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Is local competition effective in improving quality and efficiency of hospitals? Insights from an asymmetric spatial competition model[☆]

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ABSTRACT

A critical aspect of healthcare reforms in various countries revolves around the relationship between efficiency, quality, and competition. Exploring the spatial dimension of competition is essential to understand this connection thoroughly. In this study, we develop a theoretical model that examines hospitals' choices regarding quality and cost-containment efforts across different competitive environments characterized by varying spatial distributions of hospitals. We derive and fully characterize hospitals' reaction functions and Nash equilibria concerning quality and cost-containment efforts. Our findings reveal that while localized competition tends to reduce hospitals' efforts in cost containment, its impact on treatment quality can vary. This variation depends on factors such as the cost of delivering quality care, its benefits to patients, and hospitals' objectives, including their level of altruism. Our findings contribute to the ongoing debate on the role of local competition in healthcare. They offer insights into the conditions that could yield divergent outcomes, often advocated by conflicting perspectives. These conditions serve as a foundation for refining competition policy models in healthcare.

1. Introduction

Efficiency, quality, and competition are central topics in the financial and organizational reforms of healthcare systems in many countries. These subjects have sparked extensive debate in both theoretical and empirical research. While the theoretical predictions regarding the impact of competition on healthcare quality and efficiency, as briefly outlined in Section 2, have been relatively straightforward, the empirical examination of this relationship has resulted in ambiguous and heterogeneous findings. Some studies support the notion that increased competition leads to improved health outcomes (e.g., Kessler and McClellan, 2000; Bloom et al., 2015; Gaynor et al., 2016; Brekke et al., 2021), while others present evidence suggesting that competition may have detrimental effects on health (e.g., Propper et al., 2004; Moscelli et al., 2021). As for efficiency, the usual finding from previous literature is that

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competition improves hospital performance though it may come at the expense of health outcomes because of lower length of stay (e.g., Street et al., 2011; Gaynor et al., 2013; Cooper et al., 2018).

The implementation and effectiveness of competition, particularly its implications in healthcare systems, are a highly intricate matter. As emphasized by the Expert Panel on Effective Ways of Investing in Health, established by the European Commission: "The outcomes of competition, whether desirable or undesirable, hinge partly on the fulfillment of crucial market conditions. The degree to which these conditions are met varies across sub-markets and contexts" (European Commission, 2015). Thus, analyzing the impact of competition becomes highly contingent on the specific context, given that the nature and scope of competition can significantly differ within the healthcare system. A key aspect of this diversity is the predominant localization of healthcare competition, which is often characterized by a strong geographical dimension, alongside non-geographical factors such as hospital specialization.[1] This localization is influenced by various factors, including constraints on patient mobility (such as distance-related costs and information barriers) and external restrictions on patient choices (such as referral systems and Health Maintenance Organization limitations). Consequently, localized competition implies that competition is not uniform across the entire system, leading to situations where "different firms typically compete with different sets of rivals" (Verboven, 1998, p. 371).[2]

This paper seeks to examine the impact of different degrees of localized competition on the strategic choices made by healthcare providers, specifically hospitals, with regard to quality enhancement and cost containment. Specifically, it explores how the spatial clustering of hospitals influences these outcomes. In our study, we develop a hospital competition model *à la* Salop, departing from the assumption of a uniform distribution of hospitals along a circle. Instead, we allow for an asymmetric spatial distribution, where hospitals can be located at varying distances from each other. We then derive Nash equilibrium solutions for hospitals' cost-containment efforts and quality of services. This quality is characterized by their relative location, as determined by the spatial distance to their nearest competitors. We find that the impact of competition on quality is contingent on the context. The presence of nearby competitors, indicative of more intense localized competition due to spatial clustering of hospitals, does not necessarily lead to improved quality provision. This is because hospitals operating in tightly clustered areas may serve catchment areas that are too small to justify the investment in costly quality improvements. The divergent effects of competition hinge on various parameters reflecting the cost-benefit of care provision and the objectives of healthcare providers. Consequently, our model offers insights into the mixed empirical findings on the relationship between competition and performance, highlighting the significance of contextual factors in shaping these effects. Thus, our findings lay a robust groundwork for crafting more efficient and effective healthcare policies.

Our results relate to some of the general findings of spatial competition models (e.g., Brekke et al., 2011, 2017; Gravelle et al., 2014; Longo et al., 2017; Lisi et al., 2020, 2021) .[3] What differentiates our framework is that the demand served by each provider changes not only with their choices but also with the dimension of the local catchment area,[4] which is connected with their location and configuration in space. Though we do not impose a uniform distribution along the circle and thus consider asymmetric spatial distribution, we follow previous literature and consider providers location as given.[5]

The rest of the paper is organized as follows. In Section 2, we provide a literature background. In Section 3, we depict the main features of the model of spatial competition developed in the paper. Sections 4 and 5 are devoted to the derivation and discussion of the reaction functions of hospitals and, consequently, of the nature of their strategic choices of quality and cost-containment effort. Section 6 presents the Nash-equilibrium values of quality and cost-containment effort, and characterize equilibrium through some comparative statics. Concluding remarks are presented in Section 7. Finally, the main proofs of the model are reported in the Appendix.

2. Background

The debate surrounding the impact of competition on quality improvement and cost containment in healthcare has been extensively explored in both theoretical and empirical literature. It originated from the conventional perspective, often associated with the structure-conduct-performance (SCP) paradigm, which forms the foundation of numerous empirical studies.

Recent literature attempts to extend beyond the traditional SCP paradigm, with a notable focus on spatial competition models. This body of work is particularly pertinent to our study due to its examination of localized competition dynamics. Key contributions include studies by Brekke et al. (2011, 2017), Gravelle et al. (2014), Longo et al. (2017), and Lisi et al. (2020, 2021), wherein providers engage in cost containment efforts and/or quality enhancements while primarily competing with nearby rivals. At the same time, several empirical works based (mainly, but not only) on spatial econometrics models show spatial dependence and spillovers in efficiency and quality choices among providers, whose estimation takes into account their spatial proximity.

[1] Other relevant factors that may impact locally that are not discussed here may relate to health risk behaviour and its impact on avoidable mortality (e.g., Moscone, 2023).

[2] The analysis of localized competition dates back to Hotelling and Chamberlin.

[3] The features of our model are close to the ones in Brekke et al. (2017), though this latter focuses on the effects of hospitals' merger. Since they assume a uniform distribution of hospitals along the circle, their Nash competitive results can be regarded as a special case of ours.

[4] The relevance of distance and size of the market area is emphasized by several empirical works. Among others, Dranove et al. (1992) state that: "The extent of the market matters. Not only does local population predict the patterns of service provision, but so too do proximate population and distance to markets".

[5] While one could consider location as a matter of choice of hospitals, it makes sense (consistently with previous literature) to consider in healthcare sector location as given, since it reflects, as pointed out by Alderighi and Piga (2012), a characteristic of some industries for which "competition [is] among firms occupying a fixed location in geographic space, e.g., petrol stations, restaurants, hospital" (p. 48).

The analysis of competition is focused on the strategic interaction among (neighboring) competitors rather than on the general structure of competition in the sector. However, while the spatial approach provides several results in terms of the analysis of the nature of the strategic choices of providers (for instance, substitutability or complementarity of quality and efficiency), little is said about the effects of the potential heterogeneity of localized competition on these choices.

Localized competition and its influence on provider performance[6] can vary considerably, depending on factors such as the size of the geographical area where neighboring providers compete and the homogeneity of their clinical specialization. Porter and Teisberg (2004), for instance, argue that local markets are not the appropriate geographical scope for healthcare competition. They suggest that competition should occur at regional or even national levels, particularly for complex or rare conditions. They attribute this to insurer-related institutional arrangements that dissuade health plan subscribers from seeking providers outside their immediate vicinity. Conversely, Glied and Altman (2017) express concerns about shifts in healthcare demand in the US and beyond. They fear that these changes could jeopardize the financial sustainability of hospitals in many communities, ultimately diminishing competition and its positive effects in various market areas. Technological advancements driving increased hospital specialization and the concentration of certain clinical services in specialized centers can also affect localized competition by altering hospital catchment areas. Mobley and Frech (2000), in discussing the potential impacts of managed care development in the US, considered the scenario where managed care penetration heightened patients' willingness to seek better hospital services. This could potentially lead to increased hospital specialization and the emergence of centers of excellence for advanced services. As a result, patients may travel greater distances, thereby expanding hospitals' market sizes.

An important aspect of localized competition in healthcare relates to the spatial distribution of hospitals and their clustering in space, because of their potential impact on the dynamics and outcome of competition. Clusterization of firms has raised the interest of theoretical and empirical research in the industrial organization field. Typically, this matter has been explored within frameworks concerning models of spatial price competition among firms. Fik (1991) is one of the first papers considering the impact of different spatial configurations of firms. He develops a model of price competition investigating "the extent to which geographical features of a market - the configuration of firms in space - promote or inhibit competition" (p. 1545).[7] Alderighi and Piga (2012) study the propagation of cost changes in the equilibrium prices of different firms, depending on "how the same set of heterogeneous firms are positioned relative to one another" (p. 47).[8] Pennerstorfer and Weiss (2013) investigate the impact of spatial clustering on market power in the gasoline market. They emphasize that "the degree of competition is not only influenced by the number of competitors within a specific market area but also crucially depends on the degree of spatial clustering (the sequence of stations on a road) within this market" (p. 661). A few works deal specifically with the impact of the spatial location of healthcare providers. In their study on the effects of managed care, Mobley and Frech (2000) point out that, among the characteristics of health care systems, we need to include "the spatial distribution of people, hospital services, physicians", because it contributes to the distance travelled by patients and hence to the size of the market area of the competing hospitals. More recently, Adler et al. (2015) study the performance of renal transplantation centers (in terms of volumes and outcomes) in the US, finding that the spatial distribution of transplant centers (categorized as clustered, random or dispersed on the basis of the Average Nearest Neighbor index) is a significant determinant of performance. However, most of these studies, particularly those focused on healthcare, largely overlook the strategic aspect of competition among providers.

While recent models of spatial competition in healthcare provision capture the strategic interactions among providers, they often overlook a crucial aspect highlighted by Verboven (1998): the heterogeneity in the sets of rivals competing with different providers. This oversight is partly due to the localized nature of competition, where the distribution of competitors varies across geographical areas. As it will be shown in subsequent sections, the spatial arrangement of providers directly influences the size of each provider's market and, consequently, the scope over which costs and benefits of quality and efficiency enhancements are distributed, shaping providers' strategic choices.

3. The model

To conceptualize hospitals' decision-making and their competitive dynamics, we borrow some features from the model developed by Brekke et al. (2017), particularly their Nash pre-merger benchmark employed to analyze the impacts of hospital mergers. This model possesses at least two notable attributes: it endogenizes the efficiency of hospitals' production processes via the selection of a cost-containment effort, and it accommodates hospitals' objective functions that encompass both financial and non-financial goals.

For simplicity of analysis, we consider three hospitals, denoted by $i = 1, 2, 3$, located in a circle with circumference equal to 1. While we maintain the assumption of the "canonical" Salop framework, that patients selecting hospitals are uniformly distributed along the circle (with a total density of 1), we deviate from the corresponding assumption regarding the uniform distribution of hospitals. Instead, we assume that hospitals can be positioned at varying distances from each other. This allows the consideration of an

[6] Location may be also relevant for other aspects like, for instance, merger strategies (e.g., Cosnita-Langlais, 2012).

[7] Similar to our perspective, the objective of Fik (1991) was to understand "how the locational attributes of markets affect both the spatial variation of prices and the price disparities. If prices in geographic markets are construed as outcomes of the profit-maximizing motives of price (and spatially) interdependent firms, they may be viewed as signals which inherently represent rational responses to localized conditions".

[8] In Alderighi and Piga (2012), the relative location of firms is irrelevant when all the firms in a market are independent, while things change when firms operate as downstream retailers affiliated to rival upstream wholesalers. In the latter case, the relative location matters since it may change the nature of the closest neighbor, depending on whether it belongs to the same chain or not.

asymmetrical spatial distribution of hospitals, although it does not preclude the possibility of them being uniformly distributed, which represents a specific case within our broader assumption. As previously noted, this assumption facilitates a comparative analysis of different localized competition frameworks, particularly when a hospital encounters local competitors that are clustered to varying degrees. This approach enables us to assess the intensity of local competition, as more clustered hospitals are expected to compete within a more constrained catchment area, as we will show.

Hospitals choose the quality of the services provided to patients as well as a level of cost-containment effort. Regarding quality, we do not restrict it to any particular interpretation, whether clinical or related to the comfort of hospitality (representing a measure of vertical differentiation). Conversely, there is no horizontal differentiation, as hospitals provide and patients demand the same treatment.[9]

Patients receive a net benefit from using hospital services, which is increasing in quality and decreasing in distance, because of transportation costs. More precisely, we define the utility of a patient located at a position z in the circle, when treated at hospital i located at x_i, as

$$U_{z,x_i} = v + bq_i - t|z - x_i| \tag{1}$$

where v represents a uniform benefit that any patient enjoys from receiving treatment in any hospital, regardless of the quality provided, while bq_i measures the specific benefit for the patient treated at hospital i when the latter provides services of quality q_i, and t is the unit transportation cost. Since hospitals may be located at any position along the circle, to ensure full market coverage for any $q_i \geq 0$, we assume that $v \geq t/2$.[10]

Each patient chooses a hospital where to be treated, given the differences in quality and distance relative to its neighboring rivals. The overall demand for hospital i is determined by the location of the patient who is indifferent between choosing hospital i and hospital $i+1$ to its right, as well as the patient who is indifferent between hospital i and hospital i-1 to its left hand side, for given levels of quality and distances between hospitals. We denote demand for hospital i as D_i (q_i, q_j; d_{i+1}, d_{i-1}), with d_{i+1} measuring the distance between hospital i and hospital $i+1$, and d_{i-1} the distance between hospital i and hospital i-1. The location of the patient indifferent between hospital i and hospital $i+1$ can be parameterized in the following way:

$$\frac{d_{i+1}}{2} + \frac{b(q_i - q_{i+1})}{2t} \tag{2}$$

and similarly for the patient indifferent between hospital i and hospital i-1:

$$\frac{d_{i-1}}{2} + \frac{b(q_i - q_{i-1})}{2t} \tag{3}$$

The expressions [2] and [3] above not only identify the positions of the marginal patients but also represent the density of patients demanding services to hospital i on both segments of its market area (to its left and right). Therefore, the overall demand for hospital i is:

$$D_i\left(q_i, q_j; d_{i+1}, d_{i-1}\right) = \frac{d_{i+1} + d_{i-1}}{2} + \frac{b}{t}\left(q_i - \sum_{j \neq i} \frac{q_j}{2}\right) \tag{4}$$

Equation [4] shows that the demand for services at each hospital consists of two components: one determined by the distance from neighboring hospitals, and the other by their respective quality levels. As for the former, hospital i attracts an equal share of the demand from patients living in its local catchment area, defined as the region between its position on the circle and the positions of its two neighboring hospitals. For hospital i, it is represented by $\frac{d_{i+1}+d_{i-1}}{2}$. The relevance of this component would be swallowed away if we assumed a uniform distribution of hospitals along the circle, resulting in any demand asymmetry being solely affected by hospitals' quality choices. Our assumption, allowing non-uniform hospital locations, implies that demand typically changes based on this location, as dipicted in Fig. 1, which illustrates different spatial configurations of the three hospitals. The smaller the distance, the smaller is the market area shared by hospitals ($\partial D_i / \partial d_{i+1} > 0$). In other words, when a hospital faces a more localized competition (as its distance from its competitors diminishes), the volume of demand decreases for any quality distribution among hospitals. As we shall see, this has an impact on incentives for cost containment and quality provision.

Hospital i, however, can alter its share of "local" demand by choosing the quality of its services, q_i. The impact of this choice on demand depends on the differential quality it provides relative to its competitors. As in Brekke et al. (2017), the hospital's demand is increasing in its quality ($\partial D_i / \partial q_i > 0$) and decreasing in the other hospitals' qualities $\left(\partial D_i / \partial q_j > 0\right)$.

Following previous literature, we assume that each hospital's total costs vary with the volume and the quality of its treatments as well as with its cost containment effort, that is:

[9] For simplicity, we consider that patients suffer from the same illness and need the same treatment.

[10] This is is a sufficient condition for U to be always non-negative, even when hospitals are situated in the same location and provide no quality (i.e. $q_i = 0$, for any i = 1,2,3), as the farthest patient must travel a distance equal to ½. This assumption also implies that all patients always demand a treatment, and total demand is constant, with variations only in its distribution across hospitals.

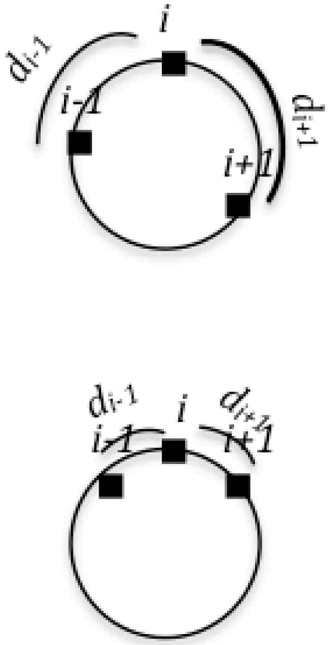

Fig. 1. Spatial configurations and catchment areas of hospitals.

$$C_i(q_i,\ D_i) = (\sigma_i + cq_i)D_i + \frac{k}{2}q_i^2 + F \tag{5}$$

where $\sigma_i = \overline{\sigma} - \varepsilon_i$, with ε_i representing the effort exerted by hospital i in containing the marginal cost of its treatments, k is the parameter governing the (increasing) marginal cost of quality, and F is fixed cost. We assume that F and $k > 0$. Total and marginal costs of providing treatments are increasing in quality $(\partial C_i / \partial q_i > 0; \partial C_i / \partial D_i \partial q_i > 0)$.

Hospitals are assumed to maximize an objective function whose arguments are financial profits, patients' welfare, and effort disutility:

$$\Omega_i = (\widehat{p} - \sigma_i - cq_i)D_i - \frac{k}{2}q_i^2 + T - F + \alpha(v + bq_i)D_i - \frac{w}{2}\varepsilon_i^2 \tag{6}$$

Each hospital receives a fee $\widehat{p}$ for each unit of treatment and a transfer T from the government. As in Brekke et al. (2017), we assume that $\widehat{p}$ and T are set by the government in such a way to ensure that each hospital's payoff is non-negative. Hospitals care about the gross benefits provided to all their patients, without taking into account their transportation costs. The relative weight of patients' benefits in the hospital's objective function is represented by α, with $\alpha \geq 0$. If $\alpha = 0$, then the hospital is just a profit oriented entity. The disutility of the cost containment effort is denoted by the very last term in equation [6], and is strictly convex in effort (assuming that $w > 0$). Using a convenient grouping of the variables, we rewrite equation [6] in the following way:

$$\Omega_i = (p + \varepsilon_i - \beta q_i)D_i - \frac{k}{2}q_i^2 + P - \frac{w}{2}\varepsilon_i^2 \tag{7}$$

where $p = \widehat{p} - \overline{\sigma} + \alpha v$ and $\beta = c - \alpha b$. As it can be clearly observed from equation [7], the welfare effect for hospitals due to their efficiency and quality choices is proportional to the volume of patients they treat.[11] Notably, the relevance of the volume of demand confirms the role that the competition faced at the local level by a hospital (as parameterized by distance in our model) has for its incentives to provide cost containment effort and quality.

We impose restrictions on the values of some parameters, so as to satisfy the appropriate conditions for the maximization problem in Section 4, and to ensure the appropriate sign of Nash equilibrium values of quality and effort. Specifically:

$$\beta > -\frac{kt}{2b};\ w > \max\left\{\frac{b^2}{t(2b\beta + kt)};\ \frac{3b^2}{t(5b\beta + 2kt)};\ \frac{b^2}{t[b\beta(1 + d_{i+1} + d_{i-1}) + kt(d_{i+1} + d_{i-1})]}\right\};$$

[11] It also depends on the sign of the parameter β, which represents the net variable impact (with the opposite sign) for the hospital in delivering a unit of quality to each patient.

$$p > -\lambda\left[\frac{d_{i+1}(\theta-\lambda b)-\theta}{bw(2\theta+\lambda b)}\right]$$

with $\lambda = tw\beta - b \gtreqless 0$ and $\theta = tw(2b\beta + kt) - b^2 > 0$.

4. Hospital reaction functions in quality and effort

First of all, let's consider the hospital's reaction function in quality (for a given level of effort). The first-order condition for maximizing the hospital i's objective function [7] with respect to the choice of quality is given by:

$$\frac{\partial \Omega_i}{\partial q_i} = (p + \varepsilon_i - \beta q_i)\frac{\partial D_i}{\partial q_i} - \beta D_i - kq_i = 0 \tag{8}$$

Equation [8] implicitly defines the best response of hospital i to the quality choices made by its competitors, considering that hospital i's demand, D_i, is also influenced by the quality they provide. The subsequent equation [9] represents the hospital i's reaction function, for any given level of effort and for any given distance between hospitals:

$$q_i\left(q_j;\varepsilon_i;d_{i+1},d_{i-1}\right) = \frac{b\left[2(p+\varepsilon_i)+\beta\sum_{j\neq i}q_j\right]-\beta t(d_{i+1}+d_{i-1})}{2(2b\beta+kt)} \tag{9}$$

Equation [9] allows for ascertaining how clusterization of hospitals influences their strategic choices, simply by differentiation of [9] with respect to distance[12]:

$$\frac{\partial q_i\left(q_j;\varepsilon_i;d_{i+1},d_{i-1}\right)}{\partial d} = -\frac{\beta t}{2(2b\beta+kt)} \gtreqless 0 \; if \; \beta \lesseqgtr 0 \Leftrightarrow \alpha b \gtreqless c \tag{10}$$

Lemma 1. *For a given effort level and for given quality choices made by its competitors, a hospital's reaction to clusterization (*i.e. *a restriction of its catchment area) can be summarized as follow:*

i. It increases the quality of the treatment if the marginal cost exceeds the marginal benefits for the hospital (i.e., *when* $c > \alpha b$).
ii. It reduces the quality of the treatment if the marginal cost is less than the marginal benefits for the hospital (i.e., when $c < \alpha b$).
iii. It maintains the quality unchanged if the marginal cost equals the marginal benefits for the hospital (*i.e.*, *when* $c = \alpha b$).

The "mechanics" of the effects of a variation in distance between hospitals can clarify the interpretation of [10]. For a given level of effort and for given qualities provided by its neighboring competitors, a reduction in distance between hospital i and its immediate neighbors, corresponding to a more clustered location and, thus, a more intense localized competition, reduces demand for hospital i. The reduction of demand, in turn, decreases the marginal cost of quality provision (equal to $cD_i + kq_i$) by c and, hence, increases the incentive for higher quality. At the same time, however, the reduction in demand decreases the marginal altruistic benefit of quality provision (equal to αbD_i) by αb and, therefore, provides an incentive for lower quality.

The parameter β, defined as $c - \alpha b$, summarizes the net impact of the two opposite effects described above. When $\beta > 0$, the first effect dominates, leading hospital i to provide higher quality as competition becomes more localized and hospitals are closer together. This suggests that intensified local competition matters when the cost of providing quality is significant relative to its benefits for patients, or when the hospital prioritizes financial objectives (i.e., for lower values of α). Conversely, when $\beta < 0$, the second effect prevails, causing hospital i to reduce quality as competition becomes more localized. Therefore, if the altruistic benefits are substantial (due to the significant benefit of a unit of quality for a single treatment and/or a high weight of α in the hospital's objective function), local competition diminishes the incentive for quality provision due to its negative impact on demand. However, if competition spans a broader market area, the increased number of patients who can benefit from higher quality makes its provision advantageous for the hospital. These arguments generally hold even outside the mere geographical paradigm of a uniform distribution of patients.

Comparing our results with the ones in Brekke et al. (2017) for their pre-merger game, it must be observed that the distance between hospitals does not affect the strategic nature of quality competition. Qualities are strategic complements or substitutes exactly under the same conditions: a change in distance shifts (upwards or downwards, according to the sign of β) the reaction curve but does not change its slope, particularly its sign.

As for the reaction function in the cost containment effort, the first-order condition for maximizing hospital i's objective function [7] is given by:

$$\frac{\partial \Omega_i}{\partial \varepsilon_i} = D_i - w\varepsilon_i = 0 \tag{11}$$

Therefore, for given quality levels chosen by hospital i and its competitors and distance between hospitals, the optimal cost containment effort will be:

[12] We differentiate [9] with respect to the distance between hospital i and one of its immediate neighbors.

$$\varepsilon_i\left(q_i, q_{j;} d_{i+1}, d_{i-1}\right) = \frac{1}{w}\left[\frac{d_{i+1} + d_{i-1}}{2} + \frac{b}{t}\left(q_i - \frac{1}{2}\sum_{j\neq i} q_j\right)\right] \tag{12}$$

The optimal effort exerted by hospitals is independent of each other, unlike qualities. For each hospital, cost containment effort and quality act as strategic complements: as hospital i increases its quality provision, demand for its treatment rises, making it more advantageous to enhance cost efficiency. This is because the benefits of cost reduction will be more widespread across a larger volume of production. Therefore, hospitals will find it less favorable to allocate effort towards cost reduction activities when their competitors are enhancing quality.

As for the distance, its impact on the optimal effort is measured by:

$$\frac{\partial \varepsilon_i\left(q_i, q_{j;} d_{i+1}, d_{i-1}\right)}{\partial d} = \frac{1}{2w} > 0 \tag{13}$$

Lemma 2. *For a given quality of treatments and for given quality choices of its competitors, a hospital reacts to clusterization by reducing its cost-containment effort.*

A reduction of distance between hospitals, therefore, reduces demand and, as a consequence, the incentive to exert the cost containment effort.

5. Hospital reaction function in quality with optimal adjustment of effort

Let's now finally derive the optimal quality response of hospital i, taking into account the optimal effort adjustment, just by substituting [12] for ε_i into [9]:

$$q_i\left(q_j; d_{i+1}, d_{i-1}\right) = \frac{2bptw - (b - \beta tw)\left[b\sum_{j\neq i} q_j - t(d_{i+1} + d_{i-1})\right]}{2tw(2b\beta + kt) - 2b^2} \tag{14}$$

Equation [14] enables us to examine how hospital i adjusts its quality selection in response to variations in distance from its neighboring competitors, assuming optimal adjustments in cost containment efforts and given qualities set by other hospitals. Hospital i's quality changes are measured by the following:

$$\begin{aligned} &\frac{\partial q_i\left(q_j; d_{i+1}, d_{i-1}\right)}{\partial d} = \frac{t(b - \beta tw)}{2tw(2b\beta + kt) - 2b^2} > \ (<)0 \\ &\text{if } \beta < 0 \text{ or } \beta > 0 \text{ and } b > \beta tw \ (\beta > 0 \text{ and } b < \beta tw); \\ &= 0 \text{ if } b = \beta tw \end{aligned} \tag{15}$$

Fig. 2 represents the variation of the sign of $\partial q_i / \partial d$ along the different potential values of the parameter.

Lemma 3. *Once the optimal level of cost containment effort is considered and given quality choices made by its competitors, a hospital's reaction to clusterization (*i.e. *a restriction of its catchment area) can be summarized as follow:*

- *i) It increases the quality of the treatment if the marginal cost is sufficiently greater than the marginal benefits for the hospital (*i.e., $\beta > b/tw \Rightarrow c \gg \alpha b$).
- *ii) It reduces the quality of the treatment if the marginal cost is less than the marginal benefits for the hospital or, if it is greater, provided that it does not exceed them by b/tw (i.e.* $\beta < \frac{b}{tw} \Rightarrow c < \alpha + \frac{b}{tw}$).
- *iii) It maintains the quality unchanged otherwise* ($\beta = \frac{b}{tw}$).

Upon integrating the optimal adjustment of cost containment effort into the hospital's quality reaction function, the depiction of the hospital's responses to clusterization outlined in Lemma 3 slightly changes compared to that in Lemma 1. We must now consider a third effect of distance, alongside the two previously discussed in the preceding section. As the distance between hospitals decreases, demand diminishes, along with the incentive to exert effort for cost reduction. Consequently, the hospital's marginal profit decreases, prompting hospital i to consider reducing quality to offset the decline in marginal profits. Even within the parameter range where a positive effect of reducing distance on quality provision incentives was previously observed (i.e., for $\beta > 0$), this third effect, associated with the optimal effort adjustment, operates in the opposite direction. For certain values of $\beta > 0$, it can lead to a reduction in quality when distance decreases. Only when β is sufficiently high (i.e., for $\beta > b/tw$), that is when the cost of providing quality outweighs its benefits for patients or when the hospital is primarily focused on financial objectives, localized competition may matter for incentivizing hospitals to enhance treatment quality. Thus, incorporating the optimal effort choice into the quality selection narrows the scope of positive impact of competition on quality. Fig. 2 depicts how variations in distance between hospitals impacts on quality, depending on the different values of β.

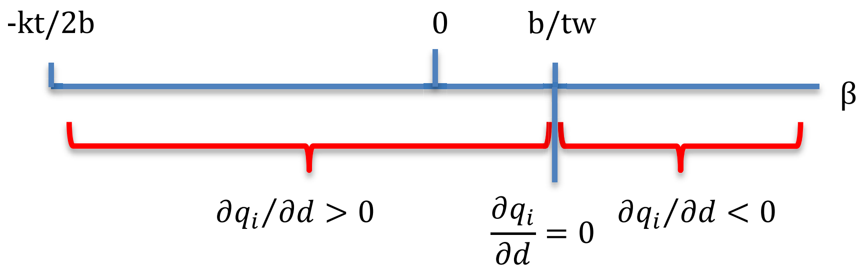

Fig. 2. Variation of the sign of $\partial q_i/\partial d$ depending on β.

6. The analysis of hospital choices in equilibrium

The Nash equilibrium values of quality and effort are derived by solving the system of equations representing the reaction functions of hospitals in quality and effort.

As for quality, the Nash equilibrium values are represented by:

$$\begin{aligned} q_i^* &= \frac{bptw(\lambda b + 2\theta) + \lambda t[(\theta - \lambda b)(1 - d_{i+1} - d_{i-1}) - \theta]}{(2\theta + \lambda b)(\theta - \lambda b)} \\ q_{i+1}^* &= \frac{bptw(\lambda b + 2\theta) + \lambda t[(\theta - \lambda b)d_{i-1} - \theta]}{(2\theta + \lambda b)(\theta - \lambda b)} \\ q_{i-1}^* &= \frac{bptw(\lambda b + 2\theta) + \lambda t[(\theta - \lambda b)d_{i+1} - \theta]}{(2\theta + \lambda b)(\theta - \lambda b)} \end{aligned} \quad (16)$$

The Nash equilibrium values for effort levels are represented by:

$$\begin{aligned} \varepsilon_i^* &= \frac{(\theta - \lambda b)(d_{i+1} + d_{i-1}) + \lambda b}{(2\theta + \lambda b)} \\ \varepsilon_{i+1}^* &= \frac{(\theta - \lambda b)(1 - d_{i-1}) + \lambda b}{(2\theta + \lambda b)} \\ \varepsilon_{i-1}^* &= \frac{(\theta - \lambda b)(1 - d_{i+1}) + \lambda b}{(2\theta + \lambda b)} \end{aligned} \quad (17)$$

Lemmas 1 to 3 examine how hospital clusterization influences the optimal decisions of individual hospitals. The analysis of the equilibrium values of quality and cost containment effort of the three hospitals enables a comprehensive discussion regarding: i) the correlation between the spatial location of hospitals (including their clustering) and the distribution of their quality and effort choices; ii) the effects of exogenous changes in the spatial configuration of hospitals on these choices; iii) the association between spatial location and the overall quality and cost containment effort offered by the three hospitals.

6.1. *The distribution of quality and cost containment effort across hospitals*

First, let's consider the distribution of quality and effort in equilibrium, across the different hospitals. It is summarized by Proposition 1.

Proposition 1. *At equilibrium, a hospital operating within a smaller catchment area relative to another hospital, will exhibit i) lower quality if λ is negative; ii) higher quality if λ is positive; iii) lower cost containment effort.*

Quite obviously, if hospitals are uniformly distributed in space ($d_{i+1} = d_{i-1} = 1/3$) a symmetric equilibrium will occur, otherwise there will be an asymmetric equilibrium, which can be characterized with respect to the clusterization of hospitals. Indeed, the equilibrium values of quality and effort in equations [16] and [17] consist of both a uniform component for each of the three hospitals, which remains constant regardless of their spatial locations, and a variable component determined by the parameters characterizing the hospitals' spatial distribution. As for quality, the variable part of [16] is equal to $\lambda t/(2\theta + \lambda b)$ multiplied by the complement to 1 of the size of each hospital's catchment area (for hospital i, for example, this is $1 - d_{i+1} - d_{i-1}$). The sign of this variable part depends on the sign of λ,[13] which in turn depends on the value of β,[14] while its magnitude is inversely proportional to the size of the catchment area. When λ is negative, hospitals operating within narrower catchment areas relative to their competitors, will exhibit lower quality compared to other hospitals. Conversely, for positive values of λ, the opposite holds true. The variable part in expressions [17] for the

[13] Because of the specific assumptions on the values of β and w, made at the end of Section 3, the sign of $2\theta + \lambda b$ is positive.

[14] Since, by definition, $\lambda = tw\beta - b$, it straightforwardly follows that $\lambda \geq 0$ for any $\beta \geq b/tw$, and < 0 otherwise (with the restriction that $\beta > -kt/2b$).

equilibrium values of the cost containment effort is given by $(\theta - \lambda b)/(2\theta + \lambda b)$ multiplied by the size of the hospital's catchment area. This variable part has always a positive sign.[15] Therefore, the larger the catchment area of a hospital relative to its competitors, the higher its cost containment effort will be, compared to other hospitals.

Overall, our model predicts that, except for a uniform spatial distribution, the spatial location of hospitals – specifically, the size of their catchment area and, consequently, their clusterization – matters for the quality and cost containment effort choices, as well as for their potential trade-off. While the cost containment effort is always increasing in the size of a hospital's catchment area, the quality of its services may either increase or decrease, depending on the sign of λ. When λ is negative, our analysis suggests that there will not be a trade-off between quality and effort among hospitals. In areas with intense local competition (i.e., where neighboring competitors are closely situated), hospitals are expected to offer lower quality and exert less effort in cost containment. Conversely, when λ is positive, we anticipate a trade-off between quality and cost containment efforts among hospitals. In regions with nearby competitors, hospitals are likely to prioritize higher quality services at the expense of reducing their efforts towards cost efficiency. The general implication is that the relationship between competition, particularly as reflected in the localized clustering of hospitals, and the decisions concerning quality and cost-efficiency, along with the presence of a trade-off between these decisions, is not straightforward. The sign of λ in our model may reflect various real-world factors, one of which is the nature of the treatment provided by hospitals in relation to the level of the costs and of the benefits of quality provision. For treatments where providing quality incurs lower costs and yields higher benefits, λ is more likely to be negative. Consequently, more intense localized competition tends to diminish both quality and cost efficiency. Additionally, transportation costs play a role, representing the costs of switching between providers. Lower transportation costs increase the likelihood of a negative value for λ. Thus, in healthcare contexts characterized, on the demand side, by high substitutability among providers, hospitals operating in more spatially clustered locations are likely to provide a lower level of quality and cost efficiency than those in less clustered areas. Furthermore, the objectives of hospitals, specifically their degree of altruism denoted by the parameter α in our model, are relevant. A higher degree of altruism, akin to greater patient benefit from quality, increases the likelihood of a negative λ. Consequently, the clusterization of hospitals in a local area may prompt more altruistic hospitals to reduce both quality and cost efficiency.

6.2. The impact of spatial configuration changes on quality and cost containment effort

We now examine what happens to the equilibrium values of quality and cost containment effort choices when the spatial configuration and, consequently, the size of the catchment area and the clusterization of hospitals in a local area changes, as the effect, for instance, of mergers, closure, or opening of hospitals.

Proposition 2. *In equilibrium, a change in the spatial configuration resulting in hospitals becoming more clustered with their neighboring competitors will lead hospitals to: i) reduce the quality of their treatment if λ is negative; ii) increase the quality of their treatment if λ is positive; iii) reduce their cost containment effort. Conversely, hospitals becoming less clustered with their neighboring competitors will exhibit the opposite behavior.*

For a proof of Proposition 2, it is enough to partially differentiate the expressions in [16] and [17] with respect to distance and consider the sign of the partial derivatives:

$$\frac{\partial q_i^*}{\partial d} = -\frac{\lambda t}{(2\theta + \lambda b)} \tag{18}$$

$$\frac{\partial \varepsilon_i^*}{\partial d} = \frac{(\theta - \lambda b)}{(2\theta + \lambda b)} \tag{19}$$

First of all, considering that a change in distance from hospital i to one of its competitors (i.e., an alteration of the size of its catchment area) corresponds to an equivalent change, but with opposite sign, for its competitor, it is easy to show that

$$\frac{\partial q_i^* \left(\partial \varepsilon_i^*\right)}{\partial d_{i+1}} = -\frac{\partial q_{i-1}^* \left(\partial \varepsilon_{i-1}^*\right)}{\partial d_{i+1}} \text{ and } \frac{\partial q_i^* \left(\partial \varepsilon_i^*\right)}{\partial d_{i-1}} = -\frac{\partial q_{i+1}^* \left(\partial \varepsilon_{i+1}^*\right)}{\partial d_{i-1}}$$

Regarding the sign of expression [18], since the denominator is positive,[16] its overall sign depends on the parameter λ. When λ is negative, the sign of [18] is positive. Hence, reducing the catchment area of a hospital decreases the quality it provides in equilibrium. Conversely, for positive values of λ, reducing the catchment area of a hospital prompts it to increase the quality of its services in equilibrium. On the other hand, expression [19] always yields a positive sign since both the numerator and denominator are positive.[17] Consequently, reducing the catchment area of a hospital results in a reduction in its cost containment effort in equilibrium.

6.3. The impact of spatial configuration changes on overall quality and cost containment effort

Proposition 2 and the subsequent discussion in Section 6.2 demonstrate that altering the spatial arrangement of hospitals triggers

[15] It is so because of the specific assumption on the value of β, made at the end of Section 3.

[16] See footnote 14.

[17] See footnote 14.

corresponding changes, albeit with opposite signs, in the quality and cost containment effort decisions of hospitals affected by variations in their catchment area. Hence, it is worthwhile to investigate whether these counteracting changes offset each other. To assess the "global" quality and cost containment effort of the three hospitals across their various spatial distributions, we will employ an index calculated as a weighted sum of the quality (q^*) and the cost containment effort (ε^*) provided by each hospital, with weights determined by the number of patients served by each hospital. This index can also be interpreted as a weighted average of quality and cost containment effort, considering the assumption of uniform patient density (equal to 1), where each hospital's demand represents its proportion of the total patients treated within the circle. Thus, the two indices are measured as follows:

$$q^* = q_i^* D_i\left(q_i^*,\ q_{i+1}^*,\ q_{i-1}^*;\ d_{i+1}, d_{i-1}\right) + q_{i+1}^* D_{i+1}\left(q_{i+1}^*,\ q_i^*,\ q_{i-1}^*;\ d_{i-1}\right) + q_{i-1}^* D_{i-1}\left(q_{i-1}^*,\ q_i^*,\ q_{i+1}^*;\ d_{i+1}\right) \tag{20}$$

$$\varepsilon^* = \varepsilon_i^* D_i\left(q_i^*,\ q_{i+1}^*,\ q_{i-1}^*;\ d_{i+1}, d_{i-1}\right) + \varepsilon_{i+1}^* D_{i+1}\left(q_{i+1}^*,\ q_i^*,\ q_{i-1}^*;\ d_{i-1}\right) + \varepsilon_{i-1}^* D_{i-1}\left(q_{i-1}^*,\ q_i^*,\ q_{i+1}^*;\ d_{i+1}\right) \tag{21}$$

Before proceeding to establish Propositions 3 and 4, which will summarize how alterations in the spatial arrangement of hospitals affect the measures outlined in [20] and [21], it is useful to make a few observations. As previously noted and evident from [20] and [21], changes in q^* and ε^* are broadly linked to alterations in each hospital's decisions regarding q and ε, respectively, multiplied by the number of patients (measured by D) affected by these adjustments. Additionally, these changes are associated with shifts in demand for each hospital multiplied by the quality and cost containment effort provided for each unit of treatment. Consequently, the overall impact of a modification in the spatial configuration of hospitals is expected to hinge on several factors. These factors include the initial spatial positioning of hospitals, which influences the initial demand (as per expression [4]), as well as the equilibrium choices of quality and cost containment effort (as per Proposition 1). Moreover, it will depend on the change in location, which affects the equilibrium decisions regarding quality and cost containment effort (as per Proposition 2). For an analytical exploration of these relationships, we can represent a generic variation in the spatial configuration of hospitals, in the context of our simple model, as a change of d_{i+1} and d_{i-1}. Each of these changes implies a variation of the catchment area of two hospitals out of three, specifically of the size of the area (and demand) shared by two neighboring competitors.[18] The initial size of the catchment areas of the three hospitals defines the initial spatial configuration, which in turn influences the initial demand and the equilibrium values of quality and cost containment effort. Conversely, any alteration in the size of these catchment areas represents a change in the spatial location of hospitals.

Proposition 3. *In equilibrium, the change in the overall quality resulting from a change in the spatial configuration of hospitals is determined by the net balance of the following effects:*

i) If λ is negative and:
  - *(a) if the change of d_{i+1} or d_{i-1} reduces the size of the smaller catchment area affected by the change, the impact on overall quality is positive;*
  - *(b) if the change of d_{i+1} or d_{i-1} increases the size of the smaller catchment area affected by the change, the impact on overall quality is negative.*

ii) If λ is positive, the statements (a) and (b) under i) hold true, but with opposite signs.

Proposition 4. *In equilibrium, the change in the overall cost containment effort resulting from a change in the spatial configuration of hospitals is determined by the net balance of the following effects:*

i) if the change of d_{i+1} or d_{i-1} reduces the size of the smaller catchment area affected by the change, the impact on overall cost-containment effort is positive;
ii) if the change of d_{i+1} or d_{i-1} increases the size of the smaller catchment area affected by the change, the impact on overall cost-containment effort is negative.

While the detailed proof of Propositions 3 and 4 is provided in the Appendix, we will briefly discuss here the underlying mechanics that lead from a change in the spatial configuration of hospitals to the resulting outcomes in terms of overall quality and cost containment effort. Since a change in the spatial distribution of hospitals can be parameterized by ∂d_{i+1} and ∂d_{i-1}, we can measure the change in overall quality and cost containment effort by the total differential expressions:

$$dq^* = \frac{\partial q^*}{\partial d_{i+1}} dd_{i+1} + \frac{\partial q^*}{\partial d_{i-1}} dd_{i-1}$$

and

$$d\varepsilon^* = \frac{\partial \varepsilon^*}{\partial d_{i+1}} dd_{i+1} + \frac{\partial \varepsilon^*}{\partial d_{i-1}} dd_{i-1}$$

Given the size and the sign of ∂d_{i+1} and ∂d_{i-1}, the sign of the marginal change of q^* (∂q^*) and ε^* ($\partial \varepsilon^*$), as induced by the marginal

[18] A change of d_{i+1}, leaving unchanged d_{i-1}, has an impact on the catchment areas of hospitals i and $i-1$ (what is lost by one of the two hospitals is gained by the other one), while the catchment area of hospital $i+1$ remains unchanged (what it gains on one side of its catchment area is lost on the other side). Equivalently, a change of d_{i-1} will have an impact on the catchment areas of hospitals i and $i+1$.

variation of distances, is crucial for understanding the results in Propositions 3 and 4. It is enough to focus on the marginal change of overall quality and cost containment effort induced by ∂d_{i+1}, since the same arguments can be analogously replicated for ∂d_{i-1}.

Let's first examine the marginal change in overall quality corresponding to a change of d_{i+1}. As we know from Proposition 2, this specific change influences the equilibrium quality decisions of hospitals *i* and *i-1*, subsequently affecting their respective demands (as indicated in expression [4]). Because this impact is symmetric and of opposite sign, the overall impact on quality (measured by ∂q^*) depends, as previously mentioned, on the initial spatial configuration and its associated implications regarding relative demand (D_i, D_{i-1}) and relative quality (q_i^*, q_{i-1}^*). When the initial spatial distribution of hospitals is asymmetrical, with one hospital having a smaller catchment area than the other, and λ is negative, hospitals operating within narrower catchment areas relative to their competitors exhibit lower quality compared to other hospitals, along with loweer demand. Further reduction in the catchment area of these hospitals leads to: a) a decrease in quality per unit of service provided to patients by the hospital with the smaller catchment area. This reduction is outweighed by the increase in quality per unit of service provided by the other hospital, as it now serves a larger patient base; b) a decline in demand for the hospital with the smaller catchment area, resulting in an overall reduction in its provided quality. However, this reduction is offset by the increased overall quality provided by the other hospital, which now serves the patients previously lost by the former hospital. Thus, when λ is negative, a change in the spatial location of hospitals leading to further reduction in the catchment area of those with smaller areas results in a marginal increase in overall quality. Conversely, when λ is positive, opposite arguments apply. In conclusion, the clusterization of hospitals can have divergent effects on overall quality, contingent upon the value of λ.

Regarding the overall cost containment effort, let's consider changes in d_{i+1} once again. From Proposition 2, we know that this affects the equilibrium effort choices of hospitals *i* and *i-1*, as well as their respective demands. Since these effects are symmetric and of opposite sign for effort choices, the marginal impact on overall effort (measured by $\partial \varepsilon^*$) depends on the initial spatial configuration and its associated implications regarding relative demand (D_i, D_{i-1}) and relative effort ($\varepsilon_i^*, \varepsilon_{i-1}^*$). Once more, as outlined in Proposition 1, hospitals operating within smaller catchment areas relative to their competitors exhibit lower effort compared to other hospitals, along with decreased demand. Further reduction in this area leads to: a) a decrease in the cost containment effort per unit of service provided to patients by the hospital with the smaller catchment area. However, this reduction is outweighed by the increase in effort per unit of service provided by the other hospital, as it now serves a larger patient base; b) a decline in demand for the hospital with the smaller catchment area, resulting in an overall reduction in its provided cost containment effort. Nevertheless, this reduction is counterbalanced by the increased overall cost containment effort provided by the other hospital, which now serves the patients previously lost by the former hospital. Overall, a change in the spatial location of hospitals leading to further clusterization increases the overall effort level in the market.

7. Concluding remarks

Although the goal of improving the quality of healthcare is one of the main accomplishments for policymakers, the underlying economics of quality competition in healthcare is complex, and depends on several factors that characterize the local market conditions. This paper has presented a model of strategic choices of hospitals about the quality and the cost-efficiency of their services, focused on the impact of their relative spatial location. Other works studying hospitals strategies in quality and efficiency have traditionally overlooked this central aspect of our analysis. In models based on Salop-type spatial competition, it is swallowed away by the assumption of uniform distribution of competitors along the circular space. The introduction of a more general assumption of non-uniform distribution of hospitals allows for considering the widely debated issue of the impact of local/localized competition in health care. Our model effectively links the influence of competition on both quality and efficiency to a combination of strategic decision-making and structural competitive conditions inherent in hospitals' operations, particularly their spatial distribution. While our findings align with those of prior research emphasizing the strategic aspect of hospital decisions concerning quality and efficiency, our model offers significant insights for guiding future empirical analyses and shaping healthcare policy more effectively. The general result is that the effects of local competition are context-dependent and they may be different according to the demand and the technology conditions characterizing the services provided by hospitals (as they affect the relative relevance of marginal costs and benefits of quality and efficiency).

The implication for carrying out empirical assessments of the impact of competition suggests conducting studies at the level of different clinical specialties. This is because the costs and benefits of quality can vary significantly across various clinical fields. While we have not directly examined the empirical findings in the existing literature in the light of our model, we suspect that the divergent conclusions on the role of competition stem from context-dependency. Many studies tend to generalize policy implications from analyses that primarily focus on specific healthcare contexts, often without considering the nuanced differences across these contexts. Additionally, our analysis sheds light on the trade-off between cost-efficiency and quality, showing that there is no straightforward conclusion on this matter. Instead, it is contingent on the structural conditions of competition among healthcare providers.

The policy implication of our results is that changes in the spatial configuration of hospital markets may influence hospitals' choices in opposing directions, contingent on the context of care (in terms of benefit and costs of quality provision) and on the local area where they occur. In this regard, by employing broad indicators to measure overall quality and cost containment effort across all hospitals, our framework enables consideration not only of the impact of spatial location changes on individual hospital decisions, but also of whether the resulting variations in these individual decisions could lead to a broader enhancement for the entire market.

CRediT authorship contribution statement

Calogero Guccio: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Domenico Lisi:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Marco Ferdinando Martorana:** Writing – original draft, Methodology, Formal analysis, Conceptualization. **Giacomo Pignataro:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

None

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used CHATGPT in order to check grammar and improve language and readability of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix

This Appendix collects the proofs of the propositions given in the manuscript.

A.1. Second-Order Condition for maximization problem [8]

$$\frac{\vartheta^2\ \Omega_i}{\vartheta\ q_i^2} = (-2\beta)\frac{\vartheta \mathrm{D}_i}{\vartheta \mathrm{q}_i} - k < 0\ \partial \mathrm{Di}$$

Given the restriction at the end of Section 2, $\beta > -\frac{kt}{2b'}\beta$, the S.O.C. above is always satisfied.

A.2. Proofs of Propositions 3 and 4

To measure the impact of a change of both d_{i+1} and $\mathrm{d}_{i\text{-}1}$ on q^* and ε^* we can use the total differential expressions:

$$dq^* = \frac{\partial q^*}{\partial d_{i+1}} dd_{i+1} + \frac{\partial q^*}{\partial d_{i-1}} dd_{i-1}$$

and

$$d\varepsilon^* = \frac{\partial \varepsilon^*}{\partial d_{i+1}} dd_{i+1} + \frac{\partial \varepsilon^*}{\partial d_{i-1}} dd_{i-1}$$

Focusing first on the expression for dq^*, we can compute the marginal changes of q^* corresponding to marginal changes of both d_{i+1} and $\mathrm{d}_{i\text{-}1}$ as :[19]

$$\frac{\partial q^*}{\partial d_{i+1}} = \frac{\partial q_i^*}{\partial d_{i+1}} D_i + q_i^* \left[\frac{\partial D_i}{\partial d_{i+1}} + \frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}} + \frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right] + \frac{\partial q_{i-1}^*}{\partial d_{i+1}} D_{i-1} + q_{i-1}^* \left[\frac{\partial D_{i-1}}{\partial d_{i+1}} + \frac{\partial D_{i-1}}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}} + \frac{\partial D_{i-1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}\right] \tag{22}$$

$$\frac{\partial q^*}{\partial d_{i-1}} = \frac{\partial q_i^*}{\partial d_{i-1}} D_i + q_i^* \left[\frac{\partial D_i}{\partial d_{i-1}} + \frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}} + \frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right] + \frac{\partial q_{i+1}^*}{\partial d_{i-1}} D_{i+1} + q_{i+1}^* \left[\frac{\partial D_{i+1}}{\partial d_{i-1}} + \frac{\partial D_{i+1}}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}} + \frac{\partial D_{i+1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}\right]$$

From the previous Section 5.2 we know that:

$$\frac{\partial q_i^*}{\partial d_{i+1}} = -\frac{\partial q_{i-1}^*}{\partial d_{i+1}} \text{ and } \frac{\partial q_i^*}{\partial d_{i-1}} = -\frac{\partial q_{i+1}^*}{\partial d_{i-1}}$$

It is also possible to show that:

$$\left[\frac{\partial D_i}{\partial d_{i+1}} + \frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}} + \frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right] = -\left[\frac{\partial D_{i-1}}{\partial d_{i+1}} + \frac{\partial D_{i-1}}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}} + \frac{\partial D_{i-1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}\right]$$

and

[19] It can be easily shown that $\partial q^*_{i+1}/\partial d_{i+1} = 0$ and $\partial q^*_{i\text{-}1}/\partial d_{i\text{-}1} = 0$ (it follows from expressions for q^*_{i+1} and $q^*_{i\text{-}1}$ in [16]). Moreover, $dD_{i+1}/dd_{i+1} = 0$ and $dD_{i\text{-}1}/dd_{i\text{-}1} = 0$ (it follows from the expression for demand in [4] and from the effects of a change of d_{i+1} ($d_{i\text{-}1}$) on q^*_i and on $q^*_{i\text{-}1}$ ($q^*_{i\text{-}1}$), which are identical in size and of opposite sign).

$$\left[\frac{\partial D_i}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right]=-\left[\frac{\partial D_{i+1}}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}\right]$$

It follows that:

$$\frac{\partial q^*}{\partial d_{i+1}}=\frac{\partial q_i^*}{\partial d_{i+1}}(D_i-D_{i-1})+\left[\frac{\partial D_i}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right]\left(q_i^*-q_{i-1}^*\right)=\frac{2\lambda t(1-2d_{i+1}-d_{i-1})(\theta-\lambda b)}{(2\theta+\lambda b)^2} \tag{23}$$

$$\frac{\partial q^*}{\partial d_{i-1}}=\frac{\partial q_i^*}{\partial d_{i-1}}(D_i-D_{i+1})+\left[\frac{\partial D_i}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right]\left(q_i^*-q_{i+1}^*\right)=\frac{2\lambda t(1-2d_{i-1}-d_{i+1})(\theta-\lambda b)}{(2\theta+\lambda b)^2}$$

While, in both expressions in [23] ($\lambda\, b$) and $(\lambda\, b)^2$ are positive, λ may be positive or negative. Moreover, the sign of $(1-2d_{i+1}-d_{i-1})$ and of $(1-2d_{i-1}-d_{i+1})$ may be positive or negative. More precisely,$(1-2d_{i+1}-d_{i-1}) \gtreqless 0$ if $(d_{i+1}+d_{i-1}) \lesseqgtr (1-$ if $d_{i+1})$, that is the sign of the expression $(1-2d_{i+1}-d_{i-1})$ depends on the relative size of the catchment areas of hospitals *i* and *i-1*. Analogously, the sign of the expression $(1-2d_{i-1}-d_{i+1})$ depends on the relative size of the catchment areas of hospitals *i* (i.e. $d_{i+1}+d_{i-1}$) and *i + 1* (i.e. $1-d_{i-1}$).

We summarize the results in the following table:

$dq^*=\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}+\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}$	λ**<0**		$\lambda>0$	
$d_{i+1}+d_{i-1}<1-d_{i+1}$	$\frac{\partial q^*}{\partial d_{i+1}}<0$	If $dd_{i+1}<0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}>0$ If $dd_{i+1}>0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}<0$	$\frac{\partial q^*}{\partial d_{i+1}}>0$	If $dd_{i+1}<0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}<0$ If $dd_{i+1}>0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}>0$
$d_{i+1}+d_{i-1}=1-d_{i+1}$	$\frac{\partial q^*}{\partial d_{i+1}}=0$	For any dd_{i+1}, $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}=0$	$\frac{\partial q^*}{\partial d_{i+1}}=0$	For any dd_{i+1}, $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}=0$
$d_{i+1}+d_{i-1}>1-d_{i+1}$	$\frac{\partial q^*}{\partial d_{i+1}}>0$	If $dd_{i+1}<0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}<0$ If $dd_{i+1}>0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}>0$	$\frac{\partial q^*}{\partial d_{i+1}}<0$	If $dd_{i+1}<0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}>0$ If $dd_{i+1}>0$, then $\frac{\partial q^*}{\partial d_{i+1}}dd_{i+1}<0$
$d_{i+1}+d_{i-1}<1-d_{i-1}$	$\frac{\partial q^*}{\partial d_{i-1}}<0$	If $dd_{i-1}<0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}>0$ If $dd_{i-1}>0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}<0$	$\frac{\partial q^*}{\partial d_{i-1}}>0$	If $dd_{i-1}<0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}<0$ If $dd_{i-1}>0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}>0$
$d_{i+1}+d_{i-1}=1-d_{i-1}$	$\frac{\partial q^*}{\partial d_{i-1}}=0$	For any dd_{i+1}, $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}=0$	$\frac{\partial q^*}{\partial d_{i-1}}=0$	For any dd_{i-1}, $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}=0$
$d_{i+1}+d_{i-1}>1-d_{i-1}$	$\frac{\partial q^*}{\partial d_{i-1}}>0$	If $dd_{i-1}<0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}<0$ If $dd_{i-1}>0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}>0$	$\frac{\partial q^*}{\partial d_{i-1}}<0$	If $dd_{i-1}<0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}>0$ If $dd_{i-1}>0$, then $\frac{\partial q^*}{\partial d_{i-1}}dd_{i-1}<0$

Moving now to the expression for $d\varepsilon^*$, similarly to what done for dq^*, we can compute the marginal changes of ε^* corresponding to marginal changes of both d_{i+1} and d_{i-1} as:

$$\frac{\partial \varepsilon^*}{\partial d_{i+1}}=\frac{\partial \varepsilon_i^*}{\partial d_{i+1}}D_i+\varepsilon_i^*\left[\frac{\partial D_i}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right]+\frac{\partial \varepsilon_{i-1}^*}{\partial d_{i+1}}D_{i-1}+\varepsilon_{i-1}^*\left[\frac{\partial D_{i-1}}{\partial d_{i+1}}+\frac{\partial D_{i-1}}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}+\frac{\partial D_{i-1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}\right] \tag{24}$$

$$\frac{\partial \varepsilon^*}{\partial d_{i-1}}=\frac{\partial \varepsilon_i^*}{\partial d_{i-1}}D_i+\varepsilon_i^*\left[\frac{\partial D_i}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right]+\frac{\partial \varepsilon_{i+1}^*}{\partial d_{i-1}}D_{i+1}$$
$$++\varepsilon_{i+1}^*\left[\frac{\partial D_{i+1}}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}\right]$$

From the previous Section 5.2 we know that:

$$\frac{\partial \varepsilon_i^*}{\partial d_{i+1}}=-\frac{\partial \varepsilon_{i-1}^*}{\partial d_{i+1}} \text{ and } \frac{\partial \varepsilon_i^*}{\partial d_{i-1}}=-\frac{\partial \varepsilon_{i+1}^*}{\partial d_{i-1}}$$

It is also possible to show that:

$$\left[\frac{\partial D_i}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right]=-\left[\frac{\partial D_{i-1}}{\partial d_{i+1}}+\frac{\partial D_{i-1}}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}+\frac{\partial D_{i-1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}\right]$$

and

$$\left[\frac{\partial D_i}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right]=-\left[\frac{\partial D_{i+1}}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}+\frac{\partial D_{i+1}}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}\right]$$

It follows that:

$$\frac{\partial \varepsilon^*}{\partial d_{i+1}}=\frac{\partial \varepsilon_i^*}{\partial d_{i+1}}(D_i-D_{i-1})+\left[\frac{\partial D_i}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i+1}}+\frac{\partial D_i}{\partial q_{i-1}^*}\frac{\partial q_{i-1}^*}{\partial d_{i+1}}\right]\left(\varepsilon_i^*-\varepsilon_{i-1}^*\right)=\frac{2(2d_{i+1}+d_{i-1}-1)(\theta-\lambda b)^2}{(2\theta+\lambda b)^2} \tag{25}$$

$$\frac{\partial \varepsilon^*}{\partial d_{i-1}}=\frac{\partial \varepsilon_i^*}{\partial d_{i-1}}(D_i-D_{i+1})+\left[\frac{\partial D_i}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial d_{i-1}}+\frac{\partial D_i}{\partial q_{i+1}^*}\frac{\partial q_{i+1}^*}{\partial d_{i-1}}\right]\left(\varepsilon_i^*-\varepsilon_{i+1}^*\right)=\frac{2(2d_{i-1}+d_{i+1}-1)(\theta-\lambda b)^2}{(2\theta+\lambda b)^2}$$

The sign of both expressions in [25] depends on the sign of $(2d_{i+1}+d_{i-1}-1)$ and $(2d_{i-1}+d_{i+1}-1)$, which may be positive or negative. More precisely, $(2d_{i+1}+\text{if } d_{i-1}-1)\gtreqless 0$ if $(d_{i+1}+d_{i-1})\gtreqless(1-d_{i+1})$, that is the sign of the expression $(1-2d_{i+1}-d_{i-1})$ depends on the relative size of the catchment areas of hospitals *i* and *i-1*. Analogously, the sign of the expression $(2d_{i-1}+d_{i+1}-1)$ depends on the relative size of the catchment areas of hospitals *i* (i.e. $d_{i+1}+d_{i-1}$) and $i+1$ (i.e. $1-d_{i-1}$).

We summarize the results in the following table:

$d\varepsilon^*=\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}+\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}$		
$d_{i+1}+d_{i-1}<1-d_{i+1}$	$\frac{\partial\varepsilon^*}{\partial d_{i+1}}<0$	If $dd_{i+1}<0$, then $\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}>0$ If $dd_{i+1}>0$, then $\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}<0$
$d_{i+1}+d_{i-1}=1-d_{i+1}$	$\frac{\partial\varepsilon^*}{\partial d_{i+1}}=0$	For any dd_{i-1}, $\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}=0$
$d_{i+1}+d_{i-1}>1-d_{i+1}$	$\frac{\partial\varepsilon^*}{\partial d_{i+1}}>0$	If $dd_{i+1}<0$, then $\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}<0$ If $dd_{i+1}>0$, then $\frac{\partial\varepsilon^*}{\partial d_{i+1}}dd_{i+1}>0$
$d_{i+1}+d_{i-1}<1-d_{i-1}$	$\frac{\partial\varepsilon^*}{\partial d_{i-1}}<0$	If $dd_{i-1}<0$, then $\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}>0$ If $dd_{i-1}>0$, then $\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}<0$
$d_{i+1}+d_{i-1}=1-d_{i-1}$	$\frac{\partial\varepsilon^*}{\partial d_{i-1}}=0$	For any dd_{i-1}, $\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}=0$
$d_{i+1}+d_{i-1}>1-d_{i-1}$	$\frac{\partial\varepsilon^*}{\partial d_{i-1}}>0$	If $dd_{i-1}<0$, then $\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}<0$ If $dd_{i-1}>0$, then $\frac{\partial\varepsilon^*}{\partial d_{i-1}}dd_{i-1}>0$

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