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Hospital interdependence in a competitive institutional environment: Evidence from Italy

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Abstract

In this paper we study the impact of competition on hospital adverse health outcomes, using data on patients admitted to hospitals located in the Lombardy region in Italy between 2004 and 2013. We propose an economic framework that incorporates both short and long range forms of competition among hospitals. In a set up where prices are regulated, and under the assumption that hospitals are profit maximisers, hospital managers compete locally in quality to attract more patients. At the same time, managers have an incentive to compete with all other hospitals within the Lombardy region as their relative quality performance will potentially affect their future states. Our empirical model exploits methods from the graphical modelling literature to estimate local rivals, as well as the degree of local and global interdependence among hospitals. Our results show a significant positive degree of short and long range dependence, which suggests the existence of forms of local and global competition among hospitals with relevant implications for the healthcare policy.

JEL Classification: I11; I18; C31; C73.

Keywords: hospital interdependence; stochastic games; graphical modelling; spatial econometrics.

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1. Introduction

In recent years, several central and local governments in Western countries have implemented pro-competition reforms in the healthcare sector with the view that, as predicted by the economic theory, more competition among healthcare providers, when prices are regulated, would lead to improvements in the quality of care and, thus, in health outcomes. Between 2002 and 2008, the UK government has launched a number of pro-competition reforms in the healthcare sector, with the aim of allowing patients to choose the provider in which to be admitted (Department of Health, 2004). Similar to the UK and the US Medicare system, in 1997 in Italy, the Lombardy regional government has implemented a pro-competition healthcare reform, according to which patients can choose among all hospitals located within the region where prices are regulated through a prospective payment system. Furthermore, this reform has introduced competition between public and private hospitals by allowing the latter to be accredited as suppliers of healthcare services, and so to be entitled to public reimbursements.

There exists an alive debate in the scientific community on the real effects of these reforms on hospital quality, with empirical evidence reporting contrasting results. While some studies corroborate the hypothesis that more competition among hospitals leads to better health outcomes (e.g., Gaynor et al., 2016), others argue that more competition may even harm the health of people (e.g., Propper et al., 2004); finally, some works report no association between quality and competition (Mukamel et al., 2002; Berta et al., 2016; Colla et al., 2016).

One common feature of these works is that they assume that hospitals compete with each other in attracting more patients within their local market, or catchment area, which is usually a pre-specified geographical area around hospitals. In this paper we explore whether, beyond this local mechanism of competition, hospitals have an incentive to compete globally, regardless of their geographical location. To this end, we have develop an economic framework that incorporates both local and long range forms of competition among hospitals, which might arise in a highly competitive institutional environment. Specifically, in a set up where prices are regulated, hospitals compete locally in quality to attract more patients (Gravelle et al., 2014; Longo et al., 2017). At the same time, our model incorporates a long range, or "global", form of competition that arises from hospital performance rankings, which might potentially affect the hospital managers' future state (such as employability, professional reputation, social status, etc.). In particular, in our stylized model we will assume that managers belonging to underperforming hospitals may not be reappointed the next period, according to a probability distribution that depends on the relative quality performance. In this context, hospital managers can observe the quality of hospitals in the region and, in order to maximise their expected value of being appointed as hospital manager, they have an incentive to improve their hospital quality relative to all other hospitals.

Moving on from our theoretical framework, we test empirically the presence of short and long range of interdependence among hospitals in the Lombardy healthcare system. Instead of relying on geographical distances to construct hospital markets (e.g., Propper et al., 2004; Gravelle et al., 2014), we adopt graphical modelling techniques to identify who the rivals are for each hospital. This allows us to better estimate the hospital reaction functions and, thus, to establish whether the assumption of strategic complementarity or substitutability holds, without relying on arbitrary assumptions on the local market for each hospital. More specifically, we assume that hospital quality follows a Conditional Auto Regressive (CAR) model where the spatial weights matrix is assumed to be unknown. Given the large number of unknown parameters to be estimated, we adopt a penalised likelihood approach (Friedman et al. 2008), and use the Flexible Block-GLASSO procedure advanced by Moscone et al. (2017) to estimate efficiently the spatial weights matrix of the CAR model. This empirical model will indirectly return the number of rivals with which each hospital competes locally, and it will also provide an estimate of the degree of "global" interdependence among hospitals arising from hospital performance rankings.

In our empirical investigation we use data on 162,927 emergency admissions for Acute Myocardial Infarction (AMI) in 170 hospitals located in the Lombardy region in Italy over the period from 2004 to 2013. Our results point at a significant interdependence among hospital qualities, which is only in part explained by local interaction. Indeed, this seems to conform well to our economic framework that includes both short and long range types of competition among hospitals.

Our empirical findings provide different contributions to the literature on hospital competition. First, our theoretical framework shows that, in a highly competitive institutional environment as the Lombardy region, interdependence among hospitals reflects only in part a mechanism of local competition, as suggested by the current literature. Our empirical results seem to suggest that the ranking system introduced in a healthcare system is an incentive for hospitals to look at the quality set by hospitals regardless of whether the hospitals are located within the catchment area. Furthermore, the adoption of graphical modelling techniques gives us the advantage to estimate the rivals in the market without relying on some pre-specified assumption on the catchment area. This fully acknowledges the potential heterogeneity in the local competition network among hospitals.

This paper is organized as follows. Section 2 provides the literature review on hospital competition. Section 3 presents the institutional setting, while Section 4 lays out the economic model. Then, Section 5 presents the empirical model, and Section 6 discusses the data. The empirical results are presented in Section 7. Section 8 concludes with some final remarks.

2. Literature review

Most papers investigating the effects of hospital competition on hospital quality have focused on the United States or United Kingdom market, and have adopted a wide range of methods to estimate hospital competition and its impact on quality (e.g., Kessler and McClellan, 2000; Tay, 2003; Propper et al., 2004; Gaynor, 2006; Cooper et al., 2011; Gaynor et al., 2016).

Several studies measure competition by means of the Herfindahl-Hirschman Index (HHI), namely the sum of the squared market share of each hospital. The HHI index is usually calculated by assuming that each hospital competes only within its geographic market, namely all hospitals located within a fixed distance. When building the HHI, Kessler and McClellan (2000) have used predicted flows based on (exogenous) patient characteristics and patient-to-hospital distance, rather than actual patient flows. This allows one to avoid endogeneity problems when studying the effect of the HHI on healthcare quality, as well as distortions in defining the geographical area representing the potential hospital market. The authors, using individual data on non-rural elderly Medicare patients hospitalized for heart attack treatment in 1985, 1988, 1991 and 1994, concluded that competition led to significantly lower 30-day mortality hospital rates. Tay (2003) using data from 1994 for AMI patients, estimated a mixed logit model and showed the importance that quality plays in patient choice, providing evidence that patients are willing to travel more if the quality of treatment is higher. Ho and Hamilton (2000) investigated the effects of hospital mergers on mortality rates, using a data set from patients who were admitted to hospitals in California for AMI treatments between 1991 and 1996. Specifically, they estimated Cox regressions and found no effect of increased market power (through a merger) on mortality rates as well as a moderate effect on readmission and early discharges rates.

A number of studies have analysed the influence of competition on healthcare quality in the UK. Propper et al. (2004, 2008) studied hospital mortality rates for AMI and found a negative effect of competition. They used aggregated hospital level measures and tried to avoid endogeneity problems in the HHI by estimating potential demand rather than observed choice. Cooper et al. (2011) implemented a difference-in-difference econometric model to study the effect of recent UK pro-competition reforms on mortality rates and found that rates decreased after the reforms in more competitive hospital markets. In a more recent study, Gaynor et al. (2016) adopted a difference-in-difference approach and found that a pro-competition reform of the healthcare system led to an increase in the average quality of hospital care. According to the authors, these improvements were achieved because allowing for a wider choice made patients more responsive to clinical quality.

Recent works have studied the effect of competition on the healthcare sector in Italy. Moscone et al. (2012) studied the effect of patient hospital choice of an imperfect measure of hospital quality (the effect of word-of-mouth social interaction given by the percentage of patients living in the same area who have previously made the same treatment choice). Using administrative data that include the whole population, they showed that the informal neighbourhood effect has no effects on health outcomes and even may lead patients to make suboptimal selections. Berta et al. (2016) using data on over 194,000 patients admitted to any of the 126 hospitals located in the Lombardy region in 2012, found no association between hospital competition and quality. The authors argued that this may be in part the result of asymmetric information, as well the difficulty in this strand of literature to find reliable quality indicators. Further, Colla et al. (2016) derived a model that expresses in a fixed-price regime the association between competition and quality. They estimated it with a national sample of Medicare fee-for-service patients during 2010-11, aggregated at hospital level, and found essentially no association between competition and quality for what should be the most competitive markets, namely elective hip and knee replacements.

There are a number of possible explanations behind these controversial empirical findings on the size and effect of competition on quality. One explanation comes from theory. If we change the assumption that people working in the hospital are altruistic providers rather than profit maximisers, then a higher level of competition can reduce hospital quality (Brekke et al., 2011). Altruistic providers may work at a negative profit margin, and therefore compete to "avoid" the marginal patient, reducing the incentive to invest in quality (Siciliani, 2017). Some authors have also called for better indicators of hospital quality used to study the effects of competition. It may be plausible that quality is affected by market competition, but empirical works do not capture this because adverse outcome indicators such as mortality rates may not be sufficiently sensitive to detect differences in hospital-level quality (Berta et al., 2016). Furthermore, many works have used health outcomes for emergency admissions as a quality measure, in order to mitigate potential bias from unobserved selection. However, this relies on the assumption that quality for emergency patients is strongly correlated with quality for elective patients (Moscelli et al., 2016). The result of no effect of hospital competition found in the literature may be due to the presence of asymmetric information about the "true" quality of hospitals (Moscone et al., 2012). In fact, asymmetric information may act as barrier for competition to work effectively, since it may reduce the possible returns from investing in hospital quality.

An alternative approach is taken by Gravelle et al. (2014), who derived the conditions on demand and cost-functions which determine whether the magnitude of the pro-competition effect depends on the slope of the hospital reaction functions. The authors empirically represented the hospital reaction functions by a spatial lag model, where rivals for each hospital are defined as all hospitals within a catchment area of 30 minutes travel time. They estimated the model using data on 16 quality indicators for 99 English hospitals in 2009/10. Their results showed a positive and significant spatial lag quality coefficient for 6 of the 16 quality indicators. A similar approach was also adopted by Mobley et al. (2009). To understand if the changes in the market structure had an impact on the price reaction function, Mobley (2003) adopted a theoretical model focusing on how equilibrium prices are impacted by shifts in the reaction function. The authors estimated the slope of the reaction function using a cross-sectional spatial lag model on data for 336 Californian hospitals for 1993 and 1999, and found a significant and positive spatial lag price. We refer to Baltagi et al. (2017) for a survey of papers that explore the link of spatial interaction between hospitals to the theoretical framework on competition and peer-effects.

Overall, the papers reviewed above require the definition of the hospitals' geographic market. This is usually assumed to be catchment areas of a certain amount of minutes-drive time, or a threshold geographical distance expressed in Kilometres. We refer to Propper (2011) for different ways of defining the market within which each hospital operates. Though reasonable they can be, these are arbitrary measures to define hospitals markets that may ultimately impact on the size and direction of competition in quality that, indeed, may not necessarily be of a geographical nature.

3. Institutional context

Founded in 1978, the Italian National Healthcare System (NHS) offers universal health care coverage through tax funding. In the early 90s, Italy deeply reformed the organization of its healthcare system, changing the financing mechanism for providers[1] and introducing the quasi-markets model, that is a separation between the buyers (i.e. local health authorities) and the providers (i.e. hospitals) of healthcare services, with the aim of boosting competition among providers. Furthermore, a wide devolution of responsibilities for the organization and financing of

[1] In general, two basic financing criteria are adopted for the hospital care (see e.g., Fattore and Torbica, 2006). The main funding mechanism is a per-case system, based on tariffs related to the DRG classification of discharges; in this respect, however, regions are free either to opt for the national DRG tariffs or to establish their own DRG tariffs. Instead, for those services (e.g., integrated care, emergency treatment, transplants) for which tariffs are deemed inadequate, hospitals are financed through lump sum transfers. Again, regions have full autonomy in the identification of these services and, thus, may alter the composition of hospital funding and reduce the role of per-case payment.

healthcare to regional governments was undertaken and, thus, financial resources are now transferred through an allocation formula to the regions to manage their regional healthcare systems. As a result, the Italian NHS can be largely considered a highly decentralized system (e.g., France et al., 2005; Guccio and Lisi, 2016; Cappellari et al., 2016). Under an empirical perspective, focusing on one region rather than on the entire Italian NHS might be advantageous, as it reduces the large heterogeneity arising from the different rules underlying the different regional healthcare systems in Italy. Among the Italian regions, Lombardy, the most populated region in Italy with 10 million inhabitants, is a very interesting case to study the effect of competition on providers, as its institutional framework can be considered a pro-competition healthcare system (Berta et al., 2016).

Since 1995, the Lombardy healthcare system has adopted a prospective payment system to reimburse the hospitals for each patient on the basis of his Diagnosis Related Group (DRG), established by using clinical information reported in the Hospital Discharge Chart (HDC). Differently from other regions, however, the DRG tariffs are set at the regional level, so as to provide specific incentives to hospitals, and the hospital funding due to the per-case payments represents the highest share of the total funding. Moreover, the 1997 Lombardy healthcare reform has promoted a large competition among providers by increasing the number of accredited hospitals, with the ultimate aim of improving the quality of healthcare services.

In 2002 the Lombardy government has established a *quality evaluation programme* to evaluate the performance of healthcare providers in terms of quality of care (e.g., Berta et al., 2013). In particular, every year the region estimates, using data from hospital discharge charts, a set of risk-adjusted outcome indicators of quality for each accredited hospital in the region, including mortality rates within 30 days from discharge, intra-hospital mortality rates and readmission rates within 12 months from discharge. The region yearly publishes the results on a web portal in which hospitals included in the regional healthcare system can access and see their performance rankings with respect to other hospitals. For each ward the region provides a hospital classification into three groups depending on whether the quality is significantly above, not different, or significantly below the regional average performance. By allowing hospitals to look at their own performance relative to others, the declared aim is to encourage them to perform well and, thus, to promote improvements in healthcare quality. Even if the programme is not officially aimed at penalizing or rewarding hospitals, sharing periodically the performance rankings among hospitals makes all healthcare stakeholders aware of hospitals' performances, which may have an impact on the future state of hospital managers (such as employability, professional reputation, social status, etc.) and, thus, on the hospital competition process. In this perspective, the regional health authority is also responsible for the selection of the hospital management and, to some extent, it could potentially take into account hospital performance when reappointing hospital managers.

In the next section we will study strategic interdependence among hospitals in the Lombardy region. To this end, we will draw from the literature on hospital competition (see, for example, Ma and Burgess, 1993; Brekke et al., 2011, 2012; Gravelle et al., 2014), extending the traditional framework to take into account the specific structure of incentives for hospitals in such institutional context.

4. The economic model

Consider *N* hospitals in the regional health authority and let q_{it} be the quality of hospital *i* at time *t*. The regional health authority is responsible for the overall quality of the healthcare system and, to this purpose, it periodically publishes the quality performance ranking of all *N* hospitals, which may have different consequences on the future state of hospital managers. In particular, in our stylized model we assume that managers belonging to underperforming hospitals may not be reappointed the next period, according to a probability distribution that depends on the relative quality performance. One might argue that not being reappointed would represent only one of the possible negative consequences for hospital managers. Under this perspective, however, we conjecture that an extended model with many different states (for example, damaged professional reputation), would markedly complicate the dynamic framework of the model, without providing any additional insight to the kind of strategic interdependence among hospitals.

The strategic environment for hospitals in this framework can be represented by a simple stochastic game with *N* players (i.e., hospital managers), in which the state for each player changes according to a probability distribution depending on the actions of players (e.g., Shapley, 1953; Mertens, 2002). In our dynamic model, time is discrete (i.e., $t = 1,2, \ldots$) and we consider an infinite-horizon that, as will be discussed below, does not imply that each hospital manager is expected to play the stage game for an infinite number of periods. In particular, the timing of the game is as follows. In each period *t*, hospital managers simultaneously choose (i.e., simultaneous stage game) the quality of healthcare services $\boldsymbol{q_t}$; then, at the beginning of the next period *t +1* the "nature" chooses the state S_{t+1} for each player between "being appointed" ($S = A$) and "not being appointed" ($S = NA$) as hospital manager, drawing from a probability distribution $Pr(S_{t+1}|\ \boldsymbol{q_t})$ depending on the qualities at time *t* of all players. Finally, each player not being reappointed leaves permanently the game and is replaced by a new hospital manager (hence, the stage game at time *t +1* is still played by *N* players)[2], which means that the infinite-horizon does not imply that each hospital manager is expected to play the game infinitely.

In this setting, when hospital managers are called to play, they know the full history of the game, given by the previous states and actions of each player $(\boldsymbol{S_0}, \boldsymbol{q_0}, \boldsymbol{S_1}, \boldsymbol{q_1}, \ldots, \boldsymbol{S_{t-1}}, \boldsymbol{q_{t-1}}, \boldsymbol{S_t})$. However, as standard in stochastic games (e.g., Mertens, 2002), in our model the actions available to each player as well as the stage payoff function depend only on the current state $\boldsymbol{S_t}$ and not on the specific history of the game; that is, the current state $\boldsymbol{S_t}$ is the payoff-relevant history of the game. The stage payoff function for each player is the standard profit function of hospitals (e.g., Brekke et al., 2011; Gravelle et al., 2014), implicitly thought to include also the managers compensation. In this institutional context, patients do not pay for the treatment, instead hospitals are reimbursed through a per-treatment prospectively fixed price *p* and, therefore, they compete on quality *q* with neighbouring hospitals to attract more patients. More specifically, suppose that hospital *i* belong to a catchment area *g*, with $g = 1, 2, \ldots, G$, and that it competes locally on quality with one or more hospitals belonging to the same catchment area. Accordingly, the demand function of hospital *i*, for $i = 1, 2, \ldots, N$, is $x_i = x(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g})$, which depends also on the quality of other hospitals *j*

[2] In this respect, as underlined by Fudenberg and Tirole (1991), in stochastic games "... a given player may play in different periods; it suffices to distinguish his various "incarnations". Thus, player *i* playing at date *t* and player *i* playing ad date *t'* can be formalized as two distinct players whose objective functions are derived from the same preferences ...", which is exactly the case of our players' replacement rule.

belonging to the same catchment group g of hospital i. Demand functions with these characteristics can be easily derived by the utility maximization of patients in the context of Hotelling or Salop spatial models (e.g., Brekke at al., 2008, 2015; Siciliani et al., 2013). We assume that the demand of hospital i is increasing in its own quality q_i and decreasing in the quality of other hospitals $\boldsymbol{q_j}$ in the same catchment group g, that is $\frac{\partial x_i}{\partial q_i} > 0$ and $\frac{\partial x_i}{\partial q_j} < 0 \ \forall \, j \ \in g$. Then, we also assume that $\frac{\partial^2 x_i}{\partial q_i^2} \leq 0$ and $\frac{\partial^2 x_i}{\partial q_i \partial q_j} \geq 0$. Finally, $\boldsymbol{\delta_i}$ and $\boldsymbol{\varphi_g}$ capture other factors affecting the demand for hospital i, such as the location of patients with respect to the location of hospital i and patients' preferences over distance and quality (e.g., Gravelle et al., 2014) that might also be group-specific.

On the other hand, the cost of providing treatment for hospital i is given by the cost function $C_i = C\big(x\big(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\big), q_i; \boldsymbol{\gamma_i}\big)$ increasing and convex in both quantity and quality[3], that is $\frac{\partial C_i}{\partial x_i} > 0$, $\frac{\partial C_i}{\partial q_i} > 0$, $\frac{\partial^2 C_i}{\partial x_i^2} > 0$ and $\frac{\partial^2 C_i}{\partial q_i^2} > 0$. In addition, we assume $\frac{\partial^2 C_i}{\partial q_i \partial x_i} \geq 0$, which implies that increasing quality is more (or, at least, not less) costly when more patients are treated (e.g., Brekke et al., 2011). Finally, the parameter vector $\boldsymbol{\gamma_i}$ captures other exogenous factors potentially affecting the costs of hospital i, such as the price of inputs.

Therefore, the instantaneous profit function of hospital i is:[4]

$$px\big(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\big) - C\big(x\big(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\big), q_i; \boldsymbol{\gamma_i}\big) \tag{1}$$

However, hospital managers are not only concerned with the instantaneous profit but also with their future state and, thus, they also consider the continuation value when they choose quality. In particular, the value of being appointed as hospital i's manager, V_i^A, can be expressed using the following recursive formulation:

$$V_i^A = \max_{q_i}\{px\big(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\big) - C\big(x\big(q_i, \boldsymbol{q_j}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\big), q_i; \boldsymbol{\gamma_i}\big) + \beta\big[Pr(A_i' |\, q_i, \boldsymbol{q_{-i}}; \boldsymbol{\theta})V_i^A + \big(1 - Pr(A_i' |\, q_i, \boldsymbol{q_{-i}}; \boldsymbol{\theta})\big)V^{NA}\big]\} \tag{2}$$

where V^{NA} is the asset value of not being reappointed, β is the discount factor and $Pr(A_i' |\, q_i, \boldsymbol{q_{-i}}; \boldsymbol{\theta})$ is the probability of being reappointed as hospital manager, which depends on the quality of hospital i but also on the quality of all other hospitals in the region, that is $\boldsymbol{q_{-i}} = (q_1, q_2, \dots, q_{i-1}, q_{i+1}, \dots, q_N)$, as well as on other exogenous factors $\boldsymbol{\theta}$. Similar modelling approaches where actions (e.g., q_i) in the current state affect the probability of being in a preferred state (e.g., V_i^A) the next period, can be found in many strands of literature, such as in the probabilistic willingness-to-pay (e.g., Jones-Lee, 1974; Weinstein, 1980) and in labour economics (e.g., Pissarides, 2000; Dolado et al., 2016).

In our model, the asset value of not being reappointed, V^{NA}, is intended to contemplate all alternative states other than that of being reappointed as hospital i manager, such as being employed in a different job or being unemployed. Clearly, one might argue that different alternative states

[3] The convexity of the cost function in output x_i captures a standard feature of the hospital sector, namely that hospitals face capacity constraints and, thus, economies of scale are quickly exhausted (e.g., Brekke et al., 2008).
[4] As standard in this framework (e.g., Gravelle et al., 2014), we assume that the price p is sufficiently high to allow hospitals at least to break even in equilibrium.

might also give different utilities. However, the only important condition needed in our model is that the value of being reappointed is higher than the value of not being reappointed, that is $V_i^A > V^{NA}$, $\forall\, i = 1, 2, \dots, N$. Therefore, for the sake of simplicity, we avoid to model many states alternative to V_i^A and, instead, we interpret V^{NA} as an absorbing state where players receive for each period the reservation utility u^R given by the best alternative, implying that $V^{NA} = \frac{u^R}{1-\beta}$. Condition $V_i^A > V^{NA}$ can be interpreted as a participation condition for each player in this game and is a mild assumption in our model.[5]

As for the probability function $Pr(A_i'|\, q_i, \boldsymbol{q_{-i}}; \boldsymbol{\theta})$, we make the reasonable assumption that a higher own quality q_i – increasing the hospital i's performance ranking – increases at a non-increasing rate the probability of being reappointed, while a higher quality of other hospitals $\boldsymbol{q_{-i}}$ – reducing the hospital i's performance ranking – decreases the probability for hospital i manager, that is $\frac{\partial Pr_i}{\partial q_i} > 0$, $\frac{\partial^2 Pr_i}{\partial q_i^2} \leq 0$ and $\frac{\partial Pr_i}{\partial \boldsymbol{q_{-i}}} < 0$. Finally, we also assume that the increase in Pr_i due to a higher own quality q_i is more effective when the quality of other hospitals $\boldsymbol{q_{-i}}$ is higher, that is $\frac{\partial^2 Pr_i}{\partial q_i \partial \boldsymbol{q_{-i}}} > 0$. In particular, the last assumption seems intuitive in a competitive environment and captures the central idea of our theory: when a hospital is surrounded by many underperforming hospitals, its relative performance will be higher and, thus, a further increase in its own quality to increase the probability of being reappointed for the hospital manager will not have a big impact; on the other hand, when the performance of surrounding hospitals is higher, its relative performance will be lower and, thus, an increase in its own quality could be particularly important in increasing its relative performance and, in turn, the probability of being reappointed for the hospital manager.

From the asset value (2), we can notice that the choice of the optimal quality q_i depends on two different vectors of qualities, namely $\boldsymbol{q_j}$ and $\boldsymbol{q_{-i}}$. The first, $\boldsymbol{q_j}$, includes all hospitals different from i belonging to the same catchment group, that is the standard set of neighbouring hospitals considered in the hospital competition framework. The second vector of qualities, $\boldsymbol{q_{-i}}$, includes all hospitals different from i in the regional health authority, which in our specific case represents a second level of competition among hospitals. Therefore, the interesting aspect of our model is that it captures two levels of competition among hospitals: a local form of competition to attract patients within a catchment group and a long range form of competition for the performance ranking, which potentially affects the future state of all hospital managers. This framework might be appropriate

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[5] To see this point, let q_i^* and $\boldsymbol{q}_{-i}^*$ be the equilibrium qualities of all players derived by the N problems (2). Then, the asset value of being appointed for the hospital i's manager is

$$V_i^A = \frac{px\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right) - C\left(x\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right), q_i^*; \boldsymbol{\gamma_i}\right)}{\left(1 - \beta Pr(A_i'|\, q_i^*, \boldsymbol{q}_{-i}^*; \boldsymbol{\theta})\right)} + \frac{\beta\left(1 - Pr(A_i'|\, q_i^*, \boldsymbol{q}_{-i}^*; \boldsymbol{\theta})\right) u^R}{\left(1 - \beta Pr(A_i'|\, q_i^*, \boldsymbol{q}_{-i}^*; \boldsymbol{\theta})\right)(1-\beta)},$$

which implies that

$$V_i^A - V^{NA} = \frac{px\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right) - C\left(x\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right), q_i^*; \boldsymbol{\gamma_i}\right) - u^R}{\left(1 - \beta Pr(A_i'|\, q_i^*, \boldsymbol{q}_{-i}^*; \boldsymbol{\theta})\right)}.$$

Therefore, the condition $V_i^A > V^{NA}$ only requires that $px\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right) - C\left(x\left(q_i^*, \boldsymbol{q_j^*}; \boldsymbol{\delta_i}, \boldsymbol{\varphi_g}\right), q_i^*; \boldsymbol{\gamma_i}\right) > u^R$, meaning that the instantaneous payoff in equilibrium has to be higher than the reservation utility given by the best alternative, which can be seen as an innocuous participation condition for the players.

also in other contexts where hospital rankings are released, as long as performance rankings impact somehow on managers' future states.

Hospital managers simultaneously choose qualities to maximise the present discounted value (2). As usual in stochastic games (e.g., Maskin and Tirole, 1987, 1988; Mertens, 2002), managers' strategies are assumed to depend only on the current state $\boldsymbol{S_t}$; that is, we look for Markov strategies. Indeed, the use of Markov strategies has some appeal because, among other reasons (e.g., Maskin and Tirole, 2001), it entails the simplest behaviour still consistent with rationality. Nonetheless, this comes at the price of ruling out other strategies depending on signals or cooperation among players. Note that, however, in a context where a large number of players (i.e., hospital managers) play for an uncertain and presumably limited number of periods, the idea of strategies depending on signals or cooperation among them seems fairly unreasonable. Therefore, Markov strategies in our model appear more consistent with reality.

A Markov Perfect Equilibrium (MPE) in our model is a subgame perfect equilibrium where the *N* hospital managers follow a Markov strategy. Since in our game the action space, the payoff function and the transition probability are (state-dependent but) time invariant, we can characterize the MPE as the best response correspondence among the *N* time-invariant Markov reaction functions maximizing the present discounted value (2). The first order condition for the hospital *i*'s maximization must satisfy

$$\frac{\partial x_i}{\partial q_i}\left(p - \frac{\partial C_i}{\partial x_i}\right) + \beta \frac{\partial Pr_i}{\partial q_i}\left(V_i^A - V^{NA}\right) = \frac{\partial C_i}{\partial q_i}. \tag{3}$$

Condition (3) states that the optimal quality must balance the marginal benefit and the marginal cost of quality. With respect to the standard competition framework, however, the marginal benefit of quality, beyond the increase in profit due to the marginal increase in demand $\frac{\partial x_i}{\partial q_i}\left(p - \frac{\partial C_i}{\partial x_i}\right)$, includes also the increase in the expected continuation value $\beta \frac{\partial Pr_i}{\partial q_i}\left(V_i^A - V^{NA}\right)$ due to the marginal increase in the probability of being reappointed. The following second order condition guarantees that the quality defined in (3) is the optimal quality for the hospital *i* manager:

$$\frac{\partial^2 x_i}{\partial q_i^2}\left(p - \frac{\partial C_i}{\partial x_i}\right) - \frac{\partial x_i}{\partial q_i}\left(\frac{\partial^2 C_i}{\partial x_i \partial q_i} + \frac{\partial^2 C_i}{\partial x_i^2}\frac{\partial x_i}{\partial q_i}\right) + \beta \frac{\partial^2 Pr_i}{\partial q_i^2}\left(V_i^A - V^{NA}\right) < 0. \tag{4}$$

Condition (3) defines implicitly the time-invariant Markov reaction function of the hospital *i* manager $q_i^R = q_i^R(\boldsymbol{q_{-i}})$, which is well-defined since $\boldsymbol{q_j} \subset \boldsymbol{q_{-i}}$. The MPE of the model is given by a strategy profile where each hospital manager in $S_t = A$ chooses the quality q_i^* given by the system of *2N* equations (3) and (2) in *2N* unknown $\boldsymbol{q}^*$ and $\boldsymbol{V^A}$. Evidently, solving algebraically for the equilibrium of the model would require a more explicit functional form than that considered so far[6];

[6] In the literature on stochastic games, a variety of existence theorems has established the existence of MPE in stationary Markov strategies for *N*-player, non-zero sum discounted stochastic games with countable state spaces (e.g., Parthasarathy, 1982). In our model, the existence and uniqueness of MPE can be easily characterized by the existence and uniqueness of a fixed-point in the system of *2N* equations, requiring that the matrix norm of the Jacobian matrix of the system is less than one. Evidently, in the general model (i.e., without explicit functional form), even if the concavity of the instantaneous payoff function and the discounting (exacerbated by the transition probability) clearly go toward the right direction, it is less straightforward to characterize the parametric restrictions such that the system of *2N* equations has a unique fixed-point. On the other hand, under standard explicit functional forms (i.e., linear demand

however, as said above, we are more interested in studying the strategic interdependence induced by such institutional context. Looking at the slopes of the time-invariant reaction curves, we can study the kind of strategic interdependence among hospitals. Specifically, applying the implicit function theorem to (3), the slopes of the Markov reaction function are given by:

$$\frac{\partial q_i^R}{\partial q_j} = \begin{cases} -\dfrac{\dfrac{\partial^2 x_i}{\partial q_i \partial q_j}\left(p - \dfrac{\partial C_i}{\partial x_i}\right) - \dfrac{\partial x_i}{\partial q_j}\left(\dfrac{\partial^2 C_i}{\partial x_i \partial q_i} + \dfrac{\partial^2 C_i}{\partial x_i^2}\dfrac{\partial x_i}{\partial q_i}\right) + \beta\dfrac{\partial^2 Pr_i}{\partial q_i \partial q_j}\left(V_i^A - V^{NA}\right)}{\dfrac{\partial^2 x_i}{\partial q_i^2}\left(p - \dfrac{\partial C_i}{\partial x_i}\right) - \dfrac{\partial x_i}{\partial q_i}\left(\dfrac{\partial^2 C_i}{\partial x_i \partial q_i} + \dfrac{\partial^2 C_i}{\partial x_i^2}\dfrac{\partial x_i}{\partial q_i}\right) + \beta\dfrac{\partial^2 Pr_i}{\partial q_i^2}\left(V_i^A - V^{NA}\right)} > 0 \quad \forall\, i,j \mid g_i = g_j \\ -\dfrac{\beta\dfrac{\partial^2 Pr_i}{\partial q_i \partial q_j}\left(V_i^A - V^{NA}\right)}{\dfrac{\partial^2 x_i}{\partial q_i^2}\left(p - \dfrac{\partial C_i}{\partial x_i}\right) - \dfrac{\partial x_i}{\partial q_i}\left(\dfrac{\partial^2 C_i}{\partial x_i \partial q_i} + \dfrac{\partial^2 C_i}{\partial x_i^2}\dfrac{\partial x_i}{\partial q_i}\right) + \beta\dfrac{\partial^2 Pr_i}{\partial q_i^2}\left(V_i^A - V^{NA}\right)} > 0 \quad \forall\, i,j \mid g_i \neq g_j \end{cases} \tag{5}$$

From (5), it clearly emerges that strategic interdependence among qualities is not limited only to hospitals within the same catchment group. In particular, the second line in (5) shows that the competition for the performance ranking potentially affecting the future states of hospital managers appears to induce an additional source of interdependence among hospitals. Therefore, we can say that in this context the hospitals' qualities are strategic complements both within and outside the catchment groups, but at two different degrees showed by the corresponding slopes in (5). As discussed above, the different degrees of strategic interdependence are, in fact, induced by the two sources of competition in this context: the standard competition to attract more patients, which concerns only the hospitals within the same catchment group, and the competition for the performance ranking, which instead concerns all hospitals in the regional health authority.

Overall, denoting with M_g the dimension (i.e., the number of hospitals) of the catchment group g, the structure of the quality interdependence among the N hospitals in this healthcare system can be represented by the following $N \times N$ symmetric matrix with a block-wise structure:

$$\boldsymbol{\frac{\partial q_i^R}{\partial q_j}} = \begin{pmatrix} \boldsymbol{w}_{11} & w_{12}\mathbf{1}_{M_1\times M_2} & \cdots & w_{1g}\mathbf{1}_{M_1\times M_g} & \cdots & w_{1G}\mathbf{1}_{M_1\times M_G} \\ w_{21}\mathbf{1}_{M_2\times M_1} & \boldsymbol{w}_{22} & \cdots & w_{2g}\mathbf{1}_{M_2\times M_g} & \cdots & w_{2G}\mathbf{1}_{M_2\times M_G} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ w_{g1}\mathbf{1}_{M_g\times M_1} & w_{g2}1_{M_g\times M_2} & \cdots & \boldsymbol{w_{gg}} & \cdots & w_{gG}\mathbf{1}_{M_g\times M_G} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ w_{G1}\mathbf{1}_{M_G\times M_1} & w_{G2}\mathbf{1}_{M_G\times M_2} & \cdots & w_{Gg}\mathbf{1}_{M_G\times M_g} & \cdots & \boldsymbol{w}_{GG} \end{pmatrix} \tag{6}$$

where $\mathbf{1}_{M_l \times M_k}$ denotes a $M_l \times M_k$ matrix of ones, w_{lk} for each $l \neq k$ is equal to the last line in (5), and $\boldsymbol{w_{gg}}$ for each g is a $M_g \times M_g$ symmetric matrix with off-diagonal elements equal to the first line in (5) and diagonal elements equal to one.

function, quadratic cost and probability functions) one can easily solve algebraically for the symmetric MPE and, then, it can be easily shown by a standard contraction mapping argument that the model has indeed a unique MPE.

In the spirit of Mobley et al. (2009) and Gravelle et al. (2014), in the empirical part we estimate hospital reaction functions $q_i^R = q_i^R(\boldsymbol{q_{-i}})$ with slope parameters (6) adopting a spatial econometrics approach. As showed below, however, the weights matrix employed in the spatial model is not pre-specified as usual, but is estimated through a Graphical Least Absolute Shrinkage and Selection Operator (GLASSO) approach where we exploit the block-wise structure (6) in the interdependence among hospital qualities (Moscone et al., 2017).

5. The empirical model

On the basis of the above economic framework, we assume that hospital quality follows a Conditional Autoregressive specification (CAR). Introduced by Besag et al. (1974), CAR models have been widely adopted in applied work, in areas ranging from image processing, disease mapping and modelling small-area disease incidence to investigate the spread of a disease, environmental studies, and the analysis of technology diffusion (see, among others, Cressie, 1993; Parent and Lesage, 2008). CAR models are often seen as an alternative to the well-known Spatial Auto Regressive (SAR) processes. Both CAR and SAR models represent data for a given spatial location as a function of data in neighbouring locations, and are used to study how a particular area is influenced by neighbouring areas.

Under the CAR specification, we assume that hospital quality, q_i, *i=1,2,...,N*, has a Gaussian conditional distribution with conditional mean and variance given by

$$E\left(q_i \middle| q_j, j = 1,2,\dots,n, j \neq i\right) = \boldsymbol{\beta}'\boldsymbol{z_i} + \sum_{j=1,j\neq i}^{n} w_{ij}\,(q_j - \boldsymbol{\beta}'\boldsymbol{z_j}) \qquad (7)$$

$$Var\left(q_i \middle| q_j, j = 1,2,\dots,n, j \neq i\right) = \sigma_i^2$$

where $\boldsymbol{\beta}$ is a *k*-dimensional vector of unknown parameters, $\boldsymbol{z_i}$ is a vector of characteristics of the hospital *i* as well as the area in which it operates, and w_{ij} belongs to a *N*×*N* matrix, $\boldsymbol{W}$, known as spatial weights matrix such that w_{ii}=0. In a spatial weights matrix the rows and columns correspond to the cross section observations, and the generic element, w_{ij}, can be interpreted as the strength of potential interaction between hospital i and *j*. $\boldsymbol{W}$ is usually assumed to be known a-priori using information on distance between units, such as the geographic, economic, policy, or social distance, and estimation of the unknown parameters is usually carried out by maximum likelihood, exploiting the link existing between the conditional and joint distribution (Cressie, 1993). In this application we will keep $\boldsymbol{W}$ unknown.

CAR models are known in the graphical modelling literature as Conditional Gaussian models, and the spatial weights matrix for CAR models can be estimated by adopting methods from the Gaussian graphical modelling literature for estimating inverse covariance matrices. In particular, it can be shown that model (7) on the conditional distribution implies the following joint normal distribution of $\boldsymbol{q} = (q_1, q_2, \dots, q_N)'$ (Besag, 1974):

$$\boldsymbol{q} \sim N(\boldsymbol{Z\beta}, (\boldsymbol{I_N} - \boldsymbol{W})^{-1}\boldsymbol{\Lambda}) \qquad (8)$$

with $\boldsymbol{\Lambda}$ = diag(σ_1^2 ,.., σ_N^2), provided that $\boldsymbol{\Sigma} = (\boldsymbol{I_N} - \boldsymbol{W})^{-1}$ is invertible and $(\boldsymbol{I_N} - \boldsymbol{W})^{-1}\boldsymbol{\Lambda}$ is symmetric, and positive-definite. It is interesting to note that the reverse also holds (Mardia, 1988). That is, if $\boldsymbol{q} \sim N(\boldsymbol{Z\beta}, \boldsymbol{\Sigma})$, where $\boldsymbol{\Sigma}$ is a $N \times N$ positive definite matrix, then (7) holds, with

$$w_{ij} = -\frac{\sigma^{ij}}{\sigma^{ii}}, \tag{9}$$

where σ^{ij} is the *(i,j)*th element of $\boldsymbol{\Sigma}^{-1}$. It follows that the problem of estimating w_{ij} in the CAR model (7) is equivalent to determining whether q_i and q_j are conditionally independent, i.e., $\sigma^{ij} = 0$. The above derivation of the conditional distribution from the joint distribution of a Gaussian random vector has been widely exploited to propose methods for estimating sparse graph models. In this paper we will use penalised likelihood estimation via the Graphical Least Absolute Shrinkage and Selection Operator (GLASSO) approach to estimate $\boldsymbol{\Sigma}^{-1}$, and hence exploit (9) to estimate the slopes of the hospital reaction functions represented by $\boldsymbol{W}$. Let $\boldsymbol{S}$ be the empirical covariance matrix, the GLASSO approach maximises the penalised log-likelihood function:

$$l_1(\theta) = log\left|\boldsymbol{\Sigma}^{-1}\right| - Tr(\boldsymbol{S}\boldsymbol{\Sigma}^{-1}) - \rho\left\|\boldsymbol{\Sigma}^{-1}\right\|_1, \tag{10}$$

where ρ is a regularization parameter controlling the trade-off between the penalty and the fit. By shrinking the elements in $\boldsymbol{\Sigma}^{-1}$ to zero, the above penalised estimator encourages the sparsity of the precisions matrix, and hence of the corresponding spatial weights matrix, thus picking only the most significant pairwise dependencies. We will assume that the structure of $\boldsymbol{\Sigma}^{-1}$ and hence of the spatial weights matrix, has the block-wise structure (6), and adopt the Flexible Block-GLASSO approach by Moscone et al. (2017) to estimate within- and between-block (catchment) spatial weights. To select the optimal regularization parameter (and associated optimal precision matrix) we use the Rotation Information Criterion (RIC) by Lysen (2009).

Estimation of the within-block spatial weights will give us an estimate of the number of rivals within the catchment group, and the level of local competition in attracting patients. Conversely, estimation of between-block (catchment) spatial weights will provide an indication of the level of global competition due to the performance ranking, which instead concerns all hospitals. As catchment area we will take the Local Health Authority. The Lombardy region is organised in 15 Local Health Authorities that are responsible for organizing and monitoring health care to the population that lives in their target area. We believe that the Local Health Authority covers an area wide enough to contain all potential local rivals for each hospital.

6. Data

We gathered administrative data on all patients admitted via emergency room to any hospitals in Lombardy, in the years from 2004 to 2013, whose principal diagnosis is AMI. Data on patients have been extracted from the Hospital Discharge Chart available for each patient. These include socio-demographic characteristics such as age, gender, and place of residence (the municipality); clinical information like principal diagnosis, severity of the illness, length of stay, the type of admission (planned or via the emergency room) the ward of admission, type of discharge (e.g. death); financial information such as the DRG, and the HDC reimbursement. We also gathered information on the zip code of residence of patients, and their mortality from the General Register Office. The characteristics of the hospital include its ownership (e.g. private or public), teaching status, whether it specialises in a particular area of treatment and its capacity expressed in number of beds. We also have information on whether the hospital has a catheterization laboratory, namely, an examination room with diagnostic imaging equipment used to support catheterization procedures, which can be taken as a proxy for the technological standards of the hospital.

We refer to Table 1 for a description of the variables included in our analysis. We only kept records for public or private hospitals that are accredited by the region, thus providing free health care (see Section 3). We also cleaned the data by eliminating records with missing entries on either the hospital or the patient identifier. After this selection process, our data set contains 162,927 AMI patients admitted to 170 hospitals.

As quality indicator we take mortality rates within 30 days from discharge, both unadjusted and risk-adjusted. Expected in-hospital mortality is calculated by estimating a logistic regression that includes as regressors gender, age on admission, co-morbidities, and financial year of discharge.

7. Empirical results

We first carry out estimation of a Spatial Auto Regressive (SAR) model as in Gravelle et al. (2014) and then compare the results with the estimation of the CAR model (7). As regressors, we include ownership and teaching status, whether the hospital is a specialty hospital, the number of beds (divided by 100), a dummy variable indicating whether the hospital has a catheterization laboratory, and a dummy variable indicating whether the hospital is located in Milan.

We have tried two alternative specifications for the spatial weights matrix. First, as in Gravelle et al. (2014), we assume as spatial weight w_{ij} the inverse of the travel distance between hospital i and hospital j, taking a 30 minutes travel time threshold, so that we set w_{ij} =0 if the time travel distance is larger than 30 minutes. We then try a specification where the catchment area is the Local Health Authority. It is interesting to note that the average distance patient to hospital is 12.67 minutes and that over 95 per cent of patients are admitted to a hospital that is within the 30 minutes travel time threshold, while nearly 100 per cent of patients are admitted to a hospital that is located in the local health authority of residence.

We take as quality indicator the crude AMI mortality rate. Table 2 and 3 show evidence of spatial correlation when taking as catchment area the 30 minutes travel time threshold and the Local Health Authority, respectively. However, once controlled for individual characteristics (risk-adjusted mortality), the spatial parameter is not significant in both regressions. This result supports the hypothesis of no association between hospital quality and competition in the Lombardy region, in line with the results in previous papers (Mukamel et al., 2002; Berta et al., 2016; Colla et al., 2016). One major concern with this result is that the metrics used to select competing hospitals is to a certain extent arbitrary. This arbitrariness may ultimately impact on the size and direction of competition of quality that may not necessarily be of a geographical nature. As for the included regressors, only the variable number of beds and technology have a significant, negative impact on the dependent variable.

Table 4 reports results on the estimation of the CAR model (7), taking the Local Health Authority as catchment area. In this regression the spatial weights matrix employed in the CAR model is not pre-specified as usual, but is estimated through a Graphical LASSO approach where we assume the block-wise structure (6) in the interdependence among hospital qualities (Moscone et al., 2017). Differently from the literature, we now estimate who the competitors are in the catchment area (i.e., within the block), and following our economic framework we also allow for an additional type of competition among hospitals that is global, represented by the interdependence between catchments (i.e., between blocks). It is interesting to observe that the average number of rivals estimated within each catchment is around 7.5, which is close to the average number of rivals derived using the geographical metric (around 8). The results point at an average spatial weight within blocks of 0.03 for mortality and 0.05 for mortality-adjusted indicators, suggesting that hospital qualities are strategic complements. The spatial effects, although small in size, are picked by the GLASSO approach as significant pairwise dependencies. Looking at the average spatial weights and number of rivals for each catchment, we also observe that a large number of rivals (e.g., in the Milan area) is associated to a lower average spatial effect. On the contrary, catchment areas with only few rivals have a higher average spatial effect. This result is in line with theoretical econometric results stating that the effect of each individual neighbour becomes less important when a spatial unit is influenced aggregately by a significant portion of other spatial units in the sample (Moscone et al., 2017). The average spatial correlation between blocks is equal to 0.07 for both unadjusted and adjusted dependent variable, indicating that hospital managers do care about the hospital quality set by other managers regardless of the geographical location of the hospital. These methods allow us to study the level of competition in each market, and appreciate that there exist a marked heterogeneity within the nature and intensity of interaction among rivals. In some markets hospital qualities are strategic complements, while in other they are strategic substitutes.

Table 4 also reports the Extended Bayes information criteria (EBIC), suitable for model selection in small T, large N sparse, generalised linear models (Chen and Chen, 2012). We calculate the EBIC of two alternative specifications, a graphical model that only allows for local rivals (within blocks only) and the full model with rivals that can come from both the hospital catchment area as well as the rest of the region (within + between blocks). We observe a sharp increase in EBIC when moving from the model only allowing for local interdependence to the model that incorporates both sources of interdependence, thus supporting the hypothesis that global correlation is a key feature of our data.

8. Concluding remarks

This paper has extended existing models for hospital competition by allowing both local and global sources of competition among hospitals and has tested it using data on the Lombardy region in the years between 2004 and 2013. The main hypothesis is that hospital managers, in order to maximize their value of being appointed as hospital manager, react not only to the quality of health services set by their local rivals, but also to that set by hospitals outside their local market. To test for this hypothesis we have assumed that hospital quality follows a CAR model, and used a penalised likelihood approach to estimate the rivals within the potential local market, as well as the long range correlation. Our results point at the presence of small but significant local competition, although there exists a marketed heterogeneity among markets, with some areas indicating that hospital qualities are strategic complements, while others that they are strategic substitutes. The econometric methods adopted have allowed us also to identify potential sources of global correlation, which suggests that hospitals managers' decisions with regards to the level of quality are influenced by other hospital managers outside their local market. From a policy perspective, our results point at the important role played by quality assessment programs. A well-designed quality assessment program may induce a long range competition mechanism among hospitals, and have the potential to improve the overall quality of the healthcare system.

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Tables

Table 1: Variable definitions and descriptive statistics

Variable	Description	Mean	Std. Dev.
30 Days Mortality rate	Death rate within 30 days	0.133	0.130
Teaching	1 if hospital is teaching	0.115	-
Private	1 if hospital is private	0.226	-
Specialist	1 if the hospital is specialist	0.018	-
Technology	1 if the hospital has a catheterization lab.	0.676	-
N. beds	Total number of beds	271.4	221.9
Milan	1 if located in the Milan province	0.133	-

Table 2: Spatial model of hospital competition and mortality rate using 30 minutes travel time threshold for the catchment area

	Mortality Rate		Risk-adjusted Mortality	
	Param.	Std.Err.	Param.	Std.Err.
Teaching	0.017	0.011	0.015	0.011
Private	-0.009	0.011	-0.005	0.011
Specialist	-0.069	0.051	-0.042	0.047
Technology	-0.105*	0.013	-0.067*	0.012
N. beds	-0.010*	0.002	-0.004*	0.001
Milan	0.034*	0.013	0.024	0.013
Spatial parameter	0.189*	0.065	0.069	0.066
Av. n. rivals	8.143			
LR test	8.414*	0.004	1.089	0.299

(*): Significant at the 5 per cent significance level.

Table 3: Spatial model of hospital competition and mortality rate using the Local Health Authority for the catchment area

	Mortality Rate		Risk-adjusted Mortality	
	Param.	Std.Err.	Param.	Std.Err.
Teaching	0.017	0.011	0.015	0.011
Private	-0.007	0.011	-0.005	0.011
Specialist	-0.069	0.052	-0.042	0.047
Technology	-0.104*	0.013	-0.066*	0.012
N. beds	-0.011*	0.002	-0.004*	0.001
Milan	0.034*	0.013	0.023	0.013
Spatial parameter	0.276*	0.071	0.046	0.041
Av. n. rivals	8.264			
LR test	15.250	0.000	1.259	0.2618

(*): Significant at the 5 per cent significance level.

Table 4: GLASSO estimation using the Local Health Authority for the catchment area

	Mortality		Adjusted Mortality	
	Par.	Std.Err.	Par.	Std.Err.
Teaching	0.0422*	0.0177	0.0698*	0.0159
Private	-0.0200*	0.0103	-0.0067*	0.0092
Specialist	-0.0700*	0.0284	-0.0609*	0.0277
Technology	-0.0515*	0.0099	-0.0187*	0.0092
N. beds	-0.0079*	0.0030	0.0036	0.0026
Milan	0.0419*	0.0164	0.0711*	0.0158
	Av. Sp. Weight	Av. n. rivals	Av. Sp. Weight	Av. n. rivals
Between blocks	0.078	-	0.0710	-
Within block:	0.032	7.480	0.053	7.561
Bergamo	0.0117	9.846	-0.012	10.462
Brescia	0.0148	11.714	-0.039	11.143
Como	0.0350	8.000	0.060	8.000
Cremona	0.4138	2.000	0.245	2.000
Lecco-Lodi	0.2426	2.000	0.205	2.000
Mantova	0.1620	4.000	-0.084	4.000
City of Milan	0.0106	14.316	0.009	14.368
Milan 1	0.0870	6.000	0.008	6.000
Milan 2	0.0517	5.000	0.0652	5.000
Milan 3	-0.0066	9.273	-0.003	9.545
Pavia	0.0420	7.556	-0.039	8.000
Sondrio-Breno	0.1444	4.000	-0.028	4.000
Varese	0.0902	8.600	0.049	8.800
Extended BIC (within blocks only)	52,419.34		52,428.48	
Extended BIC (within + between blocks)	580,730.1		580,662.7	

(*): Significant at the 5 per cent significance level.