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EFFECTS OF MARKET STRUCTURE AND PATIENT CHOICE ON HOSPITAL QUALITY FOR PLANNED PATIENTS

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Effects of Market Structure and Patient Choice on Hospital Quality for Planned Patients

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Abstract

We investigate the change in the effect of market structure on *planned* hospital quality for three high-volume treatments, using a quasi difference-in-differences approach based on the relaxation of patient constraints on hospital choice in England. We employ control functions to allow for time-varying endogeneity from unobserved patient characteristics. We find that the choice reforms reduced quality for hip and knee replacement but not for coronary bypass, This is likely due to hospitals making a larger loss on hip and knee replacements, since robustness checks rule out changes in length of stay, new competitors' entry and hospital-level mortality as possible confounders.

JEL Nos: H51, I11, I18, L32, L33.

Keywords: competition, quality, hospital, choice, endogeneity, difference-in-difference, control function.

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1 Introduction

Policy makers in many countries have attempted to increase competition amongst hospitals (EXPH, 2015; OECD, 2012). In systems with low or zero patient co-payments, hospitals facing regulated prices per patient can attract patients only by improving quality. In these circumstances it is argued that increasing competition amongst hospitals will lead to higher quality.

Theory predicts that greater competition increases quality when hospitals are profit maximisers, face regulated prices and constant marginal costs (Gaynor, 2006), and the price exceeds the cost of the marginal patient. 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. 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 to respond to competition policies, which make demand more responsive to quality, by reducing quality (Brekke *et al.*, 2011, 2014).

In this study we use a natural experiment to investigate the effect of increased competition on quality. 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 the right to choose 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 patient having an emergency hospital readmission within 28 days of discharge after their index treatment.

We make six main contributions. First, we test whether the 2006 patient choice reform had greater effects on hospital quality for *planned patients* (i.e. non-emergency patients), whereas the bulk of the literature has examined quality for emergency patients (e.g. Cooper *et al.* (2011) and Gaynor *et al.* (2013)). Second, we consider three large volume planned surgical procedures: hip and knee replacement, and coronary artery bypass grafts (CABG). CABGs belong to a different clinical specialty from hip and knee and replacements and are provided by far fewer hospitals. This enables us to investigate the heterogeneity of the effects of the choice reforms across specialties and procedures.[1] Third, we use two control function strategies (Terza *et al.*, 2008; Wooldridge, 2015) to allow for self-selection bias arising if unobserved morbidity affects patient choice of hospital. Fourth, we investigate if results are sensitive to whether we measure hospital competition across all planned care specialties (as in much of the previous literature), the clinical speciality to which the procedure belongs, or the specific procedure. Fifth, we investigate if our results are affected by confounding factors such as length of stay, entry of new competitors, or hospital-level mortality. Finally, as our theory model suggests that hospitals will be less willing to improve quality to attract patients when they make a loss on the procedure, we investigate the profitability of the three procedures.

We find evidence of time varying self-selection into hospitals. The absolute effects of the choice reforms are larger for all three procedures when we use our control function strategies to allow for this. For hip and knee replacement patients the change in the effect of market structure due to the 2006 choice reforms was to reduce quality. We estimate that the choice reform increased emergency readmissions by 0.57% for hip replacement, compared to the baseline risk of 5.72%, and by 0.30% for knee replacement patients, compared the baseline risk of 1.9%. For planned CABG patients we find no effect of the choice reform on the quality of care (whether measured by emergency readmission or mortality).

The results are robust to the competition measure, and to allowing for hospital mortality, length of stay, competition from private hospitals, and selection of patients into private hospitals.

Theory models suggest that a key factor influencing the effect of competition on quality is whether the hospital makes a profit on the marginal 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 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.

[1] As we note in section 2.3, much of the previous literature has focused AMI (acute myocardial infarction).

In Section 2, we describe the institutional settings of the English NHS and summarise previous literature. In Section 3, we sketch a theoretical model to guides 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 planned hospital care by a referral from their general practitioner (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. NHS Trusts vary in size, number of sites, whether they are teaching hospitals, and in the mix of emergency and planned services provided.

A series of changes in the market for NHS funded hospital care were introduced during our study period (2002-2011) with the intention of stimulating competition to improve quality (Department of Health, 2000; 2002) and also reducing waiting times for hospital care.

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: the provider received a lump sum from the PCT for agreeing to treat all patients belonging to the PCT who were 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 rolled out, with the proportion of treatments covered increasing over time. The prospective pricing system is based on Healthcare Resource Groups (HRGs) which are groupings of hospital services of similar costs and type and are the English analogue of Diagnosis Related Groups. The tariff is based on the average of 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).

Financial penalities for emergency readmissions following planned procedures were introduced in the NHS in 2011 (Kristensen, 2017). They will not however 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 planned 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 which did not vary with the number of patients treated (Naylor and Gregory, 2009). From 2008 onwards other private providers were also allowed to treat NHS funded patients and all treatments. These non-ISTC private providers were paid the same DRG tariff as NHS providers. As initial ISTC contracts expired, ISTCs were also paid based on the national DRG tariff from 2009 onwards.

Until 2006, the amount of choice for planned 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, planned 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 independent sector treated around 4% of all NHS planned patients (Hawkes 2012), including 7.1% of hip replacement patients and 7.3% of knee replacement patients. To complement the choice reform, an electronic booking service for outpatient appointments was rolled out from 2005 to help patients and their GPs make a firm booking during a consultation (Dusheiko and Gravelle, 2015). In 2007 the NHS Choices website was established to provide public information on all providers of NHS services.

These policies led to changes in demand patterns and increased hospital elasticity of demand with respect to quality (Gaynor *et al.*, 2016; Moscelli *et al.*, 2016).

2.2 The market for planned hip and knee replacement and coronary artery bypass

Hip and knee replacement are *orthopaedic* treatments for osteoarthritis health problems, while CABG is a cardiovascular surgery used for some *circulatory* system diseases. In the English NHS, all three are publicly-funded high-volume planned procedures, with a yearly average of about 10,000 first time CABG treatments and over 45,000 primary for both hip and knee replacement.

The supply sides of the markets for these planned 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, while NHS-funded CABG surgery was performed only in about 47 hospital sites and not in private providers. Privately funded planned CABG patients treated by private hospitals accounted for 4.87% of all CABG patients in England (NICOR, 2012). In 2010/11, 11% of the overall sum of all planned 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 has the advantage that it reduces possible bias from selection of hospitals by patients with different unobserved morbidity since 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 planned patients (Bloom *et al.*, 2015). Results from this literature 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.*, 2014; 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 planned care. Colla *et al.* (2014), relying on observables to allow for casemix differences across hospitals, find 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 is lower the greater the proportion of local providers who are affiliated with the provider. In a cross-section study of English hip replacement patients, Feng *et al.* (2015) measures quality using rich data on patient reported outcomes and find that increased competition has 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 provider to treat sicker patients who had longer post-operative length of stay. Using data from 2009 to 2012, Skellern (2017) finds that market structure has a negative effect on patient reported outcomes for hip and knee replacement, groin hernia, and varicose veins, but the effect is insignificant when hospital-level fixed effects are included.

3 Theoretical framework

The theory literature has provided a number of models which identify the conditions under which competition can increase or reduce quality even when producers face fixed prices: see, for example, Gaynor (2006), Brekke *et al.* (2011), and Katz (2013). Here we sketch a very simple model which shows how the effect of competition on quality depends on the cost function and the degree of provider altruism.

A hospital chooses quality q to maximise

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

where $B(q)$ ($B_q > 0$) captures intrinsic motivation or altruistic preferences (McGuire, 2000). p is the fixed price of the treatment. Hospital demand $D(q,\theta)$ is increasing in quality ($D_q(q,\theta) > 0$). θ is a parameter (such as policy towards patient choice, or information about quality) which increases the responsiveness of demand to quality ($D_{q\theta} > 0$) and can therefore be interpreted as a measure promoting competition. $C(.)$ is the cost function, which is increasing in both volume of patients treated and quality. The first order condition when the hospital chooses a positive level of quality is

$$v_q(q,\theta) = B_q(q) + \pi_q(q,\theta) = B_q(q) + \left[p - C_D(D(q,\theta)) \right] D_q(q,\theta) - C_q(D(q,\theta),q) = 0 \tag{2}$$

and we assume that $v_{qq} < 0$.

Using the implicit function theorem, the effect of a change in the competition policy parameter θ on quality $q(\theta,\cdot)$ is

$$q_\theta = -\frac{v_{q\theta}(q(\theta),\theta)}{v_{qq}(q(\theta),\theta)} = -\frac{(p-C_D)D_{q\theta}-(C_{DD}+C_{qD})D_\theta}{B_{qq}+(p-C_D)D_{qq}-(C_{DD}D_q+2C_{Dq})D_q-C_{qq}} \tag{3}$$

The second term in the numerator depends on whether there are economies or diseconomies of scale ($C_{DD} < 0$ or $C_{DD} > 0$), whether an increase in quality increases or reduces the marginal cost of output ($C_{Dq} > 0$ or $C_{Dq} < 0$), and whether an increase in θ increases or reduces demand ($D_\theta > 0$ or $D_\theta < 0$). Since $D_{q\theta} > 0$ the sign of the first term in the numerator depends on whether marginal profit ($p - C_D$) on additional patients is positive or negative. If price exceeds marginal cost then an increase in θ is more likely to increase quality. But, the first order condition (2) implies that that the hospital will choose q so that $p - C_D = (C_q - B_q)/D_q$ and so a sufficiently altruistic hospital will increase quality to point where the marginal profit on patients attracted by higher quality is negative. An increases in θ is then more likely to reduce quality. More elaborate specifications, in which demand also depends on the qualities of rival providers, will have more complicated comparative static properties, but the effect of competition policy changes which increase the responsiveness of demand to provider quality will still depend, *inter alia*, on the relationship between the regulated price and marginal cost.

4 Methods

4.1 Model specification

We measure quality as the patient having an emergency readmission within 28 days of their discharge from hospital after a planned procedure for hip replacement, knee replacement, or CABG. For CABG patients we also measure quality as the patient dying in or outside hospital within 30 days of admission for a CABG procedure (see Section 5.1).

We estimate linear probability models (LPM)

$$q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\psi}_2 + \mu_h + \varepsilon_{it} + \varepsilon_{ht} \tag{4}$$

where q_{iht} is equal to 1 if patient i treated in NHS site h in year t (t = 2002/3,…,2010/11)[2] 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

[2] Data is for financial years 1 April to 31 March.

equivalent number of rivals (see 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 (4) describes a *quasi* difference-in-difference strategy (Card, 1992). The parameter of interest, γ, is identified through differences in *treatment intensity*: the change in the effect of market structure after the relaxation of constraints on patient choice in 2006, rather than through the assignment to a defined treatment or control group (Angrist and Pischke, 2009). Since there can be no change in the incentive for quality from lifting restrictions on patient choice for a provider with no rivals, the effect of the 2006 choice reform on quality for a provider with $\bar{M}_h$ rivals is given by $\gamma\bar{M}_h$: the policy reform pivots the quality function about its intercept on the quality axis in (q, $\bar{M}_h$) space. Thus, the sign of γ conveys useful policy information: whether the 2006 choice reform increased or reduced readmission or mortality, and $\gamma\bar{M}_h$ is the magnitude of this effect for hospital h. As in other difference-in-differences regressions, γ is the Average Treatment on the Treated (ATT) effect (Blundell and Costa-Diaz, 2009).

We estimate Eq. (4) 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 (see Section 5.1).

There are several advantages of estimating LPMs in this context. First, we can interpret the estimated coefficients as marginal effects and obtain unbiased estimates of γ, because the LPM approximates the conditional expectation function, whether the latter is linear or non-linear (Angrist, 2001; Angrist and Pischke, 2009). Second, a LPM yields unbiased estimates when fixed effects are included, unlike nonlinear estimators for modelling limited dependent variables (Lancaster, 2000; Greene, 2004). In our study, such problems would be exacerbated by the skewed distribution of the outcome variables. Third, unlike probit or logit estimators a

LPM is not subject to bias if there is measurement error in the dependent variable (Hausman, 2001).

Fourth, the estimation of causal effects is found to be generally consistent when using instrumental variable strategies with a linear first and second stage, but not necessarily when the second stage is a nonlinear model like probit or logit, especially when the outcome variable is very rare (Basu *et al.*, 2018). In our study, we control for endogenous patient choice (see subsection 4.3) with two control function strategies. One is akin to the two stage least squares (2SLS) estimator. The other differs from 2SLS because it requires an additional restriction on the conditional mean. The use of a LPM in the second stage equation also allows a comparison between the two control function strategies, which would not be possible with logit or probit outcome equations.

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 the 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. Since 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 and other covariates but does not depend on quality (see Section 5.2). 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 measure in the pre-policy period) that is not affected by endogenous entry and exit decisions.

The main source of changes in market structure over the period 2002/3 to 2010/11 was, from 2003/4, the entry of ISTCs specialising in a small number of treatments, including hip and knee and replacements, and, from 2008/9, the entry of private hospitals which had previously only treated private patients. ISTCs were encouraged to 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 ISTC entry was more likely where existing NHS providers had longer waiting times, it was not associated with changes in length of stay or quality. The private providers who started treating NHS patients from 2008/9 onwards were already providing care to private patients. Thus endogenous private sector entry may not be a problem even if we measure market structure at treatment level.[3]

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). We can write the outcome regression (Eq. 4) as

$$q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + q_{ht} + \varepsilon_{it} + \varepsilon_{ht} \tag{5}$$

where

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

is hospital h quality in year t (its contribution to patient outcome q_{iht}). Estimation of (4) will yield biased estimates of γ, φ_2 and μ_h if $E[\varepsilon_{it}|h] \neq 0$, i.e. if unobserved patient morbidity differs systematically across hospitals, because

$$\operatorname{cov}(q_{ht}, \varepsilon_{it}) = E\left[\operatorname{cov}(q_{ht}, \varepsilon_{it}|h)\right] = \operatorname{cov}(E\left[q_{ht}|h\right], E[\varepsilon_{it}|h]) = \operatorname{cov}(q_{ht}, E[\varepsilon_{it}|h]) \,. \tag{7}$$

From Bayes' Rule[4]

$$E[\varepsilon_{it}|h] = \int \varepsilon_{it} \left[\frac{P(\varepsilon_{it}, q_{ht}, \cdot)}{\int P(\tilde{\varepsilon}_{it}, q_{ht}, \cdot) f^t(\tilde{\varepsilon}_{it}) d\tilde{\varepsilon}_{it}} \right] f^t(\varepsilon_{it}) d\varepsilon_{it} \tag{8}$$

where $P(\varepsilon_{it}, q_{ht}, \cdot) = \Pr\left[h|\varepsilon_{it}\right] = P_{iht}$ is the probability that patient i in year t chooses hospital h and $f^t(\varepsilon_{it})$ is the density function for unobserved patient morbidity in year t. Sufficient conditions for $\operatorname{cov}(q_{ht}, \varepsilon_{it}) \neq 0$ are that unobserved patient morbidity affects which hospital is chosen ($\partial P(\varepsilon_{it}, q_{ht})/\partial\varepsilon_{it} \neq 0$), otherwise $E[\varepsilon_{it}|h] = E[\varepsilon_{it}]$, and that the effect of unobserved

[3] If pressure on management to improve quality is driven by overall planned competition, as in Bloom *et al.* (2015), then the fact that private providers NHS-funded activity accounted for only 4% of all planned NHS treatments (Hawkes, 2012) even at the end of our period also suggests that endogeneity may not be an important problem if market structure is measured at the level of all planned admissions, as in one of our specifications.

[4] $\Pr\left[\varepsilon_{it}|h\right] = \Pr\left[\varepsilon_{it} \cap h\right] / \Pr\left[h\right] = \Pr\left[h|\varepsilon_{it}\right] \Pr\left[\varepsilon_{it}\right] / \Pr\left[h\right]$.

patient morbidity on the probability of choosing provider h varies with provider quality ($\partial P^2(\varepsilon_{it}, q_{ht}) / \partial q_{ht} \partial \varepsilon_{it} \neq 0$).

If the effect of unobserved morbidity on choice of hospital is time-invariant, then the estimates of γ will be unbiased, thanks to the inclusion of hospital fixed effects μ_h. But, otherwise, we need to control for selection. We do so in two ways. First, 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 remove some selection on the unobservables. Second, we use two control function strategies (Wooldridge, 2015) to tackle any remaining selection on unobservables. Both strategies are based on estimating models for patient choice of provider as a function of variables, such as patient distance to provider, which are uncorrelated with provider quality as in, for example, Gowrisankaran and Town (1999) and Wilson (2016).

In the first strategy, we estimate for each provider h and each year t a linear probability model

$$C_{iht} = \alpha_{1ht} + \alpha_{2ht} d_{ih} + \alpha_{3ht} d_{ih}^2 + \alpha_{4ht} d_{ih}^3 + \alpha_{5ht} nearest_{ih} + r_{iht} \tag{9}$$

where $C_{iht} = 1$ if patient i chooses hospital h in year t and zero otherwise, d_{ih} is the distance from the centroid of patient i's Lower Super Output Area (LSOA)[5] of residence to provider h, and $nearest_{ih}$ is an indicator for h being the nearest provider to patient i.[6] We then estimate the second stage quality model as

$$q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\Psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\Psi}_2 + \hat{\mathbf{r}}_{ih}^{LPM}{}'\boldsymbol{\Psi}_3 + \mu_h + \varepsilon_{it} + \varepsilon_{ht} \tag{10}$$

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 regressions Eq. (9). With linear first and second stage models this control function procedure of residual inclusion (2SRI) is akin to two stage least squares (2SLS), but with the advantage that a joint test on the significance of the residuals can be used to test for endogeneity of choice of provider (Wooldridge, 2002; Terza *et al.*, 2008; Wooldridge, 2010). This estimation strategy (Linear 2SRI) is fully nonparametric.

In the second strategy, we estimate a first stage conditional logit model for patient choice of hospital. We assume that the random utility obtained by patient i from provider h in year t is

[5] In the period 2002 to 2010 there were 32,482 LSOAs with an average populations of around 1500.
[6] Since Eq. (9) is estimated separately for each year and for each hospital, it cannot contain time invariant hospital characteristics such as teaching hospital status.

$$U_{iht} = V_{iht} + \xi_{iht} = \theta_{1t} d_{ih} + \theta_{2t} d_{ih}^2 + \theta_{3t} d_{ih}^3 + \theta_{4t} T_{ht} + \theta_{5t} F_{ht} + \theta_{5t} PO_{ht} + \xi_{iht} \tag{11}$$

where T_{ht}, F_{ht} and PO_{ht} are indicators for teaching, foundation trust and privately-owned hospital status. We assume that the patient choice set S_i is the closest 50 providers (accounting for over 99% of choices in each year). If the ξ_{iht} are i.i.d with an extreme value distribution then the probability that patient *i* chooses provider *h* in year *t* is (McFadden, 1974)

$$P_{iht} = \exp\left(V_{iht}\right)\left[\sum\nolimits_{h' \in S_i} \exp(V_{ih't})\right]^{-1} \tag{12}$$

Estimation of the conditional logit model yields residuals $\hat{r}_{iht}^{CLM} = C_{iht} - \hat{P}_{iht}$, which we then include in the second stage outcome regression.[7] This strategy (CL 2SRI) is semi-parametric, as it is characterized by the structural parametric estimation of the first stage conditional logit model, followed by the nonparametric estimation of the linear probability model for the outcome regression. Compared to Linear 2SRI, the identification of the parameter(s) of interest in the quality outcome model when using the CL 2SRI strategy rests on the slightly stronger assumption that $E(\varepsilon \mid \mathbf{x}, g(\xi)) = E\left[\varepsilon \mid g(\xi)\right] = E(\varepsilon \mid \hat{r}^{CLM}) = 0$ (Blundell and Powell, 2003). Given the linearity of our final outcome equation and the *multinomial* nature of the endogenous hospital choice, the estimation of Eq. (10) with a CL 2SRI correction is less likely to produce biased estimates of the effect of interest (γ) that than with fully parametric 2SRI strategies with nonlinear second stages and a *binary* endogenous treatment (Basu *et al.*, 2018).

In both control function strategies the residuals pick up the effect of unobserved patient morbidity ε_{ib} on the choice of hospital *h*, and so they control for bias due to the endogenous patient selection of hospital. The strategies are complements. The CL 2SRI strategy has a more plausible first stage specification, which should predict hospital choice more accurately and hence produce more efficient estimates of γ (Newey and McFadden, 1994). If the two CF strategies produce similar parameter estimates this is reassuring since Linear 2SRI estimation of γ is expected to be unbiased (Basu *et al.*, 2018).

Our control function strategies use distances from patient's residence to hospitals as instrumental variables (IVs), i.e. source of exogenous variation to control for endogenous patient choice of hospital. The use of distances as IVs has been common in the healthcare

[7] 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.

literature since McClellan *et al.* (1994) and Newhouse and McClellan (1998). Many studies show that distance is highly relevant in predicting hospital choice (for examples for England, see Gaynor *et al.*, 2016; Gutacker *et al.*, 2016; Moscelli *et al.*, 2016). With respect to the exogeneity requirement for an IV, Gowrisankaran and Town (1999) note that whilst the distance to the *chosen* hospital may be correlated with illness severity, the distances from patient's residence to *all* the hospitals available for treatment will not. [8]

4.4 Sample selection

We estimate our models on the effect of the choice reforms with a sample of patients treated in NHS hospitals. The main source of changes in market structure over the period 2002/3 to 2010/11 was the entry of ISTCs and (from 2008) private hospital sites. Until 2009, ISTCs were not paid per patient treated (Naylor and Gregory, 2009) and were only moved onto DRG pricing per patient treated as their long term contracts expired. Hence, ISTCs had little incentive to compete on quality for most of our period and so including NHS-funded patients treated in ISTCs could bias the estimate of γ towards zero. Nor can we include patients treated in other private providers since they were only available for NHS patients from 2008 onwards, so that it not possible to compute a time-invariant market structure measure for them. Hence we estimate the effect of the choice reforms for patients treated in NHS hospitals only. But we know that NHS patients treated in NHS providers were unobservedly more morbid than those treated in the private sector (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 in the estimate of the effect of the choice reform on patients treated in NHS hospital we augment our baseline model with a Heckman selection correction term (inverse Mills ratio) from an additional first stage model for choice of NHS rather than private hospital (Heckman, 1979). Rather than relying on non-linearities for identification, we estimate a first stage probit model for choice of NHS provider in which the latent utility from NHS treatment is

$$NHS_{it}^{*} = \rho_{0t} + \rho_{1t}(d_{itNHS} - d_{itISP}) + \mathbf{x}_{it}'\boldsymbol{\rho}_{2t} + u_{it} \tag{13}$$

[8] There is no evidence of residential sorting for planned hospital care in England. It is possible that patients in need of repeated treatments, like haemodialysis or chemotherapy, are more likely to 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 planned treatments in England from 2005 onwards (Propper *et al*., 2010).

where d_{itNHS} and d_{itISP} are the distances to the closest NHS hospital site and to the closest private provider hospital site to the patient's residence, and the patient chooses the NHS provider if and only if $NHS_{it}^{*} \geq 0$. As with the use of distance in the first stage choice models we assume, plausibly, that differential distance $d_{itNHS} - d_{itISP}$ satisfies the exclusion restriction.

4.5 Inference

In all models the standard errors are bootstrapped (with 1,000 replications) to account for the sampling error resulting from the inclusion of the imputed regressors $\hat{r}_{ht}$ (Murphy and Topel, 1985). We report *t*-statistics based on cluster-robust standard errors with clustering at hospital site level, to account for the within-cluster error correlation between hospital quality and the change in the effect of market structure (Cameron and Miller, 2015; Moulton, 1990).

5 Data

Our main data source is the Hospital Episodes Statistics (HES) database. HES has information on all admissions to NHS providers and all NHS-funded hospital admissions to private providers. We use data on planned hip replacement, knee replacement and coronary artery bypass (CABG) patients aged 35 and over (Appendix B has detailed procedure codes).

5.1 Quality

We measure quality for planned hip replacement, knee replacement, and CABG patients treated in NHS hospitals by whether the patient had an emergency admission within 28 days of discharge after their initial planned procedure. Emergency readmissions are one of the performance indicators included in the NHS Outcomes Framework [9] and a widely used measure of hospital quality in the health economics and clinical literatures (Ashton *et al.*, 1997; Weissman et al., 1999; Balla et al., 2008; Billings et al., 2012; Blunt *et al.*, 2015). Since planned CABG treatment has a mortality risk of 1.1%, which is around four times as great as for planned hip and knee replacement mortality, we also measure CABG quality by whether the patient died in *any* location (i.e. inside or outside the hospital) within 30 days of their index admission.

[9] Emergency readmissions are based on the official NHS definition (HSCIC 2016) https://files.digital.nhs.uk/C4/E99638/Spec_03K_520ISR7G.pdf. Since our analysis is based on patients treated in NHS hospitals only, the emergency readmissions to a NHS hospital following a surgery in a private hospital are excluded. Emergency readmissions are attributed to the hospital where planned care was performed, not to the hospital that provided emergency care after discharge from the index planned admission.

Alternative quality measures based on patient reported outcomes were not available for hip and knee replacements before 2009, after the 2006 choice reform, and were never collected for CABG. Emergency readmissions and mortality indicators are also available for almost admissions, unlike patient reported outcomes where missing data are more frequent and related to hospital behaviour (Gomes *et al.*, 2016).

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 hospitalization in the previous year. We also attribute to the patient the IMD[10] income deprivation, the IMD environment deprivation, the incapacity benefit claims rate, and the disability claims rate of their LSOA.

Hospital characteristics are captured by indicators for whether a hospital is Foundation Trust and hence had greater financial flexibility (Marini *et al.*, 2008), and whether it is a teaching hospital.

5.2 Market Structure

We construct measures of market structure for 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. Using actual patient flows to compute the HHI could induce reverse causality bias since the number of patients choosing a hospital is affected by its quality (Kessler and McClellan, 2000). We therefore follow the standard practice of using HHIs computed from patient flows predicted from a model of patient choice, which uses patient distances to hospital and hospital characteristics but not hospital quality (Appendix C).

It is possible that quality for a procedure depends on competition in the market for that procedure (hip replacement, knee replacement, CABG), or in the market for the speciality (musculoskeletal, circulatory), or in the market for all planned admissions. We therefore

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

compute the equivalent number of rivals using predicted HHIs defined by choice of provider by patients receiving the procedure, by all patients being treated in the speciality, and by all planned patients. As a further robustness check, we also use a count of the actual number of rival hospital sites within 30 kilometres.

6 Results

6.1 Summary statistics

Table 1 reports the descriptive statistics on NHS patients treated in NHS providers. Mean ages are 68 for hip replacement, 70 for knee replacement and 65 years for CABG. The proportion of female patients is much higher for hip and knee replacement (60% and 58%) than for CABG (18%). Hip and knee replacement patients have an average of three co-morbidities whilst CABG patients have six. Hip and knee replacement patients also had fewer emergency admission in the year prior to treatment than CABG. CABG patients travelled further to their provider than hip and knee replacement patients.

Hip and knee replacements increased and then fell slightly between 2002/3-2010/11 (Appendix Figure A1). CABGs declined over the entire period. Risk-adjusted planned care hospital quality declined (i.e. 28-days 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. After the choice reform of 2006 the proportion of patients travelling further than the closest hospital site increased by about 15% for both hip and knee replacement procedures, while for CABG surgery it initially increased by 3% and later decreased by 5.6% (Appendix Figure A3).

Table 2 reports correlations among risk-adjusted NHS hospital site quality measures for our three planned procedures. The correlations are generally small. The highest correlation (0.28) is between knee and hip replacement emergency readmission rates, which is perhaps to be expected since they are in the same speciality and 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.

Since almost all of the literature on hospital competition and quality has focused on mortality rates for emergency admissions for conditions such as AMI we also report, in italics, the correlations between our planned care quality measures with the mortality of three high volume emergency conditions (AMI, hip fracture and stroke). The emergency mortality rates are very weakly associated with the planned care quality measures and the only significant correlation is negative. Gravelle *et al.* (2014) used a larger set of measures for 2009/10 and also found find little evidence for a positive correlation between planned and emergency care hospital quality. These findings suggest that mortality for an emergency conditions is not necessarily indicative of hospital quality for planned procedures and that the relationship between market structure and measures of quality may be sensitive to the quality measure used.

Table 3 has summary statistics on measures of market structure. Most of the measures increased over the period by between 15% and 23%, with the exception of CABG market structure that was substantially unchanged, as we would expect since no private providers entered this market. The percentage increase in the actual number of NHS and private planned care providers within 30 km was very similar (24%) to that for the equivalent numbers (23%).[11]

6.2 Results

Table 4 reports the coefficient (γ) on the interaction between pre-2006 market structure and the post-2006 choice reform indicator with the market defined as the speciality (musculoskeletal or circulatory). We report four models: column (1) has just hospital and time fixed effects; column (2) adds covariates (specification Eq. (4)). Columns (3) and (4) estimate Eq. (10) by adding the first stage residuals from the linear probability choice model and from the first stage conditional logit (CL) choice models to the model in column (2).

Panel a has results for hip replacement. In all four specifications the positive coefficient γ on the *Choice Policy*Market structure* interaction implies that relaxation of constraints on choice had a larger positive effect on readmissions (i.e. negative effect on quality) on providers facing more pre-2006 competition. Adding covariates (column (2) vs column (1)) reduces γ slightly and adding the first stage residuals increases it again, though it is not statistically significant for the linear 2SRI model (column (3)). The choice model residuals are jointly statistically

[11] The correlations for the equivalent number of rival sites for all planned 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 planned admissions is 0.78 (Appendix Table A1). Figure A4 plots the trends in the competition measures.

significant for both the CL and linear specifications, indicating that there was endogenous selection, though this had only a relatively modest effect on the estimates of γ.[12]

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 doubles 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 generally small, negative and statistically insignificant effects of choice policy on emergency readmissions and on mortality for all four specifications in columns (1) to (4), whether or not we control for been endogenous selection of hospitals.

Given a pre-reform average equivalent number of rivals of 2.77, measured at orthopaedics specialty level, we estimate that the choice reform increased emergency readmissions by 0.57% ($\gamma\bar{M}_h$) for hip replacement, compared to the baseline risk of 5.72%, and by 0.30% for knee replacement patients, compared the baseline risk of 1.9%. With an estimated average £2,100 cost per 30 day readmission (Billings *et al.*, 2012), this implies an increase in NHS costs by £32.3M for hip replacements and £13M for knee replacements for the period 2006/7-2010/11.[13]

In **Table 5** we examine if our results are sensitive to the way in which market structure is measured using the reciprocals of HHIs measured for all admission (1) to (3), for procedure (columns (4) to (6)), and using a simple count of rivals within 30km HHI (columns (7) to (9)). The pattern of results for each of these three market structure measures is very similar to that with the speciality-based measure in Table 4. The magnitude of the estimated γ coefficients on Choice Policy*Market Structure vary across the market structure measures but this is likely to be 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 planned admissions and much smaller

[12] The 1st stage F-statistics of the instruments in the Linear 2SRI models are very large (Appendix Table A3). For the CL 2SRI, in the absence of a formal test, we find (Appendix Table A2**)** 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.
[13] These costs are estimated as: *patients treated in period 2006/7-2010/11* × (*baseline risk* + *increased risk*) × *cost of readmission within 30 days*, which amounted to 244,372 × (0.0572 + 0.0057) × £2,100 for hip replacement and 280,723 × (0.019 + 0.0030) × £2,100 for knee replacement.

than the simple count of rivals. This is the reverse of the rankings of the estimated γ coefficients across the market structure measures.[14]

Since the choice of measure makes little substantive difference to our results we use market structure at specialty level in subsequent models as it seems more intuitive: the all planned patients HHI combines very heterogeneous procedures, creating a risk of measurement error. Procedure-level HHI might be more prone to endogeneity – if some of the hospital characteristics included in the choice model used to estimate the predicted HHI (Appendix C) are correlated with hospital quality – and 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.

6.3 Robustness checks

Sample selection

As we explained in section 4.4 we estimate the effect of the choice reform **Table 6** on patients treated in NHS hospitals. To test if this creates sample selection bias, we include a Heckman selection correction in the second stage quality models, using the difference in distance between the nearest NHS and nearest private providers of care to NHS patients as an exclusion restriction in the first stage probit model for choosing a NHS hospital. Results 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 never statistically significant,[15] possibly because of extensive set of case-mix variables, hospital fixed-effects in the baseline specification, and the choice residuals in the two control function specifications.

[14] We also estimated models using first principal component from a principal components analysis of HHIs based on all planned 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 A5a. It shows that all market structure measures are positively correlated with the first principal component, with larger and substantially equivalent weights to the all planned admissions and planned 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 speciality HHI (Appendix Table A5b).

[15] 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% level, and the p-values of the Chi-squared tests of the overall significance of the first stage probit regressions are also significant at 1% level (Appendix Table A4).

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 and there could be trends in age and gender specific readmission or mortality over our nine year period. If so estimates of $\hat{\gamma}$ may be biased (Meyer, 1995). To allow for this we re-estimated the quality model adding an interaction the post-choice indicator and the covariates (Abadie, 2004, p. 4).[16] The results are in the first three columns of **Table 7.** 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.

Time varying market structure

In the middle three columns ((4), (5), (6)) of **Table 7** we allow market structure to vary over time rather than being frozen to its pre 2006 value. This has little effect on the results, suggesting that market structure is not endogenous.

Competition from private hospitals

The HHIs on which the competition measure is based include private providers' predicted shares of NHS patients. This treats NHS and private providers symmetrically and to allow for the possibility that NHS providers responded differently to competition from private providers we added an indicator for there being at least one private hospital site within 30 km of the NHS provider. This also has little effect on the results, as shown in **Table 7**.

The choice reform may have led to changes in other aspects of hospital behaviour, in addition to possible changes to our planned care quality measures. In particular it has been suggested that the reform led to reductions in length of stay (Cooper *et al.*, 2018; Gaynor *et al.*, 2013) for planned patients and in mortality for emergency patients (Cooper *et al.*, 2011; Gaynor *et al.*, 2013; Moscelli *et al.*, 2018b). We next investigate whether this has implications for our results for planned care quality.

[16] The Eq. (4) outcome model is replaced by $q_{iht} = \beta_t + \mathbf{x}'_{iht}\boldsymbol{\psi}_1 + \gamma \bar{M}_h A_t + \mathbf{x}'_{ht}\boldsymbol{\psi}_2 + \mathbf{x}'_{iht}\boldsymbol{\lambda}_1 A_t + \mathbf{x}'_{ht}\boldsymbol{\lambda}_1 A_t + \mu_h + \varepsilon_{it} + \varepsilon_{ht}$.

Patient length of stay

The increase in emergency readmissions for planned hip and knee replacement patients might be due to patients being discharged '*quicker but sicker*'. In **Table 8** we report models with length of stay as the outcome variable but with the same explanatories as our quality models. We find that length of stay for hip and knee replacement patients decreased more after 2006 in hospitals facing more competition, suggesting that patients were indeed discharged 'quicker' in the post choice period. According to the estimates of the CL 2SRI specification, the effect is negative and significant at 5% (1%) level for knee (hip) replacement, and negative but not statistically significant for CABG patients.

Table 8 also reports results for models for our quality measures including the patient's in-hospital length of stay as an additional covariate. Adding length of stay makes almost no difference to the estimates of γ compared with those in Table 5 (columns (1) to (3)). This implies that, although the choice policy reform affected readmissions for hip and knee replacements, the effect was direct rather than indirect via the effect of length of stay on readmissions and that our quality model is not biased by the omission of length of stay.[17]

Hospital mortality

Katz (2013) and Skellern (2017) suggests that hospital management might convey information about hospital quality through hospital mortality rates. If patients do not observe indicators for planned care quality this may induce a diversion of hospital efforts towards quality for emergency services, where mortality is high compared with planned care, generating adverse substitution or multi-tasking effects.

[17] Ignoring covariates, time and provider fixed effects, and endogenous selection for simplicity, suppose that that length of stay s_{ht} is determined as $s_{iht} = \beta_s + \gamma_s \bar{M}_h A_t + \varepsilon_{iht}^s$ (i) and quality as $q_{iht} = \beta_q + \gamma_q \bar{M}_h A_t + \theta_q s_{iht} + \varepsilon_{iht}^q$ (ii). Our baseline model Eq. (4) for quality omits length of stay so that $\mathrm{E}\hat{\gamma} = \gamma_q + \theta_q \gamma_s$. We find that whilst $\hat{\gamma}_s < 0$, $\hat{\theta}_q \approx 0$, and so $\hat{\gamma}_q$ is very similar to the estimates of $\hat{\gamma}$ in Table 4. Since s and q are outcomes with welfare significance, estimation of the full structural model of q in (ii) is potentially of policy interest if there are policy tools available, in addition to competition, which could affect length of stay. Optimal policy would then require also estimating a fuller version of (i) including the additional policy variables. On the other hand, if s cannot be controlled other than through competition policy, we only need to estimate the full effect of competition policy ($\hat{\gamma}$) as our original quality model (Eq (4)). If s is of welfare relevance interest, then the finding from estimation of (i) that is affected by competition policy should be taken into account in an evaluation of the welfare effects of competition policy.

To check whether a *diversion of hospital efforts* to reduce mortality is confounding our results, we add standardised hospital mortality to the models. Results are in **Table 9**. The first six columns use overall standardised mortality ratios (Dr Foster's HSMR) at hospital Trust level.[18] The last six columns include standardised mortality ratios for two emergency conditions in the same clinical specialty of the planned procedure performed, i.e. hip fracture for orthopaedics and AMI for circulatory disease. We also allow the effect of mortality to vary before and after the introduction of the patient choice reform (columns 4, 5, 6 and 10, 11, 12), to control for the possibility that *within hospitals* changes in clinical and organizational practices due to competition took off only after hospitals had an incentive to attract more patients from 2006 onwards. Regardless of the standardized mortality type and the presence or not of a pre/post-2006 break in the specifications, there is no substantive change in the estimates of γ in the first three columns of Table 5, suggesting that the diversion of efforts from planned to emergency care is unlikely to explain our findings.

Mortality could affect interpretation of our results if it induces survivorship bias. In order to be readmitted within 30 days of discharge after their index planned procedure, patients must be alive. This implies that we have estimated our readmission models on a sample of patients who may be healthier than the population who have the planned procedure. We tested for this using a model for the effect of competition on emergency readmissions including a Heckman correction term for CABG patients' mortality (survivorship bias is not a problem for hip and knee replacements, as shown by the mortality rates for these two procedures in Table 1) estimated from a first stage CABG mortality probit model. We find (Appendix Table A7) that the selection correction term is statistically insignificant and the effect of the choice reform on CABG readmission is still small and statistically insignificant.

Finally, we used our specification (Eq. (4)) of the effect of choice on planned care quality to test for an effect of the choice reform on the quality of care for emergency AMI admissions. We find (Appendix Table A6) that, in line with Gaynor *et al.* (2013), the choice reforms reduced AMI mortality. This suggests that our findings of negative effects of the choice reform on quality for hip and knee replacements is not due to some inherent defect in our specification.

[18] These figures were produced by Dr Foster, a data analytics and consulting company focused on the healthcare sector, and publicly available on http://www.brianjarman.com/ for all the years of our sample.

6.4 Hospital profits on planned procedures

The theory model sketched in Section 3, and the bulk of the theory literature, suggests that whether greater competition increases or reduces quality depends, *inter alia*, on whether marginal revenue is greater or smaller than marginal cost. Hospitals are paid a nationally fixed tariff P_{jt} per patient in HRG_j in year t. P_{jt} is based on average reported costs for all hospitals in the two previous years with an adjustment for input prices in the area in which the hospital is located. It is therefore possible that, if costs increase over time, perhaps because of changes in medical technology or the morbidity of patients, changes in input prices, the HRG tariff could be less than the unit cost of the procedure, thus posing a financial risk to hospitals (Dixon, 2004). To check whether this is the case, we compute the per-treatment profit by procedure and by the largest volume HRG4 codes within procedures.

The tariff for hospital h in year for HRG j is $P_{jt}*MFF_{ht}$. MFF_{ht} is the Market Forces Factor tariff adjustment for area input price variations, applied to hospital h in year t. In the absence of data on the marginal cost of HRG_j in hospital h in year t we estimate it using information on average costs.[19] Let AC_{jt} denote the national unit cost for HRG j in financial year t; and CI_{ht} the reference cost index for all planned 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 so the per unit profit (π_{hjt}) on HRG j in hospital h in year t is

$$\pi_{hjt} = MFF_{ht}* P_{jt} - (CI_{ht} / 100)*AC_{jt} \tag{14}$$

Results are in **Table 10**. Over the two years (2009/10, 2010/11) for which we have data,[20] NHS hospitals made an average loss for each patient of £750 for knee replacement, £485 for hip replacement and £370 for CABG. NHS hospitals 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

[19] We can justify this on the assumption that average cost is constant or that boundedly rational hospital management allocates effort to improve quality across procedures according to total rather than marginal profit.

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

on quality. Data limitations imply that our calculations are necessarily rough, but we think they are at least suggestive.

7 Conclusions

We have 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 planned treatments. We used two control function strategies to address possible bias induced by time varying self-selection into hospitals due to unobserved severity. For hip and knee replacements the estimated effect of the 2006 choice reforms was a relatively small increase in the risk of emergency readmissions within 28 days of discharge. For knee replacement, the effect was always statistically significant but for hip replacement, the effect was statistically significant depending on the control function approach used. Given that it is significant using the CL 2SRI, which is likely to be more efficient (Newey and McFadden, 1994), we interpret this as evidence of the effect being significant also for hip replacement. The increase in the baseline risk of emergency readmissions for this two procedures implied an extra cost of about £45 millions for the NHS in the period 2006-2010. The choice reform had no effect on emergency readmissions or mortality for CABG patients. Our results are robust to the measure of market structure, patient selection into NHS providers, allowing the effects of covariates to vary pre and post-choice reform, patient length of stay and hospital mortality.

How can these results be rationalized and reconciled with existing evidence and theory? First, negative effects on quality have also been found other empirical studies (see references in Section 2.2). Second, they are compatible with theoretical models. For example, and in line with the model sketched in Section 3, Brekke *et al.* (2011, 2104) show that the effect of increased competition leading to increased demand responsiveness to quality depend on hospital preferences and cost functions. Quality could fall following an increase in competition if the regulated price is less than the cost of treating additional patients or if the marginal cost of treatment is greater when quality is higher. Our back of the envelope hospital profit computations for years 2009 and 2010 suggest that treating planned hip and knee replacement was unprofitable for English hospitals, but less so for CABG patients.

Third, our results for planned care quality are not incompatible with those from studies of emergency quality which use the same identification strategy but find improved quality for

AMI (Cooper *et al.*, 2011; Gaynor *et al.*, 2013) and hip fracture (Moscelli *et al.*, 2018b). For example, if emergency mortality is seen as a signal of quality and influences demand, then patient choice could increase emergency quality and reduce planned care quality as the result of diverted effort (Katz, 2013; Skellern, 2017).

Fourth, our findings are also consistent with studies that find the demand elasticity to quality is generally low (about 0.1) and this is the case both for CABG (Gaynor *et al.*, 2016) and hip replacement patients (Moscelli *et al.*, 2016). This suggests that hospitals' incentives to compete for planned patients is weak and may explain the relatively small effects of the choice reforms.

Fifth, our findings are consistent with those of Gaynor *et al.* (2016). Their work evaluate the change in hospital choice before and after the choice reform for CABG patients, and they present also reduced form evidence that the effect of *choice*, not *competition*, reduced patients mortality in the post-policy period. However, they find that the reduction in CABG mortality was significantly larger for patients not vising the nearest hospitals (Table 4, p. 3545) and that this reduction in mortality was negatively correlated with an increased elastic in demand with respect to mortality rate (Table 7, p. 3550). These results are compatible with a market in which the planned care hospital quality is constant or does not vary much, but patients are instead able to self-select into hospitals for CABG treatment that better match their healthcare needs, based on their severity, and so they can obtain better health outcomes. In this context, the reduction of patient mortality is due to a better matching between patients and hospitals due to the official introduction of choice - not due to a positive effect of hospital competition. Indeed we find that hospital market structure had no significant effect on health outcomes for CABG patients.

Moreover, our results are not due to (and are compatible with) competition improving efficiency, since our results hardly change once we control for length of stay, neither they are due to cream skimming of private providers opening in the proximity of NHS hospitals; sample selection, due to easier casemix patients systematically sorting themselves into - or having preferential access to - private hospitals.

Overall, our findings contributes to the heated debate on the effect of competition on hospital quality (Bloom et al., 2011, 2012; Pollock, 2011a, 2011b) in two ways: we provide evidence that the English choice reforms had mixed effects on hospital quality for planned procedures; and we link our findings to a theory of hospital competition, shedding more light on the 'black-box' competition mechanism.

However, the reductions in quality for knee and hip replacement procedures does not necessarily imply that patients undergoing these procedures were made worse off by the 2006 choice reform. Patients may place an intrinsic value on having a choice of provider (Dixon *et al.*, 2010), or they could gain from being able to switch to previously unobtainable providers with lower mortality (Gaynor *et al.*, 2016) or lower waiting times (Moscelli *et al.*, 2018a).

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Table 1. Patient descriptive statistics.

	Hip Replacement			Knee Replacement			CABG		
	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Emergency readmission within 28 days	0.057	0.232	0	0.019	0.137	0	0.041	0.198	0
Died within 30-days (anywhere)	0.003	0.051	0	0.002	0.047	0	0.011	0.105	0
Emergency admissions in year before treatment	0.06	0.3	0	0.06	0.29	0	0.29	0.65	0
Age	68.27	10.75	69	70.03	9.23	71	65.37	9.16	66
Female	0.6	0.49	1	0.58	0.49	1	0.18	0.38	0
Number of diagnoses on admission	2.95	2.03	2	3.07	2.04	3	5.71	2.96	5
Charlson Index: zero co-morbidities	0.79	0.41	1	0.75	0.43	1	0.57	0.5	1
Charlson Index: one co-morbidity	0.16	0.37	0	0.19	0.4	0	0.3	0.46	0
Charlson Index: more than one co-morbidity	0.05	0.21	0	0.05	0.22	0	0.13	0.34	0
IMD income deprivation	0.12	0.1	0.09	0.14	0.11	0.1	0.14	0.11	0.1
IMD living environment	18.64	14.66	14.24	19.45	15.2	14.9	20.42	15.97	15.57
Incapacity claims	0.03	0.02	0.03	0.03	0.02	0.03	0.04	0.02	0.03
Disability claims	0.05	0.03	0.04	0.05	0.03	0.05	0.05	0.03	0.05
Distance to chosen hospital (km)	9.24	8	6.58	8.62	7.67	6	8.15	7.4	5.59
Distance to A&E type 1 hospital (km)	-36.74	45.56	-22.8	-35.39	44.6	-20.77	.	.	.
Distance to closest NHS hospital site (km)	8.51	7.4	6.13	7.93	7.1	5.58	.	.	.
Distance to closest Private hospital site (km)	45.26	45.96	31.1	43.31	45.06	28.83	.	.	.
Length of in-hospital stay	8.21	8.76	7	8.04	8.35	6	9.15	7.08	7
Number of patients		414,433			463,953			114,291	

Notes. Planned patients treated in financial years 2002/3 to 2010/11 in NHS hospital sites only.

Table 2. Correlations of risk-adjusted hospital planned and emergency quality.

		Readmissions			Mortality		
		Planned hip	Planned knee	Planned CABG	Planned CABG	Emergency AMI	Emergency hip fracture
Readmissions	Planned knee	0.2832***	1				
	Planned CABG	-0.097	0.037	1			
Mortality rate	Planned 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***	1
	Emergency stroke	*0.028*	*-0.119****	*0.035*	*-0.045*	0.223***	0.170***

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 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 & ISP sites within 30km	14.56	16.90	0	63	17.17	19.62	0	76
Number ISP sites within 30km	0.14	0.42	0	2	1.66	2.11	0	12

Notes. Equivalent number: inverse of the predicted Herfindahl-Hirschman Index. ISP (NHS) hospital sites: privately (NHS) owned sites treating at least 100 NHS funded planned (excluding planned) patients per year.

Table 4. Effect of choice reform with time-invariant pre reform specialty-based market structure.

	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)				
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)				
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)				
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)				
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) models as column (1) plus covariates. Column (3) augments column (2) models with the residuals for all hospitals from linear first stage choice model. Column (3) augments column (2) models with the 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 also bootstrapped (1,000 replications). *p<0.1, ** p<0.05, *** p<0.01.

Table 5. Effect of choice reform with 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)									
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)									
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)									
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)									
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 planned patients (columns 1 to 3), all patients treated for the given planned procedure of admission (columns 4 to 6); the number of rivals within 30 km from the treating hospital. Columns (2), (5), (8) use residuals from linear first stage choice models. Columns (3), (6), (9) models add residuals 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. Effect of choice reform, allowing for selection into private providers.

	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)			
Choice Policy * Market Structure	0.0018**	0.0020	0.0021**
	(2.051)	(1.539)	(2.181)
IMR (Inverse Mills Ratio)	-0.0081	-0.0061	-0.0075
	(-1.527)	(-1.107)	(-1.221)
joint Chi^2 test residuals coefficients=0		650.0738	500.4340
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)			
Choice Policy * Market Structure	0.0005**	0.0011**	0.0011***
	(2.141)	(2.386)	(3.876)
IMR (Inverse Mills Ratio)	0.0019	0.0023	0.0010
	(0.756)	(0.833)	(0.334)
joint Chi^2 test residuals coefficients=0		759.8586	549.3528
p-value joint χ2 test residuals coefficients=0		0.0000	0.0000
R^2	0.003	0.004	0.004

Notes. Dependent variable, Choice Policy and market structure defined as in Table 4. All models includes the IMR from a first stage probit regression of a dummy for patient treated by NHS hospital regressed on the differential distance between closest NHS and closest private hospital sites (i.e. the exclusion restriction variable) plus patient's case-mix covariates. The first stage probit sample includes NHS-funded planned 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.

Table 7. Robustness checks: change in effect of covariates post-policy; time-varying market structure; rival private hospitals.

		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 for all providers	CL 2SRI residuals for all providers
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		With post-policy interactions with covariates			With time-varying market structure			With controls for private hospitals within same area		
Hip Replacement - Emergency Readmissions	Choice Policy * Market Structure	0.0017*	0.0024*	0.0023**	0.0016**	0.0019	0.0019**	0.0017*	0.0017	0.0021**
		(1.852)	(1.683)	(2.304)	(2.004)	(1.583)	(2.137)	(1.892)	(1.282)	(2.148)
	Market Structure				-0.0002	0.0003	-0.0009			
					(-0.128)	(0.149)	(-0.474)			
	Any private hospital site within 30km							0.0001	0.0013	-0.0000
								(0.335)	(1.625)	(-0.034)
	joint χ^2 test residuals coefficients=0		646.1812	505.5439		638.8924	496.8123		669.5321	498.5960
	joint χ^2 test Choice*covariates coefficients=0	65.9487	59.7571	63.6272						
	R^2	0.012	0.013	0.012	0.011	0.012	0.012	0.011	0.012	0.012
Knee Replacement - Emergency Readmissions	Choice Policy * Market Structure	0.0007**	0.0018***	0.0013***	0.0006**	0.0012***	0.0011***	0.0005*	0.0011**	0.0010***
		(2.409)	(3.613)	(3.812)	(2.242)	(2.757)	(4.035)	(1.860)	(2.367)	(3.444)
	Market Structure				-0.0004	-0.0010	-0.0010			
					(-0.538)	(-0.987)	(-1.442)			
	Any private hospital site within 30km							0.0001	0.0000	0.0002
								(0.452)	(0.013)	(0.675)
	joint χ^2 test residuals coefficients=0		773.8615	559.1953		764.9685	559.0726		778.0866	558.7277
	joint χ^2 test Choice*covariates coefficients=0	74.8075	83.9956	74.0259						
	R^2	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.004	0.004
CABG - Emergency Readmissions	Choice Policy * Market Structure	-0.0004	-0.0002	-0.0008	0.0000	0.0006	-0.0000	-0.0001	0.0004	-0.0003
		(-0.766)	(-0.269)	(-1.275)	(0.103)	(1.229)	(-0.037)	(-0.244)	(0.768)	(-0.525)
	Market Structure				-0.0008	-0.0031**	-0.0014			
					(-0.811)	(-2.388)	(-1.197)			
	Any private hospital site within 30km							-0.0003	-0.0010	-0.0007
								(-0.417)	(-0.933)	(-0.850)
	joint χ^2 test residuals coefficients=0		254.6778	79.7451		258.5165	74.2910		242.3379	76.3224
	joint χ^2 test Choice*covariates coefficients=0	254.7389	248.4126	282.5588						
	R^2	0.003	0.004	0.004	0.003	0.004	0.003	0.003	0.004	0.003
CABG - Mortality	Choice Policy * Market Structure	0.0000	0.0001	-0.0002	0.0000	-0.0000	-0.0002	-0.0000	0.0000	-0.0003
		(0.073)	(0.151)	(-0.317)	(0.051)	(-0.056)	(-0.361)	(-0.104)	(0.028)	(-0.518)
	Market Structure				0.0000	0.0004	0.0002			
					(0.045)	(0.412)	(0.226)			
	Any private hospital site within 30km							-0.0001	-0.0007	-0.0004
								(-0.202)	(-1.210)	(-0.697)
	Choice Policy * pre-2006 N. of Private hospitals									
	joint χ^2 test residuals coefficients=0		278.2191	160.0936		252.9012	179.7291		266.0324	177.0431
	joint χ^2 test Choice*covariates coefficients=0	190.9180	229.6857	187.6139						
	R^2	0.016	0.017	0.017	0.016	0.016	0.016	0.016	0.016	0.016

Notes. Dependent variable, Choice Policy and market structure defined as in Table 4. Columns (1-3) include interaction terms of the choice policy dummy with all covariates to control for changes in the effect of case-mix. Columns (4-6) replace the time-invariant pre-policy market structure with the time-varying one. Columns (7-9) include a binary dummy for the presence of private hospitals in the same catchment area (30 km) where the hospital is located.

Table 8. Effect of choice reform allowing for in-hospital Length of Stay.

Procedure	Outcome variable	Coefficients / statistics of interest	FE model with covariates (1)	Linear 2SRI residuals for all providers (2)	CL 2SRI residuals for all providers (3)
a. Hip Replacement	Emergency Readmissions	Choice Policy * Market Structure	0.0017**	0.0020	0.0021**
			(2.019)	(1.546)	(2.150)
		Length of Stay in hospital	0.0000	0.0000	0.0000
			(0.214)	(0.371)	(0.241)
		joint χ^2 test residuals coefficients=0		648.6297	498.7349
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
		R^2	0.011	0.012	0.012
	Length of Stay in hospital	Choice Policy * Market Structure	-0.1777***	-0.1000	-0.1734***
			(-2.786)	(-1.246)	(-2.606)
		joint χ^2 test residuals coefficients=0		821.5415	698.4368
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
		R^2	0.190	0.193	0.192
b. Knee Replacement	Emergency Readmissions	Choice Policy * Market Structure	0.0006**	0.0011**	0.0011***
			(2.228)	(2.402)	(3.965)
		Length of Stay in hospital	0.0001***	0.0001***	0.0001***
			(4.680)	(4.676)	(4.690)
		joint χ^2 test residuals coefficients=0		773.9270	555.8283
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
		R^2	0.003	0.004	0.004
	Length of Stay in hospital	Choice Policy * Market Structure	-0.1376**	-0.0415	-0.1191**
			(-2.326)	(-0.542)	(-2.029)
		joint χ^2 test residuals coefficients=0		714.6318	594.4042
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.0000
		R^2	0.167	0.169	0.169
c. CABG	Emergency Readmissions	Choice Policy * Market Structure	-0.0002	0.0000	-0.0005
			(-0.441)	(0.038)	(-0.952)
		Length of Stay in hospital	0.0004***	0.0004***	0.0004***
			(3.788)	(3.954)	(3.810)
		joint χ^2 test residuals coefficients=0		264.4207	43.7128
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.6095
		R^2	0.003	0.004	0.004
	Length of Stay in hospital	Choice Policy * Market Structure	-0.0295	-0.0842	-0.0578
			(-0.350)	(-0.773)	(-0.477)
		joint χ^2 test residuals coefficients=0		110.4490	66.3769
		p-value joint χ^2 test residuals coefficients=0		0.0000	0.0327
		R^2	0.128	0.130	0.129

Notes. Dependent variable, Choice Policy and market structure defined as in Table 4. Model for emergency readmission as dependent variable includes here also length of in-hospital stay as covariate.

Table 9. Effect of choice reform allowing for standardized mortality.

	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 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
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Std. Mortality at for all procedures (Dr Foster's HSMR)						Std. Mortality of emergency condition within same specialty (hip fracture or AMI)					
a. Hip replacement emergency readmissions												
Choice Policy * Market Structure	0.0018**	0.0020	0.0021**	0.0017**	0.0018	0.0021**	0.0017**	0.0020	0.0021**	0.0017**	0.0021*	0.0021**
	(2.046)	(1.539)	(2.153)	(1.981)	(1.444)	(2.122)	(2.014)	(1.544)	(2.145)	(2.010)	(1.654)	(2.160)
Std. Mortality	0.0001	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0000	0.0000	0.0000	-0.0002	-0.0001
	(0.769)	(0.553)	(0.514)	(1.102)	(0.782)	(0.610)	(0.321)	(0.034)	(0.095)	(0.138)	(-0.730)	(-0.231)
Choice Policy * Std. Mortality				-0.0001	-0.0001	-0.0001				0.0001	0.0005	0.0002
				(-0.937)	(-0.629)	(-0.443)				(0.147)	(1.131)	(0.449)
b. Knee replacement emergency readmissions												
Choice Policy * Market Structure	0.0006**	0.0011**	0.0011***	0.0006**	0.0011**	0.0011***	0.0005**	0.0010**	0.0011***	0.0005**	0.0010**	0.0011***
	(2.245)	(2.351)	(3.942)	(2.201)	(2.397)	(3.915)	(2.148)	(2.339)	(3.862)	(2.071)	(2.259)	(3.792)
Std. Mortality	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002*	0.0002*	0.0002	0.0002*	0.0002	0.0002
	(1.183)	(1.131)	(0.897)	(0.933)	(0.385)	(0.750)	(1.817)	(1.772)	(1.597)	(1.647)	(1.328)	(1.387)
Choice Policy * Std. Mortality				-0.0000	0.0000	-0.0000				-0.0001	-0.0000	-0.0001
				(-0.103)	(0.521)	(-0.102)				(-0.535)	(-0.114)	(-0.321)
c. CABG emergency readmissions												
Choice Policy * Market Structure	-0.0002	0.0001	-0.0004	-0.0002	0.0001	-0.0004	-0.0000	0.0009	0.0004	0.0000	0.0009	0.0004
	(-0.381)	(0.161)	(-0.812)	(-0.360)	(0.200)	(-0.816)	(-0.019)	(1.258)	(0.521)	(0.039)	(1.239)	(0.566)
Std. Mortality	0.0000	-0.0001	-0.0000	-0.0000	-0.0002	-0.0001	-0.0003	-0.0002	-0.0003	-0.0002	-0.0002	-0.0003
	(0.079)	(-0.582)	(-0.252)	(-0.136)	(-1.135)	(-0.582)	(-1.063)	(-0.686)	(-1.356)	(-0.545)	(-0.482)	(-0.763)
Choice Policy * Std. Mortality				0.0000	0.0002	0.0001				-0.0002	-0.0000	-0.0002
				(0.306)	(1.093)	(0.557)				(-0.328)	(-0.035)	(-0.328)
d. CABG mortality												
Choice Policy * Market Structure	0.0001	-0.0001	-0.0003	0.0000	-0.0001	-0.0003	0.0001	0.0003	0.0001	0.0001	0.0003	0.0001
	(0.109)	(-0.080)	(-0.471)	(0.070)	(-0.092)	(-0.445)	(0.176)	(0.342)	(0.164)	(0.121)	(0.308)	(0.144)
Std. Mortality	0.0002*	0.0002*	0.0002**	0.0003**	0.0003*	0.0003***	0.0002	0.0003	0.0002	0.0002	0.0002	0.0001
	(1.925)	(1.934)	(2.163)	(2.380)	(1.864)	(2.677)	(1.193)	(1.268)	(0.760)	(0.646)	(0.751)	(0.459)
Choice Policy * Std. Mortality				-0.0001	-0.0001	-0.0001				0.0001	0.0001	0.0001
				(-1.168)	(-0.568)	(-1.205)				(0.466)	(0.415)	(0.303)

Notes. Dependent variable, Choice Policy and market structure defined as in Table 4. Columns (1)-(6): adding standardized hospital mortality for all procedures as covariate; columns (7)-(12): adding standardized hospital mortality for emergency procedure within the same specialty (AMI mortality for CABG; hip fracture mortality for hip and knee replacement) as covariate.

Table 10. Profit and Loss analysis at procedure and HRG4 code level.

Year	HRG code	HRG Name	Profit per patient (£)	Patients	HRG profit (£)	HRG profit (£) per hospital site
2009	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
	HB12C	Major Hip Procedures for non Trauma Category 1 without CC	-240	41,947	-10,087,077	-43,479
2010	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
	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***
2009	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
	HB23C	Intermediate Knee Procedures for non Trauma without CC	498	1,323	658,609	2,767
2010	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
	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. See section 6.4 for details of the computation of per patient profit. Last column based on 232 (238) hospitals sites for hip (knee) replacement and 47 sites for CABG.

ONLINE APPENDICES

Appendix A. Additional results

Figure A1. Volume of planned CABG, hip and knee replacement operations 2002/03-10/11.

Figure A2. Trends in risk-adjusted standardized hospital quality measures

Figure A3. Choice of hospital by distance from patient's residence

Figure A4. Time trends in Competition Measures

Table A1. Correlations amongst measures of market structure

Table A2. Goodness of Fit statistics of Conditional Logit hospital choice models

Table A3. Average F-stats for excluded instruments in linear choice model

Table A4. Marginal effects of differential distance from first stage Probit model for selection into public hospital sites.

Table A5a. Principal Component Competition measure - eigenvalues and eigenvectors

Table A5b. Effect of choice reform on planned quality: PCA market structure measure

Table A6. Effect of choice policy on AMI mortality

Table A7. CABG readmissions model controlling for mortality based selection

Appendix B. Procedure and speciality definitions

Appendix C. Measurement of market structure

Appendix A. Additional results

Figure A1. Volume of planned CABG, hip and knee replacement operations in NHS hospitals, financial years 2002/03-2010/11.

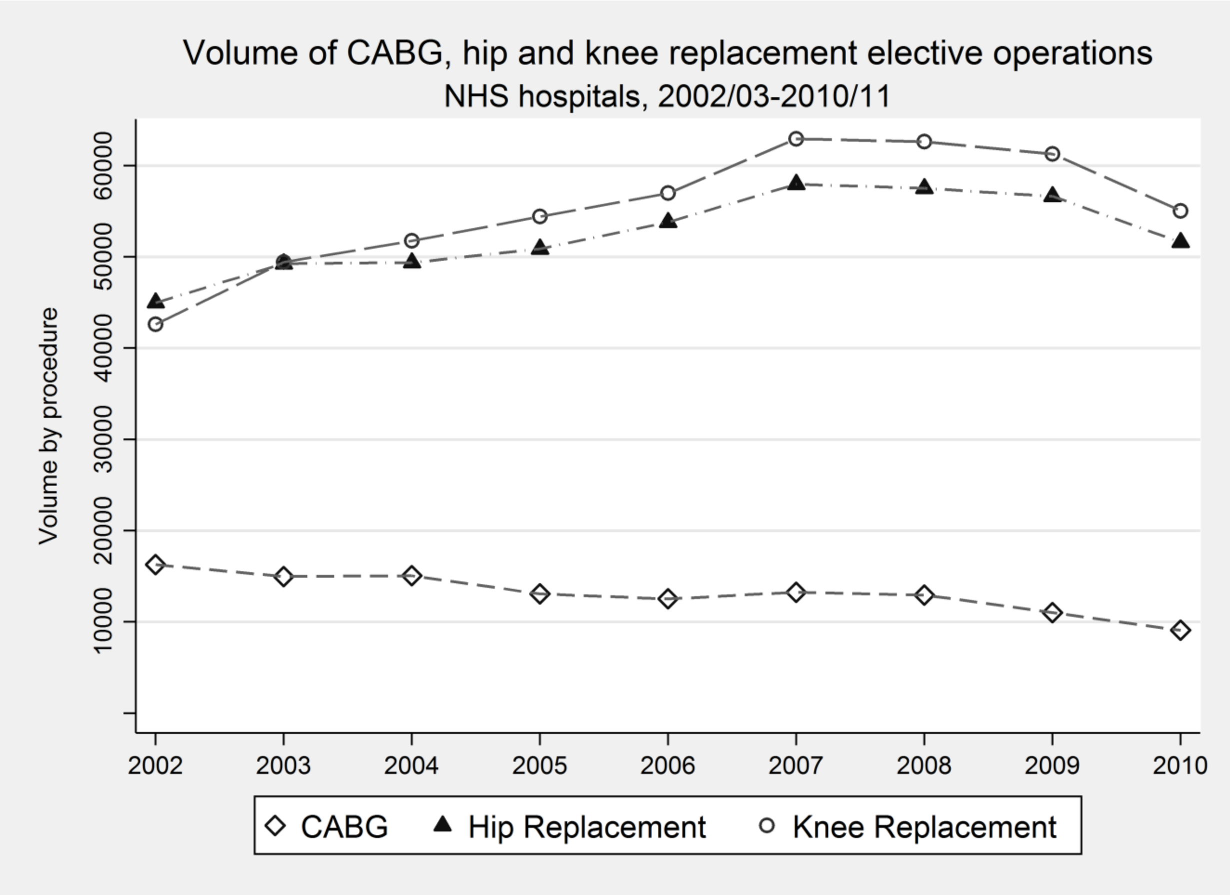
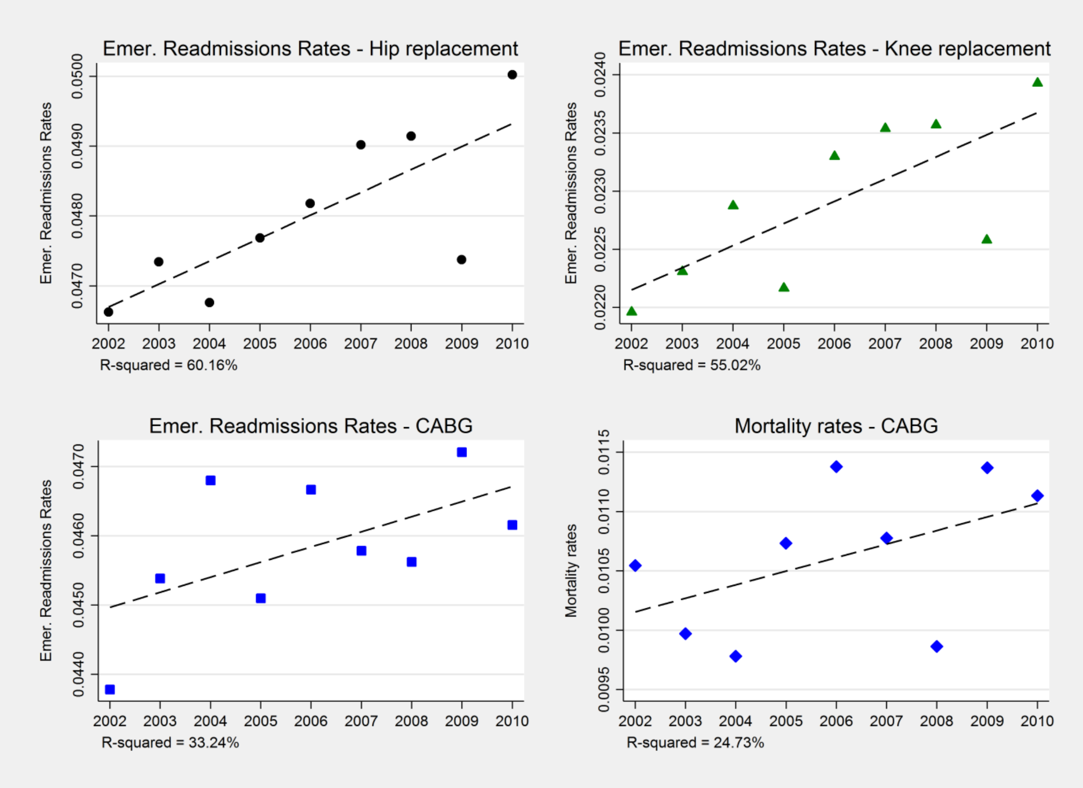


Figure A2. Trends in risk-adjusted standardized hospital quality measures.



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. Choice of hospital by distance from patient's residence.

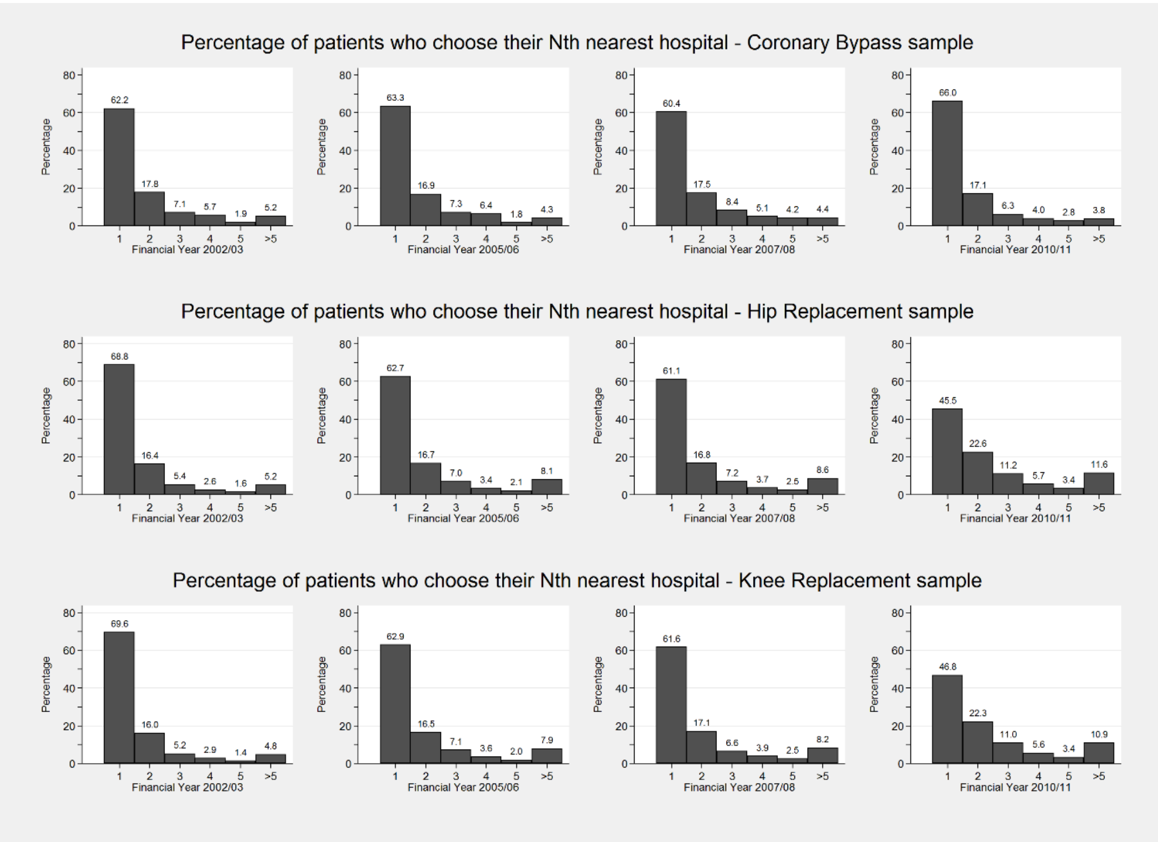


Figure A4. Time trends in Competition Measures.

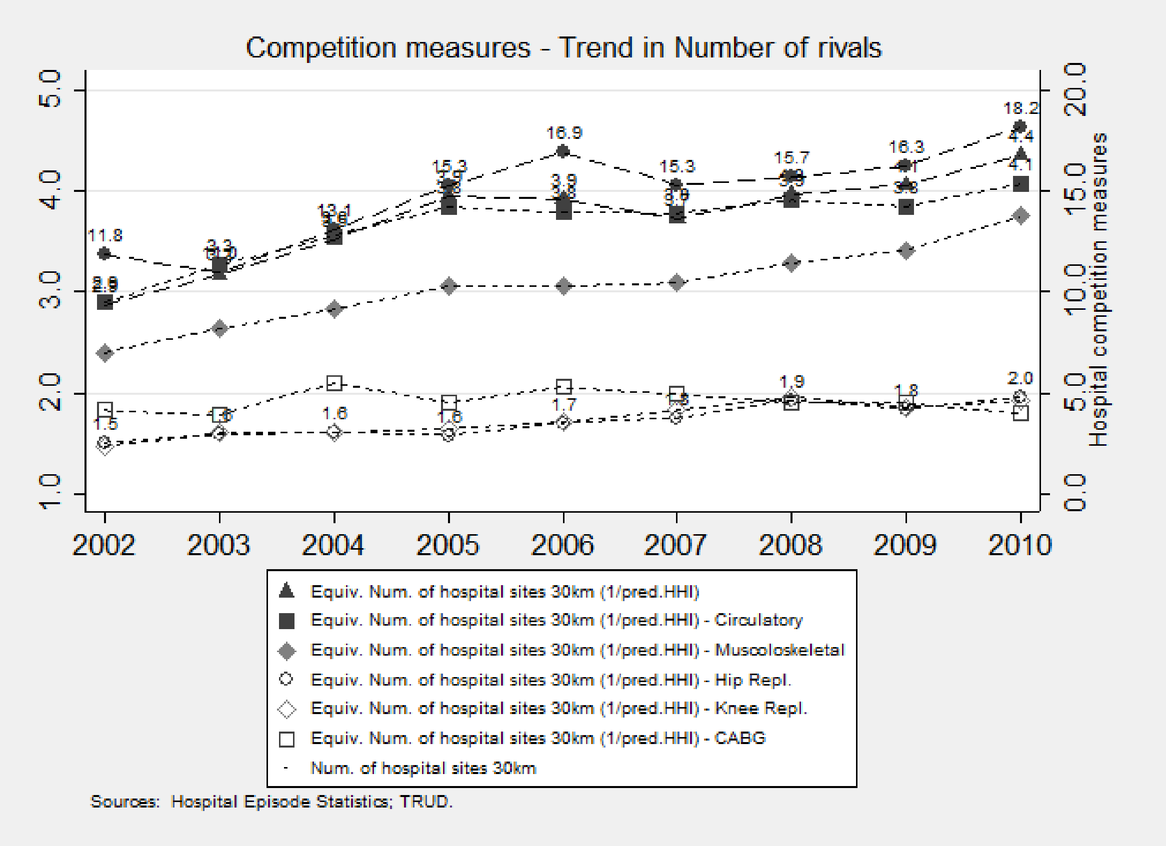


Table A1. Correlations amongst measures of market structure.

	Equiv. Num. of hospital sites within 30km					
	All planned 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 A2. Goodness of Fit statistics of first stage Conditional Logit hospital choice model by procedure.

	2002 (1)	2003 (2)	2004 (3)	2005 (4)	2006 (5)	2007 (6)	2008 (7)	2009 (8)	2010 (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 A3. Average first stage F-stats for excluded instruments in linear choice model.

	Average 1st stage F-stat	Average adjusted R-squared
Hip replacement	1280	0.1081
Knee replacement	1381	0.1041
CABG	1068	0.2293

Note. The first column report the value of the average of 1st stage F-stat statistics computed from Eq. (6). Since the model in Eq. (6) is run for each hospital site and every year, the average is computed over the sample of *number of years * hospital sites* observations.

Table A4. Marginal effects of differential distance from first stage Probit model for selection into public hospital sites.

	(1) 2004	(2) 2005	(3) 2006	(4) 2007	(5) 2008	(6) 2009	(7) 2010
Hip replacement sample							
differential distance ISP - NHS	-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 equal to 1 if patient was treated in NHS hospital site, and equal to 0 if she was treated in a private site. The model 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. Given the scarcity of private hospital sites and patients treated into these before financial year 2004/05, the probit models could not be estimated in years 2002/03 and 2003/04. An Inverse Mills Ratio equal to zero was then included for patients in years 2002/03 and 2003/04 to estimate the main outcome equation reported in Table 6.

Table A5a. PCA Competition measure - Eigenvalues and eigenvectors.

	Principal component			
	1	2	3	4
Hip replacement				
average of pre-2006 1/HHI "all planned admissions"	0.5255	-0.3017	-0.3387	-0.7198
average of pre-2006 1/HHI "all planned muscoloskeletal admissions"	0.5227	-0.2659	-0.4218	0.6915
average of pre-2006 1/HHI "all planned 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 planned admissions"	0.5260	-0.0994	-0.4618	-0.7072
average of pre-2006 1/HHI "all planned muscoloskeletal admissions"	0.5259	0.0150	-0.4797	0.7022
average of pre-2006 1/HHI "all planned 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 planned admissions"	0.5156	-0.0373	-0.5527	-0.6536
average of pre-2006 1/HHI "all planned circulatory admissions"	0.5155	-0.2612	-0.3648	0.7301
average of pre-2006 1/HHI "all planned 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 A5b. Effect of choice reform on planned quality with 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)			
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
R2	0.011	0.012	0.012
b. Knee Replacement Emergency Readmission (Patients: 461,594; hospital sites: 238)			
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
R2	0.003	0.004	0.004
c. CABG Emergency Readmission (Patients: 112,844; hospital sites: 47)			
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
R2	0.003	0.004	0.003
d. CABG Mortality (Patients: 114,291; hospital sites: 47)			
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
R2	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 planned, 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 A6. Effect of choice policy on AMI mortality

	AMI
Market structure measure:	Equivalent number of rival sites 30km
Choice policy*Frozen Market Structure	-0.0028**
	(-2.2936)
Patients	288287
Sites	238

Notes. Market structure is fixed at the average level in the pre-policy period for each hospital site. Equivalent number of rival sites 30km = 1/(predicted HHI), based on all planned admissions to hospital. Model has same covariates as text models of planned quality.

Table A7. Marginal effect of competition on CABG emergency readmissions controlling for selection due to CABG mortality with Heckman selection model.

	CABG Emergency Readmissions
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. The model is estimated 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.

Appendix B. 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) main procedure OPCS code starting with V or W (bones and joints procedures).

Appendix C. 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 planned admissions at the providers they use. It is a measure of the amount of choice they have amongst planned 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*:

$$HHI_h = \sum_j s_{hj} \times HHI_j = \sum_j s_{hj} \times \left[\sum_h \left(s_{jh} \right)^2 \right] \qquad \text{(C1)}$$

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 planned care in which choice is not allowed to depend on quality (Kessler and McClellan, 2000). We estimate Poisson choice models with the number of planned patients from LSOA *j* choosing provider *h* in year *t* having conditional mean

$$\mathrm{E}\left(n_{jht} \mid \xi_j, d_{jh}, X_{ht}\right) = \exp\left\{\xi_{jt} + \lambda_{1t} d_{jh} + \lambda_{2t} d_{jh}^2 + X_{ht}\lambda_t + d_{jh} X_{ht} \lambda_{1t}^X + d_{jh}^2 X_{ht} \lambda_{2t}^X \right\} \qquad \text{(C2)}$$

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 planned admissions as those “where the decision to admit could be separated in time from the actual admission”. We exclude planned 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. (C2) 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. (C2), instead of the actual flows, to compute the predicted HHI indices. Since the reciprocal of the HHI is the number of equal sized firms, which would yield the HHI, we use the *reciprocal of the predicted HHI* as the measure of competition facing a provider.