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Does a hospital's quality depend on the quality of other hospitals? A spatial econometrics approach to investigating hospital quality competition

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Does a hospital's quality depend on the quality of other Hospitals? A spatial econometrics approach to investigating hospital quality competition

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Abstract

We examine whether a hospital's quality is affected by the quality provided by other hospitals in the same market. We first set out a theoretical model with regulated prices which specifies conditions on demand and cost functions which determine whether a hospital will have higher quality when its rivals have higher quality. We then apply spatial econometric methods to a sample of English hospitals in 2009-10 and a set of 16 quality measures including mortality rates, readmission, revision and redo rates and three patient reported indicators to examine to examine the relationship between the quality of hospitals. We find that a hospital's quality is positively associated with the quality of its rivals for seven out of the sixteen quality measures and that in no case is there a negative association. In those cases where there is a positive association, an increase in rivals' quality by 10% increases a hospital's quality by 1.7% to 2.9%.

JEL classification: I1, L3

Keywords: Quality; regulated prices; hospitals; competition; spatial econometrics.

1 Introduction

Quality is a key concern for patients and policymakers in health care markets. It is often argued that encouraging competition among health care providers will improve quality, especially when prices are fixed, as higher quality is then the only way in which hospitals can attract more patients.[1] There is a large empirical literature on the relationship between quality and competition amongst hospitals (Gaynor and Town, 2011; Gravelle et al, 2012). The bulk of the literature has been about the US experience but some recent contributions are on the UK and other European countries. The evidence from the US is mixed. Kessler and McClellan (2000) and Kessler and Geppert (2005) find a positive effect of competition on quality, Gowrinsankaran and Town (2003) find a negative effect, Shen (2003) finds mixed results, and Shortell and Hughes (1988) and Mukamel, Zwanziger and Tomaszewski (2001) find no effect. Recent work from England where hospitals face fixed prices, suggests that competition increases quality (Cooper et al., 2011; Gaynor, et al., 2010; Bloom et al., 2011).

The traditional way to test the effect of competition on hospital's quality is to examine the relationship between quality (often measured by hospital mortality rates) and measures of competition such as the Herfindhal index or the number of rival hospitals. This traditional approach does not test directly whether and how providers respond to rivals' quality, though this is implicitly the mechanism that underlies such approach.

In this study we test directly whether a hospital's quality responds to the quality of its rivals. In industrial organisation terms, we test whether qualities are strategic complements, ie whether a provider responds to an increase in quality from rival providers by increasing quality. We do so using a spatial econometric framework: since hospitals and patients are geographically dispersed, patients must incur travel costs to receive treatment and so hospital location affects demand. Distance between hospitals also determines the extent to which decisions by one hospital affects decisions by other hospitals. The traditional approach is akin to testing for an effect of competition on quality by estimating a reduced form relating quality directly to a measure of market structure. Our approach is akin to estimating reaction functions to test if a provider's decisions on quality depend on the quality decisions of rival providers.

We first outline a theoretical model of hospital quality competition under regulated (fixed) prices. Hospitals' revenues are given by the price of a DRG (eg hip replacement, coronary bypass) times the number of patients treated. Given that prices are fixed, hospitals compete on quality to attract patients. Our theoretical model and derivation of

[1] Under the DRG system introduced in the US in the early 1980ies for hospital care provided under the Medicare programme (the public insurance programme that covers the elderly) hospitals are paid a fixed price related to patient diagnoses, rather than to the costs of individual patients. In England a system of prospective payments based on Health Care Resource Groups (HRGs) has been rolled out since 2002. Similar payment systems are in place in several other European countries.

reaction functions builds on the existing literature on quality competition with regulated prices (Ma and Burgess, 1993; Gaynor, 2006; Gravelle and Sivey, 2010; Brekke, Siciliani and Straume, 2011) which models quality competition within a Hotelling or Vickrey-Salop framework. We derive conditions under which providers respond to an increase in rivals' quality by also increasing quality, so that qualities are strategic complements. We show that qualities are complements (substitutes) if the marginal cost of treatment is increasing (decreasing) or the demand responsiveness increases (decreases) when rivals' quality is higher. Qualities are independent if the marginal cost of treatment is constant and demand is linear in qualities.

We then test whether qualities are strategic substitutes using cross-section data on English hospitals in 2009-10 and a set of 16 quality measures including mortality rates, readmission, revision and redo rates and indicators of patients' experience.

We follow the approach suggested by Mobley (2003) and Mobley, Frech and Anselin (2009). They examine whether prices are strategic substitutes, ie whether each provider responds to an increase in rivals' price by reducing its own price. They do so with a spatial econometric model in which the effect of rivals' prices depends on spatial proximity. The spatial price lag is interpreted as the slope of the reaction function. We adapt their approach to examine competition on quality (as opposed to competition on price) and interpret the spatial quality lag as the slope of the reaction function.

We find that quality responds positively to rivals' quality for seven out of the sixteen quality indicators and it does not respond for the others. When an effect is detected (for overall mortality rates, in-hospital stroke mortality, knee replacement readmissions, stroke readmission within 28 days, and three indicators on patients' experience), an increase in rivals' quality by 10% increases quality by 1.7-2.9%.

Section 2 provides the theoretical model. Section 3 describes the estimation methods and data. Section 4 presents the results, and Section 5 concludes.

2 Theoretical model

Define q_i as the quality of hospital i $(i = 1, .., N)$. The demand function of hospital i is

$$X_i = X\left(q_i, \mathbf{q}_{-i}; \delta_i\right) \tag{1}$$

where $\mathbf{q}_{-i} = (q_1, ..., q_j, ..., q_{i-1}, q_{i+1}, ..., q_N)$ is a vector of the qualities of rival providers. We assume that the demand function of provider i is increasing in its own quality q_i and decreasing in the quality of the rivals: $\partial X_i\left(q_i, \mathbf{q}_{-i}\right)/\partial q_i > 0$, $\partial X_i\left(q_i, \mathbf{q}_{-i}\right)/\partial q_j < 0$. Hospitals are demand substitutes: patients switch to a hospital if its quality is increased and away from it if a rival's quality is increased. Hospitals are imperfect substitutes because of travel costs and times, and switching costs. A marginal increase in quality

q_i implies that some but not all patients switch from the other hospitals to hospital i. This specification is akin to a Cournot quality competition model as opposed to a price competition model *a la* Bertrand.

The location of other hospitals and the spatial distribution of patients relative to hospital i will also affect demand for the hospital and we capture these by δ_i.

Hospitals are prospectively financed by a third-party payer offering a per-treatment price p and potentially a lump-sum transfer T. We assume that all the patients demanding treatment in a hospital are treated. The objective function of hospital i is[2]

$$\pi_i = T + pX_i\left(q_i, \mathbf{q}_{-i}; \delta_i\right) - C_i\left(X_i\left(q_i, \mathbf{q}_{-i}\right), q_i; \gamma_i\right), \tag{2}$$

where the cost of supplying hospital treatments is given by the cost function $C\left(X_i, q_i; \gamma_i\right)$, with $C_X > 0$, $C_q > 0$, $C_{XX} \gtreqless 0$, $C_{qq} > 0$ and $C_{Xq} \gtreqless 0$. The last assumption implies that we allow for both cost substitutability ($C_{Xq} > 0$) and complementarity ($C_{Xq} < 0$) between quality and output. The marginal cost of treatment to be constant, increasing (due to congestion, $C_{XX} > 0$) or decreasing (due to scale economies, $C_{XX} < 0$). The assumption of cost substitutability is plausible if the average cost of treatment is increasing in quality (eg $C\left(X_i, q_i; \gamma_i\right) = c(q_i; \gamma_i)X_i$, with $c_q(q_i; \gamma_i) > 0$). Cost complementarity is also possible in the presence of 'learning by doing' (with higher volumes reducing the marginal cost of quality). γ_i describes exogenous factors, such as input prices, affecting hospital i costs.

The hospitals simultaneously and independently choose qualities. Maximising (2) with respect to q_i we obtain the first order condition

$$\frac{\partial X_i\left(q_i, \mathbf{q}_{-i}; \delta_i\right)}{\partial q_i}\left(p - \frac{\partial C_i\left(X_i\left(q_i, \mathbf{q}_{-i}; \delta_i\right), q_i; \delta_i\right)}{\partial X_i}\right) = \frac{\partial C_i\left(X_i\left(q_i, \mathbf{q}_{-i}; \delta_i\right), q_i; \delta_i\right)}{\partial q_i}, \tag{3}$$

Marginal benefit from higher quality is proportional to the difference between the price and the marginal cost of treatment.[3]

Solving (3) for q_i gives the reaction function for hospital i

$$q_i^R = q_i^R(\mathbf{q}_{-i}; \delta_i, \gamma_i). \tag{4}$$

We are interested in the effect of rivals' qualities on hospital i quality. Using the implicit function theorem on (3), we obtain the slope of the reaction function as

$$\frac{\partial q_i^R}{\partial q_j} = \left(-\frac{\partial^2 \pi_i}{\partial q_i^2}\right)^{-1}\left[\left(p - \frac{\partial C_i}{\partial X_i}\right)\frac{\partial^2 X_i}{\partial q_i \partial q_j} - \left(\frac{\partial X_i}{\partial q_i}\frac{\partial^2 C_i}{\partial X_i^2} + \frac{\partial^2 C_i}{\partial q_i \partial X_i}\right)\frac{\partial X_i}{\partial q_j}\right] \tag{5}$$

[2] We can also allow for hospital altruism by writing the hospital objective function as $u(\pi_i, q_i, X_i)$ with $u_q > 0$ or $u_X > 0$. This would not alter our general conclusion that the effect of rivals' qualities on q_i depends on properties of the cost and demand functions.

[3] We assume $[\partial X_i(0, \mathbf{q}_{-i}; \delta_i)/\partial q_i][p - \partial C_i(X_i(0, \mathbf{q}_{-i}; \boldsymbol{\delta}_i), 0; \gamma_i)/\partial X_i] > \partial C_i(X(0, \mathbf{q}_{-i}; \boldsymbol{\delta}_i), 0; \gamma_i)/\partial q_i$ to rule out corner solutions.

where
$$\frac{\partial^2 \pi_i}{\partial q_i^2} = \left(p - \frac{\partial C_i}{\partial X_i}\right)\frac{\partial^2 X_i}{\partial q_i^2} - \frac{\partial X_i}{\partial q_i}\left(\frac{\partial^2 C_i}{\partial X_i \partial q_i} + \frac{\partial^2 C_i}{\partial X_i^2}\frac{\partial X_i}{\partial q_i}\right) < 0. \tag{6}$$
is the second order condition.

The reaction function of provider i depends on its demand and cost functions. Since the first term in (5) is positive, the sign of $\partial q_i^R/\partial q_j$ depends on the terms in the square brackets. To fix ideas, it is useful to consider some special cases.

Suppose that the demand function is linear in qualities so that $\partial^2 X_i/\partial q_i \partial q_j = 0$ and that the marginal cost of treatment is constant and independent of quality so that $\partial^2 C_i/\partial X_i^2 = \partial^2 C_i/\partial q_i \partial X_i = 0$. Then, from (5), we have $\partial q_i^R/\partial q_j = 0$: the quality of provider i is independent of the quality of its' rivals.

Suppose next that the demand function is linear in quality $\left(\partial^2 X_i/\partial q_i \partial q_j = 0\right)$ but the marginal cost of treatment is increasing with respect to quantity and quality so that $\partial^2 C_i/\partial X_i^2 > 0$ and $\partial^2 C_i/\partial X_i \partial q_i > 0$. Then $\partial q_i^R/\partial q_j > 0$ and qualities are strategic complements. The optimal response to an increase in rival's quality is an increase in quality. The intuition is that an increase in quality by the rival reduces demand and therefore output so that the marginal cost of treatment is reduced thus increasing the profit margin and provider's incentive to increase quality. The assumption that the marginal cost is increasing can be justified in health systems where hospitals have limited capacity.

Conversely, $\partial q_i^R/\partial q_j < 0$ if the marginal cost of treatment is decreasing in quantity $(\partial^2 C_i/\partial X_i^2 < 0)$ and quality $(\partial^2 C_i/\partial X_i \partial q_i < 0)$. In this case, qualities are strategic substitutes and the optimal response to an increase in rival's quality is to reduce quality. The rationale is that an increase in rival's quality now increases the marginal cost of treatment and therefore reduces the profit margin.

As a final example, suppose that the marginal cost of treatment is constant and independent of quality so that $\partial^2 C_i/\partial X_i^2 = \partial^2 C_i/\partial X_i \partial q_i = 0$. Then, whether qualities are strategic complements or substitutes depends on the sign of $\partial^2 X_i/\partial q_i \partial q_j$. If an increase in rivals' quality increases (reduces) the responsiveness of demand to provider's quality, then qualities are strategic complements (substitutes) and the provider increases (reduces) quality in response to rivals' quality.

2.1 Empirical specification

To test if qualities are strategic complements, strategic substitutes or independent, we estimate the reaction function as
$$q_i^R = f_i(\mathbf{q}_{-i}, \mathbf{z_i}, \varepsilon_i) \tag{7}$$

where the vector $\mathbf{z_i}$ captures observed parameters from δ_i, γ_i which shift hospital i demand and cost functions and ε_i summarises factors we do not observe. We specify a linear spatial lag model as

$$q_i = \alpha + \rho \sum\nolimits_j w_{ij} q_j + \mathbf{z_i} \beta + \varepsilon_i \tag{8}$$

where $w_{ij} \geq 0$ is a distance weight specified in more detail below and $w_{ii} = 0$.

We can write the model in matrix form

$$\mathbf{q} = \alpha + \rho \mathbf{W} \mathbf{q} + \mathbf{z} \beta + \boldsymbol{\varepsilon}. \tag{9}$$

The coefficient ρ on the quality spatial lag variable, $\mathbf{Wq}$, determines the sign of the slope of the reaction function. We use a row-standardised inverse distance matrix with a 30-minutes travel time threshold. Define d_{ij} as the distance between hospital i and j, and d_{ij}^{30} as the distance corresponding to 30 minutes travel time between hospital i and j. The weights are given by:

$$\begin{aligned} w_{ij} &= 0 & if \quad i = j \\ &= \frac{d_{ij}^{-1}}{\sum_j d_{ij}^{-1}} & if \quad d_{ij} \leq d_{ij}^{30} \text{ and } i \neq j \\ &= 0 & if \quad d_{ij} > d_{ij}^{30} \text{ and } i \neq j \end{aligned} \tag{10}$$

The inverse distance specification gives a lower weight to the quality of rivals that are more distant from hospital i. This row-standardisation permits us to interpret $\mathbf{Wq}$ as a weighted average quality of the rivals, where the weights are inversely related to the distance between providers (second line). Moreover, the quality of the rivals is included only if the rival falls within a catchment area of 30 minutes travel time (third line), as in the traditional approach to hospital competition (e.g. Gaynor et al., 2010).

We estimate (9) by maximum likelihood, since it is consistent and efficient in the presence of the spatial lag term, while OLS is biased and inconsistent (Anselin, 1988).

The spatial lag model (9) is often presented in a reduced form as (e.g. Le Gallo et al., 2003; Mobley, 2003; Mobley et al., 2009):

$$(\mathbf{I} - \rho \mathbf{W}) \mathbf{q} = \alpha + \mathbf{z} \beta + \boldsymbol{\varepsilon}, \tag{11}$$

which can be re-arranged as

$$\mathbf{q} = (\mathbf{I} - \rho \mathbf{W})^{-1} \alpha + (\mathbf{I} - \rho \mathbf{W})^{-1} \mathbf{z} \beta + (\mathbf{I} - \rho \mathbf{W})^{-1} \boldsymbol{\varepsilon}, \tag{12}$$

or

$$q_i = \alpha \sum_j a_{ij} + \sum_k \beta_k (\sum_j a_{ij} z_{jk}) + \sum_j a_{ij} \varepsilon_j \tag{13}$$

where a_{ij} is the element in the i^{th} row, j^{th} column of $(\mathbf{I} - \rho\mathbf{W})^{-1}$.

Equation (13) highlights that the quality of provider i depends not only on its own characteristics, but also on those of rivals through the spatial multiplier effect $((\mathbf{I}-\rho\mathbf{W})^{-1})$. The error process, $(\mathbf{I}-\rho\mathbf{W})^{-1}\boldsymbol{\varepsilon}$ shows that that a random shock for a specific provider not only affects the quality of this provider, but also has an impact on the quality of the rivals through the spatial multiplier effect (Le Gallo et al., 2003). Such effects are propagated to all hospitals and ε_j and z_{ij} will affect q_i even if hospital i ignores the quality of hospital j when choosing q_i.

The conventional approach is to solve the simultaneous conditions (3), or equivalently (4), for the equilibrium qualities $q_i^E = q_i^E(\boldsymbol{\delta}, \boldsymbol{\gamma})$ where, in general, the quality in hospital i depends on the demand and cost functions of all hospitals. To produce an estimatable specification it is assumed that the equilibrium quality for a hospital depends on a local subset of the demand and cost conditions for all hospitals: $q_i^E = g(\mathbf{z}_i, \varepsilon_i)$. The $\mathbf{z}_i$, as in the spatial specification, include measures of competitive structure such as the number of rivals within some radius or Herfindahl indices. Although the same measures of market structure may appear in $\mathbf{z}_i$ in the conventional and spatial specifications, they play different roles. In conventional specifications the interest is in testing for an effect of competition by examining the coefficients on the market structure measures in $\mathbf{z}_i$. In the spatial specification the market structure measures in $\mathbf{z}_i$ are covariates: the main interest is in the sign of spatial lag to test whether rival's qualities are strategic complements, which is a necessary condition for greater competition to increase quality.

3 Data

3.1 Quality measures

Much of the literature on hospital competition and quality has used hospital mortality for admissions for acute myocardial infarction (AMI) as the measure of hospital quality. AMI admissions are generally emergencies,where patients exercise a very limited amount of choice. The justification for using AMI mortality as a quality measure in competition studies is that it is correlated with quality of care for elective admissions (Cooper et al., 2011; Gaynor et al., 2011) and easier to measure than direct measures of quality for elective care. In this paper we use a mix of measures of quality for both elective and emergency admissions. We examine the correlations amongst them and whether results on the effect of rivals' quality on hospital quality are sensitive to the quality measure.

We use 16 measures of hospital quality from Dr Foster[4] for the financial year 2009/10 for 147 hospitals (NHS hospital Trusts). Details on these measures are in the Appendix. Six of the quality measures are based on standardised mortality rates: i) overall mortality

[4] http://myhospitalguide.drfosterhealth.co.uk/

rates; ii) mortality rates from high risk conditions (AMI, stroke, hip fracture, pneumonia, congestive heart failure); iii) mortality rates from low risk conditions (ie conditions with a death rate below 0.5%); iv) deaths after surgery; v) in-hospital stroke mortality; and vi) deaths resulting from hip fracture.

Seven quality measures are standardised readmission, revisions and redo rates: i) readmissions following hip replacement; ii) readmissions following knee replacement; iii) readmissions within 28 days following stroke; iv) hip revisions and manipulations within 1 year; v) knee revisions and manipulations within 1 year; vi) redo rates for prostate resection. We also measure the proportion of operations within 2 days following hip fracture. Finally, we have three measures derived from surveys of patients' experiences: i) cleanliness of hospital room/ward; ii) whether the patient was involved in decisions; iii) whether the patient had Trust in doctors.

For each hospital we define a catchment area of 30 minutes car drive. The average number of rivals within 30 minutes car drive is 2.7. On this definition of the catchment area about one third of all hospitals are monopolists, ie they do not have any other provider within a 30 minutes car drive. Another third have one or two rivals. 16% have three to five rivals, 12% have six to nine rivals, and only 7% have more than nine rivals (up to a maximum of 14).

We initially exclude monopoly hospitals from our analyses. This reduces the sample of hospitals from 147 to 99 observations. We check the sensitivity of our results to the definition of the catchment area by estimating models using catchment areas of 60 minutes and 98 minutes car drive time. With a catchment area of 60 minutes 142 hospitals have at least one rival and with a catchment area of 98 minutes all hospitals in England has at least one rival in the catchment area. The results with larger catchment areas are reported in section 4.3.

Table 1 provides summary statistics for the 16 quality measures. Five of the measures are for emergency admissions, five are for electives, and six are for both.

Most variables have been normalised to 100. Mortality rates have been computed by dividing the actual number of deaths by the expected number and multiplying the figure by 100. As an example consider overall mortality rates. The maximum value within the hospital sample is 118: this implies that the hospital with highest mortality rates has 18% more than expected mortality rates. The standard deviation is 9.5%. Readmission rates have a similar scaling. Hip and knee revisions and manipulations have a different scaling, since these are proportion of replacements with a revision procedure within 365 days of the initial procedure. The descriptive statistics suggest that on average 1.1% of patients are in need of a hip revision and manipulation. The rate for knee revisions is 0.6%. The mean redo rates for prostate section is 4.1%. The proportion of patients with hip fracture who received an operation within 2 days is on average 67.5%. On average 86% of patients found the hospital clean, 70% thought that they were involved in decisions, and 88% thought that they had confidence and Trust in doctors treating them.

3.2 Controls

We use a range of control variables. We construct three dummy variables which are equal to one if the hospital is respectively a teaching hospital, a Foundation Trust[5] or located in London. Table 1 shows that 20% are teaching hospitals, 52% are Foundation trusts and 24% are located in London. We also have a measure of overall hospital activity (the total number of inpatient spells), and index of labour costs faced by each hospital, known as the Market Forces Factor (MFF). On average a hospital has 92000 inpatient spells. The MFF has an average of 1.03 and varies between 0.9 and 1.2. We also control for the number of hospitals within a 30 minutes car drive catchment area (there are on average 4 rivals) and for population density within 15 km from the hospital (which approximately corresponds to a 30 minutes car drive).

The number of hospitals within the catchment area is one of the measures of market structure used in conventional studies of competition and quality. By including it in the model we test if it adds anything to the explanation of hospital quality once we account for the quality of rivals. We also estimate conventional models with no spatial lag but including the number of rivals within the catchment area.

4 Results

4.1 Correlation among quality measures

Correlation among different mortality rates. Table 2 (top-left quadrant) provides a correlation matrix for the six mortality indicators. Overall mortality rates are highly correlated with high-risk condition mortality (0.8). This is probably due to high-risk conditions being a large component of overall mortality rates. They have otherwise a correlation in the range 0.29-0.35 with other mortality indicators. Mortality rates from high-risk conditions have correlations in the range 0.25-0.49 with mortality rates other than overall mortality. Mortality rates from low-risk conditions have a low correlation with any other measure (in the range 0.14-0.35). The correlation between death after surgery and any other measure is in the range 0.02-0.29. Deaths resulting from hip fracture have a correlation of 0.37 with mortality rates of high risk conditions (again due to some extent to the first being included in the second), of 0.33 with overall mortality and between 0.16-0.2 with any other mortality indicator. In-hospital stroke mortality rates have a correlation of 0.49

[5] Foundation trusts were introduced in 2004 as a new type of NHS hospital run by local managers, staff and members of the public. They have more financial and operational freedom than other NHS trusts, albeit remaining in the public sector.

with mortality rates of high risk conditions (again due to some extent to the first being included in the second), of 0.32 with overall mortality rates and between 0.02-0.16 with any other mortality indicator.

Correlation among different readmission rates, revision rates and redo rates. Table 2 (bottom-right quadrant) gives such correlations. Hip readmissions have a correlation of 0.32 with knee readmissions and of only 0.07 with stroke readmissions. There is very low correlation with the other measures (in the range -0.05 to 0.02). Note that, perhaps surprisingly, there is no correlation between hip readmissions and hip revisions (0.01), and between hip readmissions and the proportion of operations within 2 days following a hip fracture (0.02). Knee readmissions have a correlation of 0.32 with hip readmissions and only 0.09 with stroke readmission. There is very low correlation with other measures (in the range -0.06 to 0.11). As for hip, there is no correlation between knee readmissions and knee revisions (-0.06). Stroke readmissions have a low correlation with all other measure (0.01 to 0.09). Hip and knee revisions have a correlation of 0.38 but there is low correlation with any other measure (in the range -0.06 to 0.11). Redo rates for prostate resection have low correlation with any other measure (in the range -0.06 to 0.11). The proportion of hip fracture patients with an operation within two days has a low correlation with all other measure (in the range -0.02 to 0.11). Note that this last indicator is a positive quality measure while the others are negative ones.

Correlation between readmission and mortality rates. Table 2 (top-right quadrant) also provides the correlation between the different readmission and mortality rates. This is generally low and varies between -0.18 (knee revisions and mortality from low risk conditions) and 0.16 (death from hip fracture and stroke readmissions). Note that there is no correlation between stroke readmission rates and stroke in-hospital mortality rates (0.04).

Correlation between patients' experience and other quality indicators. Table 3 focuses on patients' experience. The three indicators on patients' experience have a correlation which varies between 0.46 and 0.76 (bottom-right quadrant). There is a nearly zero or a negative correlation between patients' experience and the selected mortality rates (from high risk conditions and from hip fracture) and readmission rates (hip and stroke). The correlation ranges between 0.02 and -0.24. A negative correlation is to be expected since higher mortality or readmission rates measure 'negative' outcomes and the patients' experience variables measure 'positive' ones. Therefore, a negative correlation suggests that providers with better mortality rates also have higher patients' satisfaction.

4.2 Regression results

Table 4 provides the results for mortality rates. The first column suggests that teaching hospitals have 8.4% lower overall (adjusted) mortality rates. Moreover, an increase in rivals' quality by 10% increases quality by 2.8%. The second column has similar findings with teaching hospitals having 5.8% lower mortality rates from high-risk conditions, and a significant and positive coefficient for hospital activity. However, rivals' quality is not statistically significant. The third and fourth column refer to mortality from low-risk conditions, and deaths after surgery. None of the variables significantly affect these two measures of mortality. The fifth column refers to mortality rates following hip fracture. It suggests that hospitals with a Foundation Trust status have lower mortality rates by 9.3%. The sixth column focuses in-hospital stroke mortality rates. It suggests that an increase in rivals' quality by 10% increases quality by 1.8%.

Table 5 focuses on hip and knee readmissions. Column 1 suggests that hospitals with higher costs (as proxied by MFF) and higher population density have lower (standardised) hip readmission rates. Column 2 suggests that teaching hospitals have 23% lower knee readmission rates. Moreover, an increase in rivals' quality by 10% increases quality by 2.3%. Similarly, column 3 suggests that an increase in rivals' quality by 10%, as proxied by stroke readmission rates within 28 days from discharge, increase quality by 1.7%, and that teaching hospitals have lower readmission rates by 10%. Column 4 suggests that teaching hospitals have 34% lower hip revision rates; column 5 suggests that higher number of providers is associated with lower knee revisions rates and population density with higher knee revisions rates (though the p-value is about 0.12). Column 6 does not find any variable to be associated with number of hip fracture operations within two days. In column 7 higher costs and population density are associated with higher redo rates for prostate resection.

Results on patients' experience are reported in table 6. Column 1 suggests that hospitals with a Foundation Trust status have higher satisfaction on cleanliness by 1.2%. An increase in rivals' quality by 10% increases quality by 1.8%. Column 2 suggests that both teaching hospitals and hospitals with Foundation Trust status have higher patient satisfaction on patients' involvement in decisions by respectively 2.3% and 1.1%. An increase in rivals' quality by 10% increases quality by 2.5%. Finally, column 3 suggests that teaching hospitals have higher patient satisfaction on doctors' trusts by 2%. An increase in rivals' quality by 10% increases quality by 2.9%.

On the whole, the results suggest that teaching hospitals perform better: quality is significantly better for seven of the 16 quality measures and no worse for the others. This is in line with expectation since teaching hospitals tend to attract better qualified doctors. Although teaching hospitals treat more severely ill patients, this is taken into account by the case-mix standardisation of the quality measures.

Our key result is that rivals' quality either has a positive or no effect on provider's quality. We find a positive effect (a positive spatial lag coefficient) for two mortality rates (overall and stroke) and for two readmission rates (knee and stroke). The spatial lag coefficient is positive and significant for all three patient satisfaction measures. A possible explanation is that patient satisfaction has a greater effect on demand than other measures. Overall mortality rates are also used as a key performance indicator by regulators and hospitals may compare themselves against nearby hospitals on this measure.

A conventional measure of competition (the number of rivals within 30 minutes car drive) is not significant in any of the models. We also estimated the models in Tables 4-6 omitting the number of rivals and find similar results (available on request).

4.3 Sensitivity analysis

We replicate the analyses with the catchment area set to 60 minutes and to 98 minutes travel time. Larger catchment areas imply that the number of competitors is also larger and reduces the number of hospitals with no rivals. With a catchment area of 60 minutes 142 hospitals have at least one competitor in the catchment area, so that the sample size is increased to 142 compared with a 30 minute catchment area.[6] With a catchment area defined by 98 minutes travel time all hospitals in England have at least one rival in the catchment area.

For each quality indicator and catchment area, we estimate five regression models containing

i) the number of rivals weighted by distance;

ii) the spatial lag;

iii) both the spatial lag and the number of rivals weighted by distance;

iv) the number of rivals;

v) both the spatial lag and the number of rivals.

All the models have the same control variables included in Tables 4-6. Tables 7-9 have results for a catchment area of 60 minutes and Tables 10-12 those for a catchment area of 98 minutes.

The results are broadly consistent and confirm the results in Tables 4-6 for a 30 minute catchment area. Tables 7 and 10 confirm that, when overall mortality rates are used as a measure of quality, an increase in rivals' quality by 10% increases quality by 3.2-4.2%, which is higher but in line with the findings in Table 4. When knee readmission rates are used as a quality measure in Table 8, an increase in rivals' quality by 10% increases quality by 2.4-2.6%, which is in line with the results in table 5. When a catchment area of 98 minutes is used (in Table 11), the coefficient has a similar magnitude but ceases to be statistically significant. Tables 9 and 12 confirm that, when quality is measured as patient's involvement in decisions and as trust in doctors, an increase in rivals' quality by 10% increases quality respectively by 2.8-5.5% and 2.1-4.6%, which is in line with the results provided in table 6.

[6] We adjust the threshold of the weight matrix (10) to reflect the change of the catchment area.

5 Conclusions

We have investigated the effect of rivals' quality using a spatial-econometrics framework. Our theoretical model implies that the quality of provider responds to the quality of its rivals when the marginal cost of treatment is increasing and/or the responsiveness of demand to quality increases in rivals' quality. Our empirical analysis using English data England suggests that this is the case just under half of the 16 quality indicators. We do not find any cases where rivals' qualities are negatively correlated with provider quality.

Patient's satisfaction measures on cleanliness, doctors' trust and patient's involvement show the most consistent positive association with rivals' quality. Two of six mortality rates (overall mortality and in-hospital stroke mortality) and two readmission measures (knee and stroke) respond to rivals' quality. When an effect is detected and we use a catchment area of 30 minutes car drive, an increase in rivals' quality by 10% increases quality by approximately 1.7-2.9%. The results are generally robust to the use of larger catchment areas (of 60 minutes and 98 minutes car drive). Our results are broadly in line with the model of hospital prices in Mobley et al. (2009) where the spatial lag variable was found to be 0.23-0.28, which implies that a 10% reduction in rivals' price reduces prices by 2.3-2.8%.

There is always a risk of omitted variable bias in studies such as ours which use cross-section observational data. In particular, it is possible that the observed positive association of a hospital's quality with the quality of its potential rivals may be due to them all being influenced by the same unobservable area factors, rather than to competition amongst hospitals. We have tried to reduce the risk of omitted of variable bias by including area level variables in our models and in future work plan to use a panel of hospitals. With this caveat, our results provide some support for the idea that hospitals, at least to some extent, compete on quality to attract patients. Where qualities are strategic complements, this also suggests that policies which directly raise quality in one provider will have positive spillovers onto the quality of other providers within the same market.

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Appendix. Quality Measures

The quality measures are from Dr Foster (2012) Report Card 2009/10, available at:

http://www.drfosterhealth.co.uk/quality-reports, and Dr Foster (2012) Patient Experience 2009/10, available at : http://www.drfosterhealth.co.uk/patient-experience, accessed 14 May 2012.

Mortality rates. Mortality data provided by Dr Foster are risk adjusted. A logistic regression is used to estimate the expected in-hospital mortality. Each measure is adjusted for differences in case-mix: sex, age on admission, admission method, socioeconomic deprivation, primary diagnosis, co-morbidities, number of previous emergency admissions, financial year of discharge, palliative care, month of admission, ethnicity and source of admission.

The overall standardised mortality rates account for all in-hospital deaths, i.e. all spells whose method of discharge was death. Stroke and hip fracture mortality rates is restricted to in-hospital mortality whose spells' primary diagnostic was respectively acute cerebrovascular disease (ICD10: G46, I60-I64, I66) or fracture neck of femur (ICD10: S720-S722). Standardised deaths after surgery refer to surgical patients who had a secondary diagnosis such as internal bleeding, pneumonia or a blood clot and subsequently died.

High risk conditions include mortality from spells whose primary diagnosis is one of the these five groups: Acute myocardial infarction (ICD10: I21, I22), Acute cerebrovascular disease (ICD10: G46, I60-I64, I66), Pneumonia (ICD10: A202, A212, A310, A420, A430, A481, A78, B012, B052, B250, B583, B59, B671, J12-J16, J170-J173, J178, J18, J850, J851), Congestive heart failure - nonhypertensive (ICD10: I50) and Fracture of neck of femur - hip (ICD10: S720-S722). Low risk conditions include all in-hospital mortalities from all conditions with a death rate lower than 0.5%. This includes more than 100 diagnosis groups.

Readmission rates. Dr Foster also provides data on hospital readmissions within 28 days from discharge for patients admitted for stroke, knee and hip replacement. Stroke, knee and hip replacement standardised readmission ratios are the ratio of observed number of spells with emergency readmissions within 28 days of discharge with a knee replacement procedure (procedure/OPCS code O18, W40-W42,W5[234][1389](+Z844-6), W580-2(+Z846)), a hip replacement procedure (W37-W39, W93-W95) or an acute cerebrovascular disease diagnostic (ICD10: G46, I60-I64, I66), respectively, to the expected number of readmissions for each procedure estimated using a logistic regression that adjusts for factors to indirectly standardise for differences in case-mix (which is the same used for in-hospital mortality standardised ratios). The readmission rate attributed to a given hospital includes all patients who were treated in that hospital and readmitted within 28 days in that same hospital or any other hospital.

Revisions. The knee or hip revisions and manipulations within 1 year are the proportion of joint replacements with a revision procedure within 365 days of the initial (index) procedure, over the total number of joint replacements carried out at the trust over a three year period. The measure refers to a three year period since revisions occur infrequently and therefore sample size may be small in a given year.

Redo rates. Redo rates for prostate resection are the rates of endoscopy resection of outlet of male bladder procedure (OPCS code: M65) spells where a second operation was performed within three years (April 2004 and March 2007). More precisely, all spells where another TURP (transurethral resection of the prostate) procedure was performed within 3 years of the last TURP procedure are included in the numerator. The denominator includes all TURP procedures discharged between April 2004 and March 2007.

Hip fracture operations within two days. The proportion of hip fracture operations within two days is the percentage of patients with a fracture neck of femur primary diagnoses (ICD10: S720-S722) that have received a related procedure (W code) within two days.

Patients' experience. Patients' experience variables relate to the following three questions to patients: 1) "In your opinion how clean was the hospital room or ward?" (Clean hospital room/ward). The patient could give one of five possible answers: very clean, fairly clean, not very clean, not at all clean. Dr Foster measures the proportion of patients who found the hospital or room very clean or clean. 2) "Were you involved as much as you wanted to be in decisions about your care and treatment?" (Involved in decisions). The patient could answer: yes, definitely; yes, to some extent; no. Dr Foster measures the proportion of patients who answered yes. 3) "Did you have confidence and Trust in doctors treating you?" (Trust in doctors). The patient could answer: yes, always; yes, sometimes; no. Dr Foster measures the percentage of patients who answered yes.

Table 1. Descriptive statistics

	Type	Mean	SD	Min	Max
Quality measures:					
Overall mortality rate	B	98.28	9.50	71.85	117.93
Mortality from high risk conditions	M	98.46	10.09	73.02	120.59
Mortality from low risk conditions	B	90.29	27.79	31.30	150.92
Deaths after surgery	B	98.31	25.50	26.33	157.36
Deaths resulting from hip fracture	M	99.96	24.29	43.54	167.87
In-hospital stroke mortality	M	100.91	13.07	76.10	166.07
Hip replacement readmissions	L	109.09	24.24	55.29	175.31
Knee replacement readmissions	L	102.60	36.46	0.00	219.41
Stroke readmission within 28 days	M	105.91	18.98	60.44	158.08
Hip revisions and manipulations within 1 year	L	1.09	0.63	0.00	3.51
Knee revisions and manipulations within 1 year	L	0.55	0.78	0.00	7.14
Hip fracture - Operation given within 2 days	M	67.47	11.51	42.83	94.31
Redo rates for prostate resection	L	4.13	1.99	0.00	9.23
Clean Hospital room/ward	B	85.95	2.95	79.00	93.70
Involved in decisions	B	69.68	3.31	60.00	77.40
Trust in doctors	B	88.16	2.27	81.50	92.90
Controls:					
Number of rivals within 30 minutes car drive		3.99	3.50	1.00	14.00
Teaching hospital		0.20	0.40	0.00	1.00
Foundation Trust		0.52	0.50	0.00	1.00
Total number of inpatient spells (in thousands)		91.73	42.09	28.59	216.77
Staff MFF		1.03	0.10	0.91	1.20
Population density within 15km		2217	2046	264.16	7256
London Trust		0.24	0.43	0.00	1.00

Note. B: measures quality of both elective and emergency admissions. M: measures quality of emergency admissions. L: measures quality of elective admissions.

Table 2. Correlations amongst mortality and readmission variables

	Overall mortality rate	Mortality from high risk conditions	Mortality fromlow risk conditions	Deaths after surgery	Deaths from hip fracture	In hospital stroke mortality	Hip replacement readmissions	Knee replacement readmissions	Stroke readmissions	Hip revisions & manipulations within 1 year	Knee revisions & manipulations within 1 year	Hip fracture operation within 2 days	Redo rates prostate resection
Overall mortality rate	1	0.8	0.35	0.29	0.33	0.32	0.02	-0.02	-0.03	0.01	-0.09	-0.05	-0.13
Mortality from high risk conditions	0.8	1	0.25	0.25	**0.37**	**0.49**	0.04	0.02	**-0.03**	-0.09	-0.16	**-0.09**	-0.07
Mortality from low risk conditions	0.35	0.25	1	0.22	0.19	0.14	-0.07	0.11	-0.12	-0.05	-0.18	0.03	-0.04
Deaths after surgery	0.29	0.25	0.22	1	0.2	0.02	-0.08	-0.12	-0.02	-0.09	-0.11	-0.07	-0.16
Deaths from hip fracture	0.33	0.37	0.19	0.2	1	**0.16**	-0.04	-0.06	**0.16**	-0.02	-0.05	**-0.05**	-0.08
In-hospital stroke mortality	0.32	0.49	0.14	0.02	0.16	1	0.03	-0.04	0.04	-0.05	0.06	-0.03	0.02
Hip replacement readmissions	0.02	0.04	-0.07	-0.08	-0.04	0.03	1	0.32	0.07	0.01	0.02	0.02	-0.05
Knee replacement readmissions	-0.02	0.02	0.11	-0.12	-0.06	-0.04	**0.32**	1	0.09	0.11	-0.06	-0.02	-0.01
Stroke readmission	-0.03	-0.03	-0.12	-0.02	0.16	0.04	0.07	0.09	1	0.04	0.06	**0.01**	0.08
Hip revisions & manipulations within 1 year	0.01	-0.09	-0.05	-0.09	-0.02	-0.05	**0.01**	**0.11**	0.04	1	0.38	0.09	-0.06
Knee revisions and manipulations within 1 year	-0.09	-0.16	-0.18	-0.11	-0.05	0.06	**0.02**	**-0.06**	0.06	**0.38**	1	0.02	0.01
Hip fracture operation within 2 days	-0.05	-0.09	0.03	-0.07	-0.05	-0.03	0.02	-0.02	0.01	0.09	0.02	1	0.11
Redo rates for prostate resection	-0.13	-0.07	-0.04	-0.16	-0.08	0.02	**-0.05**	**-0.01**	0.08	**-0.06**	**0.01**	0.11	1

Note: absolute value of correlation of at least 0.21 required for significance at 1%. Correlations in bold above the diagonal are between measures of emergency care quality and those in bold below the diagonal are between measures of elective care quality.

Table 3. Correlations amongst satisfaction, mortality, and readmissions

	Mortality from high risk conditions	Deaths from hip fracture	Hip replacement readmissions	Stroke readmission	Clean Hospital room/ward	Involved in decisions	Trust in doctors
Mortality from high risk conditions	1	0.37	0.04	-0.03	0.02	-0.14	-0.15
Deaths resulting from hip fracture	0.37	1	-0.04	0.17	0.03	-0.04	-0.06
Hip replacement readmissions	0.04	-0.04	1	0.07	-0.1	-0.18	-0.04
Stroke readmission	-0.03	0.17	0.07	1	-0.17	-0.24	-0.22
Clean Hospital room/ward	0.02	0.03	-0.1	-0.17	1	0.5	0.46
Involved in decisions	-0.14	-0.04	-0.18	-0.24	0.5	1	0.76
Trust in doctors	-0.15	-0.06	-0.04	-0.22	0.46	0.76	1

Note: absolute correlation of 0.21 required for significance at 1%.

Table 4. Spatial models of hospital competition and risk adjusted mortality rates

	Overall mortality rate	Mortality from high risk conditions	Mortality from low risk conditions	Deaths after surgery	Deaths from hip fracture	In-hospital stroke mortality
Number rivals within 30 min	0.962	0.87	-0.860	-0.851	-0.388	0.633
	(0.123)	(0.230)	(0.705)	(0.660)	(0.840)	(0.538)
Teaching Hospital	-8.430***	-5.782**	4.248	-1.728	-8.102	-2.736
	(0.001)	(0.041)	(0.633)	(0.821)	(0.280)	(0.497)
Foundation Trust	-2.174	-0.970	1.957	-3.852	-9.307*	-0.161
	(0.210)	(0.630)	(0.757)	(0.477)	(0.083)	(0.955)
Total inpatient spells (1000)	0.0189	0.0463*	-0.0139	0.0144	-0.0179	0.00880
	(0.380)	(0.064)	(0.858)	(0.831)	(0.787)	(0.805)
Staff MFF	-22.85	-26.12	9.959	-15.92	-44.87	-5.235
	(0.110)	(0.118)	(0.846)	(0.717)	(0.303)	(0.821)
Populationdensity within 15km	-0.00242	-0.00214	0.000447	0.00186	0.00136	0.00139
	(0.114)	(0.227)	(0.936)	(0.696)	(0.773)	(0.580)
London Trust	4.013	3.688	-2.535	-21.01	-2.334	-6.480
	(0.460)	(0.559)	(0.898)	(0.217)	(0.889)	(0.471)
Constant	96.59***	107.0***	86.39	115.2**	150.5***	83.91***
	(0.000)	(0.000)	(0.114)	(0.015)	(0.001)	(0.001)
ρ (spatial quality lag)	0.276***	0.164	-0.0438	0.0511	0.0276	0.179*
	(0.004)	(0.102)	(0.699)	(0.643)	(0.807)	(0.100)
sigma2	57.09***	77.01***	757.1***	550.7***	542.8***	154.4***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	99	99	99	99	99	99
AIC	704.316	732.020	957.346	925.847	924.354	801.092
BIC	730.267	757.972	983.297	951.798	950.305	827.043

p-values in parentheses   * p<0.10, ** p<0.05, *** p<0.01

Table 5. Spatial models of hospital competition and risk-adjusted readmission, revision and redo rates

	Hip replacement readmissions	Knee replacement readmissions	Stroke readmission within 28 days	Hip revisions and manipulations within 1 year	Knee revisions and manipulations within 1 year	Hip fracture operation given within 2 days	Redo rates for prostate resection
Number of rivals within 30 minutes	2.295 (0.224)	2.939 (0.295)	-0.383 (0.792)	0.0347 (0.489)	-0.0904 (0.122)	0.0826 (0.928)	-0.181 (0.209)
Teaching Hospital	4.088 (0.579)	-23.41** (0.033)	-10.00* (0.075)	-0.336* (0.088)	-0.137 (0.548)	0.220 (0.951)	0.267 (0.633)
Foundation Trust	-4.279 (0.420)	0.451 (0.954)	-2.431 (0.546)	0.0279 (0.841)	0.139 (0.392)	3.025 (0.236)	0.309 (0.440)
Total number of inpatient spells (1000)	0.0137 (0.833)	0.136 (0.163)	-0.0228 (0.648)	0.000649 (0.707)	-0.00125 (0.536)	-0.0292 (0.358)	0.00965* (0.052)
Staff MFF	120.7*** (0.005)	-30.52 (0.630)	19.25 (0.558)	0.822 (0.471)	0.838 (0.526)	26.11 (0.207)	10.08*** (0.002)
Populationdensity within 15km	-0.00845* (0.067)	-0.00256 (0.710)	0.00455 (0.199)	-0.0000263 (0.830)	0.000221 (0.122)	0.000251 (0.911)	0.000586* (0.098)
London Trust	39.90** (0.015)	12.02 (0.626)	-11.66 (0.352)	0.0316 (0.942)	0.159 (0.756)	-3.427 (0.668)	-1.827 (0.144)
Constant	237.7*** (0.000)	93.60 (0.164)	68.00** (0.046)	0.163 (0.889)	-0.295 (0.830)	44.05** (0.049)	-7.406** (0.028)
ρ (spatial quality lag)	-0.0415 (0.706)	0.225** (0.021)	0.167* (0.100)	-0.00910 (0.936)	-0.194 (0.163)	-0.0357 (0.740)	-0.0143 (0.899)
sigma2	521.5*** (0.000)	1157.7*** (0.000)	304.2*** (0.000)	0.368*** (0.000)	0.502*** (0.000)	123.6*** (0.000)	3.023*** (0.000)
Observations	99	99	99	99	99	99	99
AIC	920.426	1001.250	868.042	201.920	234.141	777.916	410.475
BIC	946.377	1027.201	893.993	227.872	260.092	803.867	436.426

p-values in parentheses * p<0.10, ** p<0.05, *** p<0.01

Table 6. Spatial models of hospital competition and patient experience

	Clean Hospital room/ward	Involved in decisions	Trust in doctors
Number of rivals within 30 minutes	0.0245	0.0849	0.202
	(0.903)	(0.709)	(0.167)
Teaching Hospital	1.126	2.322***	1.988***
	(0.148)	(0.009)	(0.000)
Foundation Trust	1.181**	1.096*	0.399
	(0.035)	(0.083)	(0.326)
Total number of inpatient spells (1000)	0.00532	0.00139	-0.000366
	(0.441)	(0.859)	(0.942)
Staff MFF	-3.750	-5.856	-6.670**
	(0.427)	(0.261)	(0.050)
Population density within 15km	-0.000113	-0.000230	-0.000294
	(0.818)	(0.680)	(0.414)
London Trust	-1.026	0.0368	0.237
	(0.555)	(0.985)	(0.852)
Constant	73.50***	57.66***	69.02***
	(0.000)	(0.000)	(0.000)
ρ (spatial quality lag)	0.179*	0.245**	0.285***
	(0.070)	(0.012)	(0.003)
sigma2	5.854***	7.567***	3.122***
	(0.000)	(0.000)	(0.000)
Observations	99	99	99
AIC	477.100	503.607	416.832
BIC	503.052	529.558	442.783

p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 7. Spatial models of hospital competition and risk adjusted mortality rates (60 minutes car drive time catchment areas)

	Competition measure: number of rivals weighted by distance		Competition measure: number of rivals		ρ (Spatial quality lag)		BIC
Overall mortality rate	1.738	(0.765)					1040.489
					0.327**	(0.015)	1040.138
	1.337	(0.808)			0.326**	(0.015)	1045.035
			0.0899	(0.526)			1040.158
			0.0766	(0.568)	0.324**	(0.016)	1044.769
Mortality from high risk conditions	-1.412	(0.826)					1068.622
					0.0746	(0.642)	1073.415
	-1.540	(0.805)			0.0763	(0.634)	1078.310
			0.0203	(0.897)			1068.655
			0.0164	(0.914)	0.0736	(0.647)	1078.360
Mortality from low risk conditions	-18.10	(0.337)					1374.385
					0.0369	(0.803)	1380.252
	-17.85	(0.331)			0.0257	(0.862)	1384.267
			-0.587	(0.201)			1373.632
			-0.582	(0.193)	0.0210	(0.887)	1383.524
Deaths after surgery	-3.266	(0.847)					1342.844
					0.162	(0.263)	1346.625
	-3.533	(0.828)			0.163	(0.261)	1351.533
			-0.0771	(0.851)			1342.847
			-0.0822	(0.836)	0.163	(0.262)	1351.538
Deaths resulting from hip fracture	-0.443	(0.978)					1323.971
					0.0977	(0.526)	1328.531
	-1.676	(0.913)			0.0998	(0.520)	1333.475
			0.136	(0.724)			1323.840
			0.101	(0.790)	0.0911	(0.559)	1333.416
In-hospital stroke mortality	-3.965	(0.666)					1169.743
					0.0383	(0.801)	1174.833
	-3.914	(0.661)			0.0368	(0.809)	1179.596
			-0.0502	(0.823)			1169.887
			-0.0484	(0.824)	0.0372	(0.807)	1179.740

Observations: 142. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 8. Spatial models of hospital competition and risk adjusted readmission, revision and redo rates (60 minutes car drive time catchment area)

	Competition measure: number of rivals weighted by distance	Competition measure: number of rivals	ρ (Spatial quality lag)	BIC
Hip replacement readmissions	36.59** (0.031)			1344.603
			-0.0239 (0.880)	1354.374
	39.55** (0.020)		-0.116 (0.476)	1354.003
		0.752* (0.071)		1346.020
		0.824** (0.049)	-0.108 (0.512)	1355.498
Knee replacement readmissions	27.21 (0.264)			1447.455
			0.260* (0.057)	1450.331
	18.45 (0.441)		0.237* (0.092)	1454.693
		0.456 (0.445)		1448.150
		0.202 (0.731)	0.248* (0.079)	1455.169
Stroke readmission within 28 days	6.722 (0.605)			1268.995
			0.162 (0.250)	1272.948
	5.361 (0.671)		0.156 (0.270)	1277.724
		0.139 (0.662)		1269.075
		0.0987 (0.749)	0.157 (0.269)	1277.802
Hip revisions and manipulations within 1 year	-0.176 (0.677)			295.214
			0.120 (0.460)	299.821
	-0.166 (0.686)		0.118 (0.469)	304.613
		-0.00228 (0.824)		295.346
		-0.00214 (0.830)	0.119 (0.463)	304.731
Knee revisions and manipulations within 1 year	0.188 (0.671)			309.765
			-0.248 (0.248)	313.566
	0.221 (0.606)		-0.255 (0.235)	318.257
		0.00781 (0.470)		309.404
		0.00896 (0.391)	-0.265 (0.218)	317.789
Hip fracture - Operation given within 2 days	-9.058 (0.261)			1132.831
			0.0977 (0.482)	1138.634
	-8.503 (0.280)		0.0791 (0.573)	1142.428
		-0.300 (0.125)		1131.695
		-0.287 (0.134)	0.0699 (0.619)	1141.361
Redo rates for prostate resection	-3.608** (0.010)			636.635
			-0.00273 (0.985)	648.425
	-3.886*** (0.006)		-0.109 (0.458)	645.992
		-0.0957*** (0.005)		635.347
		-0.104*** (0.003)	-0.125 (0.396)	644.536

Observations: 142. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 9. Spatial models of hospital competition and patient experience (60 minutes car drive time catchment area)

	Competition measure: number of rivals weighted by distance		Competition measure: number of rivals		ρ (Spatial quality lag)		BIC
Clean Hospital room/ward	-1.012	(0.545)					686.299
					0.0880	(0.553)	691.294
	-1.007	(0.535)			0.0876	(0.554)	695.865
			-0.0317	(0.436)			686.046
			-0.0317	(0.422)	0.0881	(0.552)	695.608
Involved in decisions	-3.207*	(0.095)					725.837
					0.310**	(0.010)	727.686
	-2.733	(0.136)			0.292**	(0.017)	730.430
			-0.104**	(0.025)			723.560
			-0.0910**	(0.041)	0.281**	(0.021)	728.507
Trust in doctors	-0.577	(0.665)					621.582
					0.212*	(0.098)	624.112
	-0.467	(0.715)			0.209	(0.102)	628.935
			-0.0302	(0.351)			620.863
			-0.0276	(0.376)	0.206	(0.107)	628.285

Observations: 142. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 10. Spatial models of hospital competition and risk adjusted mortality rates (98 minutes car drive time catchment area)

	Competition measure: number of rivals weighted by distance		Competition measure: number of rivals		ρ (Spatial quality lag)		BIC
Overall mortality rate	3.164	(0.442)					1074.123
					0.423**	(0.020)	1075.048
	1.523	(0.703)			0.410**	(0.028)	1079.893
			0.0774	(0.263)			1073.426
			0.0490	(0.467)	0.396**	(0.036)	1079.510
Mortality from high risk conditions	-1.502	(0.745)					1107.597
					0.233	(0.277)	1111.582
	-2.461	(0.587)			0.255	(0.239)	1116.278
			-0.00532	(0.945)			1107.704
			-0.0200	(0.793)	0.243	(0.263)	1116.504
Mortality from low risk conditions	-7.262	(0.586)					1419.839
					0.00322	(0.990)	1425.143
	-7.405	(0.573)			-0.0178	(0.943)	1429.815
			-0.131	(0.559)			1419.791
			-0.133	(0.545)	-0.0157	(0.949)	1429.768
Deaths after surgery	13.21	(0.268)					1386.961
					0.341*	(0.081)	1390.473
	10.47	(0.367)			0.315	(0.115)	1394.651
			0.294	(0.141)			1385.980
			0.250	(0.199)	0.304	(0.128)	1393.824
Deaths resulting from hip fracture	2.911	(0.794)					1367.786
					-0.0328	(0.903)	1372.833
	3.262	(0.768)			-0.0477	(0.863)	1377.737
			0.0968	(0.607)			1367.578
			0.104	(0.576)	-0.0594	(0.830)	1377.512
In-hospital stroke mortality	-5.467	(0.438)					1232.197
					0.192	(0.433)	1237.237
	-6.194	(0.368)			0.218	(0.369)	1241.419
			-0.0674	(0.570)			1232.491
			-0.0837	(0.472)	0.219	(0.369)	1241.713

Observations: 147. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 11. Spatial models of hospital competition and risk adjusted readmission, revision and redo rates (98 minutes car drive time catchment area)

	Competition measure: number of rivals weighted by distance	Competition measure: number of rivals	ρ (Spatial quality lag)	BIC
Hip replacement readmissions	35.71*** (0.004)			1396.586
			0.317 (0.131)	1408.114
	33.30*** (0.008)		0.146 (0.530)	1406.184
		0.536** (0.010)		1398.392
		0.489** (0.020)	0.178 (0.438)	1407.793
Knee replacement readmissions	35.35** (0.037)			1490.875
			0.296 (0.148)	1498.441
	31.17* (0.070)		0.188 (0.394)	1500.158
		0.579** (0.043)		1491.119
		0.508* (0.078)	0.195 (0.376)	1500.350
Stroke readmission within 28 days	11.84 (0.195)			1308.774
			0.330* (0.081)	1312.730
	8.008 (0.386)		0.279 (0.167)	1316.969
		0.192 (0.212)		1308.897
		0.116 (0.465)	0.278 (0.178)	1317.186
Hip revisions and manipulations within 1 year	-0.0556 (0.852)			301.723
			0.303 (0.178)	305.102
	-0.0129 (0.964)		0.302 (0.183)	310.091
		0.000738 (0.883)		301.737
		0.00128 (0.792)	0.308 (0.172)	310.023
Knee revisions and manipulations within 1 year	0.0539 (0.864)			319.079
			-0.404 (0.232)	322.606
	0.0482 (0.874)		-0.403 (0.233)	327.571
		0.00223 (0.675)		318.923
		0.00240 (0.639)	-0.409 (0.227)	327.377
Hip fracture – Operation given within 2 days	-5.137 (0.366)			1168.682
			0.117 (0.538)	1174.162
	-4.614 (0.415)		0.0824 (0.674)	1178.488
		-0.0653 (0.495)		1169.054
		-0.0565 (0.551)	0.0956 (0.623)	1178.797
Redo rates for prostate resection	-2.835*** (0.004)			652.938
			0.00318 (0.990)	666.479
	-3.224*** (0.002)		-0.296 (0.285)	661.744
		-0.0429*** (0.010)		654.603
		-0.0464*** (0.006)	-0.195 (0.465)	664.038

Observations: 147. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Table 12. Spatial models of hospital competition and patient experience (98 minutes car drive time catchment area)

	Competition measure: number of rivals weighted by distance		Competition measure: number of rivals		ρ (Spatial quality lag)		BIC
Clean Hospital room/ward	-1.152	(0.331)					707.741
					0.166	(0.474)	713.234
	-1.088	(0.345)			0.147	(0.528)	717.337
			-0.0229	(0.250)			707.348
			-0.0210	(0.285)	0.119	(0.618)	717.086
Involved in decisions	-4.955***	(0.000)					743.271
					0.555***	(0.000)	751.096
	-3.736***	(0.007)			0.388**	(0.027)	748.880
			-0.0964***	(0.000)			738.280
			-0.0778***	(0.002)	0.275	(0.159)	746.400
Trust in doctors	-1.859**	(0.046)					637.729
					0.460***	(0.005)	639.994
	-1.213	(0.195)			0.392**	(0.027)	643.307
			-0.0414***	(0.008)			634.549
			-0.0294*	(0.073)	0.328*	(0.083)	641.771

Observations: 147. p-values in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$