure

In **Table 5** we examine if our results are sensitive to the way in which market structure is measured using the equivalent number of rivals for all admissions (columns (1) to (3)), for procedure (columns (4) to (6)), and using a simple count of rivals within 30 km (columns (7) to (9)). The patterns of results for these three market structure measures are very similar to those with the speciality-based measure in Table 4. The magnitude of the estimated γ coefficients on *Post-Choice Policy*Market Structure* vary across the market structure measures but this is mostly due to differences in the scale of this measure. As Table 1 shows, the mean pre-choice reform equivalent number of providers for musculoskeletal admissions is larger than for either hip or knee replacement admissions, smaller than the all elective admissions and much smaller than the simple count of rivals. This is the reverse of the rankings of the estimated γ coefficients across the market structure measures.[29]

[29] Results (**Appendix Table A10**) using HHI rather than equivalent numbers (1/HHI) produce very similar results (allowing for changes in the scale of the competition measure). We also estimated models using the first principal component from a principal components analysis of equivalent numbers of rivals derived from HHIs based on all elective admissions, specialty admissions, procedure admissions and number of rival hospital sites within 30 km. The weights of the different market structure measures in the first principal component of the composite PCA-based market structure measure are given by the eigenvectors reported in **Appendix Table A11**. All market

As the choice of measure makes little substantive difference to our results, we use market structure at specialty level in subsequent models. The all elective patients HHI combines very heterogeneous procedures, creating a risk of measurement error. Procedure-level HHI might be more prone to procedure-specific measurement error arising from large changes in HHIs due to temporary entry or exit of providers in the pre-policy period. The simple count of rivals ignores their size and distance from the hospital. A specification in which market structure is time-varying, rather than being fixed at its pre 2006 value, produces similar results to Table 4 (**Appendix Table A13**), suggesting that our measure of market structure is not endogenous.

6.2.2 Timing of choice reform

In **Appendix Table A14** we report estimates from specifications where we allow the effect of the 2008 choice extension to any qualified provider to differ from the effect of the initial relaxation of constraints on choice in 2006. There is no statistically significant difference in effects of the initial 2006 relaxation and the 2008 extension of choice and both are very similar to the results in Table 4.

6.2.3 Post choice reform change in covariate effects

It is possible that the effects of covariates on quality differed before and after the choice reform. The roll out of prospective pricing over the period could have led to changes in coding practice[30] and there could be trends in age and gender specific readmission or mortality over

structure measures are positively correlated with the first principal component, with larger and similar weights for the all elective admissions and elective specialty-level predicted HHIs. Results from the quality models using the first principal component as the measure of market structure were very similar to those from the model with equivalent numbers derived from speciality HHI (**Appendix Table A12**).

[30] As Table 1 shows the number of diagnoses on admission and the Charlson index increased after the choice reform.

our nine year period. If so, $\hat{\gamma}$ may be biased (Meyer, 1995). To allow for this we re-estimated the baseline model adding interactions of the post-choice indicator and all the covariates (Abadie, 2005, p.4).[31] The results are in **Table 6.** The pattern and magnitude of the estimated effect of the choice reform on quality are essentially unchanged. If anything, allowing covariate effects to differ pre and post the choice reform somewhat strengthens the results: $\hat{\gamma}$ increases in magnitude and is more precisely estimated for hip and knee replacements. There is little change in the CABG results.[32]

6.2.4 Sample selection

In our baseline models we estimate the effect of the choice reform on NHS-funded patients treated in NHS hospitals. To test if this creates sample selection bias, because NHS-funded hip and knee replacement patients could also have chosen NHS-funded treatment in private providers, we estimate models with Heckman selection corrections in which we use the difference in distance between the nearest NHS and nearest private providers of care in an additional first stage probit model (Equation (11)) of choice between NHS and private provider. Results in **Table 7** columns (1) and (2) are very similar to those in Table 4. The coefficient of the selection correction term is negative for hip replacement and positive for knee replacement, but not statistically significant,[33] possibly because of most of the selection related to use of private hospitals is already controlled by the inclusion of hospital fixed-effects, the extensive set of case-mix variables, and the inclusion of the choice residuals.

---

[31] The quality model is now $q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\psi}_2 + \mathbf{x}'_{iht}\boldsymbol{\omega}_1 A_t + \mathbf{x}'_{ht}\boldsymbol{\omega}_2 A_t + \mu_h + \varepsilon_{iht}$.

[32] In **Appendix Table A15** we estimate a model similar to the one in Table 6 but with Post-Choice interacted only with the number of diagnoses and Charlson Index, to test whether potential post-choice upcoding from hospitals biases our results. The estimation results confirm our main findings.

[33] In the yearly first stage probit models for the choice of public versus private hospital, the marginal effects of the differential distance between the closest public and private hospital sites are always statistically significant at 1%, and the p-values of the Chi-squared tests of the overall significance of the first stage probit regressions are also significant at 1% (**Appendix Table A16**).

As a second check that excluding NHS-funded patients treated by private hospitals does not bias our results, we also estimate the baseline model on a sample of all NHS-funded patients, whether treated in NHS or private providers. As most of the private providers were not present in the market before 2006, we proxy their missing competition measure with the pre-2006 competition measure of their closest NHS hospital site within 30 km. The results, in columns (3) and (4) of Table 7, are again very similar to those in Table 4 estimated on the sample of NHS patients treated in NHS providers.

If NHS providers facing more competition pre-reform also faced more entry by private providers post-reform this could bias the estimate of effect of the interaction of the choice reform and NHS provider pre-reform market structure. There could be greater cream-skimming of unobservedly healthier NHS patients by private providers (Moscelli *et al.*, 2018c) or NHS providers could change quality in response to post-reform private competition, especially if private rivals are more aggressive competitors. To allow for these possibilities we added the time-varying number of private hospital sites within 30 km of the NHS provider to our baseline model. As **Table 8** shows, this does not change our results.

Finally, we allow for mortality based selection or survivorship bias. If poor quality care increases patient mortality immediately after discharge from the index elective treatment, then this will reduce the probability of emergency readmission within 30 days of discharge. This suggests that we might have estimated our readmission models on a healthier sub-sample of patients. We therefore added a Heckman correction term, derived from a first stage CABG mortality probit model to our baseline CABG emergency readmission model. (The low mortality rates for elective hip and knee replacements – see Table 1 – suggest that survivorship bias is not a problem with these treatments.) We find (**Appendix Table A17**) that the selection correction term is statistically insignificant and the effect of the choice reform on CABG readmission remains small and statistically insignificant.

6.2.5 Hospital rurality and population density

In more densely populated areas there are more providers to cope with the larger demand for healthcare. Hospitals in rural areas usually treat fewer patients and may benefit less from economies of scale and experience. They may also find it difficult to attract high quality staff. We address the concern that the estimated effect of predicted HHI is at least in part due to its correlation with population density or rurality in two ways. First, we interact a time-invariant indicator of the rurality of LSOA in which the hospital site is located with the pre-2006 competition measure. We find (**Appendix Table A18**) that rurality interaction terms are never statistically significant and the estimated γ coefficients are unaffected. Second, we add time-varying measures of population density to our baseline specification and again find that this made no difference to our estimate of γ (**Appendix Table A19**).

6.3 Mechanisms

Having established the robustness of our estimates of the post-choice reform change in the effect of market structure on elective quality, we next consider possible mechanisms which could have led to this change. For policy it is important to know the extent to which the reform led directly to changes in elective quality and the extent to which it changed other aspects of hospital behaviour which in turn indirectly affected elective quality.

6.3.1 Waiting times

Our theory model in Section 3.1 suggested that changes in choice policy could affect waiting times as well quality. **Table 9** *Panel A* reports results for models of waiting times which have the same explanatories as our baseline model of emergency readmissions. Having an additional rival pre-choice increased waiting times by 5.5% for hip replacement and 6.5% for knee replacement, thus confirming the smaller leftwards shift in the distribution of waiting times for hospitals facing more competition shown in **Figure 4**. Since it is possible that longer waiting times for treatment worsen patient outcomes (Nikolova *et al.*, 2015; Reichert and Jacobs, 2018) some of the increased probability of an emergency readmission in providers facing more pre-choice competition may be due to the effect of the choice reform on waiting times.

6.3.2 Length of stay

Providers could react to increased competition by reducing patient length of stay in order to reduce costs and to free up beds to treat more patients. *Panel B* of **Table 9** reports results from models of length of stay using the same form and explanatories as the baseline CL 2SRI quality model. Length of stay for hip and knee replacement patients decreased more after 2006 in hospitals facing more competition, suggesting that patients were indeed discharged faster in the post choice period. The effect is negative and statistically significant at 5% (1%) for knee (hip) replacement, and negative but not statistically significant for CABG patients.[34]

Earlier discharge of patients can in general worsen health outcomes (Epstein *et al.*, 1990; Martin and Smith, 1996; Sudell *et al.*, 1991). However, the long term trend reduction in length of stay for hip and knee replacement (Burn *et al.*, 2018) is in part due to enhanced recovery

[34] Gaynor *et al.* (2013) find that, post-reform, hospitals facing more competition had shorter length of stay for all patients and Cooper *et al.* (2018) that the choice reform reduced pre-operative length of stay for hip replacement.

programmes intended to get patients "back on their feet" and recovering better outside hospital. Thus not all reductions in length of stay increase readmission rates. But if the relationship between length of stay and emergency readmissions is U-shaped, then providers facing more competition who reacted to the choice reform with a greater reduction in length of stay could have experienced increased emergency readmission rates relative to providers with smaller reductions in length of stay.

6.3.3 Effort diversion: quality of emergency care

Propper *et al*. (2008), Gaynor *et al*. (2013), Katz (2013), and Skellern (2018) suggest that hospital management might convey information about quality through hospital mortality rates. If patients did not observe indicators for elective care quality then the choice reform could have induced a diversion of hospital efforts towards quality for emergency services, where mortality is high compared with elective care, thereby reducing quality for elective care. Cooper *et al.* (2011) and Gaynor *et al.* (2013) found that the choice reform led to lower emergency AMI mortality for providers exposed to more rivals. In *Panel C* of **Table 9** we report results from linear probability models for mortality within 30 days following admissions for AMI and hip fracture. The specification is the same as our baseline model for emergency readmissions with a full set of covariates and hospital fixed effects (Table 4, column (2)) but with no need to allow for endogenous patient choice of hospital. We measure competition at circulatory and musculoskeletal speciality level, rather than for all electives as in previous models of emergency mortality. We find that providers exposed to more rivals pre-reform had larger reductions in mortality after the choice reform, lending some support to the effort diversion hypothesis. Since the specification is the same as that for elective quality (Equation (6)) the similarity of our results to those of Cooper *et al.* (2011) and Gaynor *et al.* (2013) for AMI and Moscelli *et al*. (2018b) for hip fracture suggests that our results for elective quality are not due some peculiarity of the specification, even though we find negative effects on quality for two elective musculoskeletal procedures and no effect for an elective circulatory procedure (CABG).[35] The lack of any effect for elective CABG, compared with a negative effect for emergency AMI quality may be because there are only 47 CABG providers compared with 213 providers of AMI care.

6.3.4 Hospital profit on elective procedures

The theory model sketched in Section 3, and the bulk of the theory literature (Brekke *et al.*, 2014), suggest that whether greater competition increases or reduces quality depends, *inter alia*, on whether the revenue from marginal patients who would be attracted by higher quality is greater or smaller than their cost. We do not have information on the marginal cost of patients but we can make some back of the envelope estimates of the average profit or loss per patient. It is plausible that capacity constraints in NHS hospitals mean that they produce where cost per patient is increasing and so marginal cost is greater than average cost. Hence if a hospital makes a loss per patient its marginal cost will exceed the price it receives and so it will not want to attract additional patients by improving quality.

Hospitals are paid a fixed tariff $P_{jht} = P_{jt}*MFF_{ht}$ per patient in HRG_j in year t where the national tariff P_{jt} is based on average reported costs for all hospitals in the two previous years and MFF_{ht} is a local adjustment for input prices. It is therefore possible that, if costs increase over time, perhaps because of changes in medical technology or the morbidity of patients, or changes in input prices, the HRG tariff could be less than the unit cost of the procedure.

[35] We also added provider hip fracture (AMI) mortality rates to our baseline models for elective hip or knee hip replacement (elective CABG) with competition measured at speciality level as additional controls for unobserved hospital level factors. This made very little difference to the results (**Appendix Table A20**).

To check whether this is the case, we computed per patient profit for our three procedures. Let AC_{jt} denote the national unit cost for HRG j in financial year t; and CI_{ht} the reference cost index for all elective procedures in hospital h in year t. CI_{ht} compares the cost of hospital h's mix of outputs with the average national cost for the same mix. We assume that the average cost of HRG j in year t for hospital h is $(CI_{ht} / 100)*AC_{jt.}$ and compute per patient profit on HRG j in hospital h in year t as $MFF_{ht}* P_{jt} - (CI_{ht} / 100)*AC_{jt}$. (See **Appendix Table A21** for details.)

Over the two years (2009/10, 2010/11) for which we have data,[36] NHS hospitals made an average loss for each patient of £750 for knee replacement, £485 for hip replacement and £370 for CABG. They sustained much larger losses on the procedures (hip and knee replacements) where we find a decrease in quality after the choice reform and had smaller losses for CABG patients where we found no effect of the choice reform on quality. The calculations are necessarily rough because of data limitations, but we think they are suggestive of why hospitals in more competitive environments responded to the choice reform by reducing quality.

7 Conclusions

We investigated whether the relaxation of constraints on patient choice in the English NHS in 2006 changed the relationship between market structure and quality for three common elective treatments. We used control function strategies to address possible bias induced by time-varying patient selection into hospitals. Controlling for this bias produces larger and more precise estimates of the effects of the choice reforms on elective quality. For hip and knee replacements the 2006 choice reforms led to 1/10th and 1/5th increases in the risk of emergency readmissions within 28 days of discharge, an increase in waiting times, and a reduction in

[36] Publicly available reference costs data for years 2006/7, 2007/8 and 2008/9 was reported used HRG4, whereas the national tariff for the same years was reported using HRG3.5, which makes it difficult to compute hospital profit and losses by HRGs in those years.

length of stay. The choice reform had no effect on emergency readmissions, mortality, waiting times or length of stay for CABG patients.

Our results are robust to measures of market structure, patient selection into NHS providers, allowing the effects of covariates to vary pre and post-choice reform. The effects on quality are relatively modest, possibly because demand elasticity with respect to quality is generally low (about 0.1) for CABG (Gaynor *et al.*, 2016) and hip replacement (Moscelli *et al.*, 2016).

Negative effects of competition on quality have been found in other empirical studies (Section 2.2). They are compatible with previous theoretical models (Brekke *et al.*, 2011) and with the new model of quality and waiting time sketched in Section 3. In these models hospitals motivated by altruistic or intrinsic concerns may make a loss on marginal patients. If demand becomes more responsive to quality and waiting time because of increased competition, providers may reduce quality and increase waiting times to reduce demand and thus losses on marginal patients. Our back of the envelope computations for 2009 and 2010 suggest that hospitals were making losses on elective hip and knee replacements, but less so for CABG patients for whom there was less evidence of a reduction in quality.

Our results for elective care are also compatible with those for emergency care which use a similar identification strategy to ours but find that the choice reform reduced mortality for AMI (Cooper *et al.*, 2011; Gaynor *et al.*, 2013) and hip fracture (Moscelli *et al.*, 2018b) for hospitals facing more competitors. If emergency mortality is used by elective patients as a salient signal of overall hospital quality, then patient choice could increase emergency quality and reduce elective care quality as the result of diverted effort (Katz, 2013; Skellern, 2018). Moreover, the reductions in mortality are likely to have generated health benefits which are larger than the health losses for elective patients as measured by higher emergency readmissions for hip and knee replacement patients.

In contrast with our results Gaynor *et al*. (2016) find that mortality for CABG patients was reduced by the choice reform. However, their focus was on the effect of the reform on the choices made by patients.[37] After the reform patients who placed a greater relative valuation on quality versus distance could exercise their right to choose from a wider set of hospitals and were treated in higher quality providers. This reduced the average mortality for patients. Our focus is on the effect of the reform on the behaviour of providers – the change in the quality they provided. We find that the reduction in CABG provider mortality rates was very small and statistically insignificant.

The reductions in quality for knee and hip replacement procedures that we find do not mean that the 2006 choice reform was welfare reducing overall. Patients undergoing elective procedures may gain from being able to switch to previously unobtainable providers with higher quality (as in Gaynor *et al.*, 2016). The evidence suggests that patient choice of hospital for non-emergency treatments became more sensitive to quality after the choice reforms (Gaynor *et al.*, 2016; Moscelli *et al.*, 2016). Moreover, patients may place an intrinsic value on having a choice of provider (Dixon *et al.*, 2010). Last, but not least, the choice reform also improved the quality of some types of emergency procedures (Cooper, et al., 2011; Gaynor, *et al.*, 2013; Moscelli *et al.*, 2018b).

[37] They also, indirectly, investigate the effect of the reform on hospital quality by showing that hospitals with a greater increase in the elasticity of demand with respect to mortality had a greater reduction in mortality, though, as they note, this investigation uses only a sample of 27 providers, and it may be subject to reverse causality.

Our findings contribute to the heated debate on the effect of competition on hospital quality (Bloom *et al.*, 2011, 2012; Pollock, 2011a, 2011b) in two ways: we show that the English choice reforms had mixed effects on hospital quality; and we link our findings to a theory of hospital competition on quality and waiting time, thereby shedding more light on the 'black-box' competition mechanism. Further research using better data on hospital costs and hospital staff behaviour is needed to fully uncover the mechanisms behind the effects of provider competition. But our work suggests that competition policies are not a 'magic bullet' and should be handled with care by policymakers, especially in systems where healthcare is rationed by waiting.

References

Abadie, A. (2005). Semiparametric difference-in-differences estimators. *The Review of Economic Studies*, 72(1), 1-19.

Angrist, J. (2001). Estimation of limited dependent variable models with dummy endogenous regressors: simple strategies for empirical practice. *Journal of Business & Economic Statistics*, 19(1), 2-28.

Angrist, J., Pischke, J. S. (2009). *Mostly Harmless Econometrics: An Empiricist's Companion.* Princeton University Press.

Arora, S., Charlesworth, A., Kelly, E., Stoye, G. (2013). Public payment and private provision. The changing landscape of health care in the 2000s. Nuffield Trust and Institute for Fiscal Studies. www.nuffieldtrust.org.uk.

Ashton, C., Del Junco, D., Souchek, J., Wray, N., Mansyur, C. (1997). The association between the quality of inpatient care and early readmission: a meta-analysis of the evidence. *Medical Care*, 35(10),1044-1059.

Balla, U., Malnick, S., Schattner, A. (2008). Early readmissions to the department of medicine as a screening tool for monitoring quality of care problems. *Medicine*, 87(5), 294-300.

Basu, A., Coe, N., Chapman, C. (2018). 2SLS versus 2SRI: Appropriate methods for rare outcomes and/or rare exposures. *Health Economics*, 27(6), 937-955.

Beckert, W. (2018). Choice in the presence of experts: The role of general practitioners in patients' hospital choice. *Journal of Health Economics*, 60, 98-117.

Bénabou, R., Tirole, J. (2006). Incentives and prosocial behavior. *American Economic Review*, 96(5), 1652-1678.

Billings, J., Blunt, I., Steventon, A., Georghiou, T., Lewis, G., Bardsley, M., (2012). Development of a predictive model to identify inpatients at risk of re-admission within 30 days of discharge (PARR-30). *BMJ Open*, 2 (4). doi:10.1136/bmjopen-2012-001667.

Blöchliger, H. (2008), Market mechanisms in public service provision. OECD Economics Department Working Papers, No. 626, OECD Publishing. doi: 10.1787/241001625762

Bloom, N., Propper, C., Seiler, S., Van Reenen, J. (2015). The impact of competition on management quality: evidence from public hospitals. *The Review of Economic Studies*, 82(2), 457-489.
Bloom, N., Cooper, Z., Gaynor, M., Gibbons, S., Jones, S., McGuire, A., Moreno-Serra, R., Propper, C., Van Reenen, J., Seiler, S. (2011). In defence of our research on competition in England's National Health Service. *The Lancet*, December 17/24/31, 2064-2065.
Bloom, N., Cooper, Z., Gaynor, M., Gibbons, S., Jones, S., McGuire, A., Moreno-Serra, R., Propper, C., Van Reenen, J., Seiler, S. (2012). A response to Pollock *et al.*, http://www.bristol.ac.uk/cmpo/publications/other/cpresponse.pdf.
Blundell, R., Powell, J. (2003). Endogeneity in nonparametric and semiparametric regression models. In M. Dewatripont, L. Hansen and S. Turnovsky. (eds.) *Advances in Economics and Econonometrics: Theory and Applications*, *Eighth World Congress*, Vol. II, Cambridge: Cambridge University Press.
Blundell, R. W., & Powell, J. L. (2004). Endogeneity in semiparametric binary response models. *The Review of Economic Studies*, 71(3), 655-679.
Blunt, I., Bardsley, M., Grove, A., Clarke, A. (2015). Classifying emergency 30-day readmissions in England using routine hospital data 2004–2010: what is the scope for reduction?. *Emergency Medicine Journal*, 32,44–50. doi:10.1136/emermed-2013-202531
Brekke, K., Gravelle, H, Siciliani, L., Straume, O. (2014). Patient choice, mobility and competition among health care providers, In R. Levaggi and M. Montefiori (eds.), *Health Care Provision and Patient Mobility, Developments in Health Economics and Public Policy*, 12, DOI: 10.1007/978-88-470-5480-6_1, Springer-Verlag.
Brekke, K., Siciliani, L., Straume, O.R. (2008). Competition and waiting times in hospital markets. *Journal of Public Economics*. 92, 1607-1628.
Brekke, K., Siciliani, L., Straume, O.R., (2011). Hospital competition and quality with regulated prices. *Scandinavian Journal of Economics*, 113, 444-469.
Brekke, K. R., Siciliani, L., & Straume, O. R. (2012). Quality competition with profit constraints. *Journal of Economic Behavior & Organization*, 84(2), 642-659.
Burn, E., Edwards, C., Murray, D., Silman, A., Cooper, C., Arden, N., Pinedo-Villaneuva, R., Prieto-Alhambra, D. (2018). Trends and determinants of length of stay and hospital reimbursement following knee and hip replacement: evidence from linked primary care and NHS hospital records from 1997 to 2014. *BMJ* Open doi:10.1136/bmjopen-2017-019146.
Cameron, A. , Miller, D. (2015). A practitioner’s guide to cluster-robust inference. *Journal of Human Resources*, 50(2), 317-372.
Card, D. (1992). Using regional variation in wages to measure the effects of the federal minimum wage. *Industrial and Labor Relations Review*, 46(1), 22-37.
Charlson, M., Pompei, P., Ales, K., MacKenzie, C. (1987). A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *Journal of Chronic Diseases*, 40(5), 373-383.
Colla, C., Bynum, J., Austin, A., Skinner, J. (2016). Hospital Competition, Quality, and Expenditures in the US Medicare Population. NBER Working Papers 22825, National Bureau of Economic Research.
Cooper, Z., Gibbons, S., Jones, S., McGuire, A. (2011). Does hospital competition save lives? Evidence from the English NHS patient choice reforms. *The Economic Journal,* 121(554), F228-F260.
Cooper, Z., Gibbons, S., Skellern, M. (2018). Does competition from private surgical centres improve public hospitals’ performance? Evidence from the English National Health Service. *Journal of Public Economics*, 166, 63-80.
Department of Health (2000). *The NHS Plan: A Plan for Investment, A Plan for Reform*. Cm 4818-I. The Stationery Office, London.
Department of Health (2002). *Delivering the NHS Plan*. Cm 5503. The Stationery Office, London.

Department of Health (2004). *The NHS Improvement Plan: Putting People at the Heart of Public Services* Cm 6268). The Stationery Office, London.

Department of Health (2006). *The Government's Response to the Health Committee's Report on Independent Treatment Centres*. Cm 6930, The Stationery Office, London.

Dixon, J. (2004). Payment by results—new financial flows in the NHS: the risks are large but may be worth while because of potential gains. *BMJ: British Medical Journal*, 328(7446), 969.

Dixon, A., Robinson, R., Appleby, J., Burge, P., Devlin, N., Magee, H. (2010). *Patient Choice: How Patients Choose and How Providers Respond*. King's Fund. London.

Dusheiko, M., Gravelle, H. (2018). Choosing and booking – and attending? Impact of an electronic booking system on outpatient referrals and non-attendances. *Health Economics.* 27(2), 357-371. DOI:10.1002/hec.3552.

EXPH - Expert Panel on Effective Ways of Investing in Health (2015). *Investigating Policy Options regarding Competition among Providers of Health Care Services in EU Member States*. European Union, http://ec.europa.eu/health/expert_panel/ index_en.htm.

Epstein, A. M., Stern, R. S., Weissman, J. S. (1990). Do the poor cost more? A multihospital study of patients' socioeconomic status and use of hospital resources. *New England Journal of Medicine*, 322(16), 1122-1128.

Feng, Y., Pistollato, M., Charlesworth, A., Devlin, N., Propper, C., Sussex, J. (2015). Association between market concentration of hospitals and patient health gain following hip replacement surgery. *Journal of Health Services Research & Policy*, 20(1), 11–17.

Gaynor, M. (2006). What do we know about competition and quality in health care markets? National Bureau of Economic Research. Working Paper w12301.

Gaynor, M., Moreno-Serra, R., Propper, C. (2013). Death by market power: reform, competition, and patient outcomes in the National Health Service. *American Economic Journal: Economic Policy,* 5(4), 134-166.

Gaynor, M., Propper, C., Seiler, S. (2016). Free to choose? reform, choice, and consideration sets in the English National Health Service. *American Economic Review,* 106(11), 3521-3557.

Geweke, J., Gowrisankaran, G., Town, R. (2003). Bayesian inference for hospital quality in a selection model. *Econometrica,* 71(4), 1215-1238.

Gowrisankaran, G., Town, R. (1999). Estimating the quality of care in hospitals using instrumental variables. *Journal of Health Economics,* 18(6), 747-767.

Grašič, K., Mason, A. R., Street, A. (2015). Paying for the quantity and quality of hospital care: the foundations and evolution of payment policy in England. *Health Economics Review*, 5(1), 15.

Gravelle, H., Santos, R., Siciliani, L. (2014). Hospital quality competition under fixed prices. *Regional Science and Urban Economics*, 49, 203-216.

Gravelle, H., Schroyan, F. (2020). Optimal hospital payment rules under rationing by waiting. *Journal of Health Economics*, 70, March. doi.org/10.1016/j.jhealeco.2019.102277

Greene, W. (2004). The behaviour of the maximum likelihood estimator of limited dependent variable models in the presence of fixed effects. *The Econometrics Journal*, 7(1), 98-119.

Gutacker, N., Siciliani, L., Moscelli, G., Gravelle, H., (2016). Choice of hospital: which type of quality matters? *Journal of Health Economics*, 50, 230–246.

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica*, 1251-1271.

Hausman, J. (2001). Mismeasured variables in econometric analysis: problems from the right and problems from the left. *Journal of Economic Perspectives*, 15(4), 57-67.

Hawkes, N. (2012). Private hospitals look to NHS for elective operations as private medical insurance falls. *BMJ: British Medical Journal (Online)*, 345.

Heckman, J. (1979). Sample selection bias as a specification error. *Econometrica*, 47(1), 153-161. doi:10.2307/1912352.

HSCIC (2016). *Compendium of Population Health Indicators*. https://files.digital.nhs.uk/C4/E99638/Spec_03K_520ISR7G.pdf.

Katz, M. L. (2013). Provider competition and healthcare quality: More bang for the buck?. *International Journal of Industrial Organization*, 31(5), 612-625.

Kessler, D., McClellan, M. (2000). Is hospital competition socially wasteful? *The Quarterly Journal of Economics,* 115(2), 577-615.

Kessler, D., Geppert, J. (2005). The effects of competition on variation in the quality and cost of medical care. *Journal of Economics and Management Strategy*, 14(3), 575-589.

Kristensen, S. (2017). Financial penalties for performance in health care. *Health economics*, 26(2), 143-148.

Lancaster, T. (2000). The incidental parameter problem since 1948. *Journal of Econometrics*, 95(2), 391-413.

Le Grand, J. (2003). *Motivation, Agency, and Public Policy: Of Knights & Knaves, Pawns & Queens*. Oxford University Press.

Lindsay, C., Feigenbaum, B. (1984). Rationing by waiting lists, *American Economic Review* 74, 404-417.

Marini, G., Miraldo, M., Jacobs, R., Goddard, M. (2008). Giving greater financial independence to hospitals—does it make a difference? The case of English NHS trusts. *Health Economics*, 17(6), 751-775.

Martin, S., & Smith, P. (1996). Explaining variations in inpatient length of stay in the National Health Service. *Journal of Health Economics*, 15(3), 279-304.

Mason, A., Street, A., Verzulli, R. (2010). Private sector treatment centres are treating less complex patients than the NHS. *Journal of the Royal Society of Medicine* 103 (8), 322–331.

McClellan, M., McNeil, B., Newhouse, J. (1994). Does more intensive treatment of acute myocardial infarction in the elderly reduce mortality? Analysis using instrumental variables. *Journal of the American Medical Association*, 272(11), 859-866.

McFadden, D. (1974). Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.) *Frontiers in Economics*, vol. 4. Academic Press, New York, pp. 105–142.

McGuire, T. (2000). Physician agency. In A. Culyer and J. Newhouse (eds). *Handbook of Health Economics*, Volume 1A. North-Holland. Amsterdam.

Meyer, B. (1995). Natural and quasi-experiments in economics, *Journal of Business and Economic Statistics*, 13, 151–161.

Monitor (2013). A guide to the Market Forces Factor. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/300859/A_guide_to_the_Market_Forces_Factor.pdf.

Moscelli, G., Siciliani, L., Gutacker, N., Gravelle, H. (2016). Location, quality and choice of hospital: evidence from England 2002-2013. *Regional Science and Urban Economics,* 60, 112-124.

Moscelli, G., Siciliani, L., Gutacker, N., Cookson, R. (2018a). Socioeconomic inequality of access to healthcare: Does choice explain the gradient?. *Journal of Health Economics*, 57, 290-314.

Moscelli, G., Gravelle, H., Siciliani, L., Santos, R. (2018b). Heterogeneous effects of patient choice and hospital competition on mortality. *Social Science & Medicine*, 216, 50-58.

Moscelli, G., Gravelle, H., Siciliani, L., Gutacker, N. (2018c). The effect of hospital ownership on quality of care: evidence from England. *Journal of Economic Behavior & Organization*, 153, 322-344.

Moulton, B. (1990). An illustration of a pitfall in estimating the effects of aggregate variables on micro units. *Review of Economics and Statistics*, 334-338.

Mukamel, D., Zwanziger, J., Tomaszewski, K.J. (2001). HMO penetration, competition and risk-adjusted hospital mortality. *Health Services Research*, 36, 1019-1035.

Murphy, K., Topel, R. (1985). Estimation and inference in two-step econometric models. *Journal of Business and Economic Statistics*, 3(4), 370-379.

Naylor, C., Gregory, S. (2009). *Independent Sector Treatment Centres*. King's Fund.

Newey, W. , McFadden, D. (1994). Large sample estimation and hypothesis testing. In Engle, R., McFadden, D. (eds.), *Handbook of Econometrics Vol. IV,* 2111-2245.

Newhouse, J., McClellan, M. (1998). Econometrics in outcomes research: the use of instrumental variables. *Annual Review of Public Health*, 19(1), 17-34.

NICOR (2012). National Adult Cardiac Surgery Audit Report. Annual Report 2010–2011. https://www.ucl.ac.uk/nicor/audits/adultcardiac/documents/reports/annualreport2010-11.

Nikolova, S., Harrison, M., Sutton, M. (2015). The impact of waiting time on health gains from surgery: evidence from a national patient-reported outcome dataset. *Health Economics*, 25, 955-968.

OECD (2012). Competition in Hospital Services, OECD Policy Roundtables, Directorate for Financial and Enterprise Affairs Competition Committee; available at www.oecd.org/daf/competition/50527122.pdf.

OECD (2019). *OECD Health Statistics 2019*. http://www.oecd.org/els/health-systems/health-data.htm

Oster, E. (2019). Unobservable selection and coefficient stability: theory and evidence. *Journal of Business & Economic Statistics*, 37, 2, 187-204

Pollock, A., Macfarlane, A., Kirkwood, G., Majeed, A., Greener, I., Morrelli, C., Boyle, S., Mellett, H., Godden, S., Price, D., Brhlikova, P. (2011a). No evidence that patient choice in the NHS saves lives. *The Lancet*, 378, December 17/24/31, 2057-2060.

Pollock, A., Majeed, A., Macfarlane, A., Greener, I., Kirkwood, G., Mellett, H., Godden, S., Boyle, S., Morrelli, C., Brhlikova, P. (2011b). Authors' reply. *The Lancet*, 378, December 17/24/31, 2065-2066.

Propper, C., Burgess, S., Green, K. (2004). Does competition between hospitals improve the quality of care? Hospital death rates and the NHS internal market, *Journal of Public Economics*, 88, 1247-1272.

Propper, C., Burgess, S., Gossage, D. (2008). Competition and quality: evidence from the NHS internal market 1991-9. *The Economic Journal*, 118, 138-170.

Propper, C., Sutton, M., Whitnall, C., Windmeijer, F. (2010). Incentives and targets in hospital care: evidence from a natural experiment. *Journal of Public Economics*, 94 (3), 318–335.

Reichert, A., Jacobs, R. (2018). The impact of waiting time on patient outcomes: Evidence from early intervention in psychosis services in England. *Health Economics*, 27(11), 1772-1787.

Sa, L., Straume, O.R., Siciliani, L. (2019). Dynamic Hospital Competition under Rationing by Waiting Times, *Journal of Health Economics*, 66, 260-282.

Shen, Y. (2003). The effect of financial pressure on the quality of care in hospitals. *Journal of Health Economics*, 22, 243-269.

Siciliani, L., Borowitz, V. Moran (2013), Waiting Time Policies in the Health Sector: What Works?, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264179080-en.

Siciliani, L.,Chalkley, M., Gravelle, H. (2017). Policies towards hospital and GP competition in five European countries. *Health Policy*, 121, 103-110.

Skellern, M. (2018). The hospital as a multi-product firm: The effect of hospital competition on value-added indicators of clinical quality. Centre for Economic Performance Research Paper *CEPDP* 1484.

Sudell, A. J., Horner, J. S., Jolly, U., & Pain, C. H. (1991). Length of stay in general medical beds; implications for the NHS White Paper of variance within one performance indicator. *Journal of Public Health*, 13(2), 88-95.

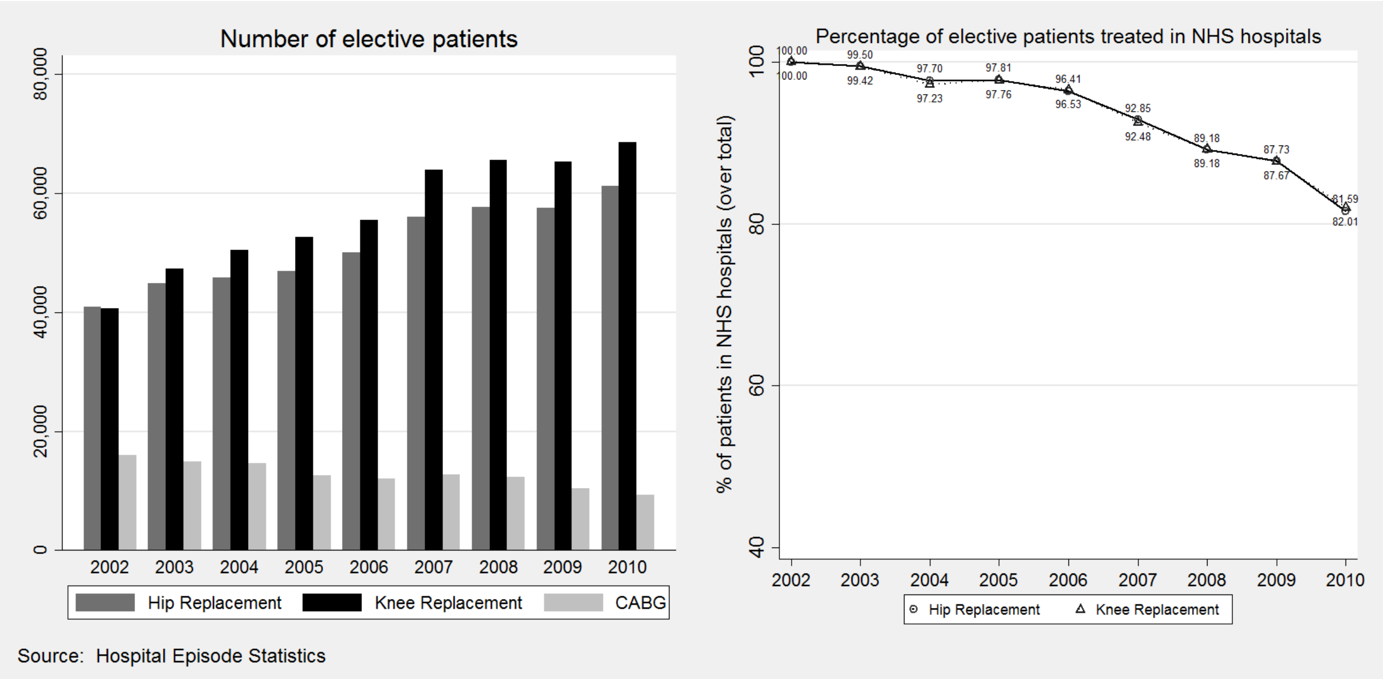
Terza, J. V., Basu, A., Rathouz, P.J. (2008). Two-stage residual inclusion estimation: addressing endogeneity in health econometric modeling. *Journal of Health Economics,* 27(3), 531-543.

Weissman, J., Ayanian, J., Chasan-Taber, S., Sherwood, M., Roth, C., Epstein, A. (1999). Hospital readmissions and quality of care. *Medical Care*, 37(5), 490-501.
Wilson, N., (2016). Market structure as a determinant of patient care quality. *American Journal of Health Economics,* 2(2), 241-271.
Wooldridge, J. (2015). Control function methods in applied econometrics. *Journal of Human Resources*, 50(2), 420-445.

Acknowledgements

The work reported in this study is based on independent research commissioned by the NIHR Policy Research Programme from the Policy Research Unit in the Economics of Health and Social Care Systems: Ref 103/0001. The views expressed are those of the authors and not necessarily those of the ESRC, the NHS, the NIHR, the Department of Health, arm's length bodies or other government departments. Hospital Episode Statistics are Copyright 2002-2019, re-used with the permission of NHS Digital. All rights reserved. We are grateful for comments received at seminars at Imperial College, the Universities of Duisburg-Essen, Oxford and York, the European Health Economics Association conference (Hamburg, July 2016), the International Association of Applied Econometrics conference (Montreal, June 2018) and the Royal Economics Society annual conference (Warwick, April 2019).

Figure 1. Trends in NHS-funded elective hip and knee replacement, CABG procedures.



Notes. "Patients" are NHS-funded patients here and in all other figures and tables unless stated otherwise.

Figure 2. Choice of Hospital by Distance from Patient's Residence.

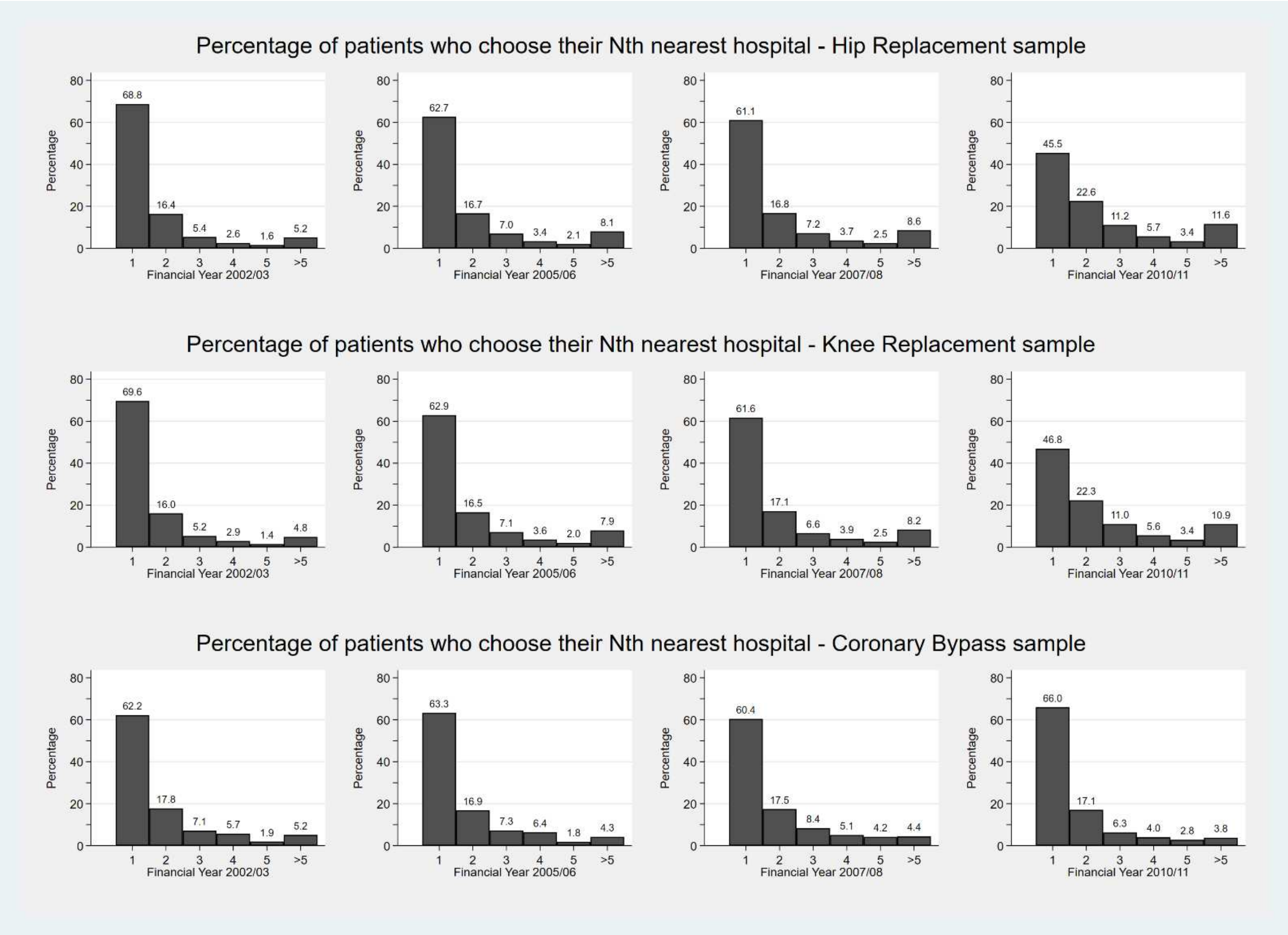
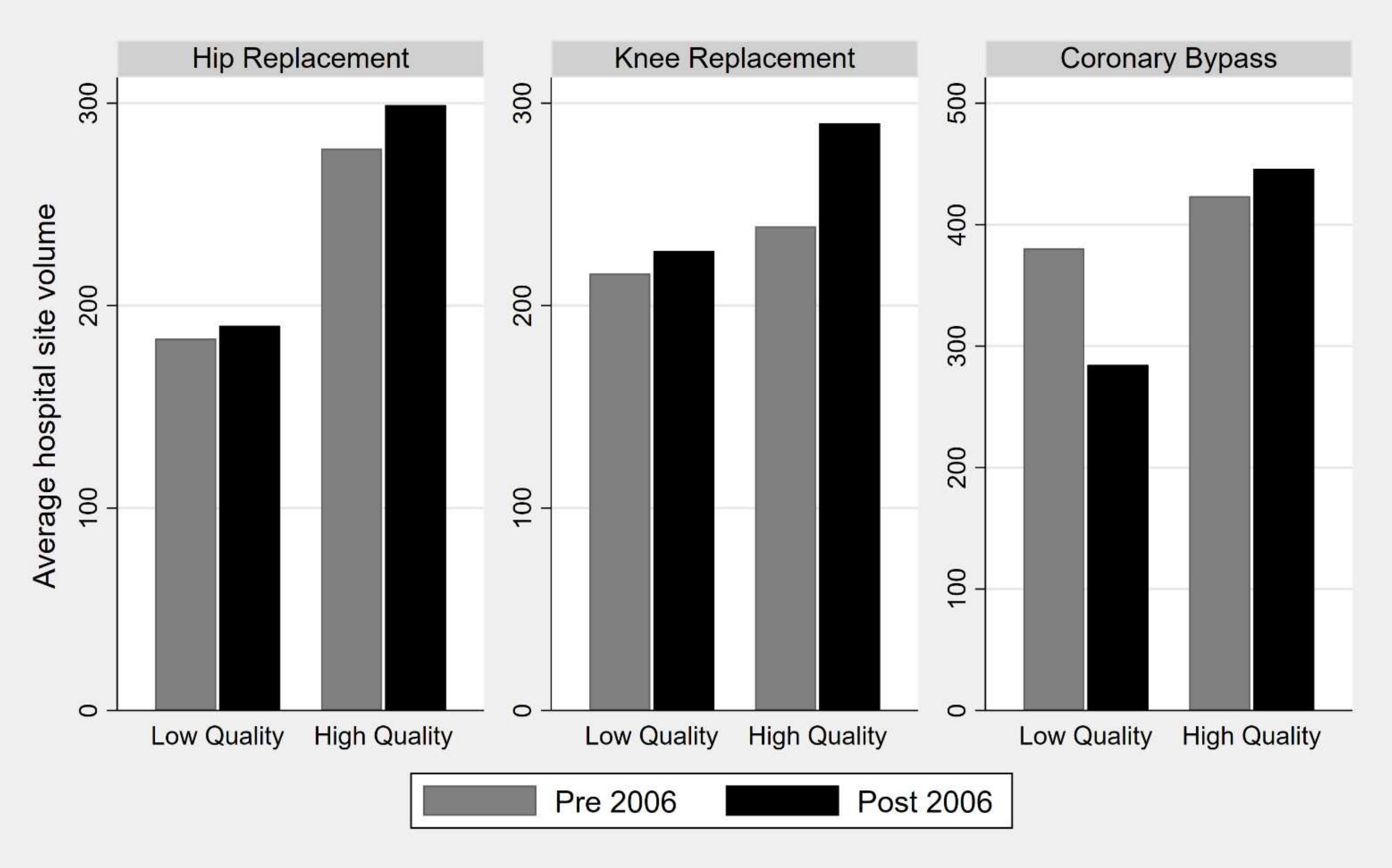
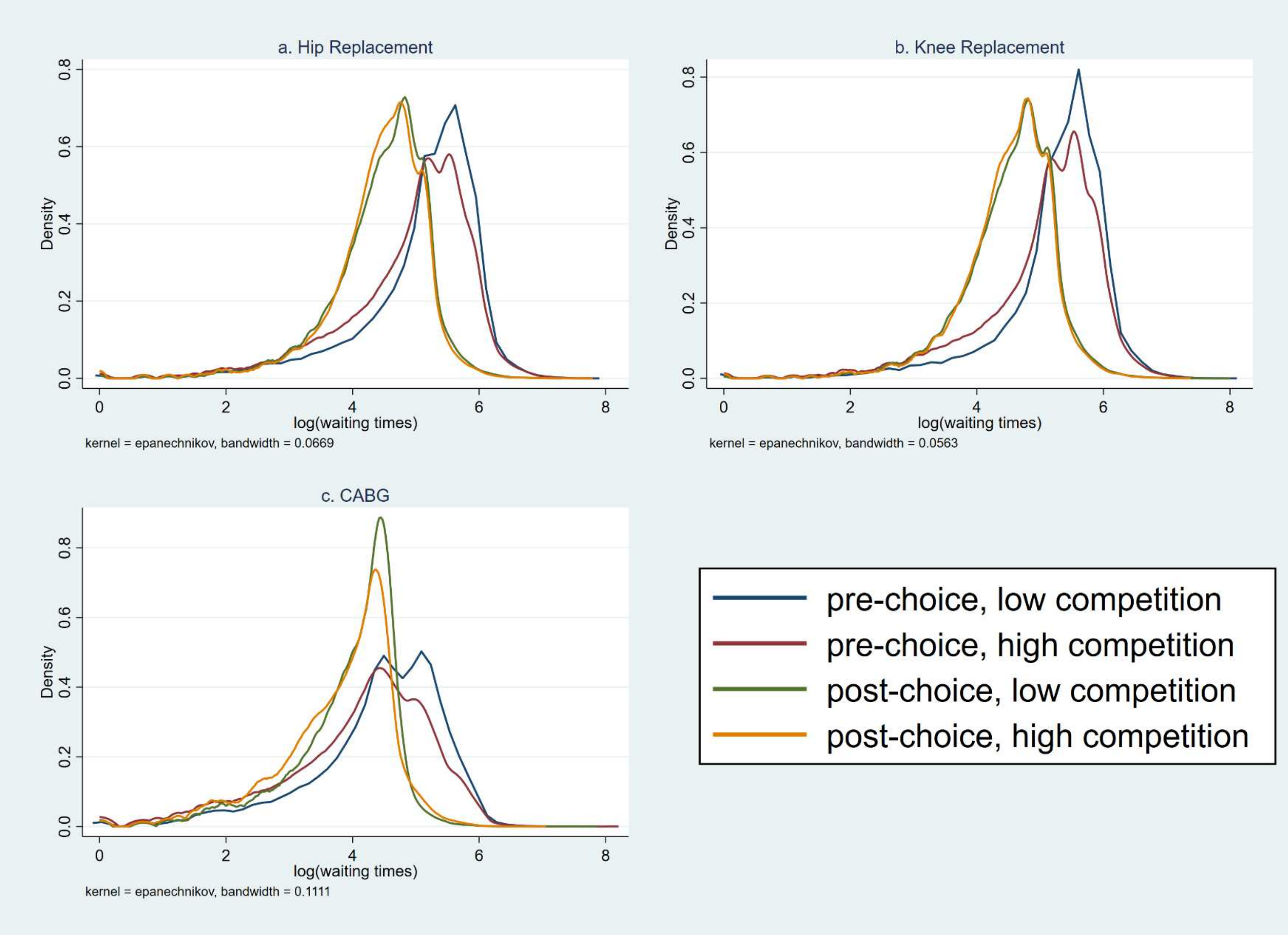


Figure 3. Patient volume at low and high quality providers pre and post choice reform.



Notes. NHS hospital sites only. Hospital sites are classified as High Quality if their risk-adjusted quality indicator (28 days emergency readmission rates for hip and knee replacements; 30 day mortality rates for coronary bypass) was above median quality.

Figure 4. **Change in Volume in High and Low Quality Providers.**



Notes. Competition is defined, consistently with Eq. (6), as the average of the pre-2006 inverse HHI. High competition = 3rd tercile of the inverse HHI distribution (i.e. large number of equivalent sized rivals in the market); Low competition = 1st and 2nd terciles.

Table 1. Patient-level descriptive statistics.

	Hip replacement patients				Knee replacement patients				CABG patients			
	pre-Choice		*post-Choice*		*pre-Choice*		*post-Choice*		*pre-Choice*		*post-Choice*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outcomes												
Emergency readmission within 28 days	0.0574	0.2326	0.0570	0.2319	0.0169	0.1290	0.0207	0.1423	0.0399	0.1958	0.0422	0.2010
Died within 30-days (anywhere)	0.0033	0.0573	0.0021	0.0461	0.0028	0.0532	0.0019	0.0431	0.0120	0.1089	0.0105	0.1017
Length of in-hospital stay	9.87	9.73	7.06	7.81	9.67	9.10	6.98	7.64	9.39	7.34	8.90	6.80
In-hospital waiting times	207.16	141.46	106.14	72.84	229.58	149.46	112.69	78.79	107.55	94.29	58.25	45.19
Logarithm of in-hospital waiting times	5.02	0.95	4.44	0.75	5.16	0.90	4.51	0.72	4.21	1.14	3.74	0.93
Patient characteristics												
Emergency admissions in year before treatment	0.06	0.29	0.07	0.31	0.06	0.28	0.06	0.30	0.26	0.63	0.31	0.67
Age	68.28	10.60	68.27	10.86	70.42	9.03	69.77	9.34	64.83	8.95	65.91	9.33
Female	0.60	0.49	0.60	0.49	0.58	0.49	0.58	0.49	0.19	0.39	0.18	0.38
Number of diagnoses on admission	2.54	1.77	3.23	2.15	2.61	1.78	3.37	2.15	4.88	2.61	6.55	3.05
Charlson Index	0.21	0.55	0.33	0.69	0.24	0.56	0.36	0.68	0.56	0.85	0.70	0.98
Charlson Index: zero co-morbidities	0.83	0.37	0.76	0.43	0.81	0.39	0.72	0.45	0.60	0.49	0.54	0.50
Charlson Index: one co-morbidity	0.13	0.34	0.18	0.39	0.16	0.37	0.22	0.41	0.29	0.45	0.31	0.46
Charlson Index: more than one co-morbidity	0.03	0.17	0.06	0.23	0.03	0.18	0.06	0.24	0.11	0.32	0.15	0.36
IMD income deprivation	0.12	0.10	0.13	0.10	0.13	0.10	0.14	0.11	0.14	0.11	0.15	0.11
IMD living environment	18.82	14.66	18.52	14.67	19.54	15.11	19.39	15.26	20.57	15.99	20.26	15.94
Incapacity claims	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.04	0.02	0.04	0.02
Disability claims	0.05	0.03	0.05	0.03	0.05	0.03	0.05	0.03	0.05	0.03	0.05	0.03
Distance to A&E type 1 hospital (km)	9.24	8.00	9.24	8.00	8.72	7.76	8.56	7.62	7.97	7.26	8.32	7.54
Differential distance closest NHS vs Private	-69.82	71.15	-25.51	36.28	-42.39	68.30	-15.73	33.04	.	.	.	.
Distance to closest NHS hospital site (km)	11.95	9.71	13.10	10.43	16.51	21.21	16.79	25.33	.	.	.	.
Distance to closest Private hospital site (km)	81.77	71.02	38.61	36.39	58.90	65.37	32.52	32.12	.	.	.	.
Distance to chosen hospital site (km)	12.90	17.94	14.68	24.33	11.97	16.68	13.73	24.58	34.18	41.44	31.44	32.17

Notes. Non-emergency NHS funded patients treated in financial years 2002/3 to 2010/11 in NHS hospital sites only. Number of patients are: 414,433 (hip replacement); 463,953 (knee replacement); 114,291 (CABG). Pre-choice period: financial years 2002/3 to 2005/6. Post-choice period: financial years 2006/7 to 20010/11.

Table 2. Correlations of Risk-Adjusted Hospital Elective and Emergency Quality.

		Readmissions			Mortality	
		Elective hip	Elective knee	Elective CABG	Elective CABG	Emergency AMI
Readmissions	Elective knee	0.2832***	1			
	Elective CABG	-0.097	0.037	1		
Mortality rate	Elective CABG	-0.132*	0.068	0.172***	1	
	Emergency AMI	*0.018*	*-0.060***	*-0.094*	*0.203****	1
	Emergency hip fracture	*0.025*	*-0.054***	*0.024*	*0.181***	*0.205****

Notes. Readmissions: risk-adjusted emergency readmission rate within 28 days of discharge. Mortality: risk-adjusted mortality rate within 30 days from index admission. NHS hospital sites, 2002/3 to 2010/11. We follow HSCIC methodology in risk adjusting for patient casemix (HSCIC, 2015). We estimate risk-adjusted emergency readmissions (or CABG mortality) based on a logit model and controlling for Charslon index co-morbidities, number of diagnosis, age groups, gender, interactions of age groups with gender, income deprivation at LSOA level, day of the week, month and year of admission. * p<0.10, ** p<0.05, *** p<0.01

Table 3. Market Structure Measures.

	2002/3-2005/6				2006/7-2010/11			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Equivalent number hospital sites within 30km								
All planned admissions	3.33	2.43	1	12.99	3.93	2.64	1	13.78
Circulatory system admissions	3.42	2.49	1	12.32	3.90	2.74	1	12.15
Musculoskeletal admissions	2.71	1.87	1	9.93	3.34	2.06	1	10.93
Hip Replacement admissions	1.60	0.78	1	4.59	1.88	0.99	1	5.50
Knee Replacement admissions	1.61	0.75	1	4.40	1.88	0.85	1	4.68
CABG admissions	2.03	1.40	1	5.04	2.00	1.44	1	4.91
Number NHS & private sites within 30km	14.56	16.90	0	63	17.17	19.62	0	76
Number private sites within 30km	0.14	0.42	0	2	1.66	2.11	0	12
HHI within 30km - Circulatory system admissions	0.46	0.28	0.08	1	0.41	0.26	0.08	1
HHI within 30km - Musculoskeletal admissions	0.53	0.28	0.10	1	0.43	0.25	0.09	1

Notes. Equivalent number: inverse of the predicted Herfindahl-Hirschman Index. Sites are those treating at least 100 NHS funded elective patients per year.

Table 4. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality.

	FE model without covariates	FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers
	(1)	(2)	(3)	(4)
a. Hip Replacement Emergency Readmission (Patients: 412,464; hospital sites: 232)				
Post-Choice Policy * Market Structure	0.0020**	0.0017**	0.0020	0.0021**
	(2.405)	(2.017)	(1.545)	(2.149)
joint Chi^2 test residuals coefficients=0			649.00	499.00
p-value joint χ2 test residuals coefficients=0			0.0000	0.0000
R^2	0.005	0.011	0.012	0.012
b. Knee Replacement Emergency Readmission (Patients: 461,594; hospital sites: 238)				
Post-Choice Policy * Market Structure	0.0007***	0.0005**	0.0011**	0.0011***
	(2.648)	(2.152)	(2.386)	(3.897)
joint Chi^2 test residuals coefficients=0			770.00	557.00
p-value joint χ2 test residuals coefficients=0			0.0000	0.0000
R^2	0.002	0.003	0.004	0.004
c. CABG Emergency Readmission (Patients: 112,844; hospital sites: 47)				
Post-Choice Policy * Market Structure	-0.0001	-0.0002	0.0001	-0.0004
	(-0.275)	(-0.417)	(0.236)	(-0.817)
joint Chi^2 test residuals coefficients=0			251.30	75.50
p-value joint χ2 test residuals coefficients=0			0.0000	0.0052
R^2	0.001	0.003	0.004	0.003
d. CABG Mortality (Patients: 114,291; hospital sites: 47)				
Post-Choice Policy * Market Structure	0.0001	-0.0001	-0.0002	-0.0004
	(0.195)	(-0.162)	(-0.250)	(-0.637)
joint Chi^2 test residuals coefficients=0			270.7	176.4
p-value joint χ2 test residuals coefficients=0			0.0000	0.0000
R^2	0.001	0.016	0.016	0.016

Notes. Dependent variable: patient in NHS provider had emergency readmission within 28 days from discharge following admission, or CABG patient in NHS provider died within 30 days. Choice Policy: indicator for 2006/7 onwards. Market structure: average of estimated equivalent number of rival hospital sites (= 1/(predicted HHI)) for patients in hospital specialty during period 2002/3 to 2005/6. Column (1) models include only hospital and year fixed effects; Column (2) as column (1) plus covariates. Column (3) as column (2) plus with residuals for all hospitals from linear first stage choice model. Column (4) as column (2) plus residuals for all hospitals from conditional logit first stage choice model. Financial years: 2002/3- 2010/11. *t*-statistics in parentheses are based on hospital site cluster-robust standard errors and in models including estimated residuals the standard errors are bootstrapped (1,000 replications). *p<0.1, ** p<0.05, *** p<0.01.

Table 5. Post Choice Reform Change in Effect of Pre-Reform Market Structure on Elective Quality: Alternative Market Structures.

	All admissions Predicted HHI			Procedure-based Predicted HHI			Number of rivals		
	FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers	FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers	FE model with covariates	Linear 2SRI residuals	CL 2SRI residuals for all providers
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
a. Hip Replacement Emergency Readmission (Patients: 412,464; hospital sites: 232)									
Post-Choice Policy * Market Structure	0.0012*	0.0009	0.0013	0.0043**	0.0053*	0.0051**	0.0002**	0.0003*	0.0003**
	(1.747)	(0.904)	(1.577)	(2.262)	(1.664)	(2.276)	(2.311)	(1.947)	(2.407)
joint Chi^2 test residuals coefficients=0		641	491		648.76	513.21		650.5	539.1
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
R^2	0.011	0.012	0.012	0.011	0.012	0.012	0.011	0.012	0.012
b. Knee Replacement Emergency Readmission (Patients: 461,594; hospital sites: 238)									
Post-Choice Policy * Market Structure	0.0004*	0.0007**	0.0008***	0.0015**	0.0031***	0.0031***	0.0001*	0.0002***	0.0001***
	(1.865)	(2.015)	(3.375)	(2.492)	(2.792)	(4.379)	(1.718)	(2.856)	(3.851)
joint Chi^2 test residuals coefficients=0		766	554		768.10	564.71		7676.0	563.4
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
R^2	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004
c. CABG Emergency Readmission (Patients: 112,844; hospital sites: 47)									
Post-Choice Policy * Market Structure	-0.0002	0.0001	-0.0004	0.0001	0.0016	-0.0002	-0.0000	-0.0000	-0.0001
	(-0.384)	(0.145)	(-0.828)	(0.119)	(1.324)	(-0.193)	(-0.538)	(-0.425)	(-1.353)
joint Chi^2 test residuals coefficients=0		247.2	75.48		253.30	76.22		254	77.57
p-value joint χ2 test residuals coefficients=0		0.0000	0.0053		0.0000	0.0045		0.0000	0.0033
R^2	0.003	0.004	0.003	0.003	0.004	0.003	0.003	0.004	0.003
d. CABG Mortality (Patients: 114,291; hospital sites: 47)									
Post-Choice Policy * Market Structure	-0.0000	-0.0001	-0.0003	0.0007	0.0016	0.0007	0.0000	0.0001	0.0000
	(-0.101)	(-0.211)	(-0.535)	(0.728)	(1.125)	(0.497)	(0.479)	(0.709)	(0.038)
joint Chi^2 test residuals coefficients=0		270	176		235.96	171.40		239.4	173.5
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000		0.0000	0.0000		0.0000	0.0000
R^2	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016

Notes. Dependent variable: patient in NHS provider had emergency readmission within 28 days from discharge following admission, or CABG patient in NHS provider died within 30 days. Choice Policy: indicator for 2006/7 onwards. Market structure: average of estimated equivalent number of rival hospital sites (= 1/(predicted HHI)) from patient flows in year 2002/3 to 2005/6. Market defined as: all elective patients (columns 1 to 3), all patients treated for the relevant elective procedure of admission (columns 4 to 6); the number of rivals within 30 km of treating hospital. Columns (2), (5), (8) use residuals from linear first stage choice models. Columns (3), (6), (9) models add residuals from conditional logit first stage choice model. Financial years: 2002/3- 2010/11. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table 6. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure with Effects of Covariates Varying Pre and Post-Reform.

	Hip Replacement - Emergency Readmissions	Knee Replacement - Emergency Readmissions	CABG - Emergency Readmissions	CABG - Mortality
	(1)	(2)	(3)	(4)
Post-Choice Policy * Market Structure	0.0023**	0.0013***	-0.0008	-0.0002
	(2.304)	(3.812)	(-1.275)	(-0.317)
joint χ^2 test residuals coefficients=0	505.5439	559.1953	79.7451	160.0936
joint χ^2 test Choice*covariates coefficients=0	63.6272	74.0259	282.5588	187.6139
R^2	0.012	0.004	0.004	0.017

Notes. CL 2SRI baseline model of Table 4 plus interactions of post-choice reform indicator with all covariates. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01._Results for models with hospitals fixed effects only or with hospitals fixed effects and Linear 2SRI are also similar to those in Table 4 and available from the authors upon request.

Table 7. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure, allowing for Selection into Private Providers.

Dependent variable	Hip Replacement Emergency Readmission	Knee Replacement Emergency Readmission	Hip Replacement Emergency Readmission	Knee Replacement Emergency Readmission
Specification	*Heckman selection model - sample of patients treated by NHS hospitals only*		*Baseline model - sample of patients treated by NHS and Private hospitals*	
	(1)	(2)	(3)	(4)
Post-Choice Policy * Market Structure	0.0021**	0.0011***	0.0021**	0.0011***
	(2.181)	(3.876)	(2.208)	(3.865)
IMR (Inverse Mills Ratio)	-0.0075	0.0010		
	(-1.221)	(0.334)		
joint Chi^2 test residuals coefficients=0	500.4340	549.3528	578.5689	538.6782
p-value joint χ2 test residuals coefficients=0	0.0000	0.0000	0.0000	0.0000
R^2	0.012	0.004	0.014	0.004
Patients	412,464	461,594	436,434	490,520
Hospital sites	232	238	277	288

Notes. Baseline model of Table 4 with CL 2SRI with (a) selection correction for choice of NHS provider (cols (1), (2)) or (b) estimated for all NHS patients treated in NHS or private providers (cols (3), (4)). Models in columns (1) and (2) include the IMR from a first stage probit regression of treatment in NHS hospital using the differential distance between closest NHS and closest private hospital sites plus patient's case-mix covariates. The first stage probit sample includes NHS-funded elective hip and knee replacement patients treated in both NHS and private providers. NHS + Private hip replacement sample: 436,950 patients in 279 hospital sites; NHS + Private knee replacement sample: 491,395 patients in 290 hospital sites. For models in columns (3) and (4), the sample includes NHS-funded planned hip and knee replacement patients treated in either NHS and Private providers. The small differences in the samples size compared with the first stage probit models in Appendix Table A4 arise because two private hospital sites with a missing competition measure did not have any close NHS hospital site rival within 30km, and so their patients were excluded from estimation.

Table 8. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure, allowing for Changing Number of Rival Private Hospitals.

	Hip Replacement Emergency Readmissions	Knee Replacement Emergency Readmissions	CABG Emergency Readmissions	CABG Mortality
	(1)	(2)	(3)	(4)
Post-Choice Policy * Market Structure	0.0021**	0.0010***	-0.0003	-0.0003
	(2.148)	(3.444)	(-0.525)	(-0.518)
Number of private hospital site within 30km	-0.0000	0.0002	-0.0007	-0.0004
	(-0.034)	(0.675)	(-0.850)	(-0.697)
joint χ^2 test residuals coefficients=0	498.5960	558.7277	76.3224	177.0431
R^2	0.012	0.004	0.003	0.016

Notes. Baseline model of Table 4 with CL 2SRI plus time varying number of private rivals sites. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01. Results for models with hospitals fixed effects only or with hospitals fixed effects and Linear 2SRI are similar to those in Table 4 and available from the authors upon request.

Table 9. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Waiting Times and Length of Stay

	Musculoskeletal		Circulatory system
	Hip Replacement	Knee Replacement	CABG
	(1)	(2)	(3)
Panel A. Effect of pre-reform market structure on logarithm of patient waiting time			
Post-Choice Policy * Market Structure	0.0540***	0.0647***	0.0209
	(3.558)	(4.044)	(0.785)
joint χ^2 test residuals coefficients=0	464.0301	523.3858	88.6372
p-value joint χ^2 test residuals coefficients=0	0.0000	0.0000	0.0002
R^2	0.237	0.289	0.182
Panel B. Effect of pre-reform market structure on patient in-hospital length of stay			
Post-Choice Policy * Market Structure	-0.1734***	-0.1191**	-0.0578
	(-2.606)	(-2.029)	(-0.477)
joint χ^2 test residuals coefficients=0	698.4368	594.4042	66.3769
p-value joint χ^2 test residuals coefficients=0	0.0000	0.0000	0.0327
R^2	0.192	0.169	0.129
Panel C. Effect of pre-reform market structure on mortality for emergency care			
	Hip fracture		AMI
Post-Choice Policy * Market Structure	-0.0022**		-0.0038***
	(-2.078)		(-2.804)
Patients	288,279		91,005
Sites	238		213

Notes. Models for waiting time and length of stay have same explanatories and specification as Table 4 model of emergency readmissions as do models for 30 day mortality for emergency hip fracture and AMI except that there are no choice residuals in the emergency admissions models. Competition is at speciality level (orthopaedics for hip and knee replacement and hip fracture, cardiovascular system for CABG and AMI). t-statistics in parentheses are based on hospital site cluster-robust standard errors. *p<0.1, ** p<0.05, *** p<0.01.

Appendix A. Additional descriptive statistics and results

Appendix B.

Appendix C: Theory model: competition, choice and quality.

Appendix A. Additional descriptive statistics and results

Figure A1. Volume of Elective CABG, Hip and Knee Replacement Operations in NHS Hospitals, Financial Years 2002/03-2010/11.

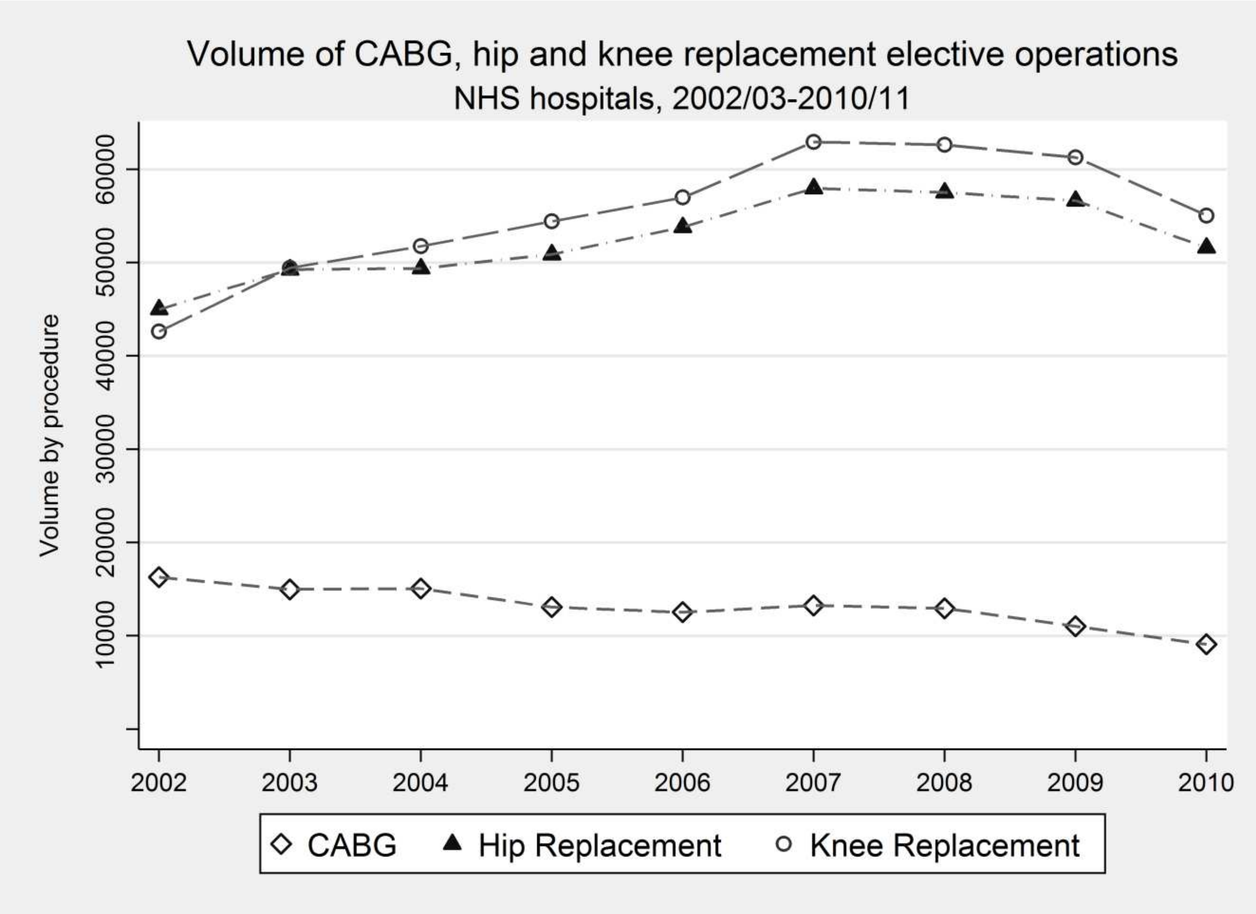
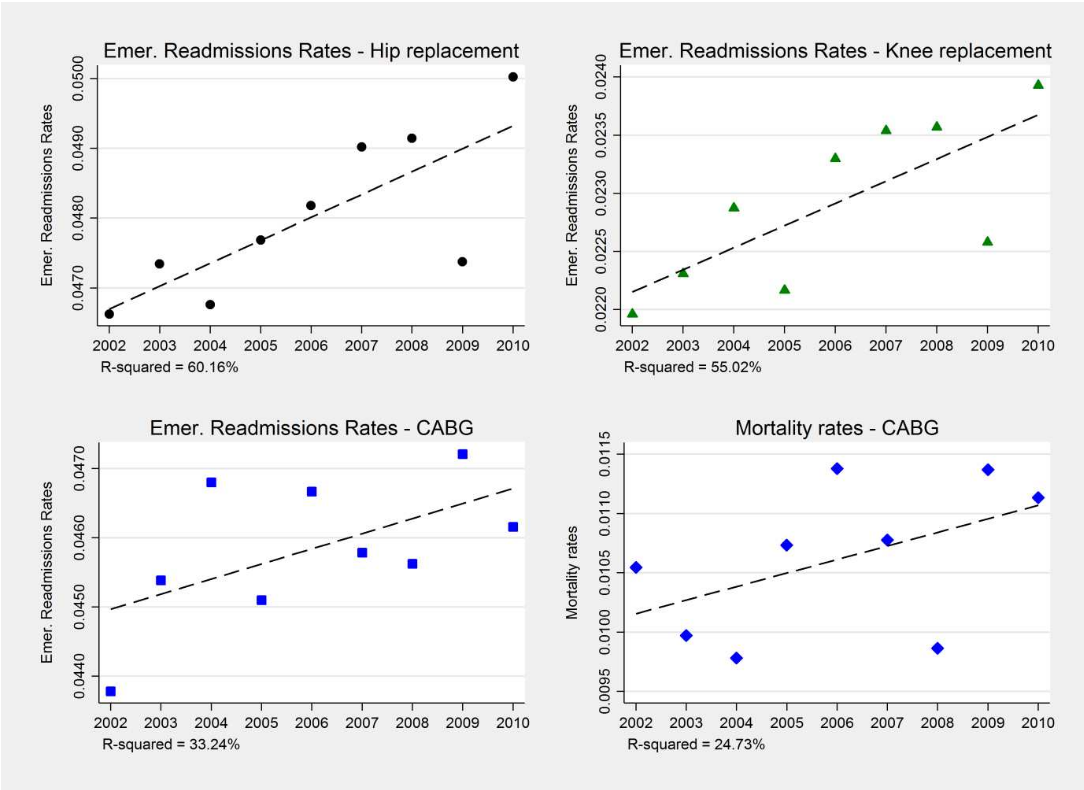


Figure A2. Trends in Risk-Adjusted Standardized Hospital Quality Measures.



Note: Data points plot from an OLS regression of the hospital quality measures (readmission or mortality rates) on years. Regression R^2 provided in the graphs.

Figure A3. Trends in Competition Measures.

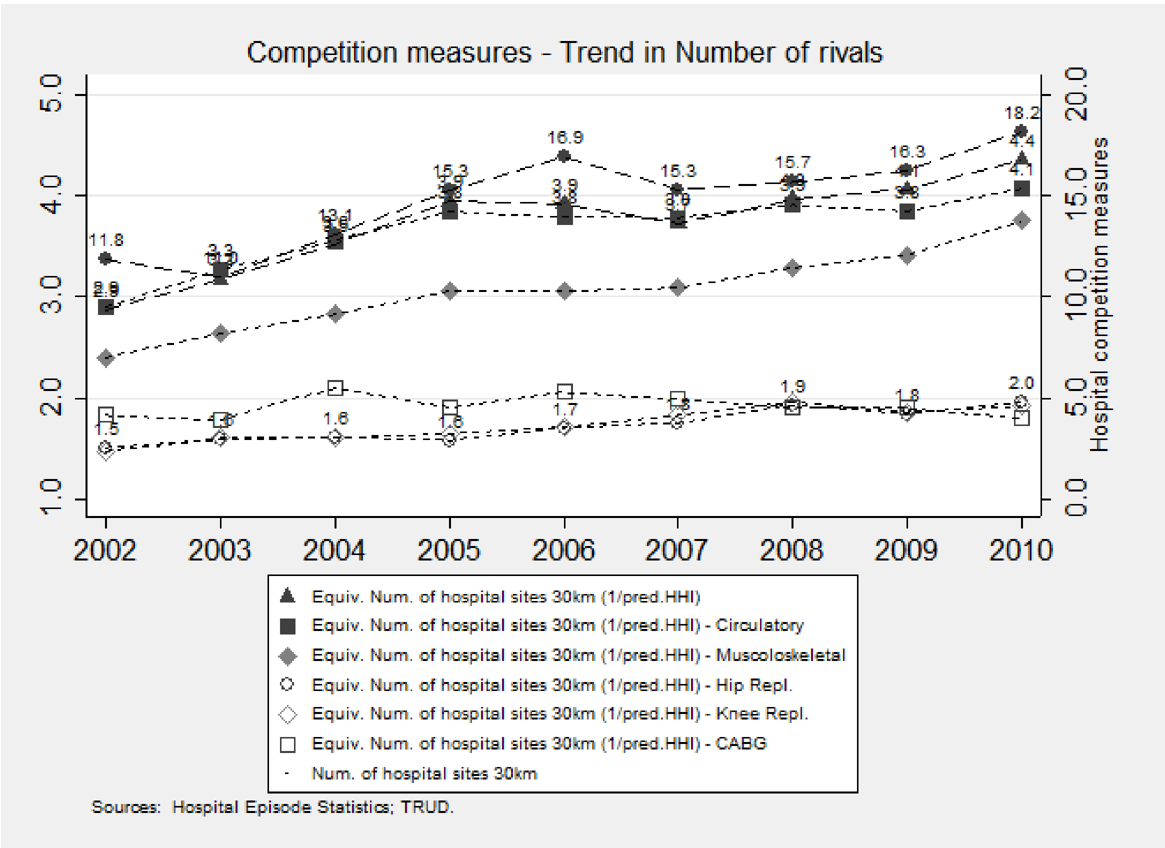


Table A1. Admissions by year, procedure and hospital ownership type.

	Hip Replacement			Knee Replacement			CABG
	Hospital of treatment			Hospital of treatment			
Financial year	NHS	Private	% Private	NHS	Private	% Private	NHS hospitals
2002/03	38,940	-	0.00%	38,583	-	0.00%	15,937
2003/04	42,813	-	0.00%	45,315	-	0.00%	14,647
2004/05	43,308	414	0.95%	47,682	659	1.36%	14,622
2005/06	43,749	590	1.33%	50,050	632	1.25%	12,563
2006/07	46,517	1,436	2.99%	52,599	1,725	3.18%	11,988
2007/08	50,120	3,692	6.86%	58,232	4,473	7.13%	12,634
2008/09	49,878	4,553	8.36%	57,548	5,567	8.82%	12,265
2009/10	48,807	5,667	10.40%	56,334	7,075	11.16%	10,363
2010/11	48,332	7,618	13.62%	55,251	8,795	13.73%	9,272
Total	412,464	23,970	5.81%	461,594	28,926	5.90%	114,291

Notes. NHS-funded patients admitted for non-emergency hip/knee replacement surgery in English hospital (hospitals with at least 100 admissions per financial year). NHS-funded CABG patients were treated almost exclusively by NHS hospitals: 196, 39 and 60 NHS funded CABG patients were treated by private providers in 2003, 2007 and 2008 and are excluded from our analysis.

Table A2. Correlations amongst Measures of Market Structure.

	Equiv. Num. of hospital sites within 30km					
	All elective admissions	Circulatory admissions	Musculoskeletal admissions	Hip Replacement admissions	Knee Replacement admissions	CABG admissions
Equiv. Num. of hospital sites within 30km						
Circulatory admissions	0.9707					
Musculoskeletal admissions	0.9692	0.9544				
Hip Replacement admissions	0.8495	0.8941	0.8568			
Knee Replacement admissions	0.8891	0.9120	0.9043	0.9335		
CABG admissions	0.8508	0.8814	0.8044	0.8745	0.7683	
Num. of NHS & ISP sites within 30km	0.7808	0.8551	0.7476	0.8939	0.7997	0.9020

Notes. Correlations are across sites and years. All correlations are significant at a p-value level of 1%.

Table A3. Differences in Main Variables by Market Structure.

Panel A. Pre-Reform Differences in Patient Outcomes and Characteristics by Market Structure

Elective Hip Replacement	Pre-2006 Market Structure below mean	Pre-2006 Market Structure above mean	Difference: Means	Difference: t-statistic	Difference: p-value
Emergency Readmissions	0.0617	0.0547	-0.0070	-2.6570	0.0085
Inpatient Waiting Time	215.5000	193.0000	-22.5000	-2.8660	0.0046
Length of Stay	9.8682	10.3673	0.4991	2.2942	0.0228
Past Year Emergency Readmissions	0.0591	0.0648	0.0057	1.6479	0.1009
Female Patient	0.6032	0.6045	0.0013	0.2708	0.7868
Patient Age	68.7923	67.6164	-1.1759	-4.9344	0.0000
Number of Diagnosis	2.5209	2.5126	-0.0083	-0.0799	0.9364
Charlson Index = 1	0.1339	0.1383	0.0043	0.5331	0.5946
Charlson Index > 1	0.0303	0.0341	0.0038	1.5153	0.1312
Elective Knee Replacement	Pre-2006 Market Structure below mean	Pre-2006 Market Structure above mean	Difference: Means	Difference: t-statistic	Difference: p-value
Emergency Readmissions	0.0432	0.0390	-0.0042	-0.9448	0.3511
Inpatient Waiting Time	108.1649	92.3649	-15.8000	-1.8212	0.0769
Length of Stay	9.6117	9.7881	0.1763	0.2112	0.8339
Past Year Emergency Readmissions	0.2628	0.2495	-0.0133	-0.6377	0.5277
Female Patient	0.1829	0.1847	0.0018	0.2636	0.7936
Patient Age	64.7421	64.8735	0.1314	0.4213	0.6760
Number of Diagnosis	4.9780	4.5455	-0.4325	-0.9211	0.3631
Charlson Index = 1	0.2872	0.2893	0.0021	0.0783	0.9380
Charlson Index > 1	0.1073	0.1257	0.0184	1.0394	0.3055
Elective CABG	Pre-2006 Market Structure below mean	Pre-2006 Market Structure above mean	Difference: Means	Difference: t-statistic	Difference: p-value
Emergency Readmissions	0.0177	0.0157	-0.0021	-2.1532	0.0325
Inpatient Waiting Time	244.2000	214.0000	-30.2000	-3.3215	0.0011
Length of Stay	9.6226	9.9273	0.3046	1.4558	0.1470
Past Year Emergency Readmissions	0.0537	0.0580	0.0043	1.6263	0.1054
Female Patient	0.5711	0.6050	0.0339	4.8747	0.0000
Patient Age	70.6897	69.9141	-0.7757	-4.6221	0.0000
Number of Diagnosis	2.5678	2.6290	0.0612	0.5312	0.5958
Charlson Index = 1	0.1548	0.1690	0.0142	1.4936	0.1368
Charlson Index > 1	0.0343	0.0378	0.0035	1.1948	0.2335

Panel B. Difference-in-Difference of patient severity variables

	Pre-2006 Low quality hospitals		Pre-2006 High quality hospitals		
	Baseline (Pre-2006 Mean)	Difference (Post-2006 Mean - Pre-2006 Mean)	Baseline (Pre-2006 Mean)	Difference (Post-2006 Mean - Pre-2006 Mean)	Difference-in-Difference
	Elective Hip Replacement Patients				
Number of diagnoses	2.6244	0.5812***	2.5152	0.8836***	0.3025**
	(0.0911)	(0.0914)	(0.0998)	(0.1232)	(0.1528)
Charlson Index	0.2108	0.1205***	0.2177	0.1159***	-0.0047
	(0.0093)	(0.0098)	(0.0117)	(0.0141)	(-0.0171)
Past Emergency Admissions	0.0577	0.0046**	0.0591	0.0127***	0.0080**
	(0.0018)	(0.002)	(0.0026)	(0.0028)	(0.0034)
Sample size	61,886	149,397	47,899	115,830	265,227
	Elective Knee Replacement Patients				
Number of diagnoses	2.6565	0.6145***	2.6138	0.9912***	0.3767**
	(0.103)	(0.0952)	(0.1238)	(0.1346)	(0.1643)
Charlson Index	0.2333	0.1211***	0.2506	0.1365***	0.0154
	(0.012)	(0.0106)	(0.0147)	(0.0144)	(0.0178)
Past Emergency Admissions	0.0547	0.0023	0.0562	0.0113***	0.0090***
	(0.0016)	(0.0015)	(0.0019)	(0.0022)	(0.0026)
Sample size	61,060	154,354	56,236	141,434	295,788

	Elective CABG Patients				
Number of diagnoses	5.0004	1.5005***	4.348	1.8005***	0.3
	(0.5216)	(0.3692)	(0.4603)	(0.2538)	(0.4381)
Charlson Index	0.5556	0.1007	0.5975	0.1297**	0.029
	(0.0483)	(0.0581)	(0.072)	(0.0563)	(0.0791)
Past Emergency Admissions	0.2693	0.0314**	0.2429	0.0519***	0.0206
	(0.01)	(0.0124)	(0.0161)	(0.0117)	(0.0167)
Sample size	19,137	34,055	17,483	31,821	65,876

Notes. Panel A: Patient characteristics are averaged at hospital site level in the pre-reform years 2002-2005. Panel B: ***, **, and * indicate significance at the 0.01, 0.05, and 0.1 percent critical level. Standard errors (in brackets) are clustered at hospital site level. Low (High) competition hospitals = 1st (3rd) tercile of pre-2006 hospital competition distribution.

Table A4. Summary of F-statistics for First Stage Linear Choice Models.

	CABG			Hip Replacement			Knee Replacement		
	1st stage F-stat	Shea Partial R^2	Adj. R^2	1st stage F-stat	Shea Partial R^2	Adj. R^2	1st stage F-stat	Shea Partial R^2	Adj. R^2
mean	1566.2	0.225	0.229	1977.2	0.107	0.108	2136.2	0.103	0.104
st. dev.	2029.3	0.186	0.185	1640.3	0.071	0.071	1806.5	0.070	0.070
min	23.7	0.009	0.012	11.1	0.001	0.001	11.1	0.001	0.001
max	11200.0	0.745	0.746	10200.0	0.395	0.396	10900.0	0.382	0.382
p1	23.7	0.009	0.012	310.5	0.020	0.020	334.4	0.019	0.020
p10	109.3	0.027	0.028	581.2	0.036	0.037	576.3	0.032	0.033
p25	316.9	0.074	0.078	888.7	0.055	0.057	926.1	0.051	0.053
p50	709.3	0.157	0.160	1525.9	0.091	0.091	1647.2	0.086	0.088
p75	2270.4	0.357	0.365	2465.1	0.137	0.139	2580.8	0.131	0.133
p90	3515.2	0.473	0.484	3921.7	0.203	0.204	4203.4	0.193	0.193
p99	11200.0	0.745	0.746	9271.4	0.372	0.372	10600.0	0.375	0.375

Note. The F-statistics are for the 230 linear first stage choice models (Equation (7)).

Table A5. Goodness of Fit Statistics for First Stage Conditional Logit Hospital Choice Model by Procedure.

	2002	2003	2004	2005	2006	2007	2008	2009	2010
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	a. Hip replacement sample								
Pseudo R-Squared	0.7133	0.6785	0.6583	0.6564	0.6571	0.6373	0.6186	0.6199	0.5711
Cragg & Uhler's R-Squared	0.9966	0.9954	0.9946	0.9945	0.9945	0.9936	0.9925	0.9926	0.9889
McFadden's adjusted R-Squared	0.7133	0.6784	0.6583	0.6563	0.6570	0.6372	0.6186	0.6198	0.5711
	b. Knee replacement sample								
Pseudo R-Squared	0.7201	0.6945	0.6612	0.6602	0.6731	0.6436	0.6215	0.6347	0.5825
Cragg & Uhler's R-Squared	0.9968	0.9960	0.9947	0.9947	0.9952	0.9939	0.9927	0.9934	0.9899
McFadden's adjusted R-Squared	0.7201	0.6945	0.6612	0.6602	0.6730	0.6436	0.6215	0.6347	0.5824
	c. CABG sample								
Pseudo R-Squared	0.6483	0.6181	0.6397	0.6736	0.6792	0.6612	0.6927	0.6917	0.6927
Cragg & Uhler's R-Squared	0.9902	0.9895	0.9902	0.9919	0.9923	0.9920	0.9936	0.9930	0.9930
McFadden's adjusted R-Squared	0.6482	0.6179	0.6396	0.6735	0.6791	0.6610	0.6926	0.6915	0.6925

Table A6. Test for Coefficient Stability and Unobservable Selection.

	OLS regression, no controls (1)	*Baseline FE model, no controls* (2)	*Bias-adjusted β* (3)
a. Hip Replacement - Emergency Readmissions			
R_{max} (δ=1, Π=1.3)		0.0047	0.0061
Post-Choice Policy * Market Structure	-0.0001	0.0020	0.0321
t-stat	-0.1943	3.8114	5.0020
p-value	0.8459	0.0001	0.0000
b. Knee Replacement - Emergency Readmissions			
R_{max} (δ=1, Π=1.3)		0.0017	0.0021
Post-Choice Policy * Market Structure	-0.0000	0.0007	0.1398
t-stat	-0.2892	2.4914	42.1388
p-value	0.7724	0.0127	0.0000
c. CABG - Emergency Readmissions			
R_{max} (δ=1, Π=1.3)		0.0011	0.0015
Post-Choice Policy * Market Structure	-0.0001	-0.0001	-0.0035
t-stat	-0.1788	-0.2744	-2.0811
p-value	0.8581	0.7838	0.0374
d. CABG - Mortality			
R_{max} (δ=1, Π=1.3)		0.0013	0.0017
Post-Choice Policy * Market Structure	-0.0001	-0.0001	-0.0137
t-stat	-0.1784	-0.2606	-0.0928
p-value	0.8584	0.7944	0.9260

Notes: estimates from linear regressions with bootstrapped standard errors with 1000 replications. Column (2) estimates: OLS regression with hospital fixed effects and financial years dummies only. Column (3) estimates from Oster (2019) coefficient stability procedure, obtained through the *psacalc* command in Stata.

Table A7. Post Choice Reform Change in Effect of Pre-Reform Speciality Market Structure on Elective Quality with Residuals from First Stage Conditional Logit Hospital Choice Model. Control Non-Linear Control Function Strategy (Full Results).

	Hip Replacement emergency readmissions	Knee Replacement emergency readmissions	CABG emergency readmissions	CABG mortality
	(1)	(2)	(3)	(4)
Choice Policy * Market Structure	0.0021**	0.0011***	-0.0004	-0.0004
	(2.149)	(3.897)	(-0.817)	(-0.637)
2002	-0.0002	-0.0023**	-0.0031	0.0052**
	(-0.074)	(-2.228)	(-1.074)	(2.243)
2003	-0.0016	-0.0005	-0.0040*	0.0037**
	(-0.805)	(-0.543)	(-1.700)	(1.963)
2004	-0.0017	-0.0020**	-0.0009	0.0021*
	(-0.987)	(-2.088)	(-0.329)	(1.707)
2006	-0.0045	-0.0008	-0.0007	0.0002
	(-1.476)	(-0.715)	(-0.236)	(0.077)
2007	-0.0099***	-0.0024**	0.0026	-0.0051*
	(-3.404)	(-1.969)	(0.673)	(-1.939)
2008	-0.0083***	-0.0018	-0.0007	-0.0042*
	(-2.626)	(-1.466)	(-0.175)	(-1.647)
2009	-0.0118***	0.0003	-0.0035	-0.0059**
	(-3.843)	(0.216)	(-0.966)	(-2.139)
2010	-0.0180***	0.0026*	-0.0008	-0.0133***
	(-5.538)	(1.895)	(-0.199)	(-4.559)
35-44 years old	-0.0219***	-0.0014	0.0035	-0.0067***
	(-11.373)	(-0.608)	(0.719)	(-4.616)
45-54 years old	-0.0183***	-0.0021**	-0.0023	-0.0072***
	(-13.969)	(-2.333)	(-1.157)	(-7.846)
55-64 years old	-0.0098***	-0.0020***	-0.0021	-0.0049***
	(-10.509)	(-3.785)	(-1.608)	(-5.846)
75-84 years old	0.0115***	0.0053***	0.0043**	0.0096***
	(10.887)	(10.099)	(2.056)	(7.439)
85-94 years old	0.0209***	0.0129***	-0.0134*	0.0339***
	(9.144)	(8.175)	(-1.769)	(3.426)
95 and over years old	0.0551***	0.0337*	-0.0284***	0.0065**
	(2.581)	(1.773)	(-8.011)	(2.473)
number of previous year emergency admissions	0.0196***	-0.0018***	-0.0016*	0.0021***
	(12.596)	(-2.718)	(-1.859)	(3.337)
Female	-0.0115***	-0.0027***	0.0040***	0.0056***
	(-15.101)	(-6.975)	(2.661)	(5.565)
Number of diagnosis	0.0043***	0.0013***	0.0017***	0.0033***
	(16.702)	(9.228)	(7.143)	(7.076)
Charlson Index = 1	0.0081***	0.0006	0.0027*	0.0012
	(6.865)	(0.965)	(1.763)	(1.043)
Charlson Index > 1	0.0145***	0.0013	0.0056***	0.0152***
	(6.549)	(1.231)	(2.748)	(8.888)
IMD 2002/07/10 income domain	0.0058	0.0073*	0.0273***	-0.0015
	(0.742)	(1.646)	(2.996)	(-0.265)
IMD 2002/07/10 living environment domain	0.0001***	0.0000*	0.0000	0.0000*
	(2.890)	(1.687)	(0.122)	(1.680)
Incapacity claims %	-0.1606***	-0.0506*	-0.1662**	0.0246
	(-3.051)	(-1.957)	(-2.546)	(0.572)
Disability claims %	0.2071***	0.0426**	0.1053**	-0.0317
	(5.336)	(2.139)	(2.133)	(-1.043)
Teaching hospital	-0.0022	-0.0045	0.0105	0.0090**
	(-0.367)	(-1.568)	(1.170)	(2.347)
Foundation Trust hospital	-0.0003	0.0002	-0.0011	0.0018
	(-0.131)	(0.285)	(-0.448)	(1.013)
patient distance from A&E type1 hospital	-0.0003***	-0.0001*	-0.0001*	0.0000
	(-4.272)	(-1.738)	(-1.846)	(0.293)
admitted on Sunday	0.0014	0.0001	0.0003	0.0005
	(0.931)	(0.188)	(0.214)	(0.462)
admitted on Tuesday	0.0001	0.0002	0.0029	0.0004
	(0.075)	(0.351)	(1.470)	(0.336)
admitted on Wednesday	-0.0003	0.0011	-0.0015	0.0011
	(-0.196)	(1.571)	(-0.808)	(1.050)
admitted on Thursday	0.0003	0.0002	-0.0031	0.0001
	(0.268)	(0.260)	(-1.445)	(0.047)
admitted on Friday	0.0005	-0.0011	-0.0020	0.0025**
	(0.372)	(-1.370)	(-0.716)	(2.225)
admitted on Saturday	0.0001	0.0029**	0.0005	0.0050**
	(0.043)	(2.550)	(0.131)	(2.028)
admitted in in February	0.0037**	-0.0021**	0.0069***	-0.0011

	(2.119)	(-2.125)	(2.638)	(-0.968)
admitted in in March	0.0006	-0.0011	0.0057***	0.0010
	(0.319)	(-1.102)	(2.672)	(0.571)
admitted in in April	0.0072***	0.0000	0.0120***	0.0028*
	(3.818)	(0.015)	(4.095)	(1.935)
admitted in in May	0.0062***	0.0004	0.0154***	0.0041**
	(3.187)	(0.362)	(6.196)	(2.358)
admitted in in June	0.0055***	0.0012	0.0108***	0.0001
	(3.272)	(1.058)	(3.867)	(0.059)
admitted in in July	0.0041**	-0.0001	0.0098***	0.0007
	(2.348)	(-0.079)	(3.700)	(0.511)
admitted in in August	0.0059***	-0.0007	0.0089***	0.0001
	(3.360)	(-0.708)	(3.449)	(0.058)
admitted in in September	0.0049***	-0.0012	0.0024	0.0019
	(2.669)	(-1.137)	(1.068)	(1.513)
admitted in in October	0.0010	-0.0017	0.0058***	-0.0003
	(0.568)	(-1.597)	(2.902)	(-0.194)
admitted in in Novemeber	0.0018	-0.0020*	0.0026	0.0045***
	(1.095)	(-1.920)	(1.080)	(2.660)
admitted in in December	0.0017	-0.0011	0.0024	0.0004
	(0.997)	(-0.993)	(0.875)	(0.229)
Constant	0.0445***	0.0141***	0.0186*	-0.0154**
	(13.394)	(8.810)	(1.949)	(-2.149)
R^2	0.012	0.004	0.003	0.016
Patients	412464	461594	112842	114289
Hospital Sites	232	238	47	47
p-value joint Chi-squared test residuals coefficients = 0	0.0000	0.0000	0.0052	0.0000
stat. joint Chi-squared test residuals coefficients = 0	498.6380	556.7877	75.4979	176.4244
Hospital sites Fixed Effects	YES	YES	YES	YES
Control Function residuals	YES	YES	YES	YES

Note. The outcome models are eqn (14) and also contain the residuals (not shown) from the first stage conditional logit choice model.

Table A8. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality: Marginal Effects from Logit Model.

	Baseline FE model	2SRI with all residuals	Baseline FE model	2SRI with all residuals	Baseline FE model	2SRI with all residuals	Baseline FE model	2SRI with all residuals
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Hip Replacement Emergency Readmission		Knee Replacement Emergency Readmission		CABG Emergency Readmission		CABG Mortality	
Logit coefficient								
Post Choice Policy * Market Structure	0.0330**	0.0407**	0.0361**	0.0706***	-0.0038	-0.0091	0.0005	-0.0301
	(2.047)	(2.280)	(2.463)	(4.340)	(-0.405)	(-0.854)	(0.014)	(-0.700)
Marginal effect								
Post Choice Policy * Market Structure	0.00176**	0.00216**	0.000678**	0.00133***	-0.000150	-0.000357	0.00000562	-0.000368
	(2.05)	(2.28)	(2.46)	(4.34)	(-0.40)	(-0.85)	(0.01)	(-0.70)
Pseudo R-squared	0.025	0.027	0.016	0.019	0.009	0.010	0.100	0.104
Patients	412464	412464	461469	461469	112818	112818	114047	114047
Hospital Sites	232	232	237	237	46	46	43	43
p-value joint Chi-squared test residuals coefficients = 0		0.0000		0.0000		0.0000		0.0000

Notes. Baseline model as in Table 4, but with logit instead of linear probability model. Dependent variable: patient in NHS provider had emergency readmission within 28 days from discharge following admission, or CABG patient in NHS provider died within 30 days. Choice Policy: indicator for 2006/7 onwards. Market structure: 1/predicted speciality-based HHI. Odd numbered models include hospital fixed effects. Even-numbered models include hospital fixed effects and residuals from a first stage conditional logit choice model. Number of patients and hospital sites differ slightly from Tables 4 and A4 as hospitals-patients observations from hospitals with only positive or negative outcomes are ignored in logit estimation. Financial years: 2002/3- 2010/11. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table A9. Three-step estimation of the change in the effect of market structure on quality.

	Baseline FE model	Linear 2SRI + FEs	Nonlinear 2SRI + FEs
	(1)	(2)	(3)
a. Hip Replacement Emergency Readmission (Patients: 412,464; hospital sites: 232)			
Post-Choice Policy * Market Structure	0.0016**	0.0023***	0.0018***
	(2.3429)	(2.7954)	(2.6493)
R-squared	0.464	0.994	0.721
b. Knee Replacement Emergency Readmission (Patients: 461,594; hospital sites: 238)			
Post-Choice Policy * Market Structure	0.0005	0.0016***	0.0012***
	(1.6048)	(3.7702)	(3.8107)
R-squared	0.320	0.996	0.648
c. CABG Emergency Readmission (Patients: 112,844; hospital sites: 47)			
Post-Choice Policy * Market Structure	-0.0001	-0.0005	-0.0006
	(-0.1084)	(-0.8005)	(-0.9830)
R-squared	0.392	0.987	0.925
d. CABG Mortality (Patients: 114,291; hospital sites: 47)			
Post-Choice Policy * Market Structure	0.0003	0.0007*	0.0007
	(0.7956)	(1.7954)	(1.5656)
R-squared	0.606	0.982	0.917

Notes. Three step estimation: (i) model for hospital choice (linear or conditional logit) distance and nearest hospital explanatories; (ii) linear regression of patient outcome on patient covariates, choice residuals from first step, and hospital by year fixed effects; (iii) linear regression of hospital by year effects from second step on year dummies, hospital time varying characteristics, interaction of post choice indicator and frozen pre choice market structure $A_t\bar{M}_h$, and hospital fixed effect. t-statistics in parentheses are based on robust bootstrapped (1,000 replications) with standard errors. *p<0.1, ** p<0.05, *** p<0.01.

Table A10. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality using HHI as Competition Measure

	Baseline FE model	Linear 2SRI	Nonlinear 2SRI
	(1)	(2)	(3)
a. Hip Replacement Emergency Readmission			
Post-Choice Policy * Market Structure	-0.0069	-0.0080	-0.0083
	(-1.360)	(-1.084)	(-1.526)
R^2	0.011	0.012	0.012
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
b. Knee Replacement Emergency Readmission			
Post-Choice Policy * Market Structure	-0.0026*	-0.0056**	-0.0049***
	(-1.665)	(-2.135)	(-2.918)
R^2	0.003	0.004	0.004
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
c. CABG Emergency Readmission			
Post-Choice Policy * Market Structure	0.0048	0.0023	0.0053
	(0.780)	(0.325)	(0.777)
R^2	0.003	0.004	0.003
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0093
d. CABG Mortality			
Post-Choice Policy * Market Structure	0.0074	0.0115	0.0108
	(1.240)	(1.466)	(1.549)
R^2	0.016	0.016	0.016
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000

Notes. Samples as in Table 4. *t*-statistics in parentheses are based on hospital site cluster-robust standard errors bootstrapped with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01. Market structure is measured as the pre 2006 mean of HHI.

Table A11. Principal Component Analysis of Market Structure Measure - Eigenvalues and Eigenvectors.

	Principal component			
	1	2	3	4
Hip replacement				
average of pre-2006 1/HHI "all elective admissions"	0.5255	-0.3017	-0.3387	-0.7198
average of pre-2006 1/HHI "all elective muscoloskeletal admissions"	0.5227	-0.2659	-0.4218	0.6915
average of pre-2006 1/HHI "all elective hip replacement admissions"	0.4659	0.8844	-0.0171	-0.0225
average of pre-2006 number of rival hospital sites	0.4833	-0.2369	0.8409	0.0564
Eigenvalue	3.3622	0.3454	0.2760	0.0164
Knee replacement				
average of pre-2006 1/HHI "all elective admissions"	0.5260	-0.0994	-0.4618	-0.7072
average of pre-2006 1/HHI "all elective muscoloskeletal admissions"	0.5259	0.0150	-0.4797	0.7022
average of pre-2006 1/HHI "all elective knee replacement admissions"	0.4698	0.7528	0.4577	-0.0552
average of pre-2006 number of rival hospital sites	0.4755	-0.6505	0.5892	0.0603
Eigenvalue	3.3914	0.3555	0.2384	0.0147
CABG				
average of pre-2006 1/HHI "all elective admissions"	0.5156	-0.0373	-0.5527	-0.6536
average of pre-2006 1/HHI "all elective circulatory admissions"	0.5155	-0.2612	-0.3648	0.7301
average of pre-2006 1/HHI "all elective CABG admissions"	0.4729	0.8334	0.2685	0.0984
average of pre-2006 number of rival hospital sites	0.4947	-0.4857	0.6995	-0.1735
Eigenvalue	3.6316	0.2596	0.1016	0.0071

Table A12. Post Choice Reform Change in Effect of Pre-Reform Market Structure on Elective Quality, using PCA Market Structure Measure.

	PCA proxy Predicted HHI		
	FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers
	(1)	(2)	(3)
a. Hip Replacement Emergency Readmission (Patients: 412,464; hospital sites: 232)			
Post Choice Policy * Market Structure	0.0018**	0.0022	0.0023**
	(2.168)	(1.590)	(2.240)
joint Chi^2 test residuals coefficients=0		644.3655	512.0634
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000
R^2	0.011	0.012	0.012
b. Knee Replacement Emergency Readmission (Patients: 461,594; hospital sites: 238)			
Post Choice Policy * Market Structure	0.0006**	0.0013***	0.0013***
	(2.147)	(2.681)	(4.170)
joint Chi^2 test residuals coefficients=0		769.2175	562.5360
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000
R^2	0.003	0.004	0.004
c. CABG Emergency Readmission (Patients: 112,844; hospital sites: 47)			
Post Choice Policy * Market Structure	-0.0002	0.0003	-0.0007
	(-0.340)	(0.326)	(-0.908)
joint Chi^2 test residuals coefficients=0		250.7090	76.6179
p-value joint χ2 test residuals coefficients=0		0.0000	0.0041
R^2	0.003	0.004	0.003
d. CABG Mortality (Patients: 114,291; hospital sites: 47)			
Post Choice Policy * Market Structure	0.0002	0.0003	-0.0002
	(0.247)	(0.300)	(-0.215)
joint Chi^2 test residuals coefficients=0		255.9031	175.1718
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000
R^2	0.016	0.016	0.016

Notes. Dependent variable: patient in NHS provider had emergency readmission within 28 days from discharge following admission, or CABG patient in NHS provider died within 30 days. Choice Policy: indicator for 2006/7 onwards. Market structure: first principal component from PCA model using HHIs for all elective, speciality, procedure, number of rival providers. Column (2) models use residuals from linear first stage choice models. Columns (3) models add residuals from conditional logit first stage choice model. Financial years: 2002/3- 2010/11. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table A13. Pre and Post-Reform Effects of Speciality Market Structure on Elective Quality: Time-Varying Market Structure.

		FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers
		(1)	(2)	(3)
Hip Replacement - Emergency Readmissions	Post-Choice Policy * Market Structure	0.0016**	0.0019	0.0019**
		(2.004)	(1.583)	(2.137)
	Market Structure	-0.0002	0.0003	-0.0009
		(-0.128)	(0.149)	(-0.474)
	joint χ^2 test residuals coefficients=0		638.8924	496.8123
	R^2	0.011	0.012	0.012
Knee Replacement - Emergency Readmissions	Post-Choice Policy * Market Structure	0.0006**	0.0012***	0.0011***
		(2.242)	(2.757)	(4.035)
	Market Structure	-0.0004	-0.0010	-0.0010
		(-0.538)	(-0.987)	(-1.442)
	joint χ^2 test residuals coefficients=0		764.9685	559.0726
	R^2	0.003	0.004	0.004
CABG - Emergency Readmissions	Post-Choice Policy * Market Structure	0.0000	0.0006	-0.0000
		(0.103)	(1.229)	(-0.037)
	Market Structure	-0.0008	-0.0031**	-0.0014
		(-0.811)	(-2.388)	(-1.197)
	joint χ^2 test residuals coefficients=0		258.5165	74.2910
	R^2	0.003	0.004	0.003
CABG - Mortality	Post-Choice Policy * Market Structure	0.0000	-0.0000	-0.0002
		(0.051)	(-0.056)	(-0.361)
	Market Structure	0.0000	0.0004	0.0002
		(0.045)	(0.412)	(0.226)
	joint χ^2 test residuals coefficients=0		252.9012	179.7291
	R^2	0.016	0.016	0.016

Notes. Baseline model of Table 4 with time varying market structure M_{ht} instead of frozen pre-reform market structure. . t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table A14. Post Choice Introduction and Choice Extension Changes in Effect of Market Structure on Elective Quality.

	Baseline FE model	Linear 2SRI model	Nonlinear 2SRI model
	(1)	(2)	(3)
a. Hip Replacement readmissions			
Pre-2006 rivals * 2006 reform introduction (γ_1)	0.0019**	0.0018	0.0023**
	(2.070)	(1.326)	(2.175)
Pre-2006 rivals * 2008 reform extension (γ_2)	0.0016*	0.0022	0.0020*
	(1.702)	(1.617)	(1.858)
R^2	0.011	0.012	0.012
p-value joint χ^2 test residuals coefficients = 0		0.0000	0.0000
joint χ^2 test residuals coefficients = 0		571.9412	484.7643
χ^2 test H_0: $\gamma_1=\gamma_2$	0.2585	0.2670	0.1021
p-value χ^2 test H_0: $\gamma_1=\gamma_2$	0.6111	0.6054	0.7493
b. Knee Replacement readmissions			
Pre-2006 rivals * 2006 reform introduction (γ_1)	0.0006*	0.0011**	0.0011***
	(1.868)	(2.236)	(3.128)
Pre-2006 rivals * 2008 reform extension (γ_2)	0.0005*	0.0010**	0.0011***
	(1.705)	(2.065)	(3.438)
R^2	0.003	0.004	0.004
p-value joint χ^2 test residuals coefficients = 0		0.0000	0.0000
joint χ^2 test residuals coefficients = 0		742.5510	531.2343
χ^2 test H_0: $\gamma_1=\gamma_2$	0.0887	0.0543	0.0019
p-value χ^2 test H_0: $\gamma_1=\gamma_2$	0.7658	0.8158	0.9656
c. CABG readmissions			
Pre-2006 rivals * 2006 reform introduction (γ_1)	0.0003	0.0006	-0.0000
	(0.729)	(0.945)	(-0.055)
Pre-2006 rivals * 2008 reform extension (γ_2)	-0.0007	-0.0005	-0.0011
	(-1.167)	(-0.871)	(-1.500)
R^2	0.003	0.004	0.003
p-value joint χ^2 test residuals coefficients = 0		0.0000	0.0042
joint χ^2 test residuals coefficients = 0		291.1864	76.4574
χ^2 test H_0: $\gamma_1=\gamma_2$	2.4312	2.0806	2.0782
p-value χ^2 test H_0: $\gamma_1=\gamma_2$	0.1189	0.1492	0.1494
d. CABG mortality			
Pre-2006 rivals * 2006 reform introduction (γ_1)	-0.0002	-0.0005	-0.0005
	(-0.424)	(-0.598)	(-0.786)
Pre-2006 rivals * 2008 reform extension (γ_2)	0.0001	0.0002	-0.0001
	(0.230)	(0.307)	(-0.216)
R^2	0.016	0.016	0.016
p-value joint χ^2 test residuals coefficients = 0		0.0000	0.0000
joint χ^2 test residuals coefficients = 0		233.4264	148.5499
χ^2 test H_0: $\gamma_1=\gamma_2$	1.0191	2.1086	1.0790
p-value χ^2 test H_0: $\gamma_1=\gamma_2$	0.3127	0.1465	0.2989

Notes. Samples as in Table 4. *t*-statistics in parentheses are based on hospital site cluster-robust standard errors bootstrapped with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table A15. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure with Effects of Number of Diagnosis and Charlson Index Varying Pre and Post-Reform.

	Baseline FE model	Linear 2SRI	Nonlinear 2SRI
	(1)	(2)	(3)
a. Hip Replacement Emergency Readmission			
Post-Choice Policy * Market Structure	0.0017**	0.0019	0.0021**
	(2.040)	(1.483)	(2.136)
Number of diagnosis	0.0030***	0.0032***	0.0031***
	(7.093)	(7.512)	(7.391)
Charlson Index	0.0081***	0.0078***	0.0080***
	(5.845)	(5.650)	(5.790)
Post-Choice Policy * number of diagnosis	0.0019***	0.0017***	0.0017***
	(3.699)	(3.358)	(3.514)
Post-Choice Policy * Charlson Index	-0.0016	-0.0014	-0.0016
	(-0.941)	(-0.849)	(-0.929)
R^2	0.012	0.013	0.012
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
b .Knee Replacement Emergency Readmission			
Post-Choice Policy * Market Structure	0.0005**	0.0010**	0.0011***
	(2.166)	(2.327)	(3.896)
Number of diagnosis	0.0010***	0.0010***	0.0010***
	(4.622)	(4.524)	(4.622)
Charlson Index	0.0007	0.0007	0.0007
	(1.044)	(1.028)	(1.118)
Post-Choice Policy * number of diagnosis	0.0005*	0.0005*	0.0005*
	(1.757)	(1.901)	(1.828)
Post-Choice Policy * Charlson Index	-0.0002	-0.0002	-0.0002
	(-0.209)	(-0.252)	(-0.277)
R^2	0.003	0.004	0.004
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
c. CABG Emergency Readmission			
Post-Choice Policy * Market Structure	-0.0003	-0.0001	-0.0005
	(-0.683)	(-0.257)	(-1.115)
Number of diagnosis	0.0018***	0.0019***	0.0018***
	(4.268)	(4.134)	(4.252)
Charlson Index	0.0017	0.0017	0.0017
	(1.256)	(1.257)	(1.281)
Post-Choice Policy * number of diagnosis	-0.0002	-0.0002	-0.0001
	(-0.317)	(-0.360)	(-0.194)
Post-Choice Policy * Charlson Index	0.0003	0.0003	0.0003
	(0.211)	(0.183)	(0.195)
R^2	0.003	0.004	0.003
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0048
d. CABG Mortality			
Post-Choice Policy * Market Structure	-0.0002	-0.0003	-0.0004
	(-0.426)	(-0.436)	(-0.732)
Number of diagnosis	0.0031***	0.0032***	0.0031***
	(4.994)	(5.038)	(5.047)
Charlson Index	0.0071***	0.0072***	0.0072***
	(5.946)	(6.094)	(6.021)
Post-Choice Policy * number of diagnosis	-0.0005	-0.0006	-0.0005
	(-0.988)	(-1.104)	(-1.004)
Post-Choice Policy * Charlson Index	0.0009	0.0008	0.0008
	(0.524)	(0.496)	(0.511)
R^2	0.017	0.018	0.018
p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000

Notes. Samples as in Table 4. *t*-statistics in parentheses are based on hospital site cluster-robust standard errors bootstrapped with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table A16. Marginal Effects of Differential Distance on Choice of NHS rather than Private Provider, Probit Model.

	(1) 2004	(2) 2005	(3) 2006	(4) 2007	(5) 2008	(6) 2009	(7) 2010
Hip replacement sample							
differential distance	-0.0004***	-0.0007***	-0.0014***	-0.0028***	-0.0036***	-0.0027***	-0.0065***
	(-9.953)	(-16.131)	(-32.892)	(-39.355)	(-28.039)	(-24.815)	(-29.350)
Pseudo R^2	0.112	0.189	0.394	0.237	0.063	0.068	0.057
Chi-squared	527.68	1185.10	5090.52	6385.81	1985.31	2482.99	2553.41
Chi-squared p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BIC	4177.6	5108.3	7841.9	20583.9	29382.9	33938.6	42038.2
Patients	43,879	44,526	48,120	53,980	54,580	54,609	56,067
Knee replacement sample							
differential distance ISP - NHS	-0.0004***	-0.0007***	-0.0016***	-0.0028***	-0.0046***	-0.0039***	-0.0071***
	(-10.882)	(-15.919)	(-39.819)	(-40.407)	(-36.177)	(-35.161)	(-33.399)
Pseudo R^2	0.098	0.202	0.438	0.227	0.078	0.088	0.060
Chi-squared	682.80	1373.03	6714.60	7320.11	2931.78	3890.22	3103.27
Chi-squared p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
BIC	6311.6	5440.1	8617.8	24993.4	34799.2	40536.1	48224.4
Patients	48,519	50,854	54,504	62,885	63,275	63,551	64,172

Notes. Dependent variable is {1,0} indicator for treatment in NHS hospital site versus private site. Differential distance: distance to nearest private provider minus distance to nearest NHS provider. Models includes controls for: age, gender, number of comorbidities and past emergency admissions, Charlson index, income and living enviroment deprivation at LSOA level, disability and incapacity claims at LSOA level. Models could not be estimated in years 2002/03 and 2003/04 because of the small numbers of private sites treating NHS patients. An Inverse Mills Ratio equal to zero was included for patients in years 2002/03 and 2003/04 to estimate the main outcome equation reported in Table 6.

Table A17. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on CABG Emergency Readmissions, using Heckman Probit Selection Model to Control for Selection due to CABG Mortality.

	CABG Emergency Readmissions
Post Choice Policy * Market Structure	-0.0001
	(-0.3519)
IMR (Inverse Mills Ratio)	-0.2692
	[-0.7845; 0.4650]
Patients	114289
Hospital Sites	47
Number of censored patients	1447

Notes. Market structure is fixed at the average level in the pre-policy period for each hospital site. Unlike CABG emergency readmissions models reported in the main texts, this is an Heckman probit model, i.e. it is estimated as a probit outcome regression for patient emergency readmission wih the inclusion of a Heckman selection correction term from a first stage probit model with dependent variable being a dummy for the patient surviving for at least 30 days after discharge from the index CABG surgery.

Table A18. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality: Controlling for Hospital Rurality.

		FE model with covariates	Linear 2SRI residuals for all providers	CL 2SRI residuals for all providers
		(1)	(2)	(3)
Hip Replacement - Emergency Readmissions	Post-Choice Policy * Market Structure	0.0017**	0.0019	0.0021**
		(2.006)	(1.496)	(2.151)
	Post-Choice Policy * Market Structure * Rural hospital	-0.0032	-0.0035	-0.0033
		(-1.341)	(-1.259)	(-1.327)
	joint χ^2 test residuals coefficients=0		654.2712	497.2813
	R^2	0.011	0.012	0.012
Knee Replacement - Emergency Readmissions	Post-Choice Policy * Market Structure	0.0006**	0.0011**	0.0011***
		(2.139)	(2.426)	(3.895)
	Post-Choice Policy * Market Structure * Rural hospital	0.0002	0.0004	0.0004
		(0.169)	(0.382)	(0.398)
	joint χ^2 test residuals coefficients=0		765.3331	557.2278
	R^2	0.003	0.004	0.004
CABG - Emergency Readmissions	Post-Choice Policy * Market Structure	-0.0002	-0.0001	-0.0007
		(-0.454)	(-0.197)	(-1.228)
	Post-Choice Policy * Market Structure * Rural hospital	-0.0027	-0.0025	-0.0028
		(-0.819)	(-0.640)	(-0.904)
	joint χ^2 test residuals coefficients=0		272.1123	77.4665
	R^2	0.003	0.004	0.003
CABG - Mortality	Post-Choice Policy * Market Structure	-0.0001	-0.0001	-0.0004
		(-0.147)	(-0.154)	(-0.534)
	Post-Choice Policy * Market Structure * Rural hospital	0.0004	0.0006	0.0004
		(0.492)	(0.476)	(0.329)
	joint χ^2 test residuals coefficients=0		275.1723	180.2128
	R^2	0.016	0.016	0.016

Notes. Same specification as baseline model of Table 4 with addition of interaction of *Post-Choice Policy * Market Structure * Rural hospital*. Rural hospital: not located in urban settlement types, i.e. located in: town or fringe; village; hamlet. For the 2004 rural/urban definitions, see: https://www.ons.gov.uk//methodology/geography/geographicalproducts/ruralurbanclassifications/2001ruralurbanclassification/ruralurbandefinitionenglandandwales.

t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01

Table A19. Post Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality: Controlling for Population Density.

	Hip Replacement Emerg. Readmissions		Knee Replacement Emerg. Readmissions		CABG Emerg. Readmissions		CABG Mortality	
	Linear 2SRI	CL 2SRI	Linear 2SRI	CL 2SRI	Linear 2SRI	CL 2SRI	Linear 2SRI	CL 2SRI
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post-Choice Policy * Mkt Structure	0.0017	0.0019**	0.0010**	0.0011***	-0.0000	-0.0004	-0.0001	-0.0002
	(1.378)	(1.977)	(2.306)	(3.903)	(-0.056)	(-0.733)	(-0.106)	(-0.305)
2nd decile of population density	0.0044	0.0075	0.0009	0.0016	-0.0037	-0.0037	0.0027	0.0034
	(0.906)	(1.457)	(0.466)	(1.076)	(-0.302)	(-0.314)	(0.345)	(0.412)
3rd decile of population density	0.0025	0.0061	0.0036	0.0041***	0.0093	0.0065	0.0054	0.0076
	(0.477)	(1.027)	(1.638)	(2.719)	(0.404)	(0.285)	(0.654)	(0.840)
4th decile of population density	-0.0017	0.0021	0.0007	0.0022	0.0061	0.0039	-0.0005	0.0017
	(-0.308)	(0.338)	(0.281)	(1.182)	(0.274)	(0.174)	(-0.076)	(0.228)
5th decile of population density	0.0022	0.0037	-0.0003	0.0012	0.0044	0.0009	-0.0002	0.0014
	(0.357)	(0.573)	(-0.137)	(0.612)	(0.192)	(0.039)	(-0.026)	(0.179)
6th decile of population density	0.0027	0.0047	0.0003	0.0021	0.0007	-0.0018	0.0002	0.0022
	(0.438)	(0.710)	(0.111)	(1.011)	(0.030)	(-0.080)	(0.024)	(0.276)
7th decile of population density	-0.0003	0.0016	-0.0004	0.0012	0.0001	-0.0041	0.0051	0.0067
	(-0.043)	(0.229)	(-0.167)	(0.627)	(0.004)	(-0.180)	(0.666)	(0.808)
8th decile of population density	-0.0032	-0.0023	-0.0000	0.0016	-0.0014	-0.0032	0.0087	0.0092
	(-0.506)	(-0.324)	(-0.001)	(0.741)	(-0.059)	(-0.139)	(1.223)	(1.166)
9th decile of population density	-0.0028	-0.0021	0.0015	0.0032	-0.0079	-0.0107	0.0073	0.0088
	(-0.431)	(-0.300)	(0.504)	(1.445)	(-0.342)	(-0.468)	(1.024)	(1.103)
10th decile of population density	-0.0032	-0.0024	0.0016	0.0038	-0.0090	-0.0124	0.0031	0.0058
	(-0.472)	(-0.316)	(0.476)	(1.466)	(-0.391)	(-0.545)	(0.394)	(0.701)
joint χ^2 test residuals coefficients=0	636.89	502.74	734.23	554.77	273.04	96.82	234.98	181.44
p-value joint $\chi2$ test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Notes. Same specification as baseline model of Table 4 with addition of indicators for decile of hospital LSOA population density computed for each year. t-statistics in parentheses, based on bootstrapped hospital site cluster-robust standard errors with 1,000 replications. *p<0.1, ** p<0.05, *** p<0.01.

Table 20. Mechanism: Effort diversion. Post-Choice Reform Change in Effect of Pre-Reform Speciality Based Market Structure on Elective Quality, Controlling for Emergency Mortality.

	(1)	(2)	(3)	(4)
	Hip replacement emergency readmissions			
Post-Choice Policy * Market Structure	0.0021**	0.0021**	0.0021**	0.0021**
	(2.153)	(2.122)	(2.145)	(2.160)
Std. Mortality	0.0000	0.0001	0.0000	-0.0001
	(0.514)	(0.610)	(0.095)	(-0.231)
Post-Choice Policy * Std. Mortality		-0.0001		0.0002
		(-0.443)		(0.449)
	Knee replacement emergency readmissions			
Post-Choice Policy * Market Structure	0.0011***	0.0011***	0.0011***	0.0011***
	(3.942)	(3.915)	(3.862)	(3.792)
Std. Mortality	0.0000	0.0000	0.0002	0.0002
	(0.897)	(0.750)	(1.597)	(1.387)
Post-Choice Policy * Std. Mortality		-0.0000		-0.0001
		(-0.102)		(-0.321)
	CABG emergency readmissions			
Post-Choice Policy * Market Structure	-0.0004	-0.0004	0.0004	0.0004
	(-0.812)	(-0.816)	(0.521)	(0.566)
Std. Mortality	-0.0000	-0.0001	-0.0003	-0.0003
	(-0.252)	(-0.582)	(-1.356)	(-0.763)
Post-Choice Policy * Std. Mortality		0.0001		-0.0002
		(0.557)		(-0.328)
	CABG mortality			
Post-Choice Policy * Market Structure	-0.0003	-0.0003	0.0001	0.0001
	(-0.471)	(-0.445)	(0.164)	(0.144)
Std. Mortality	0.0002**	0.0003***	0.0002	0.0001
	(2.163)	(2.677)	(0.760)	(0.459)
Post-Choice Policy * Std. Mortality		-0.0001		0.0001
		(-1.205)		(0.303)
Hospital Trust-level Mortality type:				
a) Standardized Mortality all procedures (Dr Foster's HSMR)	YES	NO	YES	NO
b) Std. Mortality emergency condition within same specialty (hip fracture or AMI)	NO	YES	NO	YES

Notes. Dependent variable, Choice Policy and market structure defined as in Table 4. Columns (1)-(2): add standardized hospital mortality for all procedures as covariate; columns (3)-(4): add standardized hospital mortality for emergency procedure within the same specialty (AMI mortality for CABG; hip fracture mortality for hip and knee replacement) as covariate. Estimated model: CL 2SRI residuals for all providers. Results for models with hospitals fixed effects only or with hospitals fixed effects and Linear 2SRI produce similar results in Table 4 and are available from the authors upon request.

Table A21. Profit and Loss at procedure and HRG4 code level.

Year	HRG code	HRG Name	Profit per patient (£)	Patients	HRG profit (£)	HRG profit (£) per site
	HB11C	Major Hip Procedures for non Trauma Category 2 without CC	-963	1,244	-1,198,088	-5,164
	HB12A	Major Hip Procedures for non Trauma Category 1 with Major CC	-2,247	2,372	-5,329,339	-22,971
	HB12B	Major Hip Procedures for non Trauma Category 1 with CC	-675	2,575	-1,739,358	-7,497
2009	HB12C	Major Hip Procedures for non Trauma Category 1 without CC	-240	41,947	-10,087,077	-43,479
	HB11C	Major Hip Procedures for non Trauma Category 2 without CC	4	6,651	25,195	109
	HB12A	Major Hip Procedures for non Trauma Category 1 with Major CC	-2,202	2,132	-4,694,774	-20,236
	HB12B	Major Hip Procedures for non Trauma Category 1 with CC	-883	2,565	-2,263,682	-9,757
2010	HB12C	Major Hip Procedures for non Trauma Category 1 without CC	-586	35,230	-20,651,498	-89,015
		TOTAL (over 2 years)	***-485***	***94,716***	***-45,938,620***	***-198,011***
	HB21A	Major Knee Procedures for non Trauma Category 2 with Major CC	-316	3,052	-963,551	-4,049
	HB21B	Major Knee Procedures for non Trauma Category 2 with CC	-1,099	3,066	-3,369,046	-14,156
	HB21C	Major Knee Procedures for non Trauma Category 2 without CC	-1,475	47,983	-70,765,048	-297,332
2009	HB23C	Intermediate Knee Procedures for non Trauma without CC	498	1,323	658,609	2,767
	HB21A	Major Knee Procedures for non Trauma Category 2 with Major CC	-522	3,298	-1,720,921	-7,231
	HB21B	Major Knee Procedures for non Trauma Category 2 with CC	53	3,562	189,590	797
2010	HB21C	Major Knee Procedures for non Trauma Category 2 without CC	-117	46,250	-5,425,497	-22,796
		TOTAL (over 2 years)	***-750***	***108,534***	***-81,395,863***	***-341,999***
2009	EA14Z	Coronary Artery Bypass Graft (First Time)	-831	8,227	-6,837,579	-145,480
	EA16Z	Coronary Artery Bypass Graft (First Time) with PCI, Pacing, EP or RFA +/- Catheter	2,968	1,410	4,184,621	89,034
2010	EA14Z	Coronary Artery Bypass Graft (First Time)	-755	6,392	-4,827,282	-102,708
	EA16Z	Coronary Artery Bypass Graft (First Time) with PCI, Pacing, EP or RFA +/- Catheter	328	2,210	725,259	15,431
		TOTAL (over 2 years)	***-370***	***18,239***	***-6,754,980***	***-143,723***

Notes. Profit per patient: $MFF_{ht} * P_{jt} – (CI_{ht} / 100) * AC_{jt}$ where MFF_{ht} is the market forces factor, P_{jt} is the national price per patient for HRG *j*, CI_{ht} is the reference cost index, AC is the national average unit cost. National PbR tariff: https://data.gov.uk/dataset/96d530ef-8fa5-4167-8863-5b6e0d69bcfb/nhs-payment-by-results-2010-11-national-tariff-information; 2009/10 PbR tariff: obtained from NHS Improvement. HRG reference costs: https://www.gov.uk/government/collections/nhs-reference-costs; MFF and RCI data: https://www.gov.uk/government/collections/nhs-reference-costs. Last column based on 232 (238) hospitals sites for hip (knee) replacement and 47 sites for CABG.

Appendix B.

B1. Procedure and speciality definitions

Hip replacement admissions are those with
(i) a first OPCS procedure code: W371, W381, W391, W931, W941, W951, W378, W379, W388, W389, W398, W399, W938, W939, W948, W949, W958, W959; (ii) W581 as the 1st procedure and Z843 in 2nd to 4th procedure fields.

Knee replacement admissions are those with
(i) a first OPCS procedure code W401, W411, W421, W408, W408, W418, W419, W428, W429; (ii) W581 as the 1st procedure and Z846 in 2nd to 4th procedure fields.

CABG admissions are those with
(i) a first OPCS procedure code K40, K41, K42, K43, K44, K45, K46 excluding patients simultaneously undergoing a heart valve replacement (any procedure being coded from K23 to K38) or a dominant angioplasty (PTCA) operation (in the first procedure coded as K751, K752, K753, K754, K758, K759, K49 , K501, K504, K508, K509).

Circulatory admissions are those with a main ICD10 diagnostic code starting with I (diseases of the circulatory system) or main procedure OPCS code starting with K or L (heart, arteries and veins procedures). Musculoskeletal admissions are those with main ICD10 diagnostic code starting with M (diseases of the musculoskeletal system) or main procedure OPCS code starting with V or W (bones and joints procedures).

B2. Measurement of market structure

Market structure: predicted equivalent number of sites

Our main market structure measure is based on the Herfindahl-Hirschman Index (HHI): the sum of the square of provider market shares. For a market with N firms it varies between 1 (monopoly) and $1/N$. The HHI for patients in LSOA j is the sum of the squared shares of their elective admissions at the providers they use. It is a measure of the amount of choice they have amongst elective care providers. We compute the HHI for site h as a weighted average of the HHIs for patients in LSOAs within 30 km of site h:

$$HHI_h = \sum_j s_{hj} \times HHI_j = \sum_j s_{hj} \times \left[\sum_h \left(s_{jh} \right)^2 \right] \tag{B1}$$

where $j=1,...,J$ indexes English LSOAs, s_{jh} is the proportion of patients from LSOA j treated at a site h within 30km of their LSOA, and s_{hj} is the proportion of site h patients from LSOA j within 30km of site h.

To remove possible bias arising from the effect of quality on utilisation we compute *predicted HHIs* derived from models of patient choice of provider (NHS and private sites) for elective care in which choice is not allowed to depend on quality (Kessler and McClellan, 2000). We estimate Poisson choice models with the number of elective patients from LSOA j choosing provider h in year t having conditional mean

$$\mathrm{E}\left(n_{jht} \mid \varsigma_j, d_{jh}, X_{ht}\right) = \exp\left\{\varsigma_{jt} + \lambda_{1t} d_{jh} + \lambda_{2t} d_{jh}^2 + X_{ht}\lambda_t + d_{jh} X_{ht} \lambda_{1t}^X + d_{jh}^2 X_{ht} \lambda_{2t}^X\right\} \tag{B2}$$

where d_{jh} is the distance from the centroid of LSOA j to hospital site h within 30km. X_{ht} is a vector of dummies for hospital characteristics (belonging to a Foundation Trust, belonging to a teaching Trust). NHS Foundation Trusts have more discretion in paying staff, using surpluses, do not have to break even each year and can borrow from the capital market (Marini *et al.*, 2008). Foundation Trusts status was introduced in 2004 and by 2010 60% of NHS Trusts were Foundation Trusts. About 20% of NHS hospitals have Teaching status, undertaking additional activities including teaching and research, and treating more complex patients.

HES defines elective admissions as those "where the decision to admit could be separated in time from the actual admission". We exclude patients whose admissions were part of a planned course of treatment (for example, patients on dialysis, or cancer patients on chemotherapy).

The Poisson model yields the same estimated coefficients as the conditional logit model (Guimaraes *et al.*, 2003; Guimaraes, 2004) but is quicker to estimate. Models interacting patient characteristics with hospital site characteristics yielded very similar predicted patient flows.

The predicted $\hat{n}_{jht}$ from Eq. (B2) are used to compute the predicted shares $\hat{s}_{jht} = \hat{n}_{jht} / \sum_h \hat{n}_{jht}$ and $\hat{s}_{hjt} = \hat{n}_{jht} / \sum_j \hat{n}_{jht}$, and used in eq. (B2), instead of the actual flows, to compute the predicted HHI indices. We use the *reciprocal of the predicted HHI* (the number of equal sized firms, which would yield the HHI) as the measure of competition facing a provider.

Appendix C: Model of competition, waiting time, and quality

Totally differentiating the first order conditions (2) and (3) on w and q (Section 3) and solving gives

$$\frac{\partial w}{\partial \theta}=\left[v_{q\theta}v_{wq}-v_{w\theta}v_{qq}\right]\Delta^{-1},\ \ \frac{\partial q}{\partial \theta}=\left[v_{w\theta}v_{wq}-v_{q\theta}v_{ww}\right]\Delta^{-1}$$

where $\Delta=v_{ww}v_{qq}-v_{wq}v_{qw}>0$ is the determinant of the Jacobian of v and is positive at the maximised value of v. The second order partial derivatives of v without, and then with the simplifying assumptions in Section 3 that $B(w,q)$: $B_{wq}=0$, $D_{ww}=0$, $D_{qq}=0$, $D_{wq}=0$, $C_{DD}=0$, $C_{qD}=0$), are

$$v_{w\theta}=\left(p-C_D\right)D_{w\theta}-C_{DD}D_wD_\theta=\left(p-C_D\right)D_{w\theta}$$

$$v_{q\theta}=\left(p-C_D\right)D_{q\theta}-\left(C_{DD}D_w+C_{qD}\right)D_\theta=\left(p-C_D\right)D_{q\theta}$$

$$v_{ww}=\left(p-C_D\right)D_{ww}-C_{DD}D_wD_w+B_{ww}=\left(p-C_D\right)D_{ww}+B_{ww}$$

$$v_{qq}=\left(p-C_D\right)D_{qq}-\left(C_{DD}D_q+C_{qD}\right)D_q+B_{qq}=\left(p-C_D\right)D_{qq}+B_{qq}$$

$$v_{wq}=v_{qw}=\left(p-C_D\right)D_{wq}-\left(C_{DD}D_q+C_{qD}\right)D_w=0$$

With the simplifying assumptions the Jacobian is $\Delta=v_{ww}v_{qq}>0$ and so

$$\frac{\partial w}{\partial \theta}=\left[v_{q\theta}v_{wq}-v_{w\theta}v_{qq}\right]\Delta^{-1}=-v_{w\theta}/v_{ww},\ \ \frac{\partial q}{\partial \theta}=\left[v_{w\theta}v_{wq}-v_{q\theta}v_{ww}\right]\Delta^{-1}=-v_{q\theta}/v_{qq}\ .$$