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# Regional regulators in health care service under quality competition: A game theoretical model

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**Abstract**

In several countries, health care services are provided by public and/or private subjects, and they are reimbursed by the government, on the basis of regulated prices (in most countries, diagnosis-related group). Providers take prices as given and compete on quality to attract patients. In some countries, regulated prices differ across regions. This paper focuses on the interdependence between regional regulators within a country: It studies how price setters of different regions interact, in a simple but realistic framework. Specifically, we model a circular city as divided in two administrative regions. Each region has two providers and one regulator, who sets the local price. Patients are mobile and make their choice on the basis of provider location and service quality. Interregional mobility occurs in the presence of asymmetries in providers' cost efficiency, regulated prices, and service quality. We show that the optimal regulated price is higher in the region with the more efficient providers; we also show that decentralisation of price regulation implies higher expenditure but higher patients' welfare.

**KEYWORDS**

diagnosis-related group, health care services, quality competition, two-stage noncooperative game

## 1 | INTRODUCTION

In several countries, health care services are provided by public and/or private subjects, and they are reimbursed by the government. Typically, the reimbursement mechanism is based on a prospective per case payment system, with the ultimate goal of leading providers to compete in quality, in order to attract consumers or patients, and to increase the average quality of offered services. In the specific case of hospital services, for instance, the payment system is based on diagnosis-related group (DRG) mechanism, firstly introduced in the United States in 1983, and currently adopted in most European countries (Busse, Geissler, Quentin, & Wiley, 2011). According to the DRG system, each specific diagnosis treatment is associated to a specific price. This means that health care providers are reimbursed a fixed tariff for each patient treated, according to DRG classification. Thus, providers take price as given, and the competition to attract patients is mainly based on quality.

Not surprisingly, the design of the reimbursement mechanism differs across countries. Differences concern the extent of the use of the DRG system to finance hospital care (the system can hold only for a subset of health care services), the size of the specific reimbursement associated to each DRG, the possible difference between prices paid to different providers, and so on (see also Siciliani, Chalkley, & Gravelle, 2017).

Here, we focus on the fact that, in several countries, the payment design also differs across the regions. In Italy, for instance, the reimburse mechanisms, and the price levels for the same treatment, significantly differ across regions: More specifically, there are "national tariffs" for each DRG, but the regions, that have the institutional duty of supervising the health care provision, can decide—and have decided indeed—to reimburse their hospitals according to different prices. The same holds for Spanish regions and autonomous communities, or in Sweden, just to mention a few countries. In Germany, several recent reforms have tried to reduce the price dispersion across Länder (Klein-Hitpass & Scheller-Kreinsen, 2015). Although the theoretical literature on the per case payment system, like the DRG system (rather than a system based on cost reimbursement), is very large in health economics, scanty attention is devoted to the aspect of competition among regional regulators; this article aims at dealing with this specific aspect.

The seminal contributions of Ellis and McGuire (1986); Ma (1994); Street, O'Reilly, Ward, and Mason (2011); among others show that hospital payment schemes based on full reimbursement of the incurred costs lead to a "medical arms race" among hospitals and, thus, to an escalation of health care costs (Cavalierie, Guccio, Lisi, & Pignataro, 2016); a prospective per case reimbursement system seems to be appropriate, to lead hospitals to more efficient choices. The empirical literature concerning the determinants and the effects of DRG prices (see, e.g., various chapters in Culyer & Newhouse, 2000; Pauli, McGuire, & Barros, 2011; see also Mikkala, Keskimaki, & Hakkinene, 2002; Schreyoegg, Stargardt, Tiemann, & Busse, 2006) show that the determinants of price levels typically include the estimated cost, taking into consideration different components, with a different weight of past history and prospective evolution, according to different countries. It goes without saying that different reimbursement schemes imply different incentives for health care providers. Just to give some intuitive examples, if providers were paid by a fixed price for every treatment, they would be expected to cream-skim patients by selecting the more lucrative cases. A repayment system based on DRG should limit (though not completely overcome) this obvious problem (Ellis & Miller, 2008). The fixed price per each DRG treatment should induce the providers to reduce the average length of stay, in order to reduce inpatient costs and increase profit margins, and to reduce unnecessary medical procedures for each patient treated, and so on.

The body of theoretical investigation concerning *price design* is more restricted. In particular, to the best of our knowledge, interaction of price regulation between regions within a given country is an aspect that is overlooked by available literature, even if relevant contributions are available as far as the difference in quality levels of service across regions are concerned (Brekke, Levaggi, Siciliani, & Straume, 2014, 2016; Aiura, 2016).

It is well-known that regional differences in the provision and utilization of health care service (and hospital services) may be relevant, due to both demand and supply side factors. Skinner (2011) provides an excellent overview: regional differences in demographic structure, consumer or patients' preferences or income, health status, price levels, and dynamics drive to different demand functions. Heterogeneity in factor endowments, public budget choices, and other institutional characteristics may drive to different supply functions. It has been suggested, and empirically shown, that the different payment mechanisms across regions impact on the composition of hospital care supply side across regions, for example, in terms of public–private mix, condition of private and public subjects, and the degree of competition in the health care market (Cavalieri, Gitto, & Guccio, 2013). The payment design—and the DRG specifically—affects the efficiency of providers (Busse et al., 2011; Moreno Serra & Wagstaff, 2010); moreover, it affects the high technology equipment choices and technology diffusion (Bech et al., 2009; Bokhari, 2009; Finocchiaro Castro, Guccio, Pignataro, & Rizzo, 2014; Levaggi, Moretto, & Pertile, 2012, 2014). Hence, different reimbursement mechanisms have an impact on patients' satisfaction.

Clearly, if patients are free to choose the health care provider, expected satisfaction drives the individual choices about the provider, and patient mobility has to be expected. Patient mobility—both across the regions of any given country and even across countries—is a widely observed phenomenon indeed (see, e.g., Rosenmoller, McKee, & Baeten, 2004; Balia, Brau, & Marroccu, 2014); the phenomenon is expected to increase in next future, at least in the European Union in front of recent directives.[1] This mobility, per se, is not a negative by-product of the system; it associates with the aim of stimulating competition and increasing quality. However, the mobility entails social and monetary costs and has welfare implication. Reasoning by backward induction, the regional price setter, while fixing the price, has to take into account the reaction of health providers and, in turn, patient choices. Moreover, it is clear that the choice of each regional regulator affects the outcome for all hospitals and regions.

Here, we propose a simple sequential game to describe the relevant interdependence links that are in operation in a similar framework, with the final aim to investigate the individual and social welfare implications of different institutional rules. Our model permits to evaluate pros and cons of the introduction of national coordination, or national fixing of DRG prices, as compared with regionally decentralized regulation.

In our model, we will assume that regional authorities aim to maximize the regional social welfare; admittedly, we overlook a potentially large set of considerations concerning the real goals of policy makers and regional regulators in

[1]For example, Directive 2011/24/EU of the European Parliament; Brekke et al. (2016), among others, provide further references to norms entailing a higher expected mobility.

this sector. In any case, if patients are free to choose the provider to patronize, then interregional mobility occurs, with relevant effects for regional social welfare. Though specific to the health sector, our theoretical model may be of interest for industrial economics in general, provided that competition among different regional regulators occurs in several sectors (education, long-term care, transportation, and so on) and in several countries. In all these cases, consumers, providers, and regional authorities are characterized by different objective functions and related by similar strategic interdependence links. Interregional competition across providers, mainly based on product quality, and patients' mobility are the rule.

Two specific available articles are close to our present investigation, namely, Brekke et al. (2014, 2016). In the former, differentiated levels of skills and, hence, differences in "potential" quality levels across regions are considered: The point under investigation is whether or not patient mobility is desirable from an individual and social welfare perspective. The article employs a Hotelling spatial competition model and shows that consumer (patient) mobility enhances the quality of offered service in "high skill" regions and improves the number of treated patients there, but such an outcome depends on the payment mechanism: Price has to exceed marginal cost; otherwise, a "race to the bottom" occurs, with lower welfare levels in all regions. In general, the effects of different transfer mechanisms to pay the region attracting extraregional demand are studied: Welfare implications and the ability of different rules to lead to Pareto improvements are investigated. However, there is no room to deal with a price setting problem, because both firm (hospital) and regional policy maker consider quality as the choice variable. In the latter (Brekke et al., 2016), the spatial competition model considers a Salop circle, where three regions exist, characterized by different income levels: Regional policy makers choose quality to maximize the utility of its own residents, and the total cost of health services is financed by general income taxation, in the presence of budget constraint. The model studies the implications of consumer mobility upon quality choice and public expenditure, the welfare effects of change in monetary and nonmonetary costs of mobility, and the effects of income distribution, within and across regions, upon equilibrium allocation, that is, quantity and quality of regional services. Also in this model, there is no distinction between provider and regional policy maker, and the game is not sequential: Regional policy makers set by themselves the quality of the service offered in each region, and hospitals are not considered as autonomous subjects.

We propose here a theoretical model with a focus on the effects of interaction among *regional regulators as price setters*. We spend attention in articulating the objectives of providers and in modeling their interaction with patients, on the one side and policy makers on the other side. Moreover, our present model allows to analyze spatial competition among providers as articulated in intraregional and interregional competition. Three different classes of subjects are relevant in our model: (a) the patients, who choose the provider (i.e., the hospital) to patronize, within or outside the region where they live; (b) the health care providers, which are profit oriented, face given price (set by the regional policy maker), compete on quality to attract patients, in front of a spatial monopoly position which is weakened by costly patient mobility; and (c) the regional authorities, that is, price setters, that fix the price, ideally taking care of the regional welfare, and are aware that interdependence links with other regional price setters exist. The value added of our present model, with respect of the two specific articles mentioned above, rests on the clear distinction between regulator and provider: This distinction is relevant in the real world, where the decision chain is well structured, and the links and reciprocal influences between providers and regulators play a relevant role.

The structure of the article is as follows. Section 2 presents the basic setup of the model, introducing the characteristics of demand and supply side and the characteristics of the game under scrutiny. Section 3 provides the equilibrium of the game. Section 4 depicts the equilibrium outcome under the assumption of centralized decision concerning DRG prices. Section 5 draws the policy implications of our game theoretical model. Section 6 provides some extensions, namely, the (very realistic) cases that the price for extraregional treatments is set by a central national authority and that income and opportunity cost levels differ across regions. Section 7 provides concluding comments.

## 2 | THE MODEL SETUP

We propose a model to study quality competition between hospitals, taking into due account that prices are set by a regulator at regional level. The competition between hospitals occurs both in the same region and outside the region, under different regulation rules. This is the case in several Organization for Economic Cooperation and Development countries indeed. We consider a two-stage noncooperative game with complete information, with prices that are fixed by different regional authorities. Our model differs from the existing literature: As already mentioned, unlike in Brekke, Cellini, Siciliani, and Straume, (2012) and Brekke et al. (2014), in the baseline version of our model, hospitals are profit seeking and autonomous subjects with respect to the regional regulator. Moreover, our model also differs from Brekke, Siciliani, and Straume (2011), who consider the case of an unique price and from Ma and Burgess (1993), who present a model with different prices that are fixed by the hospitals and are paid by the patients. In our present model, at the first stage, the regions fix the DRG prices to be paid in; then, at the second stage, the hospitals—taken the prices as given—choose the quality levels of their services, which in turn determine the demand, with possible mobility of patients across regions. The market is fully covered: Each patient demands one unit of service and can choose the provider to patronize, within or outside the region where (s)he lives. Patients do not bear any out-of-pocket payment, and the price is paid by the government, which attaches an opportunity cost to such public expenditure. Thus, hospitals can compete on quality to attract patients.

As in Siciliani, Straume, and Cellini (2013) and Brekke et al. (2016), we adopt a localization model à la Salop (1979)[2] where the hospitals are exogenously and equally localized around a circle with circumference equal to 1, so that the distance between any two neighboring hospitals is equal to $1/n_H$. The patients are uniformly distributed along the circumference with *total mass* normalized at 1. The utility of a consumer located at $x$ and served by hospital $H$, located at $z_H$, is

$$u(x, z_H) = v + q_H - \tau |x - z_H|, \tag{1}$$

where $v$ is the gross valuation of consumption, $q_H \geq 0$ is the quality offered by provider $H$, and $\tau$ is the marginal disutility of traveling. The assumption $v > \tau$ ensures that the market is fully covered.[3]

Each patient can only move to the two adjacent hospitals. The consumer who is indifferent between hospital $i$ and hospital $i + 1$ is located at $\hat{x}_i^{i+1}$, which, measured clockwise from hospital $i$, is given by

$$\hat{x}_i^{i+1} = \frac{1}{2n_H} + \frac{q_i - q_{i+1}}{2\tau}. \tag{2}$$

Similarly, the consumer indifferent between hospital $i$ and $i - 1$ is located at $\hat{x}_i^{i-1}$, which, measured anticlockwise from hospital $i$, is given by

$$\hat{x}_i^{i-1} = \frac{1}{2n_H} + \frac{q_i - q_{i-1}}{2\tau}. \tag{3}$$

Thus, the demand function for each hospital $i \in \{1, \ldots, n_H\}$ is

$$x_i^D = \frac{1}{n_H} + \frac{q_i - q_{i+1}}{2\tau} + \frac{q_i - q_{i-1}}{2\tau}. \tag{4}$$

We propose to consider here the case of a country (the circle) with two regions ($n_R = 2$) and two hospitals in each region. Thus, each of the $n_H = 4$ hospitals in the country is in "direct competition" (in quality) with both one hospital in the same region and one hospital in the other region, and the regions are in direct competition (in prices). Therefore, we consider the simplified localization model in Figure 1, in which the region $R_A$ is located above the segment $L_1L_2$ and contains the hospitals $H_1$ and $H_2$; similarly, the region $R_B$ includes hospitals $H_3$ and $H_4$, which are located in under the segment $L_1L_2$.

Let us assume that the cost function of each hospital is linear in the quantity and quadratic in the quality of the produced service: $C_i = c_i x_i + \frac{\beta}{2} q_i^2$, where $c_i$ and $\beta$ are positive parameters. While admitting that this function is chosen for analytical convenience reasons, we also note that linear and/or quadratic cost functions are generally considered by all models belonging to this literature line.[4] Each hospital receives a price $p_i$ (set by the regional regulator) for each unit of produced service. Hence, the profit function for hospital $i$ is

[2]See also Ishida and Matsushima (2004) and Hamoudi and Risueno (2012), inter alia, as examples of models employing the circular city localization model in the presence of regulation policies.
[3]Further economic interpretations of these assumptions are provided by Siciliani et al. (2013). We also note that the existence of a minimum quality standard is not explicitly considered in the present model (see, e.g., Cellini & Lamantia, 2016), but parametric restrictions consistent with $q_H \geq 0$ will be assumed.
[4]See Brekke, Cellini, Siciliani, and Straume (2018) for a discussion on characteristics and implications of linear and quadratic cost function in the production of hospital services. See also below, Section 6, where a different cost function is assumed and some characteristics of linear versus quadratic costs are briefly discussed.

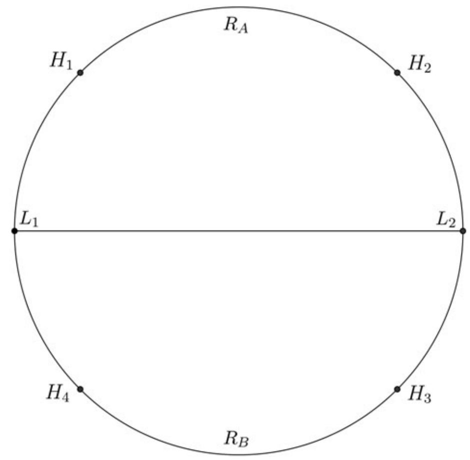


**FIGURE 1** Localized model à la Salop with two regions and four hospitals

$$\Pi_i = (p_i - c_i)x_i^D - \frac{\beta}{2}q_i^2, \tag{5}$$

where $x_i^D$ is given by (4).[5]

Moreover, we assume that constant marginal $c_i$ is equal for the hospitals of the same region, while it differs across regions; this corresponds to the fact that institutional (organizational) aspects matter on the cost structure. It is well known, as in the Italian or Spanish cases among many others, that differences in efficiency between hospitals in different regions exist, which result in different (marginal and average) costs for hospitalization and treatments. Clearly, the assumption of a common marginal cost for the hospitals belonging to the same region is a simplification that can be removed in a more general version of the model with differences across providers of the same region. Again, the fact that parameter $\beta$ is equal for all hospitals in all regions is a simplifying assumption that can be removed in a more general model.

## 3 | THE GAME

We propose to analyze the interaction between regulators and hospitals, by resorting to a simple sequential two-stage game. In the first stage, each regional regulator sets the (DRG) price for the hospitals in its region. In the second stage, each hospital chooses the quality level of its service; hospitals' choices about quality are taken simultaneously. Then, patients make their choice, to maximize individual utility.[6] Each hospital aims to maximize its profit. The regional regulator aims to maximize a social welfare function that takes into account the welfare of the inhabitants of the region, the profit of the hospitals belonging to the region, and attaches an opportunity cost to public spending for health. The subgame perfect Nash equilibrium can be simply found, solving the model by backward induction.

### 3.1 | Second stage game

The Nash equilibrium strategy of the game at the second stage for the hospitals is obtained from the Equation 5:

$$q_i = \frac{p_i - c_i}{\beta\tau}. \tag{6}$$

It is worth noting that the optimal qualities for each hospital only depend on the DRG price of its own region and on its marginal costs as a consequence of the constant marginal costs hypothesis; in game theory terms, qualities are strategic independent (in Section 6, we show that different results arise in the case of a quadratic cost function in both quality and

[5]Thus, to make the model easier, we assume nil fixed cost; under this assumption, we will find that operative profits are always positive in equilibrium, so that we do not need to consider lump-sum transfers to breakeven.
[6]The demand functions have already been derived in the previous section.

patients' number). Not surprisingly, the equilibrium quality level is increasing in the DRG price: the higher the price, the stronger the incentive for the hospital of attracting additional patients and, hence, the stronger the incentive to provide higher quality services. Costs of quality and quantity exert a negative effect on the equilibrium quality. The negative effect of patients' transportation cost simply tells that higher transportation costs imply less fierce quality competition among hospitals, that is, higher (local) monopoly power.

### 3.2 | Regional welfare functions

In principle, the differences in terms of DRG prices across regions may be motivated by structural differences across regions (e.g., in populations structure, preferences, and even income levels) and by differences in efficiency between hospitals of different regions (which drive, as already mentioned, to different costs for hospitalization and treatments), not to mention policy considerations, which could matter when defining the regional social welfare. Here, we consider the occurrence of differences across regions, concerning both the DRG prices ($p_A$ and $p_B$) and the costs ( $c_A$ and $c_B$).

As a result, the quality levels of the hospitals in the same region are the same, and so the patients located between $H_1$ and $H_2$ will go to the closer hospital (similarly for the patients between $H_3$ and $H_4$): A demand quota of $\frac{1}{8}$ is ensured to each hospital.

Therefore, given the strategies (6), the DRGs fixed by the region (and the cost differences) will affect competition between hospitals in different regions, in particular, $H_1$ and $H_4$ from one side and $H_2$ and $H_3$ from the other (see again Figure 1): The competition occurs between two providers located at the edges of a Hotelling line of length $\frac{1}{4}$. From Equations 4 and 6, it follows that the patients (that are $\frac{1}{4}$) located between the hospitals $i$ and $j$, where $(i,j) \in \{(1,4),(2,3)\}$ will move to the hospital $i$ according to the following quota (which corresponds to $\hat{x}_i^{i+1}$):

$$\hat{x}_i^{i+1} = \frac{1}{8} + \frac{\Delta p - \Delta c}{2\beta\tau^2},$$

where $\Delta p = p_i - p_j$ and $\Delta c = c_i - c_j$. Therefore, both the hospitals $i$ and $i+1$ have a (strictly) positive demand if $\frac{\Delta p - \Delta c}{2\beta\tau^2} < \frac{1}{8}$.

By taking into account also the latter condition, we distinguish between two different cases:

1. If $\Delta c < \Delta p < \Delta c + \frac{\beta\tau^2}{4}$, then the patients using hospital in region $i$ are patients resident in region $i$ that remain in region $i$ that are $x_i^i = \frac{1}{8}$ and patients from the region $j$ moving to region $i$ that are $x_i^j = \frac{\Delta p - \Delta c}{2\beta\tau^2}$. Obviously in this case, $x_j^i = 0$;
2. If $\Delta c - \frac{\beta\tau^2}{4} < \Delta p < \Delta c$, then patients in region $i$ remaining in the same region are given by $x_i^i = \frac{1}{8} + \frac{\Delta p - \Delta c}{2\beta\tau^2}$ and patients moving from region $i$ to $j$ are $x_j^i = -\frac{\Delta p - \Delta c}{2\beta\tau^2}$. In this case, we have $x_i^j = 0$.

If none of the two above inequalities hold true, then only one of the two hospitals gets a positive demand level, as far as only the patients in between them are considered.

Due to symmetry reasons, the same happens both in the competition between $H_1$ and $H_4$ and in the competition between $H_2$ and $H_3$.

Given the structure of the model, at the first stage of the game, the regions $R_A$ and $R_B$ fix their own DRG price in order to maximize a regional social welfare function, which takes into account public expenditure, with opportunity cost $\lambda > 0$; regional hospitals' profits; and the region inhabitants' welfare.

As a result, the social welfare of each region $R_i$, with $i \in \{A,B\}$, writes as follows:

$$W_i = W_i^I + 2W_i^E - \beta q_i^2,$$

where $W_i^I$ is the "internal" welfare that is the welfare computed in the zone between the two hospitals of the same region, whereas $W_i^E$ is the "external" welfare that is computed in the area between two hospitals in two different regions. In particular, we have:

$$W_i^I = \frac{1}{4}(-\lambda p_i - c_i) + 2\int_0^{\frac{1}{8}} (v + q_i - \tau x)dx.$$

If $\Delta p > \Delta c$ (i.e., region $i$ attracts patients from region $j$), then it results

$$W_i^E = \frac{1}{8}(-\lambda p_i - c_i) + (p_i - c_i)\left[\frac{\Delta p - \Delta c}{2\beta\tau^2}\right] + \int_0^{\frac{1}{8}} (v + q_i - \tau x)\, dx,$$

where the first two summands represent the sum of public expenditure and hospital profits deriving from patients located, respectively, in regions $i$ and $j$, and the third summand is the welfare of regional patients.

If, instead, $\Delta p < \Delta c$ (i.e., region $j$ attracts patients from region $i$), then

$$W_i^E = (-\lambda p_i - c_i)\left[\frac{1}{8} + \frac{\Delta p - \Delta c}{2\beta\tau^2}\right] - (1+\lambda)p_j\left[-\frac{\Delta p - \Delta c}{2\beta\tau^2}\right] +$$
$$+ \int_0^{\frac{1}{8}+\frac{\Delta p - \Delta c}{2\beta\tau^2}} (v + q_i - \tau x)\, dx + \int_{\frac{1}{8}+\frac{\Delta p - \Delta c}{2\beta\tau^2}}^{\frac{1}{8}} (v + q_j - \tau(\frac{1}{4} - x))\, dx,$$

where the terms in the first row give the sum of public expenditure and hospital profits deriving from patients located, respectively, in regions $i$ and $j$, and the terms in the second row give the welfare of regional patients.

Let us assume, without loss of generality $c_A < c_B$.

*Remark* 1. In this model, in order to assure feasibility of the obtained solutions, that is, assuring strictly positive quality levels that also constitute a Nash equilibrium for the static first stage game between the regions and a maximum point in the central government decision case, we have to make the following assumption:

$$\frac{1}{\beta\left(\lambda + \frac{1}{2}\right)} < \tau < \frac{1}{\beta\lambda}. \tag{7}$$

Verbally, assume that the parameter capturing the marginal disutility of distance to travel, $\tau$, is (a) above a lower bound and (b) below an upper bound threshold level. Among other implications, the latter entails that the second-order condition of the price setters' problems is met; otherwise, the maximum problem of price setting would have no finite solution. The former entails positive quality levels in equilibrium and optimal price levels above marginal costs; these features—though not strictly necessary—make the solutions more immediate to understand and comparisons across different solutions easier. More in general, it makes sense to assume that the travel cost disutility is included in a limited range. Loosely speaking, if the disutility of travel was "too low," only service quality would matter in the consumer choice, and the problem of local regulation would lose significance, along with the problems linked to patients' mobility. On the contrary, if the disutility of travel was "too high," a world without mobility across regions would emerge, with no interest for the investigation at hand. Neither of these outcome is realistic. A closed range for the parameter capturing the disutility of travel is consistent with the existence of an economically meaningful equilibrium, with a positive degree of interregional mobility of consumer or patients: This is consistent with the empirical evidence provided by the real world.

In addition to this, we restrict our attention to interior solutions, that is, we only focus on the more interesting (and realistic) equilibria in which both $H_1$ and $H_4$ from one side, hence, both $H_2$ and $H_3$ from the other, have a strictly positive demand. To this aim, we also impose the following assumption:

$$c_B - c_A < \frac{\tau[\beta\tau(2\lambda+1) - 1]}{4(\lambda+1)} \tag{8}$$

Given Equation 7, a sufficient condition in order for Equation 8 to be satisfied is[7]:

$$c_B - c_A < \frac{1}{2\beta(\lambda+1)(2\lambda+1)}. \tag{9}$$

In the remainder, with a slight abuse of terminology, we call *interior Nash equilibrium* a Nash equilibrium of the first-stage static game between the regions that leads to an interior subgame perfect solution, that is, to quality levels

[7]In fact, under Equation 7, the threshold specified in the right-hand side (RHS) of Equation 8 is increasing in $\tau$; therefore, by considering $\tau = \frac{1}{\beta\left(\lambda+\frac{1}{2}\right)}$, the considered sufficient condition is obtained.

ensuring strictly positive demand levels for both $H_1$ and $H_4$ from one side, hence, both $H_2$ and $H_3$ from the other. Lastly, coherently with the notation used above, we denote $\Delta p = p_A - p_B, \Delta c = c_A - c_B < 0$.

### 3.3 | First stage game: DRG price setting by regional regulators

The following proposition[8] provides the Nash equilibrium of the noncooperative first-stage static game between the regions that leads to an interior subgame perfect solution.

**Proposition 1.** *Under Equations 7 and 8, the interior Nash equilibrium of the noncooperative first-stage static game between the regions is given by the pair $(p_A^*, p_B^*)$, where*

$$p_A^* = \frac{-\beta^2\tau^3\lambda(2\lambda+1) + \beta\tau[2\lambda c_A + \lambda(3\tau + 2c_B) + \tau + 2c_B] - 2c_A - \tau}{2[\beta\tau(2\lambda+1) - 1]}, \quad p_B^* = c_B + \frac{\tau}{2}(1 - \lambda\beta\tau), \tag{10}$$

*and it holds $p_A^* > p_B^*$, hence, in the considered Nash equilibrium*[9] $\Delta p > \Delta c$.

*Consequently, the subgame perfect solution is given by*

$$q_A^*(p_A^*) = \frac{-\beta^2\tau^2\lambda(2\lambda+1) + \beta[\lambda(3\tau + 2c_B) + \tau + 2c_B - 2c_A(\lambda+1)] - 1}{2\beta[\beta\tau(2\lambda+1) - 1]},$$

$$q_B^*(p_B^*) = \frac{1 - \beta\lambda\tau}{2\beta},$$

*with $q_A^*(p_A^*) > q_B^*(p_B^*)$.*

Some comments are in order. First, the cost parameter of hospitals located in $R_A$ does not enter the optimal price of $R_B$, whereas the opposite is not true. We do not spend several words on this feature, because it depends on the very simple structure of the problem and the linearity of the objective function of the $R_A$'s regulator: The problem of the $R_A$'s regulator has a finite solution only if the DRG price set by $R_B$ is given by the production cost in that region plus a markup. Second, DRG price exceeds marginal cost, in all regions. Third, in equilibrium, the optimal DRG price is higher in the region where hospitals are more efficient. This theoretical result may appear counterintuitive at the first sight; however, it is due to the larger incentive for the regional regulator to attract an external demand. Fourth, in the considered equilibrium, under the sufficient condition for an interior Nash equilibrium (9), the hospitals' operative profits (i.e., the profits computed by disregarding fixed cost and possible transfer) are such that $\Pi_A^* > \Pi_B^* > 0$. Lastly, the larger the difference in cost efficiency, the larger the difference in quality level, with the more efficient region providing the higher quality service.

Interestingly, the DRG fixed by the more efficient region is negatively dependent on the treatment cost of its own provider, while the opposite holds true for the other region. Furthermore, only the price of the more efficient region is also a function of the cost of the other provider, and in particular, $p_A^*$ is positively dependent on $c_B$. Accordingly, the quality level of the more efficient provider is positively dependent on $c_B$ and negatively dependent on $c_A$, whereas the quality of the less efficient provider is independent on both $c_A$ and $c_B$.

All together and in terms of comparative statics, these results imply that both the regulated prices increase, as well as the quality of the more efficient providers, as the asymmetry in the providers' efficiency levels increases. As for the role played by the transportation cost, an increase in $\tau$ results in an increase (resp. decrease) of $p_B^*$ for low (high) value of the transportation cost itself,[10] while it always results in a lower value for $p_A^*$, as well as for both the equilibrium quality levels. The level of transportation cost can be interpreted as an inverse measure of the market competition fierceness: the lower $\tau$, the lower the local market power, the harsher the competition. So, a higher degree of competition (as measured by transportation cost) improves the equilibrium product quality of the less efficient provider ($\partial q_B^*/\partial\tau < 0$), while it has nonmonotonic effect on the equilibrium quality of the most efficient provider. The absence of clear-cut effect of competition fierceness on equilibrium quality is a cornerstone of this literature vein (see, e.g., the review in Brekke et al., 2018). Not surprisingly, the regulated prices are also decreasing in the opportunity cost of public funds.

[8]All the proofs are shown in the Appendix.

[9]In Appendix A.1, we prove that there not exists any interior Nash equilibrium such that $\Delta p < \Delta c$.

[10]This result applies for the most realistic cases with $\lambda < \frac{1}{2}$. All the details about the comparative static can be found in Appendix A.1.

## 4 | DRG PRICE SETTING UNDER A CENTRAL AUTHORITY DECISION

We now determine the price levels that, given the Nash equilibrium strategies of the hospitals, a central government would fix in order to maximize the aggregated social welfare function, in which we consider

$$q_A = q_1^*(p_A) = q_2^*(p_A),\ q_B = q_3^*(p_B) = q_4^*(p_B).$$

We still develop the computations under the assumptions that rule out corner solutions (i.e., we assume that the demand is positive for each hospital) and in the benchmark case $c_A < c_B$. We observe

$$x_1^D + x_2^D = \frac{1}{4} + 2\left(\frac{1}{8} + \frac{q_A - q_B}{2\tau}\right) = \frac{1}{2} + \frac{q_A - q_B}{\tau}.$$

Analogously,

$$x_3^D + x_4^D = \frac{1}{2} - \frac{q_A - q_B}{\tau}.$$

Therefore, by considering the same opportunity cost $\lambda$ of public expenditures, we obtain the following aggregated social welfare function

$$S = (-\lambda p_A - c_A)\left(\frac{1}{2} + \frac{q_A - q_B}{\tau}\right) + (-\lambda p_B - c_B)\left(\frac{1}{2} - \frac{q_A - q_B}{\tau}\right) - \beta(q_A^2 + q_B^2) +$$

$$+2\int_0^{\frac{1}{8}} (v + q_A - \tau x)dx + 2\int_0^{\frac{1}{8}} (v + q_B - \tau x)dx +$$

$$+2\int_0^{\frac{1}{8}+\frac{q_A-q_B}{2\tau}} (v + q_A - \tau x)\,dx + 2\int_{\frac{1}{8}+\frac{q_A-q_B}{2\tau}}^{\frac{1}{4}} (v + q_B - \tau(\frac{1}{4} - x))dx,$$

where the terms in the first row represent the hospitals' profits and the public expenditures; the terms in the second row are the internal welfare of the patients of the two regions, and the terms in the third row constitute their external welfare.

**Proposition 2.** *Under Equations 7 and 8, the centralized optimal prices are given by*

$$\bar{p}_A = \frac{-\beta^2\lambda\tau^3(2\lambda+1) + \beta\tau[2c_A(3\lambda+1) + \lambda(3\tau + 2c_B) + \tau + 2c_B] - 4c_A - \tau}{4[\beta\tau(2\lambda+1) - 1]}, \tag{11}$$

$$\bar{p}_B = \frac{-\beta^2\lambda\tau^3(2\lambda+1) + \beta\tau[2c_A(\lambda+1) + 3\lambda(\tau + 2c_B) + \tau + 2c_B] - 4c_B - \tau}{4[\beta\tau(2\lambda+1) - 1]}, \tag{12}$$

*where $\bar{p}_A > \bar{p}_B$. Therefore, $\Delta p > \Delta c$.*

*The corresponding optimal qualities are thus given by*

$$q_A^*(\bar{p}_A) = \frac{-\beta^2\tau^2\lambda(2\lambda+1) + \beta[\lambda(3\tau + 2c_B) + \tau + 2c_B - 2c_A(\lambda+1)] - 1}{4\beta[\beta\tau(2\lambda+1) - 1]},$$

$$q_B^*(\bar{p}_B) = \frac{-\beta^2\tau^2\lambda(2\lambda+1) + \beta[2c_A(\lambda+1) + \lambda(3\tau - 2c_B) + \tau - 2c_B] - 1}{4\beta[\beta\tau(2\lambda+1) - 1]},$$

*with $q_A^*(\bar{p}_A) > q_B^*(\bar{p}_B)$.*

Thus, even under a central authority setting the DRG prices in all regions, the optimal price is higher for the regions with more efficient hospitals. Hence, it is intriguing to observe that the price setting rule suggested by our theoretical model is the opposite with respect to what we often observe in the real world, where higher DRG prices are in operation in regions where hospitals are more inefficient. Furthermore, the quality of the services is higher for the region with the more efficient hospitals and higher regulated price.

Differently from what we get in the previous section, both the centralized prices are increasing with respect to both $c_A$ and $c_B$. The equilibrium quality level of each provider is a decreasing function of his own treatment cost, and it is increasing (resp. decreasing) in the cost of the other provider if the cost of investments in quality is relatively big (small) with respect to the opportunity cost of public funds, in particular if $\beta > \frac{1}{2(\lambda+1)}$.

In Appendix A.2, we also show that the quality level of the most efficient provider is always decreasing with respect to the transportation cost, while, as for the other hospital, this can be true, depending on the cost differential, either for all $\tau$ or only for high values of $\tau$. Lastly, as in the previous model, the regulated prices (hence, the quality levels) are decreasing with respect to the opportunity cost of public funds.

## 5 | POLICY IMPLICATIONS: A BRIEF COMPARISON AMONG THE SOLUTIONS

A comparison between the equilibrium solution in the case of regionally decentralized regulation and the national regulation can be easily made.

It holds[11] $\bar{p}_A < p_A^*$ and $\bar{p}_B < p_B^*$. It is also easy to see that $q_A^*(\bar{p}_A) = \frac{1}{2} q_A^*(p_A^*)$ and $q_B^*(\bar{p}_B) < q_B^*(p_B^*)$. Notice that the interregional mobility—and, as a consequence, the hospitals demand levels—coincide under both decision regimes (the regional decentralized regulation and the central national authority), because we get the same difference in the DRG values[12]:

$$\Delta p^* = \Delta \bar{p} = \frac{(1 - \beta\lambda\tau)(c_B - c_A)}{\beta\tau(2\lambda + 1) - 1}.$$

Thus, the following conclusions emerge from this simple model. (a) Regionally decentralized price regulation leads to higher price levels. (b) This entails higher quality levels of the produced services, under regionally decentralized price regulation. (c) The degree of interregional consumers' mobility does not change between the regimes of regional versus national price regulation. (d) Hence, regional decentralization entails higher consumer welfare, in front of the same degree of interregional mobility and higher quality levels. (e) No clear-cut analytical conclusions can be reached concerning the providers' operative profits: Indeed, price (and hence, revenue) levels are higher under the regional regulation, but quality levels are also larger, entailing larger costs; thus, operative profit may be larger or smaller, depending on parameter configuration. (f) Under both the regional decentralized regime and the central national authority, the lower the providers' marginal cost of production, the higher the optimal regulated price. (g) The differential between regulated price levels across regions is proportional to the differential in marginal costs.

Surely, strategic interdependence among regional price regulators is a source of allocative inefficiency, but at the same time, this characteristic is beneficial to patients. It is also worth underlining, as already noted by Miraldo, Siciliani, and Street (2011), that, in contexts like this, price has two effects or plays a double role: The first is the usual one in terms of attaining allocative efficiency; the second is in terms of rent extraction.

Lastly, we emphasize that, in both the decision models, as the transportation cost increases, the DRG differential decreases. As a consequence, also the quality difference decreases. Nevertheless, a decrease in the migrational flow obtains (see Appendix A.2): as expected, a costlier patient mobility leads, in both the examined solutions, the regulators to set prices which, in equilibrium, entail a lower migrational flow.

## 6 | EXTENSIONS

The present article flows in a literature where similar models are already available. Our present analysis contributes in highlighting the sequential structure of decision chain, where policy makers set price in a previous stage and then profit-oriented providers take their decisions on quality, which in turn determines the patients' choice. The model can be modified or extended along different routes. As a first exercise, we check what happens in the presence of increasing marginal cost of treatment (Section 6.1). Then, we consider two substantial modifications to the model, namely, the (realistic) case in which the price for extraregional treatment is centrally set by a national authority, as it happens in

[11]In fact, the following inequalities are satisfied for $c_B - c_A > \theta_1$, with $\theta_1 < 0$ given by (A2) in Appendix A.1.
[12]However, this specific result is driven by the simple functional forms considered in the basic version of the model.

several Western countries, included, for example, Italy (Section 6.2) and the case in which opportunity costs of public funds for health differ across regions, as a realistic consequence of different income levels across regions (Section 6.3). Other modifications are possible, and left to the readers.[13]

## 6.1 | Increasing marginal cost of treatment

In this subsection, we limit to sketch how the outcome of the second stage of our basic model changes, by assuming a cost function that is quadratic not only in the quality levels but also in the produced quantity. Clearly, the linear versus convex form of the cost function (that is, the assumption of constant vs. increasing marginal cost) corresponds to different features concerning the pattern of productivity and diseconomies of scale. A large body of theoretical and empirical literature is available concerning the linear versus convex cost function for production by hospitals. A convex function captures the presence of excess demand and/or capacity constraint.[14]

Under the assumption of increasing marginal cost, and specifically the quadratic cost function, the profit function for hospital $i$ (still apart from fixed cost and lump-sum transfer) is given by

$$\Pi_i = p_i x_i^D - c_i[x_i^D]^2 - \frac{\beta}{2}q_i^2, \tag{13}$$

where

$$x_i^D = \frac{1}{4} + \frac{q_i - q_{i+1}}{2\tau} + \frac{q_i - q_{i-1}}{2\tau}.$$

**Proposition 3.** *The Nash equilibrium of the second-stage game among the providers is given by*

$$q_A^*(p_A, p_B) = \frac{2[c_A(p_B - c_B) + p_A c_B] - \beta\tau^2(c_A - 2p_A)}{2\beta\tau(\beta\tau^2 + c_A + c_B)},$$

$$q_B^*(p_A, p_B) = \frac{2[c_A(p_B - c_B) + p_A c_B] - \beta\tau^2(c_B - 2p_B)}{2\beta\tau(\beta\tau^2 + c_A + c_B)}.$$

*And we get*

$$q_A^*(p_A, p_B) > q_B^*(p_A, p_B) \iff p_A - p_B > \frac{c_A - c_B}{2}.$$

Therefore, the quadratic structure of the costs leads to Nash equilibrium strategies for all the hospitals that depend on the DRG prices chosen by both regions. A sufficient condition for the positivity of the quality levels is that $p_i \geq c_i$. Here, both $q_A^*$ and $q_B^*$ are clearly increasing in both $p_A$ and $p_B$.

## 6.2 | Exogenous DRG for extraregional treatments

It is interesting to consider the coexistence of differentiated regional DRG prices for regional residents, joint with an unique DRG price, fixed by a national authority, for extraregional treatments; this configuration is the closest to the current situation in countries like Italy.[15]

[13]For instance, the regions may differ in size: Following the seminal paper of Kanbur and Keen (1993), one could assume that the mass of people populating the regions is different. In such a circumstance, one can consider the case that the more populated region is the one with hospitals with higher or lower cost efficiency; in this case, the problem of endogenous spatial location of providers does make sense (see, e.g., Gravelle, Scott, Sivey, & Yong, 2016), and the location choice can be made by providers themselves or by regional regulators. Again, following the seminal contribution of Ellis and McGuire (1986) or the more recent Siciliani et al. (2013), one could consider the case in which providers differ as far as their objective function is concerned, by assuming that one provider is "mission oriented" and exhibits semialtruistic preferences. In such a case, conflicting incentives are in operation, and conclusions heavily depend on parameter configuration.

[14]The form of cost function corresponds to specific features of service organization and institutional arrangements. Excess demand and capacity constraints are usual in more regulated systems, like Italy, Spain, and also the United Kingdom. A strictly convex cost structure means that treating one extra patient becomes increasingly costly. Rigid capacity (where marginal cost is infinite at production levels beyond the capacity) is rare to observe, as long as hospitals usually have way to increase production beyond the efficient level, for example, by leaving patient in corridors, making personnel and machinery work overtime, and so on. See, for example, the review in Folland, Goodman, and Stano (2004); see also Brekke, Cellini, Siciliani, and Straume (2010) where constant or increasing marginal costs are associated to equilibria with strongly different properties.

[15]Brekke et al. (2014) specifically investigate the effects of different regimes in the extraregional treatment prices.

Let $\varphi$ denote the DRG fixed by the national authority for extraregional treatments. For simplicity, we take this value as exogenously given. Then, the profit of each provider $i = 1, \dots, 4$ is given by

$$\Pi_i = (p_i - c_i)x_i^I + (\varphi - c_i)x_i^E - \frac{\beta}{2}q_i^2, \tag{14}$$

where $x_i^I$ and $x_i^E$, respectively, denote the domestic (intraregional) and external (extraregional) demand for the hospital $i$ under consideration, respectively. Let $i - 1$ be the provider located in the same region as $i$, while the $i + 1$ provider is located in the other region. Hence,

$$x_i^I = \frac{1}{8} + \frac{q_i - q_{i-1}}{2\tau} + \min\left(\frac{1}{8}, \frac{1}{8} - \frac{q_{i+1} - q_i}{2\tau}\right),$$
$$x_i^E = \max\left(0, \frac{q_i - q_{i+1}}{2\tau}\right).$$

In the remainder, we focus on an interior Nash equilibrium entailing higher quality levels for the two more efficient providers, namely, those located in Region A. In order for such an equilibrium to exist, besides Equation 7, we consider the following restriction on the price[16] $\varphi$:

$$\frac{(\lambda+1)(\tau+4c_B) - 2\beta\tau^2(\lambda+1)^2 - 2c_A(\lambda+2)}{2\lambda} < \varphi < \frac{\lambda(\tau+4c_B) + 4c_B - 2\beta\lambda\tau^2(\lambda+1) - 2c_A(\lambda+2)}{2\lambda}. \tag{15}$$

Under such requirements, at the second-stage game, for given prices $p_A, p_B$, and $\varphi$, the providers located in Regions A and B set the quality levels:

$$q_A = \frac{p_A + \varphi - 2c_A}{2\beta\tau}, \qquad q_B = \frac{p_B - c_B}{\beta\tau}. \tag{16}$$

The equilibrium prices and the subgame perfect outcome are shown in the following proposition.

**Proposition 4.** *An interior Nash equilibrium of the noncooperative first-stage static game between the regions is given by the pair* $(p_A^*, p_B^*)$, *where*

$$p_A^* = \frac{\tau + 2c_A - 2\beta\lambda\tau^2}{2},$$
$$p_B^* = \frac{-2\beta^2\lambda\tau^3(\lambda+1) - \beta\tau[2\lambda c_A - \lambda(6\varphi + 3\tau + 4c_B) - 2(2\varphi + \tau + 2c_B)] + 2(c_A - \varphi) - \tau - 4c_B}{4(2\beta\tau(\lambda+1) - 1)}. \tag{17}$$

*Consequently, the subgame perfect solution is given by*

$$q_A^*(p_A^*) = \frac{2(\varphi - c_A) + \tau - 2\beta\lambda\tau^2}{4\beta\tau},$$

$$q_B^*(p_B^*) = \frac{-2\beta^2\lambda\tau^3(\lambda+1) - \beta\tau[2\lambda c_A - \lambda(6\varphi + 3\tau - 4c_B] + 2(2\varphi + \tau - 2c_B)) + 2(c_A - \varphi) - \tau}{4\beta\tau(2\beta\tau(\lambda+1)) - 1}.$$

Simple comparative static shows that, as $\varphi$ increases, both the equilibrium quality levels increase, but the quality differential and the migration flow decreases. Hence, the higher the price for extraregional treatment, the lower the quality differential across regions.

## 6.3 | Asymmetries in the opportunity cost of public funds

In this subsection, a different kind of asymmetry between regions is introduced, concerning the opportunity cost of public spending for health: Parameter $\lambda$ may differ across regions, representing different political views between local authorities. A good reason why opportunity costs may be different across regions can rest on income differentials and the consequent different needs for additional policy interventions: Roughly speaking, one can imagine that the lower the regional average income is, the larger the opportunity cost associated with health are, in front of the more urgent need to policy intervention in other fields. We consider $\lambda_A < \lambda_B$ and, for simplicity, the same marginal cost $c$ across providers.

[16]The lower bound condition to $\varphi$ implies $q_A^*(p_A^*) > q_B^*(p_B^*)$, whereas the upper bound condition assures an interior solution.

Accordingly, the Nash equilibrium of the second-stage game between the providers is

$$q_i = \frac{p_i - c}{\beta\tau}.$$

As usual, we confine our attention on an interior Nash equilibrium entailing higher quality levels for the providers of the more efficient region (i.e., Region A). The existence for such an interior equilibrium requires

$$\frac{1}{\beta(2\lambda_A + 1)} < \tau < \frac{\sqrt{4\lambda_A + 4\lambda_B^2 + 1} + 2\lambda_B + 1}{2\beta(\lambda_B - \lambda_A)}. \tag{18}$$

Under such a condition, the following results hold.

**Proposition 5.** *An interior Nash equilibrium of the noncooperative first-stage static game between the regions is given by the pair* $(p_A^*, p_B^*)$*, where*

$$p_A^* = \frac{-\beta^2\tau^3[2\lambda_A(\lambda_B + 1) - \lambda_B] + \beta\tau[2c(2\lambda_B + 1) + \tau(\lambda_A + 2\lambda_B + 1)] - 2c - \tau}{2[\beta\tau(2\lambda_B + 1) - 1]},$$

$$p_B^* = \frac{2c + \tau - \beta\lambda_A\tau^2}{2}. \tag{19}$$

*Whereas the centralized optimal prices are given by*

$$\bar{p}_A = \frac{-2\beta^2\tau^3[\lambda_A(\lambda_B + 1) + \lambda_B^2] + \beta\tau[8c(2\lambda_B + 1) + \tau(\lambda_A + 5\lambda_B + 2)] - 2(4c + \tau)}{8[\beta\tau(2\lambda_B + 1) - 1]},$$

$$\bar{p}_B = \frac{-2\beta^2\lambda_B\tau^3(\lambda_A + \lambda_B + 1) + \beta\tau[8c(2\lambda_B + 1) + \tau(\lambda_A + 5\lambda_B + 2)] - 2(4c + \tau)}{8[\beta\tau(2\lambda_B + 1) - 1]}. \tag{20}$$

In Appendix, we show that (a) in both the models, the migrational flow is a decreasing function with respect to $\lambda_A$, whereas it is an increasing function with respect to $\lambda_B$; (b) if $\tau$ is small (resp. big) enough in relation to $\beta$, then we have a higher migrational flow in the decentralized (resp. centralized) solution. As an interesting implication of the former property, we can observe that the larger the disparity in opportunity costs—motivated, for instance, by a larger disparity in income levels—the larger the interregional migration flow; hence, an (exogenous) convergence in regional income levels implies a reduction in migration flow.

## 7 | CONCLUDING REMARKS

In this paper, we have proposed a modification of the spatial competition model à la Salop, able to distinguish between intraregional and interregional competition. Our model is particularly appropriate to study markets in which producers (or, more generally, service providers) compete in quality, prices are regulated by local public authorities, and consumers are mobile across regions and choose on the basis of providers' location and service quality. In such a framework, interdependence links do exist not only among providers and between providers and authorities but also among authorities. The health care markets, and specifically the market for hospital services, is the most clear empirical counterpart for our theoretical model. However, the theoretical model can be easily applied to other sectors, like school and education, or long-term care, where competition is typically based on quality, and prices are regulated, usually by local or regional authorities.

The interdependence among regional regulators as price setters is the key contribution of the present article to the theoretical literature dealing with service provision with quality competition under regulated prices. We have specifically thought of the health care markets, where the interactions between local authorities, and their consequences, are well documented by empirical investigations but are overlooked by theoretical models, which mainly focus on quality decisions.

More specifically, in our model, the regulator controls one instrument, namely, the price of local providers; with such a unique instrument, the regulator affects both quality and interregional migration flow. Clearly, the fact that the regulated price is the unique instrument used by local regulator is disputable with respect to the real world. However, price regulation is much simpler than other forms of regulation, and it is widely used: The price regulation is very pervasive, in most Western countries through the DRG system. Thus, we do believe that the present model has relevant elements of realism: The interdependence among regional price regulators is an important aspect overlooked by available literature but deserving theoretical attention. Our present model can be a useful starting point for policy analysis and the investigation about the effects of different institutional designs in the presence of links of strategic interdependence in the stage of price design.

In the simple framework at hand, we have shown that higher regulated prices associate, in equilibrium, with more efficient providers; however, this also joins with higher quality levels of the provided service. From a policy perspective, our model suggests that national price regulation drives to lower regulated price levels and hence to smaller public expenditure. However, this fact is detrimental to the consumers or patients' welfare, because the fierceness of (interregional) competition is more limited. So, in other words, the well-known static trade-off between sound public finance and citizens' welfare does emerge here, with specific respect to costs and benefit of decentralization: Decentralized regulation is detrimental to public finance but beneficial to consumers.

Simple and realistic variants to the basic model have driven to show that a price for extraregional treatment, set by a central national authority, can affect service quality and interregional migration flowing: Higher price for extraregional treatment leads to smaller quality differential and more limited interregional flow. Again, higher asymmetry across opportunity costs of public funds for health, motivated, for example, by larger differential in regional income levels, associate with larger interregional migration flow.

Admittedly, additional ingredients would deserve deeper attention. For instance, partial reimbursement for extraregional treatment is an element of realism, able to affect some conclusions concerning the interregional migration flows, especially in the case in which income levels differ across regions. The existence of strict capacity constraints, with reference to the number of admissible patients, could be taken into account, and so on. Although these research questions are in our research agenda, we observe that the present simple model has the advantage of focussing on costs and benefits of the price-regulation decentralization, which is a very common feature of national health systems in the real world.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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## APPENDIX A: PROOFS

### A.1 Proof of Proposition 1 and related results

Given the Nash equilibrium strategies of the hospitals, it holds

$$W_i^I = \frac{1}{4}(-\lambda p_i - c_i) + \frac{1}{4}\left(v + \frac{p_i - c_i}{\beta\tau}\right) - \frac{\tau}{64},$$

for $i \in \{A, B\}$.

Let us consider the case

$$p_A - p_B > c_A - c_B, \tag{A1}$$

that is, $\Delta p > \Delta c$.

Under this assumption, in the case of the Region $A$ ($R_A$), we have

$$W_A^E = \frac{1}{8}(-\lambda p_A - c_A) + (p_A - c_A)\left[\frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right] + \frac{1}{8}\left(v + \frac{p_A - c_A}{\beta\tau}\right) - \frac{\tau}{128}.$$

For the Region$B$ ($R_B$), we obtain

$$\begin{aligned} W_B^E = {} & (-\lambda p_B - c_B)\left[\frac{1}{8} - \frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right] - (1+\lambda)p_A\left[\frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right] + \\ & + \left(v + \frac{p_B - c_B}{\beta\tau}\right)\left[\frac{1}{8} - \frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right] - \frac{\tau}{2}\left[\frac{1}{8} - \frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right]^2 + \\ & + \left(v + \frac{p_A - c_A}{\beta\tau} - \frac{\tau}{4}\right)\left[\frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right] + \frac{\tau}{2}\left\{\frac{1}{64} - \left[\frac{1}{8} - \frac{(p_A - p_B) - (c_A - c_B)}{2\beta\tau^2}\right]^2\right\}. \end{aligned}$$

Notice that $R_A$ receives a welfare benefit from the fact that patients from $R_B$ are served by hospitals located in $R_A$, as long as $p_A^* > c_A$. For these "migrant patients" the payment is done from $R_B$ to $R_A$; however, it is reasonable to include the individual welfare of these patients in the social welfare function of origin region.

After some algebra, we have

$$W_A = W_A^I + 2W_A^E - \beta q_A^2 = \frac{16(c_A - p_A)(2p_B - 2c_B - \tau) - \beta\tau^2(16c_A + 16\lambda p_A + \tau - 16v)}{32\beta\tau^2}$$

$$\begin{aligned} W_B = W_B^I + 2W_B^E - \beta q_B^2 = {} & \frac{1}{32\beta^2\tau^3}\{-\beta^2\tau^3[16\lambda p_B + \tau + 16(c_B - v)] + \\ & +16\beta\tau\{2c_A[\lambda(p_A - p_B) + p_A - c_B] + 2\lambda(p_A - p_B + c_B)(p_B - p_A) - 2p_A^2 + 2p_Ap_B + (c_B - p_B)(2p_B - \tau)\} + \\ & +16(c_A - p_A + p_B - c_B)^2\}. \end{aligned}$$

Notice that $W_A$ is linear in the choice variable $p_A$; thus, the best reply function $p_A = p_A(p_B)$ is a degenerate function in which $p_A$ is plus (or minus) infinite, according to the fact that the coefficient of $p_A$ in $W_A$ is positive (or negative). The only finite solution corresponds to the case in which the coefficient of $p_A$ in $W_A$ is nil (which, by the way, correspond to the condition $\partial W_A/\partial p_A = 0$). From the first-order condition (FOC) $\partial W_B/\partial p_B = 0$, a well-behaved best reply function of the regulator of Region B can be easily derived. It is immediate to verify that the function $p_B = p_B(p_A)$ is positively sloped, as long as Equation 7 is met. Thus, the Nash equilibrium shown in Proposition 1 derives from the system:

$$\begin{cases} -\dfrac{\beta\lambda\tau^2 + 2p_B - \tau - 2c_B}{2\beta\tau^2} = 0 \\ -\dfrac{\beta^2\lambda\tau^3 + \beta\tau[2\lambda c_A - 2\lambda(2p_A - 2p_B + c_B) - 2p_A + 4p_B - \tau - 2c_B] - 2(c_A - p_A + p_B - c_B)}{2\beta^2\tau^3} = 0. \end{cases}$$

Because it holds that

$$\frac{\partial^2 W_A}{\partial p_A^2} = 0, \quad \frac{\partial^2 W_B}{\partial p_B^2} = \frac{1 - 2\beta\tau(\lambda+1)}{\beta^2\tau^3},$$

the FOCS are also sufficient if

$$\tau > \frac{1}{2\beta(\lambda+1)}.$$

This condition is verified under Equation 7.

In order $(p_A^*, p_B^*)$ to be the Nash equilibrium, we have to check that $p_A^* - p_B^* > c_A - c_B$ (A1). Because we have assumed $c_A < c_B$, this condition is verified if

$$\tau > \frac{1}{\beta\left(\lambda + \frac{1}{2}\right)}.$$

The last condition is implied by Equation 7.

By substituting $p_A^*$ and $p_B^*$ in the Nash equilibrium strategies of the hospitals, we obtain the subgame perfect solution given in Proposition 1.

It holds that

$$q_A^*(p_A^*) - q_B^*(p_B^*) = \frac{(c_B - c_A)(\lambda+1)}{\beta\tau(2\lambda+1) - 1} > 0,$$

under Equation 7, because it must hold $\tau > 1/\left[\beta\left(\lambda + \frac{1}{2}\right)\right]$.

Finally, it is worth noting that the condition $\tau < \frac{1}{\beta\lambda}$ in Equation 7 assures positivity of the Nash equilibrium quality levels: $q_A^*(p_A^*) > q_B^*(p_B^*) > 0$ .

We now consider the case $\Delta c > \Delta p$. In this case, patients move from $R_A$ to $R_B$, and the welfare functions switch between regions. Thus, equilibrium prices would be

$$p_B^* = \frac{\beta^2\tau^3\lambda(2\lambda+1) - \beta\tau[2\lambda c_B + \lambda(3\tau + 2c_A) + \tau + 2c_A] + 2c_B + \tau}{2[1 - \beta\tau(2\lambda+1)]}, \quad p_A^* = c_A + \frac{\tau}{2}(1 - \lambda\beta\tau).$$

The corresponding second-order conditions (SOC) requires $\tau > 1/[2\beta(\lambda + 1)]$. Moreover, the condition $\Delta p < \Delta c$, joint with $c_A < c_B$, requires $\tau < 1/[\beta(2\lambda + 1)]$. The latter implies that the condition ensuring positive quality levels, that is, $\tau < 1/(\beta\lambda)$, is met. Hence, the appropriate assumption to make in the case $\Delta c > \Delta p$, replacing Equation 7, is

$$\frac{1}{2\beta(\lambda+1)} < \tau < \frac{1}{\beta(2\lambda+1)}.$$

However, this requirement is not compatible with Equation 8. In fact, for $\tau = \frac{1}{2\beta(\lambda+1)}$, Equation 8 becomes $c_B - c_A < -\frac{1}{16\beta(\lambda+1)^3} < 0$, whereas for $\tau = \frac{1}{\beta(2\lambda+1)}$, it it reads $c_B - c_A < 0$, thus, contradicting $c_A < c_B$. This proves that an interior Nash equilibrium in which $\Delta p < \Delta c$ does not exist.

As for the comparative static[17] of the relevant quantities with respect to the transportation cost, it holds

$$\frac{\partial p_B^*}{\partial \tau} = \frac{1 - 2\beta\lambda\tau}{2}.$$

For every[18] $\lambda < \frac{1}{2}$, this quantity is positive (resp. negative) for $\frac{1}{\beta(\lambda+\frac{1}{2})} < \tau < \frac{1}{2\beta\lambda}$ (resp. $\frac{1}{2\beta\lambda} < \tau < \frac{1}{\beta\lambda}$ ). When $\frac{\partial p_B^*}{\partial \tau} < 0$, so it is also $\frac{\partial p_A^*}{\partial \tau}$, because it holds

$$\frac{\partial p_A^*}{\partial \tau} = \frac{\beta(c_A - c_B)(\lambda+1)}{(\beta\tau(2\lambda+1)-1)^2} + \frac{\partial p_B^*}{\partial \tau}.$$

However, simple calculations show that this quantity is always negative in the feasible range of the parameters when $\lambda$ is sufficiently high ($\lambda > \frac{1}{16}$).

We now turn on the quality levels:

$$\frac{\partial q_A^*(p_A^*)}{\partial \tau} = -\frac{\beta^2\lambda\tau^2(2\lambda+1)^2 - 2\beta\lambda\tau(2\lambda+1) + 2\beta(2\lambda+1)(c_B - c_A)(\lambda+1) + \lambda}{2[\beta\tau(2\lambda+1)-1]^2},$$

this quantity is negative, because the discriminant of the second degree inequality (in $\tau$): $\beta^2\lambda\tau^2(2\lambda+1)^2 - 2\beta\lambda\tau(2\lambda+1) + 2\beta(2\lambda+1)(c_B - c_A)(\lambda+1) + \lambda > 0$ is given by $-8\beta^3\lambda(c_B - c_A)(\lambda+1)(2\lambda+1)^3 < 0$. It is straightforward to get

$$\frac{\partial q_B^*(p_B^*)}{\partial \tau} = -\frac{\lambda}{2} < 0.$$

As far as the opportunity cost of public funds is concerned, we have

$$\frac{\partial p_A^*}{\partial \lambda} = \frac{\beta\tau(c_A - c_B)(\beta\tau+1)}{(2\beta\lambda\tau + \beta\tau - 1)^2} - \frac{\beta\tau^2}{2} < 0$$

and

$$\frac{\partial p_B^*}{\partial \lambda} = -\frac{\beta\tau^2}{2} < 0.$$

We can also compute the Nash equilibrium profits (or, more precisely, the operative profits which disregard fixed cost and possible transfer):

$$\Pi_A^* = \frac{[1-\beta\tau(\lambda+1)]\{\beta^2\lambda\tau^2(2\lambda+1) + \beta[2c_A(\lambda+1) - \lambda(3\tau+2c_B) - \tau - 2c_B] + 1\}}{8\beta[\beta\tau(2\lambda+1)-1]}$$

$$\Pi_B^* = \frac{1}{1-8\beta[\beta\tau(2\lambda+1)]} \cdot \{\beta^3\lambda\tau^3(\lambda+1)(2\lambda+1) + \beta^2\tau[2\lambda c_A(\lambda+1) - \lambda(\lambda+1)(5\tau+2c_B) - \tau] + \\ -2\beta[c_A(\lambda+1) - \lambda(2\tau+c_B) - \tau - c_B] - 1\}.$$

Therefore, we have

$$\Pi_A^* - \Pi_B^* = \frac{\beta\tau(\lambda+1)(c_B - c_A)}{4[\beta\tau(2\lambda+1)-1]} > 0.$$

Finally, we notice

$$\Pi_A^* \wedge \Pi_B^* > 0 \iff \theta_1 < c_B - c_A < \theta_2,$$

where, under Equation 7,

[17]The computation of the derivatives of the equilibrium prices and qualities with respect to the treatment costs is trivial.

[18]For very high opportunity cost of public funds, that is, $\lambda > \frac{1}{2}$, we have $\frac{\partial p_B^*}{\partial \tau} < 0$ for all $\tau$satisfying our assumption.

$$\theta_1 = \frac{\beta^2\lambda\tau^2(2\lambda+1) - \beta\tau(3\lambda+1) + 1}{2\beta(\lambda+1)} < 0, \tag{A2}$$

$$\theta_2 = \frac{\beta^2\tau^2(\lambda+1)(2\lambda+1) - \beta\tau(3\lambda+2) + 1}{2\beta(\lambda+1)} > 0.$$

Hence, $c_B - c_A > \theta_1$ is automatically satisfied. It is easy to prove that $c_B - c_A < \theta_2$ is implied by the sufficient condition for an interior Nash equilibrium (9). In fact, we have that the threshold specified in (9) is lower than (or equal to) $\theta_2$ if

$$-\frac{\beta^2\tau^2(\lambda+1)(2\lambda+1)^2 - \beta\tau(2\lambda+1)(3\lambda+2) + 2\lambda}{2\lambda+1} \leq 0.$$

Under Equation 7, the left-hand side (LHS) is decreasing[19] in $\tau$; hence, it takes its maximum value (compatible with Equation 7) for $\tau = \frac{1}{\beta(\lambda+\frac{1}{2})}$, but this maximum value turns out to be equal to zero.

### A.2 Proof of Proposition 2

By substituting the Nash equilibrium qualities, we obtain the FOCs:

$$\begin{cases} \dfrac{\partial S}{\partial p_A} = 0 \iff \dfrac{\beta^2\lambda\tau^3 - \beta\tau[2c_A(\lambda+1) + 2\lambda(2p_B - c_B) + \tau + 2c_B] + 2(c_A + p_B - c_B)}{2[1 - 2\beta\tau(\lambda+1)]} = 0, \\ \dfrac{\partial S}{\partial p_B} = 0 \iff \dfrac{\beta^2\lambda\tau^3 - \beta\tau[-2c_A(\lambda-1) + 2\lambda(2p_A + c_B) + \tau + 2c_B] + 2(c_B + p_A - c_A)}{2[1 - 2\beta\tau(\lambda+1)]} = 0. \end{cases}$$

The solution of this system is given by the values for $\bar{p}_A$ and $\bar{p}_B$ given in Proposition 2. This solution provides the absolute maximum of $S$ if and only if

$$\tau > \frac{1}{\beta(2\lambda+1)}. \tag{A1}$$

In fact, the Hessian matrix of $S$ is given by

$$H_S = \begin{pmatrix} \frac{1-2\beta\tau(\lambda+1)}{\beta^2\tau^3} & \frac{2\lambda\beta\tau-1}{\beta^2\tau^3} \\ \frac{2\lambda\beta\tau-1}{\beta^2\tau^3} & \frac{1-2\beta\tau(\lambda+1)}{\beta^2\tau^3} \end{pmatrix},$$

and it holds

$$\mathrm{tr}H_S = 2\frac{1-2\beta\tau(\lambda+1)}{\beta^2\tau^3} < 0 \iff \tau > \frac{1}{2\beta(\lambda+1)}$$
$$\det H_S > 0 \iff \tau > \frac{1}{\beta(2\lambda+1)},$$

so the sufficient condition for a maximum implies $\tau > \max\left(\frac{1}{2\beta(\lambda+1)}, \frac{1}{\beta(2\lambda+1)}\right)$, but because $\frac{1}{\beta(2\lambda+1)} > \frac{1}{2\beta(\lambda+1)}$, we obtain the condition (A1), which is implied by Equation 7.

It is worth noting that, if this condition is not satisfied, then $(\bar{p}_A, \bar{p}_B)$ constitutes a saddle point. The economic meaning is immediate: If the condition is not met, the problem is not concave, and the solution is not an internal, finite solution: The optimal DRG prices would be either plus or minus infinite—which is clearly meaningless from an economic point of view.

Because we are considering $c_A < c_B$, if condition (A1) holds, we have that

$$\bar{p}_A > \bar{p}_B \iff \frac{1}{\beta(2\lambda+1)} < \tau < \frac{1}{\beta\lambda},$$

and this must be verified because of Equation 7.

[19]In fact, it is increasing in $\tau$ for $\tau < \frac{3\lambda+2}{2\beta(2\lambda^2+3\lambda+1)} < \frac{1}{\beta(\lambda+\frac{1}{2})}$.

As for the comparative static, we get, for[20] $i = 1, 2$:

$$\frac{\partial \bar{p}_i}{\partial c_i} < 0 \iff \tau < \frac{2}{\beta(3\lambda + 1)} < \frac{1}{\beta(\lambda + \frac{1}{2})},$$

$$\frac{\partial q_A^*(\bar{p}_A)}{\partial \tau} = \frac{1}{2}\frac{\partial q_A^*(p_A^*)}{\partial \tau} < 0,$$

$$\frac{\partial q_B^*(\bar{p}_B)}{\partial \tau} > 0 \iff \beta^2\lambda(2\lambda + 1)^2\tau^2 - 2\beta\lambda(2\lambda + 1)\tau - 2\beta(2\lambda + 1)(\lambda + 1)(c_B - c_A) + \lambda < 0.$$

The latter inequality is verified for $\tau_1 < \tau < \tau_2$, where

$$\tau_{1,2} = \frac{2\beta\lambda(2\lambda + 1) \mp \sqrt{8\beta^3\lambda(c_B - c_A)(\lambda + 1)(2\lambda + 1)^3}}{2\beta^2\lambda(2\lambda + 1)^2},$$

and it holds $\tau_1 < \frac{1}{\beta(\lambda+\frac{1}{2})}$, $\tau_2 < \frac{1}{\beta\lambda}$ (because the opposite would hold true for $c_B - c_A > \frac{\lambda+1}{2\beta\lambda(2\lambda+1)}$, which contradicts the sufficient condition 9 for an interior Nash equilibrium), $\tau_2 > \frac{1}{\beta(\lambda+\frac{1}{2})}$ if $c_B - c_A > \frac{\lambda}{2\beta(\lambda+1)(2\lambda+1)}$, which is compatible with (9) for every $\lambda < 1$.

The comparative static with respect to $\lambda$ gives

$$\frac{\partial \bar{p}_i}{\partial \lambda} = \frac{\beta\tau(\beta\tau + 1)(c_i - c_j)}{2(2\beta\lambda\tau + \beta\tau - 1)^2} - \frac{\beta\tau^2}{4}.$$

hence, $\frac{\partial \bar{p}_A}{\partial \lambda} < 0$, while the same is not true in general for $\bar{p}_B$; however, it can be seen that this holds true, at least for $\tau$, which is sufficiently high.

In both the decision models, it holds

$$\Delta q^* = \frac{(c_B - c_A)(\lambda + 1)}{\beta\tau(2\lambda + 1) - 1},$$

which is decreasing with respect to $\tau$.

Lastly, we compute

$$\frac{\partial \widehat{x_A^B}}{\partial \tau} = -\frac{(c_B - c_A)(\lambda + 1)[2\beta\tau(2\lambda + 1) - 1]}{2\tau^2[\beta\tau(2\lambda + 1) - 1]^2} < 0.$$

### A.3 Proof of Proposition 3

The FOC for the profit function maximization with respect to the choice variable $q_i$ leads to

$$q_i = \frac{2\tau p_i + c_i[2(q_{i-1} + q_{i+1}) - \tau]}{2(\beta\tau^2 + 2c_i)}.$$

Without loss of generality, we assume that, for the considered hospital $i$, the hospital $i - 1$ belongs to his region, while the hospital $i + 1$ belongs to the other region. Then, due to the symmetry between the regions, we impose $q_i = q_{i-1}$. This lets us to obtain the optimal response function of the hospital $i$ to the quality set by the hospitals belonging to the opponent region:

$$q_i(q_j) = \frac{\tau p_i + c_i(q_j - \frac{\tau}{2})}{\beta\tau^2 + c_i},$$

with $i, j \in \{A, B\}, i \neq j$. Finally, by solving this algebraic two-equation system, we get the Nash equilibrium of the second-stage game, given in Proposition 3.

[20]The other computations related to the parameters $c_A$ and $c_B$ are trivial; hence, we omit them.

It is easy to check that

$$q_A^*(p_A, p_B) - q_B^*(p_A, p_B) = \frac{\tau[2(p_A - p_B) + c_B - c_A]}{2(\beta\tau^2 + c_A + c_B)}.$$

We have, for $i, j = 1, 2, i \neq j$:

$$q_i^*(p_i, p_j) > 0 \iff p_i > c_i \frac{\beta\tau^2 - 2(p_j - c_j)}{2(\beta\tau^2 + c_j)},$$

where the RHS is strictly smaller than $c_i$.

### A.4 Proof of Proposition 4

Assume that, in equilibrium, $q_A^*(p_A^*) > q_B^*(p_B^*)$. Then, the “external” welfare of Region A is given by

$$W_A^E = \frac{1}{8}(-\lambda p_A - c_A) + (\varphi - c_i)\left[\frac{q_A^*(p_A) - q_B^*(p_B)}{2\tau}\right] + \int_0^{\frac{1}{8}} (v + q_A - \tau x)\, dx,$$

and the external welfare of Region B is given by

$$W_B^E = (-\lambda p_B - c_B)\left[\frac{1}{8} + \frac{q_A^*(p_A) - q_B^*(p_B)}{2\tau}\right] - (1+\lambda)\varphi\left[\frac{q_A^*(p_A) - q_B^*(p_B)}{2\tau}\right] +$$

$$+ \int_0^{\frac{1}{8} - \frac{q_A^*(p_A) - q_B^*(p_B)}{2\tau}} (v + q_B - \tau x)\, dx + \int_{\frac{1}{8} - \frac{q_A^*(p_A) - q_B^*(p_B)}{2\tau}}^{\frac{1}{8}} (v + q_A - \tau(\frac{1}{4} - x))\, dx.$$

The the internal welfare functions of both regions are as in the baseline model. The FOCs lead to the Nash equilibrium values given by Equation 17, while the SOCs are satisfied if and only if $\tau > \frac{1}{2\beta\tau(\lambda+1)}$, which is implied by Equation 7.

By substituting these values into the providers' Nash equilibrium quantities, given in Equation 16, we obtain the subgame perfect outcome. Then, imposing $q_A^*(p_A^*) > q_B^*(p_B^*)$ and $\frac{q_A^*(p_A^*) - q_B^*(p_B^*)}{2\tau} < \frac{1}{8}$, we derive the restrictions on $\varphi$ imposed in Equation 15.

Comparative static gives

$$\frac{\partial p_B^*}{\partial \varphi} = \frac{\partial q_B^*(p_B^*)}{\partial \varphi} = \frac{\beta\tau(3\lambda + 2) - 1}{2\beta\tau(2\beta\tau(\lambda + 1) - 1)},$$

this quantity being positive, because $\tau > \frac{1}{2\beta\tau(\lambda+1)} > \frac{1}{\beta(3\lambda+2)}$. We also compute

$$\frac{\partial \Delta q^*}{\partial \varphi} = -\frac{\lambda}{2(2\beta\tau(\lambda + 1) - 1)} < 0.$$

### A.5 Proof of Proposition 5

Assume that, in equilibrium, $q_A^*(p_A^*) > q_B^*(p_B^*)$. Then, the regional welfare functions are as in the baseline model, provided that $c_A = c_B = c$ and that the opportunity cost of public funds, considered in the welfare function of Region $i$, is given by $\lambda_i$. The FOCs lead to the equilibrium values of Equation 19, whereas the SOCs are satisfied if $\tau > \frac{1}{2\beta(\lambda_B+1)}$, which is implied by Equation 18. By substituting $p_A^*$ and $p_B^*$ into the providers' equilibrium qualities, we get

$$q_A^*(p_A^*) = \frac{-\beta^2\tau^2[2\lambda_A(\lambda_B + 1) - \lambda_B] + \beta\tau[\lambda_A + 2\lambda_B + 1] - 1}{2\beta[\beta\tau(2\lambda_B + 1) - 1]},$$

$$q_B^*(p_B^*) = \frac{1 - \beta\tau\lambda_A}{2\beta}.$$

It holds $q_A^*(p_A^*) > q_B^*(p_B^*)$ for $\tau > \frac{1}{\beta(2\lambda_B+1)}$. Under such condition, which is, again, implied by Equation 18, we have $\frac{q_A^*(p_A^*) - q_B^*(p_B^*)}{2\tau} < \frac{1}{8}$ for $\tau > \frac{1}{\beta(2\lambda_A+1)}$, which gives the first inequality of Equation 18.

We now turn to the centralized solution. Assume that $q_A^*(\bar{p}_A) > q_B^*(\bar{p}_B)$, then, the aggregate welfare function, which, given the asymmetry in the opportunity costs, should take into account the interregional transfers, is as follows:

$$S = (-\lambda_A p_A - c)\frac{1}{2} + (-\lambda_B p_A - c)\frac{q_A - q_B}{\tau} + (-\lambda_B p_B - c)\left[\frac{1}{2} - \frac{q_A - q_B}{\tau}\right] - \beta(q_A^2 + q_B^2) +$$
$$+2\int_0^{\frac{1}{8}}(v + q_A - \tau x)\,dx + 2\int_0^{\frac{1}{8}}(v + q_B - \tau x)\,dx +$$
$$+2\int_0^{\frac{1}{8}+\frac{q_A-q_B}{2\tau}}(v + q_A - \tau x)\,dx + 2\int_{\frac{1}{8}+\frac{q_A-q_B}{2\tau}}^{\frac{1}{4}}(v + q_B - \tau(\frac{1}{4} - x))\,dx.$$

By substituting the Nash equilibrium quantities as functions of $p_A$ and $p_A$ and maximizing with respect to the prices, the FOC lead to the values shown in Equation 20. As for the SOC, the Hessian matrix of $S$ is

$$H_S = \frac{1}{\beta^2\tau^3}\begin{pmatrix} 1 - 2\beta\tau(\lambda_B + 1) & 2\beta\tau\lambda_B - 1 \\ 2\beta\tau\lambda_B - 1 & 1 - 2\beta\tau(\lambda_B + 1) \end{pmatrix},$$

which is negative definite for $\tau > \max\left(\frac{1}{2\beta(\lambda_B+1)}, \frac{1}{\beta(2\lambda_B+1)}\right) = \frac{1}{\beta(2\lambda_B+1)}$, which is implied by Equation 18. By substituting $p_A^*$ and $p_B^*$ into the providers' equilibrium qualities, we get

$$q_A^*(\bar{p}_A) = \frac{-2\beta^2\tau^2[\lambda_A(\lambda_B + 1) + \lambda_B^2] + \beta\tau(\lambda_A + 5\lambda_B + 2) - 2}{8\beta[\beta\tau(2\lambda_B + 1) - 1]},$$
$$q_B^*(\bar{p}_B) = \frac{-2\beta^2\tau^2\lambda_B(\lambda_A + \lambda_B + 1) + \beta\tau(\lambda_A + 5\lambda_B + 2) - 2}{8\beta[\beta\tau(2\lambda_B + 1) - 1]}.$$

For all $\tau > \frac{1}{\beta(2\lambda_B+1)}$, we have $q_A^*(\bar{p}_A) > q_B^*(\bar{p}_B)$. Lastly, imposing the condition for an interior solution $\frac{q_A^*(\bar{p}_A)-q_B^*(\bar{p}_B)}{2\tau} < \frac{1}{8}$, we get the condition $\tau < \frac{\sqrt{4\lambda_A+4\lambda_B^2+1}+2\lambda_B+1}{2\beta(\lambda_B-\lambda_A)}$.

As for the comparative static,

$$\frac{\partial\Delta q^*(p_A^*, p_B^*)}{\partial\lambda_B} = \frac{\beta\tau^2[\beta\tau(2\lambda_A + 1) - 1]}{2[\beta\tau(2\lambda_B + 1) - 1]^2},$$
$$\frac{\partial\Delta q^*(\bar{p}_A, \bar{p}_B)}{\partial\lambda_B} = \frac{\beta^2\tau^3[\beta\tau(2\lambda_A + 1) - 1]}{4[\beta\tau(2\lambda_B + 1) - 1]^2},$$

both quantities being positive under Equation 18. We finally get

$$\Delta q^*(p_A^*, p_B^*) - \Delta q^*(\bar{p}_A, \bar{p}_B) = \frac{\beta\tau^2(\lambda_A - \lambda_B)(\beta\tau - 2)}{4[\beta\tau(2\lambda_B + 1) - 1]},$$

hence, under our assumption $\Delta q^*(p_A^*, p_B^*) > \Delta q^*(\bar{p}_A, \bar{p}_B) \iff \tau < \frac{2}{\beta}$.