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Abstract

This paper analyzes the regulation of payment schemes for health care providers competing in both quality and product differentiation of their services. The regulator uses two instruments: a prospective payment per patient and a cost reimbursement rate. When the regulator can only use a prospective payment, the optimal price involves a trade-off between the level of quality provision and the level of horizontal differentiation. If this pure prospective payment leads to underprovision of quality and overdifferentiation, a mixed reimbursement scheme allows the regulator to improve the allocation efficiency. This is true for a relatively low level of patients' transportation costs. We also show that if the regulator cannot commit to the level of the cost reimbursement rate, the resulting allocation can dominate the one with full commitment. This occurs when the transportation cost is low or high enough, and the full commitment solution either implies full or zero cost reimbursement.

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1 Introduction

The literature dealing with the optimal regulation of health care providers' payments has been prolific. It has mainly focused on the desirability of mixed reimbursement schemes in the presence of providers' moral hazard, variable quality of care and cream skimming. As summarized in Newhouse (1996), prospective payment schemes induce more effort on cost containment while inducing risk selection and lower quality. Conversely, retrospective payments may be useful to elicit a sufficient quality level or to avoid cream skimming strategies but jeopardize cost containment. This literature usually adopts a principal-agent framework in which imperfect competition between health care providers is not an issue. The goal of this paper is precisely to revisit the question of the desirability of mixed payment schemes in a setting with non contractible horizontal and vertical differentiation on the providers' side. While non contractible vertical differentiation (understood here as the quality provision) has been the object of many studies,[1] non contractible horizontal differentiation - like the physical location or product differentiation of health care providers - has not so far drawn much attention in the regulation literature. Indeed, empirical and anecdotal evidence shows that both providers' location and health services' differentiation are important features of health care markets, possibly affecting the nature of competition between providers and the quality of health care delivered to patients.

We use the generic expression of health care providers to cover an alphabet soup of different agents such as hospitals, groups of physicians, agreement between hospitals and groups of physicians (see Gal-Or, 1999), individual physicians, *etc*... For all these agents, interpretations of horizontal differentiation may differ but nevertheless have in common that they remain non contractible. For instance, it is generally impossible to contract directly the degree of spatial differentiation of physicians or groups of physicians which belong to local markets.[2] While reimbursement schemes are usually different across medical specialities, doctors who belong to a given speciality group are often not providing exactly the same kind of services. In ambulatory medicine, doctors can differ in their medical practices, sometimes due to the so-called school effect (Phelps and Mooney, 1993). Doctors can also attempt to accentuate the perceived differentiation by other means. A look at the advertisements posted by general practitioners on the Yellow pages, though anecdotal, is fairly instructive. On the Paris Yellow Pages, one post says: "University Lecturer in Homeopathy. Fluent English" On the London Yellow Pages, one can find a general practice describing itself with these words: "All women doctors. Physiotherapist, Counselors, Acupuncture, Dermatology..." At least in terms of marketing, the attempt to differentiate is quite clear. Another example of differentiation is the specialization in alternative medical practices. Again in the Paris Yellow Pages, one can easily verify that 20% of general practitioners are specialized in some kind

[1] See for instance Chackley and Macolson (1998) and McGuire (2000).

[2] According to the level of decentralization in the health care system, some regulatory differences can appear between hospitals which belong to different regions. As we study competition in local markets, this situation is out of the scope of this paper.

of alternative medicine such as homeopathy and acupuncture.[3] At the level of health care supplied in hospitals, medical practices might not be homogeneous due to different treatment styles of affiliated doctors. As long as these differences are perceived by patients, this creates or accentuates horizontal differentiation across services provided in hospitals which belong to the same area. For instance, Epstein and Nicholson (2003) point out that in the case of cesarean sections, the small area variation in hospital medical practices can be huge within markets. Empirical evidence suggests that distance from providers is an important determinant of patients' choice. Tay (2003) estimates the importance of distance and quality in the hospital choice of acute myocardial infarction patients. She shows that spatial differentiation is important in explaining hospital choices, even though patients seem to trade-off quality and distance.

Following Brekke *et al.* (2006), we use a standard Hotelling model of spatial competition in a third payer institutional context, *i.e.* patients do not bear any out-of-pocket, to analyze health providers' strategies in terms of location and quality.[4] Spatial competition can be interpreted either as geographical distance but also as providers' specialization. Patients choose a provider and incur a transportation cost according to the distance between their location and the provider's one. Following Ma (1994), we assume that patients are also sensitive to the level of quality provided. We consider that this non contractible quality not only affects the fixed cost of the health care but differently to Brekke *et al.* (2006), also increases the variable cost incurred by providers. Indeed, in most cases, the purchase of equipment by providers constitutes some fixed costs while their utilization generate variable costs. On top of that, the regulator uses two instruments: a fixed payment per patient and a cost reimbursement rate related to the variable cost.[5] For instance, in some countries, general practitioners and specialists are reimbursed by a mix of capitation and fee-for-service, where the fee-for-service rate can be adjusted according to the procedures involved to reimburse to some extent the variable component of the cost. In most European health systems, hospitals are nowadays remunerated on a D.R.G. basis but some cost-based adjustments are still rather common (*e.g.* through *per diem* reimbursement for long inpatient treatments, or through adjustments based on the patients' mix).[6] Even in countries that only use DRG mechanisms, the fact that the system is often combined with a global budget constraint introduces some form of cost sharing (see Mougeot and Naegelen [2004] and van de Ven

[3] In France, visits to general practitioners are equally remunerated, whatever is the G.P. specialization. In practice, the regulation and the level of reimbursements are usually different across specialities but the same regulatory scheme is likely to apply to all doctors in the same speciality. In the case of general practitioners, acupuncture treatments are not reimbursed at the same rate, and a big share of the price is paid out-of-pocket by the patient. If the acupuncture treatment is performed by the family general practitioner, however, the visit is totally reimbursed to the patient (as a practitioner visit).

[4] Our application to hospitals markets is restricted to health care systems where hospitals are characterized by a price regulation such as in many European health care systems or the US Medicare and Medicaid programmes (see Brekke *et al.* [2006] for a similar caveat).

[5] In presence of a regulated price, the introduction of a reimbursement rate on the fixed cost would be redundant, as it is pointed out in section 2.2.1.

[6] See Cesifo DICE Report (2010) and Casto and Layman (2006) for a review of hospital payment in Europe and the US respectively .

[2005]).

Our results show that if the degree of horizontal differentiation were contractible, the standard result would hold: a pure prospective scheme achieves the first best allocation (Ma, 1994). On the contrary, there is room for some cost reimbursement when such differentiation is not contractible. Similarly to a multitasking setting *à la* Holmstrom and Milgrom (1992), horizontal and vertical differentiation are strategic substitutes in our model: an increase in horizontal differentiation leads to a decrease in quality, since locating further apart allows providers to relax quality competition. Gaynor *et al.* (2010) also reveal the existence of a negative relation between market power and quality.[7] If the only instrument available to the regulator is a capitation payment, a trade-off between quality and differentiation occurs. This trade-off can be partially relaxed by some level of cost reimbursement.

In the benchmark case, where the regulator can commit on both instruments, our results reveal that a mixed reimbursement scheme is welfare improving if the allocation induced by an optimal prospective payment alone is characterized by underprovision of quality and overspecialization. The intuition for this result is that, if the transportation cost is low, providers have strong incentives to locate far apart, in order to dampen quality competition. Since the level of differentiation increases with the regulated price, the latter must be so low to elicit the optimal locations, that the resulting level of quality is too low. The regulator optimally introduces some cost reimbursement to make quality less costly.

In practice, according to the institutional organization at play, it may happen that the regulator is not able to fully commit on the regulation announced. For instance, such situation may occur when the regulation of health providers intervenes at different levels, *i.e.* the local level has the possibility to modify at the margin parameters of the regulation set at the central level. The policy of "floating points" experimented in France and Germany constitute other examples of lack of commitment that may occur. Our results reveal that when the regulator cannot commit to any instrument or can only commit to a cost reimbursement rate, the quality level is equal to its first best value while maximum differentiation occurs. Alternatively, when the regulator can only commit to a prospective payment, the optimal payment mechanism may improve the level of welfare obtained under full commitment. This occurs when the transportation cost is low or high enough, *i.e.* when the full commitment solution either implies full or zero cost reimbursement.

Quite importantly, since cost sharing decreases with the transportation cost in both scenari, we highlight that cost reimbursement is a useful instrument when the health care providers'market is characterized by a high degree of competitiveness.

This paper relates to and borrows from two strands of the literature. In a framework where the demand for health care is sensitive to quality and costs are observable *ex post*, Ma (1994) shows that a pure prospective reimbursement leads to an optimal allocation. However, as Allen and Gertler (1991) and Ma (1994) point out, a mixed remuneration

[7]Even though it must be underlined that the horizontal differentiation is not necessarily the unique source of hospitals' market power.

scheme may be optimal in the presence of cream skimming or dumping. This reimbursement system is motivated by the necessity to obtain uniform levels of quality and access to care, even if it reduces the effort in cost containment.[8] Economides (1989) analyzes the price competition market outcome in a Hotelling model with horizontal and vertical differentiation. Calem and Rizzo (1995) consider the strategic behavior of hospitals that compete in quality and that choose their location in a setting in which hospitals internalize part of the patients' transportation costs. The ingredients of their model are similar to ours but they focus on the equilibrium outcome and do not study the optimal regulation. Ma and Burgess (1993) and Wolinsky (1997) look at price competition and price regulation in a spatial duopoly model including the quality dimension. However, they do not consider the interaction between quality and location. To our knowledge, the only paper that tackles the problem of regulation when locations are endogenous is the one by Brekke *et al.* (2006).[9] As already pointed out, their set-up is very close to ours but it does not include a variable cost that depends on the provider's quality levels. As we discuss later on, this rules at any possible role for cost reimbursement.

The paper is structured as follows: section 2 is devoted to the presentation of the model. Section 3 characterizes the optimal regulation in presence of full commitment, while section 4 considers the case of partial commitment. The last section concludes.

2 The model

We consider a standard Hotelling model, with two providers indexed by $i = 1, 2$, both located on a line of length one. Without loss of generality, we call provider 1 the provider whose location x_1 is on the left, and provider 2 the one whose location x_2 is on the right. There is a mass one of patients all purchasing one unit of medical care. Both providers offer the medical good with quality q_i, $i = 1, 2$. Quality is the result of providers' investments in machines, diagnostic tests, amenities that may improve the outcome of the treatment or patients' comfort. It should not be interpreted as the quality of the provider (for instance the academic reputation of the medical school one provider attended), which is assumed to be exogenous and homogenous in the model. Patients incur some quadratic transportation costs but do not face any out-of-pocket payments since a third payer remunerates the providers. This assumption is not restrictive as long as there is no uncertainty and patients' utility functions are linear. Having some cost sharing on the patients' side would not change the results since it would only represent a transfer from patients to providers which has no impact on our social welfare function (see section 3).[10]

For each unit of medical good supplied, each provider receives a prospective payment P and a cost reimbursement rate $\alpha \in [0, 1]$ based on quality-related variable costs

[8] Similarly, Chalkley and Malconsom (1998) show that a mixed reimbursement scheme improves on a prospective one when it is not efficient to treat all the patients.

[9] Seel also Brekke *et al.* (2007) for a similar framework applied to a gatekeeping issue.

[10] We exclusively focus on the providers' regulation. Introducing uncertainty and risk aversion would be necessary to study the policy mix issue *i.e.* how to split incentives on both sides (see for instance Ma and McGuire (1998) and Bardey and Lesur (2006) for papers dealing with this issue).

reported. Since the per-patient demand of health care is fixed to one, each provider gets a payment $P - \hat{c}q_i$ per-patient where $\hat{c} = (1-\alpha)\,c$ and c is the cost per-unit of quality q_i supplied. On top of variable costs, providers also incur some fixed costs which we assume for analytical convenience to be quadratic in the level of quality.[11] Note that we do not allow the regulator to reimburse fixed costs. As it will appear in section 2.2.1, this instrument would be redudant with the prospective price.

Importantly, the payment scheme is not conditioned on the degree of product differentiation or on the location of a provider. As pointed out in the introduction, in spite of the fact that health providers may differentiate themselves in order to reduce the competition intensity, they receive the same payment. In case of hospitals' competition, the payment to hospitals for the same treatments are generally the same and are independent of their location or kind of medical practice within the same DRG.

In the benchmark model in which the regulator can fully commit on both instruments, the timing is as follows:

Stage 1 The regulator chooses the payment scheme $R = \{P, \hat{c}\}$ that optimizes an utilitarian social welfare function.

Stage 2 Providers decide where to locate over the line which defines an equilibrium vector $X = \{x_1, x_2\}$.

Stage 3 Providers set the level of quality provided which defines an equilibrium vector of $Q = \{q_1, q_2\}$.

Stage 4 Patients choose which provider they visit.

For ease of notation, we use subscript s to denote symmetric equilibria *i.e.* $X_s = \{x_1, 1 - x_1\}$ and $Q_s = \{q, q\}$. In section 4, we consider an alternative timing in order to cope with partial commitment issues. The following sections consider the behavior of the different actors. First, we focus on patients' choice in terms of providers. Next, we analyze the providers' incentives with respect to health care quality and location decisions assuming that the regulator can commit on both instruments.

2.1 Patients' behavior

Patients are uniformly located along the line and they incur quadratic transportation costs. They perfectly observe the level of quality and the location of each provider. The patient with address $x \in [0, 1]$ choosing provider i with address x_i has a utility:

$$U_x(X, Q) = \max_{i=1,2} \left\{ u_i(x_i, q_i, x) = \bar{s} + q_i - t(x - x_i)^2 \right\}$$

[11]This assumption implies that the marginal cost of quality is strictly increasing. As stressed by Brekke *et.al.* (2011), a convex cost function is supported by empirical evidence showing that scale economies are rapidly exhausted in the hospitals'sector (*e.g.* see Folland *et al.* [2004] for empirical evidence).

where $\bar{s}$ is the common utility that each patient gets from a visit to a provider. In other words, we implicitly assume out any heterogeneity in the severity of the illness. Moreover, the patients' utility is increasing in the quality q_i supplied by the provider i and is decreasing in the transportation cost t. We assume that $\bar{s}$ is large enough so as to ensure that the market is fully covered for any value of $q_i,\ i = 1,\ 2$.[12] We also assume without loss of generality that $t \geq (1-c)/2\gamma$. This assumption ensures that every regulatory equilibria considered in the paper exist. The demand D_1 and D_2 faced by providers 1 and 2 are thus equal to:

$$D_1 \equiv D_1(X,Q) = \frac{1}{2}S + \frac{q_1 - q_2}{2t\Delta}, \quad (1)$$

$$D_2 \equiv D_1(X,Q) = 1 - \frac{1}{2}S + \frac{q_2 - q_1}{2t\Delta} \quad (2)$$

where $S = x_1 + x_2$ and $\Delta = x_2 - x_1$ represents the degree of horizontal differentiation between providers.

2.2 Providers' behavior

Each provider also incurs some fixed costs which we assume to be quadratic in the level of quality. For instance, a provider may decide to buy the equipment to make radiographies inside his practice. The purchase of the machine constitutes a fixed cost while it affects the variable cost of the provider's diagnostic according to the number of radiographies provided. We also explain below at the end of section 2.2.1 why the fixed costs are an important ingredient of our setting. Provider's i profit function thus write

$$\pi_i \equiv \pi_i(R,X,Q) = (P - \hat{c}q_i)\,D_i(X,Q) - \frac{\gamma}{2}q_i^2,\ i = 1,2 \quad (3)$$

where $D_i, i = 1,2$ are respectively given by (1) and (2). $\gamma > 0$ measures the relative importance of the fixed cost.[13] As in Ma (1994), the cost reimbursement only depends on variable costs. The provision of quality may require to invest in equipment and machines needed to perform some tests or treatments. We allow health care providers to report the functioning cost of these machines but we assume out the possibility to claim the reimbursement of the fixed cost. First, this assumption is realistic as the imputation of the fixed cost to each single act may be difficult or even prohibited by law. Usually the fixed costs related to the equipment of a practice are completely in charge of the provider. Second, as we discuss at the end of the following section, regulating fixed costs reimbursements would be a redudant instrument in our setting.

As in a standard backward analysis, we first analyze the providers' quality choice. Then, we focus on the location sub-game equilibrium.

[12] In a symmetric equilibrium, the market is fully covered for every $q_i \geq 0$ if and only if $\bar{s} \geq Max\left[t(\tilde{x})^2,\ t(1-2\,\tilde{x})/2)\right]$, where $\tilde{x}$ is the distance between the provider's location and the middle of the line.

[13] Although we study pure for profit providers, the parameter γ that measures the relative importance of the fixed cost could include an altruistic component so that γ would measure the importance of fixed costs net of altruistic concern. The important point is that providers do not internalize patient's concern for the level of differentiation.

2.2.1 Quality choice

Providers choose the level of quality that maximizes their profit for any location vector X. Maximizing π_i in (3) with respect to q_i yields the following first order condition:

$$(P - \hat{c}q_i)\frac{\partial D_i}{\partial q_i} - \hat{c}D_i - \gamma q_i = 0 \text{ for } i = 1, 2. \tag{4}$$

The optimal quality level is the result of a trade-off between a higher market share through the demand's increase (first term in the LHS of (4)) and the associated variable and fixed quality costs increase (respectively the second and last term of (4)). Differentiating and substituting the demand functions (1) and (2) in (4), these equations define the vector of qualities $Q(R, X) = \{q_1(R, X), q_2(R, X)\}$ explicitly given by:

$$q_1(R, X) = \frac{P}{\hat{c} + 2t\gamma\Delta} - \frac{\hat{c}t\Delta}{\hat{c} + 2t\gamma\Delta}\left(\frac{(2 + S)\hat{c} + 2St\gamma\Delta}{3\hat{c} + 2t\gamma\Delta}\right), \tag{5}$$

$$q_2(R, X) = \frac{P}{\hat{c} + 2t\gamma\Delta} - \frac{\hat{c}t\Delta}{\hat{c} + 2t\gamma\Delta}\left(\frac{(4 - S)\hat{c} + 2(2 - S)t\gamma\Delta}{3\hat{c} + 2t\gamma\Delta}\right). \tag{6}$$

Applying the implicit function theorem to (4), the comparative statics of quality levels with respect to the location choices can be written as

$$\frac{\partial q_i}{\partial x_j} = -\frac{(P - \hat{c}q_i)\frac{\partial D_i}{\partial q_i \partial x_j} - \hat{c}\frac{\partial D_i}{\partial x_j}}{SOC} \text{ for } i, j = 1, 2 \tag{7}$$

where $SOC < 0$ is the second order derivative of the left hand side of (4) with respect to q_i. Consider *e.g.* the effect of a move to the right of the line by provider 2 on the level of quality chosen by provider 1. The first term in the numerator of (7) measures the *competition effect*: the further is the competitor from the middle of the line, the lower are the incentives to provide high quality levels, since the demand is more captive due to the large distance between providers. Since this effect is decreasing with the price-cost margin, the extent to which the competition effect is large negatively depends on the net variable cost. The second term in the numerator of (7) measures the *cost containment effect*: a higher market share increases variable costs which induce provider 1 to lower his level of quality. Quite obviously, the size of this effect depends positively on the level of the net variable cost parameter. However, if provider 1 moves closer to the middle of the line, the impact on his own quality level is ambiguous. In this case, the competition and the cost containment effects generate countervailing incentives. On the one hand, moving towards the other provider increases competition and enhances quality. On the other hand, it also expands his market share and thus the variable costs for any given level of quality. This reduces the incentive to invest in quality.

With our model specification, one can indeed show that, at a symmetric equilibrium:

$$\frac{\partial q_1}{\partial x_1}(R, X_s) = -\frac{\partial q_2(R, X)}{\partial x_2} = \frac{t\left(\hat{c}^2 + 2\gamma P\right)}{(\hat{c} + 2t\gamma\Delta)^2} - \frac{\hat{c}t\Delta}{(3\hat{c} + 2t\gamma\Delta)}, \tag{8}$$

$$\frac{\partial q_1}{\partial x_2}(R, X_s) = -\frac{\partial q_2(R, X)}{\partial x_1} = -\frac{t\left(\hat{c}^2 + 2\gamma P\right)}{(\hat{c} + 2t\gamma\Delta)^2} - \frac{\hat{c}t\Delta}{(3\hat{c} + 2t\gamma\Delta)} < 0. \tag{9}$$

The competition and cost containment effects are respectively represented by the first and second terms in the right hand side of (8) and (9).

Two important remarks should be emphasized. First, the cost containment effect is absent in Brekke *et al.* (2006). In their model quality does not affect variable costs. As a result, the level of quality only depends on the distance between providers and not on the market shares. Second, one can notice that reimbursing fixed costs would be a redudant instrument in our setting. Suppose indeed that fixed costs are reimbursed at a rate β. The first order condition (4) would be the same but with γ replaced by $\hat{\gamma} = (1-\beta)\gamma$. This has two immediate consequences. First, one can see that regulating $P, \hat{c}$ and $\hat{\gamma}$ would be equivalent to regulate only $P/\hat{\gamma}$ and $\hat{c}/\hat{\gamma}$. This explains why reimbursing fixed costs is meaningless in this kind of setting and in particular the one of Brekke *et.al.* (2006). Second, fixed costs play an important role in our approach. Suppose indeed that there are no fixed costs associated with the level of quality. A similar argument would imply that price and variable cost reimbursements would be redudant instruments.

2.2.2 Location choice

For given levels of regulatory parameters R, each provider sets his location on the Hotelling line.[14] More precisely, provider i maximizes his profit function (3) with respect to x_i where $Q \equiv Q(R, X)$ is given by (5) and (6). Provider's i problem is thus:

$$\max_{x_i} \pi_i (R, X) = (P - \hat{c} q_i (R, X)) D_i (X, Q(R, X)) - \frac{\gamma}{2} (q_i (R, C))^2, i = 1, 2$$

Using the envelop theorem, the first order condition yields:

$$\frac{\partial D_i}{\partial x_i} - \frac{\partial D_i}{\partial q_j} \frac{\partial q_j}{\partial x_i} = 0, \; i, j = 1, 2; i \neq j. \tag{10}$$

As usual in horizontal differentiation models, there are two opposite effects at work: a demand and a strategic effect. On the one hand, for a given location of the competitor, reducing the level of differentiation leads to higher market shares (demand effect). On the other hand, less differentiation leads to tougher competition on quality which drives the providers to increase the level of differentiation in order to dampen quality competition (strategic effect). These two effects are respectively represented by the first and the second term in the LHS of (10).

At a symmetric equilibrium,[15] the demand effect for provider 1 is simply $\partial D_1 / \partial x_1 = 1/2$ while the strategic effect is:

$$\frac{\partial D_1}{\partial q_2} \frac{\partial q_2}{\partial x_1} = \frac{1}{2\Delta} \left(\frac{\hat{c}^2 + 2\gamma P}{(\hat{c} + 2t\gamma\Delta)^2} + \frac{\hat{c}\Delta}{(3\hat{c} + 2t\gamma\Delta)} \right). \tag{11}$$

[14] We restrict the location strategy set of provider 1 to be $[0, 1/2[$, and the strategy set of provider 2 to $]1/2, 1]$. By excluding the possibility that the providers both locate in the point 1/2, we ensure that the problem is well defined for each value of the regulatory parameters. Indeed, equations (5) and (6) reveal that if $\Delta = 0$ and $\hat{c} = 0$, there would exist no Nash equilibrium in the quality subgame.

[15] Of course there may exist other equilibria in which $x_1 + x_2 \neq 1$. We show that a symmetric equilibrium exists and in appendix A we prove that this equilibrium is the unique symmetric equilibrium. This does not rule out the existence of asymmetric equilibria. However, given the symmetric structure of the game we consider, we will limit the analysis to symmetric equilibria.

This expression shows that the strategic effect has two components: the competition and the cost containment effects discussed in the preceding section. Solving (10) thus defines implicitly $\Delta^* \equiv \Delta^*(R)$ as the solution to the following fourth degree polynomial:

$$\Delta^* \left(2\hat{c} + 2t\gamma\Delta^*\right)\left(\hat{c} + 2t\gamma\Delta^*\right)^2 - \left(2\gamma P + \hat{c}^2\right)\left(3\hat{c} + 2t\gamma\Delta^*\right) = 0. \tag{12}$$

We show in appendix A that there is a unique positive Δ^* and that it is a global maximum in $\Re^{++}$. Furthermore, Δ^* is strictly greater than zero. However, Δ^* may be greater than one. In this case, a corner solution characterized by $\Delta^* = 1$ arises. Proposition 1 characterizes the quality-location equilibrium and some useful comparative statics (see appendix B for computations):[16]

Proposition 1 *(i) The symmetric equilibrium of the two-stage game is represented by the vectors*

$$\begin{aligned} X_s^*(R) &= \{(1 - \Delta^*(R))/2, (1 + \Delta^*(R))/2\} \\ Q_s^*(R) &= \{q^*(R), q^*(R)\} \end{aligned}$$

where $\Delta^*(R)$ is implicitly given by (12) and $q^*(R)$ is given by:

$$q^*(R) = \frac{P - \hat{c}t\Delta^*(R)}{\hat{c} + 2t\gamma\Delta^*(R)} \tag{13}$$

(ii) Comparative statics show that the equilibrium values of $\Delta^*(R)$ and $q^*(R)$ are both increasing in P and decreasing in t. The effect of $\hat{c}$ on the level of $\Delta^*(R)$ is ambiguous while $q^*(R)$ is decreasing in $\hat{c}$.

Let us first comment the comparative statics concerning the level of differentiation. When P increases, the price-cost margin increases. As can be seen from (11), this implies a stronger strategic effect due to the stronger competition effect while the cost containment effect is not affected. Since the demand effect does not depend on the price, providers choose a higher level of differentiation. The impact of $\hat{c}$ on the strategic effect is however ambiguous. On the one hand, as stressed in the preceding section, the size of the competition effect is decreasing with the net variable cost which tends to increase the level of differentiation. On the other hand, the cost containment effect becomes stronger which induces a lower level of differentiation. Finally, as can be observed from (11), the strategic effect is decreasing with the level of transportation cost so that the level of differentiation is decreasing with t.

[16] To ensure the existence of a symmetric equilibrium in the two stage game, we need to check that, for every pair of locations such that $x_1 = 1 - x_2$, the providers earn non negative profits by setting their quality according to the rule $q^*(R)$. The condition that has to hold to ensure non negative profits is

$$(\hat{c} + 2t\gamma\Delta)(2t\gamma\Delta P + \hat{c}^2 t\Delta) \geq \gamma(P - \hat{c}t\Delta)^2.$$

For the moment we assume that the condition hold and prove later that it is indeed satisfied at the optimum. In appendix D we show that the optimal regulatory parameters indeed insure positive profits and thus existence of the symmetric equilibrium.

Now consider the equilibrium level of quality defined in (13). For a given level of differentiation, the quality level increases with the price (direct effect). However, since the level of differentiation increases as well, the equilibrium quality level may also decrease because of the reduction in quality competition (indirect effect). Proposition 1 states that the direct effect dominates so that the equilibrium level of quality increases. Direct effects also dominate for a change in the net variable cost and the transportation cost, so that the equilibrium level of quality decreases in t.

3 Optimal regulation with full commitment

In this section, we analyze the optimal regulation scheme. As usual, we start with a first best analysis. We show how the first best can be implemented through a prospective payment when locations are exogenous (Ma, 1994). Next, we characterize the optimal regulation scheme when providers can strategically set their locations.

3.1 First best allocation

The social planner maximizes an utilitarian social welfare function. For purpose of simplicity, we assume that the social planner puts the same weight on the consumers' surplus and the providers' profit. The optimal allocation (X, Q) thus maximizes the following social welfare function:

$$W(X,Q) = \int_0^1 U_x(X,Q)\,dx + \sum_i \pi_i - \sum_i \left(P + (c - \hat{c})\,q_i(X,Q)\right) D_i(X,Q)\,. \tag{14}$$

Note that the third term is the total cost of the regulatory scheme. Since we chose to put the same weight on patients and providers linear payoffs, this cost may be either paid lump sum by patients or providers without changing the level of welfare. For any symmetric equilibrium, the social welfare function can be rewritten as[17]:

$$W(X_s, Q_s) = q(1-c) - \gamma q^2 + \frac{t\left[3\left(\Delta - \Delta^2\right) - 1\right]}{12}. \tag{15}$$

The social planner takes into account social benefits and costs of quality and minimizes the level of transportation costs. The optimal levels of quality and differentiation are

[17] Total transportation costs T are computed as follows:

$$T = -\int_0^{x_1} t(x_1 - x)^2 dx + \int_{x_1}^{\frac{1}{2}} t(x - x_1)^2 dx - \int_{\frac{1}{2}}^{x_2} t(x_2 - x)^2 dx + \int_{x_2}^{1} t(x - x_2)^2 dx.$$

Since in a symmetric equilibrium $x_2 = 1 - x_1$,

$$\begin{aligned} T &= \frac{2}{3}t\left[x_1^3 + (\frac{1}{2} - x_1)^3\right] \\ &= \frac{2}{3}t\left[\frac{1 + 6x_1(2x_1 - 1)}{8}\right]. \end{aligned}$$

Since $\Delta = 1 - 2x_1$, this yields $T = 1/12t\,[1 - 6x_1\Delta]$.

then:

$$q^{FB} = \frac{1-c}{2\gamma}, \quad (16)$$

$$\Delta^{FB} = \frac{1}{2}. \quad (17)$$

The assumption $c < 1$ ensures that a positive level of quality is always optimal. The optimal level of quality is obviously decreasing with the marginal cost c and with the parameter γ that weights the fixed cost. The optimal level of differentiation is equal to $1/2$, a standard result in the Hotelling model with a line of length one.

Note that this optimal allocation can easily be achieved when locations are exogenously set to their optimal value. This corresponds to the case where the regulator can directly control the level of horizontal differentiation (for instance by issuing licences conditioned on location). Indeed, if the differentiation level is equal to $1/2$, the social planner is able to elicit the optimal level of quality by a prospective payment P such that the right hand side of (13) and (16) are equalized. This result, first pointed out in Ma (1994) is resumed in the following remark:

Remark 1 *If locations are contractible, a pure prospective payment*

$$P = \left(c + \gamma t - c^2\right)/2\gamma$$

allows to implement the first best allocation.

Ma's result holds as long as the demand is sensitive to the quality level offered by the providers. Note that, with exogenous locations, the optimal regulated price is increasing in the transportation cost parameter t. High level of transportation costs reduce the providers' incentives to offer a high level of quality since the demand they face becomes less elastic with respect to quality. Thus in order to enhance competition among providers, the regulator has to increase the prospective payment.

3.2 Endogenous locations

Consider now the case in which providers' locations are not contractible. The optimal regulatory parameters P and $\hat{c}$ are the solutions of the following problem:

$$\max_{R=\{P,\hat{c}\}} (1-c)q^*(R) - \gamma q^2 q^*(R) + \frac{t\left[3\left(\Delta^*(R) - \Delta^{*2}(R)\right) - 1\right]}{12},$$
$$\text{s.t. } (\nu)\ \hat{c} \le c,\ (\mu)\ \hat{c} \ge 0,$$

where ν and $\mu \ge 0$ are the Lagrange multipliers associated to the feasible domain of $\hat{c}$. If $\nu > 0$ $(\mu = 0)$, then $\hat{c} = c$ which corresponds to the case where there is no cost reimbursement *i.e.* $\alpha = 0$, while $\mu > 0$ $(\nu = 0)$ implies full cost reimbursement *i.e.*

$\alpha = 1$. The first order conditions with respect to P and $\hat{c}$ are respectively:[18]

$$\frac{dq^*}{dP}(1 - c - 2\gamma q^*) + \frac{t}{4}\frac{d\Delta^*}{dP}(1 - 2\Delta^*) = 0, \tag{18}$$

$$\frac{dq^*}{d\hat{c}}(1 - c - 2\gamma q^*) + \frac{t}{4}\frac{d\Delta^*}{d\hat{c}}(1 - 2\Delta^*) - \nu + \mu = 0. \tag{19}$$

In the following sections, we characterize the optimal regulation in two cases. First, we consider a regulator constrained to use a pure prospective payment. We show that, in general, this single instrument does not allow to implement the first best allocation. We thus turn to the case where the regulator has one more instrument, namely the cost reimbursement rate α.

3.2.1 Optimal pure prospective price

To make a parallel between our analysis and the one of Brekke *et al.* (2006), let us first assume that the regulator is constrained to use a prospective payment alone. We obtain the following result:

Proposition 2 *If the regulator is constrained to use a pure prospective payment, the first best allocation described by equations (16) and (17) can be reached if and only if* $t = \bar{t} = \left[(2 - 3c) + \sqrt{c^2 + 12c + 4}\right]/2\gamma$. *Otherwise, if t is greater(lower) than $\bar{t}$, the second best allocation is characterized by over(under)provision of quality and under(over)differentiation.*

Proof. See appendix C. ■

This result is in line with the findings of Brekke *et al.* (2006). The intuition for this result is related to the size of the above mentioned demand and strategic effects. If t is low enough, the strategic effect is strong, since the change in the level of differentiation necessary to dampen competition is high. In this case, the price inducing the first best level of differentiation is so low that underprovision of quality occurs. The optimal price realizes the trade-off between these two effects so that one ends up with underprovision of quality and overdifferentiation. The reverse reasoning can be applied to the case in which t is high.

3.2.2 Optimal policy mix

In this subsection, we characterize the optimal reimbursement scheme that can be achieved when the regulator has two instruments: a prospective price and a cost reimbursement rate. There are three regimes to consider depending upon the values of $\hat{c}$.

- Regime A: $\hat{c}$ is constrained to be equal to 0.

[18] We assume that the second order conditions of the problem always hold.

- Regime B: $\hat{c} \in [0, c]$.
- Regime C: $\hat{c}$ is constrained to be equal to c.

Denote each regime's symmetric equilibrium values of quality and differentiation at the optimum by $\left(q^{*k}, \Delta^{*k}\right)$ where $k = A, B$ or C. Consider now the price $\tilde{P}$ that decentralizes the first best level of horizontal differentiation. Equalizing the RHS of (12) and (17) and allowing some cost reimbursement yield:

$$\tilde{P} = \frac{(\hat{c} + t\gamma)(2\hat{c} + t\gamma)}{4\gamma(3\hat{c} + t\gamma)} - \frac{\hat{c}^2}{2\gamma}.$$

Substituting this expression in (13), this gives the following equilibrium level of quality:

$$q^* \left(\tilde{P}, \hat{c}\right) = \frac{(\hat{c} + t\gamma)(2\hat{c} + t\gamma)}{4\gamma(3\hat{c} + t\gamma)} - \frac{\hat{c}}{2\gamma}. \tag{20}$$

Note that this level of quality is monotonically decreasing in $\hat{c}$. Thus setting an appropriate level of $\hat{c}$ allows to decentralize the first best level of quality. Of course, the level of $\hat{c}$ can only belong to a certain range of parameters. When the regulator uses a cost reimbursement rate in addition to a pure prospective payment, the following result applies:

Proposition 3 *For any triplet (c, t, γ) and $\underline{t} = 2(1-c)/\gamma$ and any $t \geq (1-c)/2\gamma$,*[19] *the following statements hold:*

(i) If $t < \underline{t}$, regime A is optimal. The second best allocation is then characterized by $q^{*A} < q^{FB}$ and $\Delta^{*A} > \Delta^{FB}$ so that there is underprovision of quality and overdifferentiation.

(ii) If $t \in \left[\underline{t}, \overline{t}\right]$, regime B is optimal. The first best allocation $\left(q^{*B}, \Delta^{*B}\right) = \left(q^{FB}, \Delta^{FB}\right)$ can be implemented with a mixed reimbursement scheme $\left(P^B, \hat{c}^B\right)$ such that:

$$P^B = \frac{(1-c)(\hat{c} + t\gamma) + \hat{c}t\gamma}{2\gamma}, \tag{21}$$

$$\hat{c}^B = \frac{t\gamma - 6(1-c) + \sqrt{36(1-c)^2 + 17(t\gamma)^2 - 44t\gamma(1-c)}}{8}. \tag{22}$$

(iii) If $t > \overline{t}$, regime C is optimal. The second best allocation is then characterized by $q^{*C} > q^{FB}$ and $\Delta^{*C} < \Delta^{FB}$ so that there is overprovision of quality and underdifferentiation.

Proof. See appendix D. ■

The regulator faces a trade-off since both quality and differentiation increase with the reimbursement parameter. For given levels of the cost parameters, the providers

[19] This assumption ensures that symmetric equilibra always exit at the optimum (see appendix D).

have strong incentives to locate apart if the transportation cost is low. Decreasing the regulated price in order to reduce the level of horizontal differentiation has a negative effect on quality as well. However, if an additional instrument, such as a cost reimbursement rate, is available to the regulator, the latter can use it to balance these incentives. This allows to enhance welfare and, for a certain range of parameters, to reach the first best allocation.

Remember that when $t < \bar{t}$, the pure prospective payment inducing the first best level of differentiation is so low that there is underprovision of quality. Since this level of quality is decreasing in the level of $\hat{c}$, increasing the cost reimbursement (or decreasing $\hat{c}$) allows to increase the level of quality without changing the level of horizontal differentiation. The trade-off occurring when the regulator can only use the pure prospective payment thus disappears. However, the maximal reimbursement rate is constrained to be lower than one. Thus, for lower values of t ($< \underline{t}$), the regulator can only partially increase the level of equilibrium quality by reimbursing all the variable costs. In this case, the trade-off mentioned in the previous section still occurs and the second best optimum still leads to underprovision of quality with overdifferentiation. Finally, when t is larger than $\bar{t}$, using cost reimbursement is no longer optimal. Indeed, since the quality level $q^*\left(\tilde{P}, \hat{c}\right)$ in (20) is decreasing in $\hat{c}$ and the social planner would like to decrease the level of quality, there is no room for using a cost reimbursement mechanism (one would like to tax variable costs associated to the level of quality instead of subsidizing them).

In other words, if transportation costs are low enough, providers have incentives to impose high (transportation) costs on the patients located close to the center (competitive area) in order to reduce their sensitivity to quality and relax competition. In this model there is no cream skimming since demand is inelastic and the level of quality is the same for all patients. However, location is a way to discriminate among patients, since not all of them incur the same transportation costs. In this context, cost reimbursement is a useful tool to prevent providers to overdifferentiate and offer a suboptimal level of quality.

Let us now relate our results to policy recommendations. A direct implication of proposition 2 can be summarized in the following corollary:

Corollary 1 *Variable cost reimbursement should decrease with the level of transportation cost.*

Very often, the transportation cost is used as a proxy for competition intensity.[20] This parameter indeed approximates how far the market is from a situation of perfect competition. Our results thus reveal that for highly competitive markets, the regulator should use a high (if not full) level of cost sharing. On the contrary, for a low competition intensity on the provider's side, the level of cost sharing should be low (if not zero).

[20] See e.g. Tay (2003) who measures hospitals markets competitiveness through a spatial differentiation analyzis.

4 Optimal regulation with partial commitment

So far, we have assumed that the government is able to commit to a prospective and a retrospective payment. However, a regulation policy set before the providers' differentiation choice is done might be non credible. In particular, once the level of differentiation is chosen, the regulator has always an incentive to renegotiate the remuneration scheme in order to obtain first best quality levels.

4.1 Lack of commitment issues

When the regulator is not able to commit to both instruments (*i.e.* its policy is set after the providers location's choice), the final allocation has the same form as in the non commitment case depicted in Brekke *et al.* (2006). The regulator chooses *ex post* the first best level of quality. But for a given level of quality, maximum differentiation occurs so that the two providers locate at the two extremes of the Hotelling line.

In our setting however, it is interesting to consider the case in which the regulator cannot fully commit to the level of only one policy instrument. For instance, the prospective and retrospective components of the payment schedule may not be negotiated at the same time. In many countries, the amount of the prospective reimbursement is fixed by law for each diagnostic group (DRG), while some cost reimbursement such that a *per diem* can be the object of further negotiations.[21] This situation occurs in health care systems where the budget for some specialities are voted by law. In this context, the regulator announces a reimbursement rate that can be the object of several revisions during the current year in order to satisfy the budget constraint. In health care systems which are characterized by a public administration that intervenes at different levels, some commitment problems may arise as well. In Italy for instance, the reimbursement rates are activity based. For hospitalizations they rely on DRGs' nomenclature. In spite of the fact that DRGs are determined at the national level, the regions are allowed to modify the nomenclature or the amounts corresponding to the DRGs. In such a case, the different levels of government involved tend to reduce the commitment of the regulator.

Let us consider the case where the regulator cannot commit to a prospective price. The latter instrument will be used so as to implement first best quality levels. But for any net variable cost, providers will choose their locations such that there is maximal differentiation. As a result, a cost reimbursement policy has no impact on the level of welfare. This somehow generalizes the result of Brekke *et. al.* (2006) in which they consider partial commitment on the prospective price but without variable cost on quality.

In the following section, we focus on another interesting case in which the regulator can only commit to a prospective price.

[21] This system is called "floating point" (*e.g.* see experiences in Germany and France).

4.2 Commitment on the prospective payment

Formally, the timing of the game is now as follows:

Stage 1 The regulator chooses the price P that maximizes an utilitarian social welfare function.

Stage 2 Providers decide where to locate over the line which defines an equilibrium vector $X = \{x_1, x_2\}$.

Stage 3 The regulator chooses the cost reimbursement policy $\hat{c}$ that maximizes an utilitarian social welfare function.

Stage 4 Providers set the level of quality provided which defines an equilibrium vector $Q = \{q_1, q_2\}$.

Stage 5 Patients choose which provider they visit.

As in the benchmark case, we successively present the results of stage 3 to stage 1.

4.2.1 Optimal cost reimbursement

When the regulator can only commit to a prospective price, the levels of quality continue to be given by (5) and (6). For any locations $X = \{x_1, x_2\}$, total transportation costs are given so that maximizing the social welfare function given in (14) with respect to $\hat{c}$ is equivalent to solve:

$$\max_{\hat{c}} \sum_{i=1,2} \left((1-c) q_i(R,X) D_i\left(X, Q\left(R,X\right)\right) - \gamma \frac{q_i(R,X)^2}{2} \right)$$
$$\text{s. to } (\nu)\ \hat{c} \leq c,\ (\mu)\ \hat{c} \geq 0,$$

where ν and $\mu \geq 0$ again denote the Lagrange multipliers associated to the feasible domain of $\hat{c}$. The first-order condition is:

$$\sum_{i=1,2} \left[(1-c) D_i + q_i \sum_{j=1,2} \frac{\partial D_i}{\partial q_j} - \gamma q_i(R,X) \right] \frac{\partial q_i(R,X)}{\partial \hat{c}} - \nu + \mu = 0 \tag{23}$$

This equation defines $\hat{c}^k\left(P,X\right)$ where $\hat{c}^A\left(P,X\right) = 0$ (*i.e.* when $\mu > 0$), $\hat{c}^B\left(P,X\right) \in (0,c)$ (*i.e.* when $\nu = \mu = 0$) and $\hat{c}^C\left(P,X\right) = c$ (*i.e.* when $\nu > 0$). Again, we concentrate on symmetric equilibria. The first order condition for an interior solution (*i.e.* regime B) simply reads $(1-c) - \gamma q = 0$. In other words, first best qualities are implemented. Equalizing (5) and (6) to (16) yields

$$\hat{c}^B\left(P, X_s\right) = \tilde{c} = 2\gamma \frac{P - (1-c)t\Delta}{(1-c) + 2t\gamma\Delta} \tag{24}$$

and $Q_s\left(P, X_s\right) = \left\{q^{FB}, q^{FB}\right\}$. Straightforward manipulation of (24) shows that in order to fulfill $\hat{c}^B\left(P, X_s\right) \in (0,c)$, one needs $P \in \left[\underline{P}\left(\Delta\right), \bar{P}\left(\Delta\right)\right]$ where $\underline{P}\left(\Delta\right) = (1-c)t\Delta$ and $\bar{P}\left(\Delta\right) = (1-c)c/2\gamma + t\Delta$. This leads to the following lemma:

Lemma 1 *At a symmetric equilibrium, the optimal cost reimbursement policy is given by:*
(i) $\hat{c}^A(P, X_s) = 0$ *and* $Q_s(P, X_s) < \{q^{FB}, q^{FB}\}$ *if* $P < \underline{P}(\Delta)$.
(ii) $\hat{c}^B(P, X_s) = \tilde{c}$ *and* $Q_s(P, X_s) = \{q^{FB}, q^{FB}\}$ *if* $P \in [\underline{P}(\Delta), \bar{P}(\Delta)]$.
(iii) $\hat{c}^C(P, X_s) = c$ *and* $Q_s(P, X_s) < \{q^{FB}, q^{FB}\}$ *if* $P > \bar{P}(\Delta)$.

As shown by (24), the optimal cost reimbursement policy is such that cost reimbursement decreases (resp. decreases) with the level of the price (resp. the level of horizontal differentiation). As a consequence, regime A in which there is full cost reimbursement emerges when the price is too low. It directly implies that there will be underprovision of quality. On the contrary, when the price is too large, regime C occurs and there is no cost reimbursement. In this case, there is overprovision of quality.

In order to solve the location subgame (stage 2), one needs the comparative statics of $\hat{c}$ with respect to the location parameters for any (possibly asymmetric) location equilibrium. In appendix E, we show the following lemma:

Lemma 2 *For any* $X = \{x_1, x_2\}$

$$\left.\frac{\partial \hat{c}^B(P, X)}{\partial x_1}\right|_{X=X_s} = -\left.\frac{\partial \hat{c}^B(P, X)}{\partial x_2}\right|_{X=X_s} = \frac{t\left(\tilde{c}^2 + 2\gamma P\right)}{P + 2t^2\gamma\Delta^2} > 0$$

while $\partial \hat{c}^k / \partial x_i = 0$ *for* $k = A, C$, $i = 1, 2$.

This lemma shows that at any symmetric equilibrium in regime B, the cost reimbursement decreases when providers move to the middle of the line. As shown below, this property has an important consequence on the location choice of providers.

4.2.2 Location choice

For a given prospective payment level, each provider chooses his location. The problem of provider i is

$$\max_{x_i^k}(P - \hat{c}^k(P, X)q_i^k(P, X))D_i\left(X, Q^k(P, X)\right) - \frac{\gamma}{2}(q_i^k(P, X))^2, k = A, B, C$$

The first order condition with respect to x_i is:

$$(P - \hat{c}^k q_i^k)\left(\frac{\partial D_i}{\partial x_i} + \frac{\partial D_i}{\partial q_j^k}\frac{\partial q_j^k}{\partial x_i}\right) + \frac{\partial \hat{c}^k}{\partial x_i}\left((P - \hat{c}^k q_i^k)\frac{\partial D_i}{\partial q_j^k}\frac{\partial q_j^k}{\partial \hat{c}^k} - q_i^k D_i\right) = 0, i = 1, 2; i \neq j. \tag{25}$$

which, for a symmetric equilibrium defines $\Delta^A(P)$ if $P < \underline{P}(\Delta^A)$, $\Delta^B(P)$ if $P \in [\underline{P}(\Delta^B), \bar{P}(\Delta^B)]$ and $\Delta^C(P)$ if $P > \bar{P}(\Delta^C)$. The first term in the left hand side of equation (25) represents the demand and the strategic effect already present in the full commitment case. The second term represents the strategic cost reimbursement effect. As shown in lemma 2, moving towards the center of the line decreases the level of cost reimbursement. This generates two countervailing effects on profits: a negative direct cost effect since total variable costs will increase by $q_i D_i$ and a positive market share effect since the demand will increase through the negative impact on quality chosen by the competitor.

Consider first regime B in which $P \in \left[\underline{\Delta}(P), \bar{\Delta}(P)\right]$. One can easily show that the strategic cost reimbursement effect is negative *i.e.* the second term in the LHS of (25) is negative. In other words, the above mentioned direct cost effect is dominated by the market share effect. A direct consequence of this is that, for a net variable cost equal to $\tilde{c}$, the equilibrium level of differentiation in regime B is always lower under partial commitment. More formally, one has $\Delta^B(P) < \Delta^{B*}(P, \tilde{c})$. One can also show that Δ^B is indeed the solution of the following fourth degree polynomial:

$$\begin{aligned}&\Delta^B\left((1-c)+2t\gamma\Delta^B\right)\left(4\gamma P-2t\gamma\Delta^B(1-c)+4t^2\gamma^2\Delta^B\right)-\\&(1-c)\left(6\gamma P-4t\gamma\Delta^B(1-c)+4t^2\gamma^2\Delta^B\right)=0\end{aligned} \tag{26}$$

Finally the location choice has no impact on cost reimbursement when $P \notin \left[\underline{P}\left(\Delta^B\right), \bar{P}\left(\Delta^B\right)\right]$. Thus one ends up with $\Delta^A(P) \equiv \Delta^{A*}(P, 0)$ if $P < \underline{P}\left(\Delta^A\right)$ and $\Delta^C(P) = \Delta^{C*}(P, c)$ if $P > \bar{P}\left(\Delta^C\right)$ where $\Delta^{k*}(R)$ is given in proposition 1 for $k = A, C$. In other words, when $P \notin \left[\underline{\mathrm{P}}(\Delta), \bar{\mathrm{P}}(\Delta)\right]$, the equilibrium level of differentiation is given by its full commitment counterpart. We sum up all these findings in the following proposition:

Proposition 4 *The partial commitment symmetric equilibrium is defined by:*
(i) $R^A(P) = \{P, 0\}$, $\Delta^A(P) = \Delta^*\left(R^A(P)\right)$ *and* $Q_s^A(P) = \left\{q^*\left(R^A(P)\right), q^*\left(R^A(P)\right)\right\}$ *if* $P < \underline{P}\left(\Delta^A(P)\right)$.
(ii) $R^B(P) = \{P, \tilde{c}\}$, $\Delta^B(P)$ *is given by* (26) *with* $\Delta^B(P) < \Delta^{B*}(P, \tilde{c})$ *and* $Q_s^B = \left\{q^{FB}, q^{FB}\right\}$ *if* $P \in \left[\underline{P}\left(\Delta^B(P)\right), \bar{P}\left(\Delta^B(P)\right)\right]$.
(iii) $R^C(P) = \{P, c\}$, $\Delta^C(P) = \Delta^{*C}\left(R^C(P)\right)$ *and* $Q_s^C(P) = \left\{q^*\left(R^C(P)\right), q^*\left(R^C(P)\right)\right\}$ *if* $P > \bar{P}\left(\Delta^C(P)\right)$.

4.2.3 Partial commitment optimum

The optimum welfare level is given by the following program:

$$\max_{k=A,B,C}\left\{\arg\max_P\left\{(1-c)q^k\left(R(P)\right)-\gamma\left(q^k\left(R(P)\right)\right)^2+\frac{t(3\left(\Delta^k(P)-\Delta^k(P)\right)-1)}{12}\right\}\right\}$$

where $q^k(R(P))$ and $\Delta^k(P)$ are defined in proposition 4 for $k = A, B, C$. In order to simplify the exposition we proceed in two steps. First we derive the properties and existence of the 3 regimes separately. Next, we turn to the optimal regime. Figure 1 below resumes our findings.

Characterization and existence of the different regimes In appendix F, we prove the following lemma.

Lemma 3 *(i) Regime A can only occur only if* $t < \underline{t}$. *Corresponding optimal allocations are those described by point* (*i*) *of proposition 3.*

(ii) Regime C can only occur only if $t > \bar{t}$. Corresponding optimal allocations are those described by point (iii) of proposition 3.

(iii) For any t, regime B can occur. Corresponding optimal allocations are such that $Q_s^B = \{q^{FB}, q^{FB}\}$ while

(a) for any $t < \underline{\underline{t}}$, $\tilde{c} = 0$ and $\Delta^A > \Delta^B > \Delta^{FB}$.

(b) for any $t \in \left[\underline{\underline{t}}, \bar{\bar{t}}\right]$, $\tilde{c} \in (0, c)$ and $\Delta^B = \Delta^{FB}$.

(c) for any $t > \bar{\bar{t}}$, $\tilde{c} = c$ and $\Delta^B < \Delta^{FB} < \Delta^C$.

where $\underline{\underline{t}} = (1-c)/\gamma < \underline{t}$ and $\bar{\bar{t}} = \left((1-3c) + \sqrt{1+10c-7c^2}\right)/2 < \underline{t}$.

Points (i) and (ii) come at no surprise. Since regimes A and C lead to their full commitment counterparts, they are credible for the same range of t and lead to the same prices and allocations. As stressed in section 4.2.2, the level of differentiation in regime B is lower than its full commitment counterpart because of the strategic cost reimbursement effect. Thus, at any optimal allocations, the maximal (resp. minimal) value of t for which there is under(over)differentiation is lower than their full commitment counterparts.

Optimum In appendix G, we prove the following proposition describing the optimum regime depending upon the level of the transportation cost.

Proposition 5 *There always exists $\underset{\cdot}{t} \in \left[\bar{\bar{t}}, \underline{t}\right]$ and there* can *exist $\dot{t} > \bar{t}$ such that:*

(i) for any $t \in \left]\underset{\cdot}{t}, \underline{t}\right[$, regime A is optimal.

(ii) for any $t \leq \underset{\cdot}{t}$, $t \in \left[\underline{t}, \bar{t}\right]$ and $t \geq \dot{t}$, regime B is optimal.

(iii) for any $t \in \left]\bar{t}, \dot{t}\right[$, regime C is optimal.

Consider first the case where $t < \bar{\bar{t}}$. As described in lemma 3, only regime A and B are credible. Regime B is characterized by first best quality levels and overdifferentiation while regime A is characterized by underprovision of quality and overdifferentiation. But the level of differentiaton is lower in regime B so that regime B always dominates regime A. When $t \in \left[\bar{\bar{t}}, \underline{t}\right]$, regime B is characterized by first best quality levels and underdifferentiation while regime C still implies underprovision of quality and overdifferentiation. The optimum thus trade-offs regimes B's underdifferentiation with regime C's underprovision of quality and overdifferentiation. We show in the appendix that there exists a value $\underset{\cdot}{t}$ for which the two regimes lead to the same level of welfare while regime B (resp. C) dominates for lower (resp. higher) values of t. Now for $t \in \left[\underline{t}, \bar{t}\right]$, only regime B is credible so that the optimum is characterized by first best quality levels and underdifferentiation. Lastly, for $t > \bar{t}$, regimes C and B are credible. The optimum trade-offs regime C in which there is overprovision of quality and underdifferentiation and regime B in which first best levels of quality are implemented but with underdifferentiation. As shown by figure 2 below,[22] there may exists a value $\dot{t}$ for which regime C and B lead to the same level of welfare while regime C (resp. B) dominates for lower (resp. higher)

[22] These illustrations assume $\gamma = 1.5$ and $c = 0.3$ and only consider $t \geq \bar{t}$.

values of t. If $\dot{t}$ does not exist, then regime C is always the optimum in this range of transportation cost parameters.

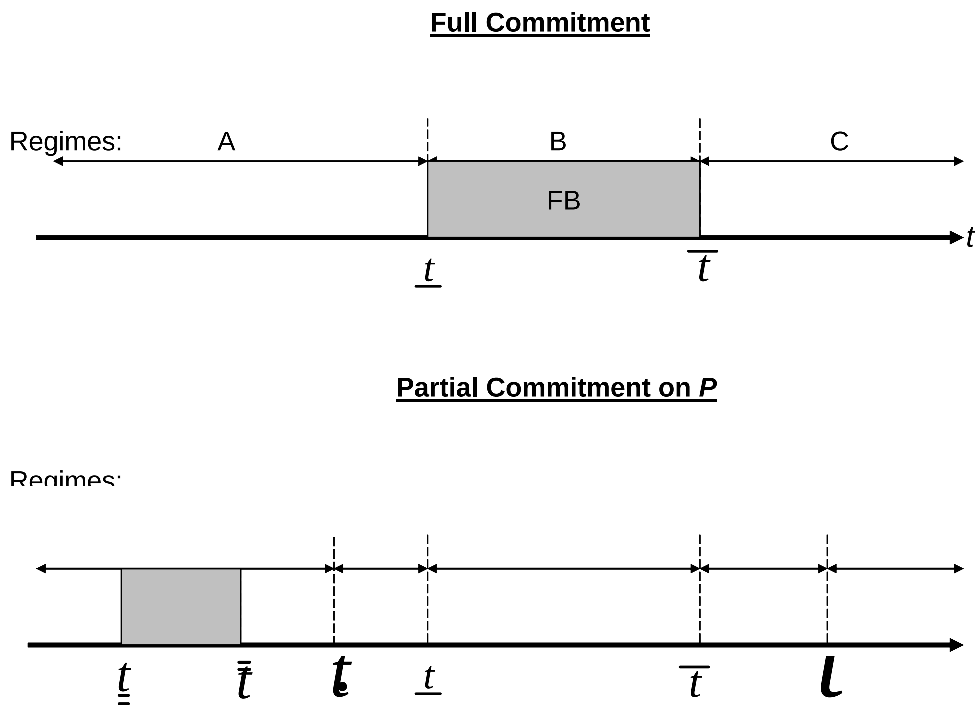

Figure 1

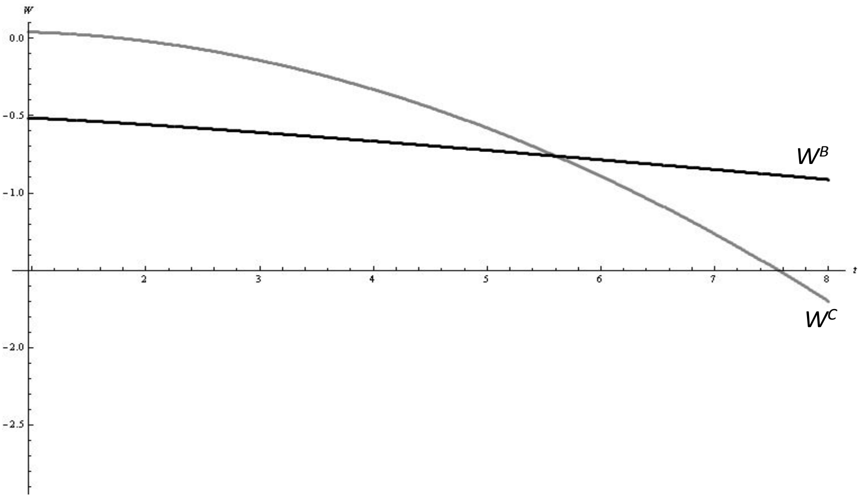

Figure 2

Let us finally comment our results in terms of policy recommendations. When the regulator cannot commit to a retrospective payment, the cost reimbursement again decreases with the level of transportation cost. As in the full commitment case, it means that cost sharing should be used in more competitive markets.

5 Conclusion

In this paper, we analyze the optimality of a mixed cost reimbursement when providers set strategically their levels of horizontal differentiation and of quality provided. The question is relevant since a pure prospective reimbursement scheme may fail to decentralize the optimal allocation when there is more than one dimension of choice on the providers' side. Moreover, cost reimbursement has been many times advocated in the literature dealing with the regulation of payments to health care providers. The main reason is the possibility of dumping or cream-skimming behaviors on the supply side of the health care sector. We consider the model of Ma (1994), applied to a context in which two providers compete over quality on an Hotelling line. Extending the framework adopted in Brekke *et al.* (2006), we allow the health care providers to incur some variable costs for each unit of quality supplied. This gives the regulator the opportunity to use a mixed reimbursement scheme involving a pure prospective payment and a cost reimbursement rate applied to variable costs as in Ma (1994).

We show that a pure prospective payment implies a trade-off between the desirable provision of quality and horizontal differentiation. Then we show that this trade-off can be mitigated or even eliminated when allowing the regulator to reimburse partially or totally the variable costs due to higher quality levels. This happens when a pure prospective payment leads to underprovision of quality and overdifferentiation. In this case, cost reimbursement allows to increase the provision of quality while keeping the price level low enough to limit horizontal differentiation. The main conclusion of this paper is that a pure prospective reimbursement scheme itself may be not suitable in cases in which the level of specialization is not contractible. This gives a new rationale for retrospective payments to health care providers.

If the regulator is not able to commit *ex ante* to the reimbursement scheme, or can only commit to the cost reimbursement rate, this results in maximal differentiation and optimal provision of quality. Conversely, if the government can only commit on the prospective payment, the resulting allocation depends on the parameters' value. In particular, this form of partial commitment is an improvement over the full commitment scenario if the transportation costs are very low. In some cases, partial commitment is superior in terms of welfare results even when transportation costs are very high. Interestingly, some cost reimbursement may be optimal with partial commitment, while it is not under full commitment.

In terms of policy recommendation, cost sharing decreases with the transportation cost in both scenarii. Cost reimbursement is thus a useful instrument when the health care providers'market is characterized by a high degree of competitiveness. This certainly calls for a high coordination between competition policy issues and the regulation of health care markets.

This paper could be extended in several directions. First, similarly to Brekke *et al.* (2010), a dynamic approach in which quality investment are long run decisions could be useful to understand the design of an optimal dynamic regulation. Second, it would provide useful insights to consider a mixed oligopoly framework in which hospitals are characterized by different objectives (private, public, collective, *etc...*) as in Cremer and Thisse (1991) or more recently in Herr (2009). Finally, our paper assumes that the market is fully covered. It would be interesting to see how the results change if one assumes that the market is only partially covered. In such a case, one should carefully consider the possibility of cost sharing on the patients' side.

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Appendix

A Uniqueness of Δ^* and maximum globality of the locational solution

To prove that Δ^* as defined by (12) is unique in $\Re^{++}$ and such that x_i^* is a global maximum, we proceed in two steps. The first step consists in showing that Δ^* is unique. The second step consists in showing that Δ^* is a global maximum. To do so, we first show that the profit function of firm 1 is monotonically increasing in x_1 up to the point x_1^* and then monotonically decreasing in x_1.

- The set of candidates for the optimal value of Δ are the roots of the following fourth degree polynomial:

$$\mathcal{P}(\Delta) = \Delta - \frac{\left(2\gamma P + \hat{c}^2\right)}{(\hat{c} + 2t\gamma\Delta)^2} \frac{(3\hat{c} + 2t\gamma\Delta)}{(2\hat{c} + 2t\gamma\Delta)}.$$

  The derivative of the polynomial with respect to Δ has the form:

$$\frac{\partial \mathcal{P}(\Delta)}{\partial \Delta} = \frac{(\hat{c} + 2t\gamma\Delta)^3 (2\hat{c} + 2t\gamma\Delta)^2 + 2t\gamma \left(2\gamma P + \hat{c}^2\right) \left[13\hat{c}^2 + 22t\gamma\Delta\hat{c} + 8t^2\gamma^2\Delta^2\right]}{(\hat{c} + 2t\gamma\Delta)^3 (2\hat{c} + 2t\gamma\Delta)^2},$$

  which is strictly positive for any $\Delta \in \Re^{++}$. Thus, $\mathcal{P}(\Delta)$ is strictly increasing. As a consequence, if there exists a positive root to this polynomial, it has to be unique. The existence of such a root follows from $\mathcal{P}(0) < 0$.

- To show that Δ^* is such that x_1^* is a global maximum in the set $\Re^{++}$, consider the second order derivative of the firm's 1 profit function with respect to x_1.

$$\begin{aligned} \frac{\partial^2 \pi_1}{\partial x_1^2} &= (P - \hat{c}q^*)\frac{1}{2}\left[\left(\frac{\partial q_1}{\partial x_1} - \frac{\partial q_2}{\partial x_1}\right)\frac{1}{t\Delta^2} - \frac{3\,(q_1 - q_2)}{t\Delta^3} - \frac{\partial q_2}{\partial x_1}\frac{1}{t\Delta^2} - \frac{\partial^2 q_2}{\partial x_1^2}\frac{1}{t\Delta}\right] \\ & \quad -\hat{c}\frac{\partial q_2}{\partial x_1}\left(\frac{1}{2} + \frac{q_1 - q_2}{2t\Delta^2} - \frac{\partial q_2}{\partial x_1}\frac{1}{2t\Delta}\right). \end{aligned}$$

  Evaluated at Δ^*, this yields

$$\frac{\partial^2 \pi_1}{\partial x_1^2} = (P - \hat{c}q^*)\frac{1}{2} = \left[-\left(\frac{2\hat{c}}{(3\hat{c} + 2t\gamma\Delta)}\right)\frac{1}{t(\Delta^*)^2} - \frac{\partial q_2}{\partial x_1}\frac{1}{t(\Delta^*)^2} - \frac{\partial^2 q_2}{\partial x_1^2}\frac{1}{t\Delta^*}\right]$$

  which is negative for any $\Delta^* > 0$. Since Δ^* is the unique positive root of $\mathcal{P}(\Delta)$, it is also the global maximum of the profit function.

B Proof of proposition 1

Differentiation of (12) with respect to P, $\hat{c}$ and t respectively leads to:

$$\begin{aligned}
\frac{\partial \Delta^*(.)}{\partial P} &= \frac{2\gamma(\hat{c}+2t\gamma\Delta^*)(2\hat{c}+2t\gamma\Delta^*)^2}{(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M} > 0,\\
\frac{d\Delta^*(.)}{d\hat{c}} &= \frac{2t\gamma\Delta\hat{c}M+2\gamma P\left[2t\gamma\Delta(\hat{c}+2t\gamma\Delta)-2(3c+2t\gamma\Delta)(2\hat{c}+2t\gamma\Delta)\right]}{(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M}\\
\frac{d\Delta^*(.)}{dt} &= \frac{-2\gamma\Delta\left(2\gamma P+\hat{c}^2\right)M}{(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M} < 0.
\end{aligned}$$

where $M = 13(\hat{c})^2 + 22t\gamma\Delta\hat{c} + 8t^2\gamma^2\Delta^2 > 0$.

Using the above expressions and differentiation of (13) with respect to P, $\hat{c}$ and t respectively leads to:

$$\begin{aligned}
\frac{dq^*(.)}{dP} &= \left(\frac{\partial q(\Delta^*,.)}{\partial \Delta}\frac{\partial \Delta^*(.)}{\partial P}+\frac{\partial q(\Delta^*,.)}{\partial P}\right)\\
&= \frac{(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma\left(2\gamma P+\hat{c}^2\right)\left(9(\hat{c})^2+18t\gamma\Delta\hat{c}+4t^2\gamma^2\Delta^2\right)}{(\hat{c}+2t\gamma\Delta)\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M\right]} > 0,\\
\frac{dq^*(.)}{d\hat{c}} &= \left(\frac{\partial q(\Delta^*,.)}{\partial \Delta}\frac{\partial \Delta^*(.)}{\partial \hat{c}}+\frac{\partial q(\Delta^*,.)}{\partial \hat{c}}\right)\\
&= \frac{-\left(2\gamma t^2\Delta^2\right)\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma\left(2\gamma P+\hat{c}^2\right)M\right] - \hat{c}^2 t\left[2t\gamma\Delta\hat{c}M+2\gamma P\left[2t\gamma\Delta(\hat{c}+2t\gamma\Delta)-2(3c+2t\gamma\Delta)(2\hat{c}+2t\gamma\Delta)\right]\right]}{(\hat{c}+2t\gamma\Delta)^2\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M\right]}\\
&\quad - \frac{-2t\gamma\left(2\gamma P+\hat{c}^2\right)P(\hat{c}+2t\gamma\Delta)^2}{(\hat{c}+2t\gamma\Delta)^2\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M\right]} < 0,\\
\frac{dq^*(.)}{dt} &= \left(\frac{\partial q(\Delta^*,.)}{\partial t}\frac{\partial \Delta^*(.)}{\partial t}+\frac{\partial q(\Delta^*,.)}{\partial t}\right)\\
&= \frac{-\left(2\gamma P+\hat{c}^2\right)\Delta\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2\right]}{(\hat{c}+2t\gamma\Delta)^2\left[(\hat{c}+2t\gamma\Delta)^3(2\hat{c}+2t\gamma\Delta)^2+2t\gamma(2\gamma P+\hat{c}^2)M\right]} < 0.
\end{aligned}$$

C Proof of proposition 2

If the regulator is constrained to a pure prospective payment, his problem is:

$$\max_P (1-c)q(P)-\gamma(q(P))^2+\frac{t\left[3\left(\Delta(P)-(\Delta(P))^2\right)-1\right]}{12}.$$

The first order condition with respect to P can be written as:

$$\Phi(P) = (1-c-2\gamma q(P))\frac{\partial q^*(.)}{\partial P}+\frac{t}{4}(1-2\Delta(P))\frac{\partial \Delta^*(.)}{\partial P} = 0. \quad (27)$$

Consider now the price P^L that decentralizes the first best location choices *i.e.* $P^L = \left[(c+t\gamma)^2(2c+t\gamma) - 2c^2(3c+t\gamma)\right]/4\gamma(3c+t\gamma)$ which is increasing in t. The left hand side of (27) thus becomes:

$$\Phi\left(P^L\right) = \left(1 - c - 2\gamma q\left(P^L\right)\right)\frac{\partial q\left(P^L\right)}{\partial P}.$$

(i) P^L decentralizes the first best level of quality if and only if $\Phi\left(P^L\right) = 0$ and $q^L\left(P^L\right) = q^{FB}$. Using (13),

$$q\left(P^L\right) = \left(2P^L - ct\right)/2\left(c+t\gamma\right) = \left[(c+t\gamma)\left(2c+t\gamma\right)/\left(3c+t\gamma\right) - 2c\right]/4\gamma.$$

Thus comparing this last expression to (16), $q\left(P^L\right) = q^{FB} = (1-c)/2\gamma$ if and only if $t = \left[(2-3c) + \sqrt{c^2+12c+4}\right]/2\gamma = \bar{t}$.

(ii) If $t > \bar{t}$, $q\left(P^L\right) > q^{FB}$ since q^L is increasing in t. As a consequence $(1 - c - 2\gamma q\left(P^L\right)) < 0$. Moreover, we showed in appendix B that $\left(\partial q\left(P\right)/\partial\Delta\right)\left(\partial\Delta\left(P\right)/\partial P\right) + \left(\partial q\left(P\right)/\partial P\right) > 0$ so that $\Phi\left(P^L\right) < 0$. Then P^L cannot be the optimal price. By concavity of the problem, the second best price P^{SB} is such that $P^{SB} < P^L$. Since $\Delta\left(P\right)$ is increasing in P in equilibrium, $\Delta\left(P^{SB}\right) < 1/2$. The second best is thus characterized by underdifferentiation. Furthermore, $(t/4)\left(1 - 2\Delta\left(P^{SB}\right)\right)\left(\partial\Delta\left(P^{SB}\right)/\partial P\right) > 0$. Thus, in order to satisfy the first order condition (27), the optimal price must be such that $\left(1 - c - 2\gamma q\left(P^{SB}\right)\right)\left(\left(\partial q\left(P^{SB}\right)/\partial\Delta\right)\left(\partial\Delta\left(P^{SB}\right)/\partial P\right) + \left(\partial q\left(P^{SB}\right)/\partial P\right)\right) < 0$, which is true if and only if $q^{SB} > q^{FB}$. The second best is thus characterized by overprovision of quality.

(iii) The reverse reasoning can be applied to the case in which $t < \bar{t}$.

D Proof of proposition 3

(i) To obtain the first best allocation, setting (16) and (17) equal to (13) and (12) respectively yields:

$$\frac{2P - \hat{c}t}{\hat{c} + \gamma t} = \frac{1-c}{2\gamma},$$
$$\frac{\left(2\gamma P + \hat{c}^2\right)}{(\hat{c}+t\gamma)^2}\frac{(3\hat{c}+t\gamma)}{(2\hat{c}+t\gamma)} - \frac{1}{2} = 0.$$

From these conditions, we obtain the regulatory parameters as described in (21) and (22). In particular, the optimal net cost parameter $\hat{c}$ defined by (22) is the only positive root (if any) of the following second order polynomial:

$$4\left(\hat{c}\right)^2 + \left(6(1-c) - t\gamma\right)\hat{c} + t\gamma\left(2(1-c) - t\gamma\right) = 0$$

If $t \geq 2(1-c)/\gamma$, the determinant of this polynomial is always greater than $(t\gamma - 6(1-c))^2$. Thus, the only positive solution is $\hat{c}^B$ defined by (22).

Note that $\hat{c}^B$ belongs to the set $[0,\ c]$ if and only if $t \in \left[2(1-c)/\gamma, \left[(2-3c)+\sqrt{c^2+12c+4}\right]/2\gamma\right]$. As shown in proposition 2, the first best allocation can be decentralized using a simple prospective reimbursement if $t = \bar{t} = \left[(2-3c)+\sqrt{c^2+12c+4}\right]/2\gamma$. If $t = \underline{t} = 2(1-c)/\gamma$, costs are fully reimbursed. It remains to be checked that the first best regulatory parameters ensure positive profits in a symmetric equilibrium. Substituting the first best values of quality, location and regulatory parameters in the profit function we obtain:

$$\pi^* = \left[\frac{(1-c)(\hat{c}+t\gamma)+\hat{c}t\gamma}{2\gamma} - \hat{c}\frac{(1-c)}{2\gamma}\right]\frac{1}{2} - \frac{(1-c)^2}{8\gamma}.$$

The non-negative profit condition thus reduces to:

$$2(1-c)t\gamma + 2\hat{c}t\gamma - (1-c)^2 \geq 0,$$

which is always true if $t \in \left[\underline{t}, \bar{t}\right]$.

(ii) When $t > \bar{t}$, equation (22) says that the constraint $\hat{c} \leq c$ is binding so that $\nu > 0$ and $\hat{c} = c$. This case corresponds to the one where the regulator only uses the prospective payment P so that by proposition 2 there is overprovision of quality and under-differentiation. It remains to be checked that the regulatory parameters ensure positive profits in a symmetric equilibrium. In this regime, the profit can be rewritten as

$$\pi^C = \frac{t\left(2\gamma P^C + c^2\right)^2}{\left(c+2t\gamma\Delta^{*C}\right)^2}\frac{\left(3c+2t\gamma\Delta^{*C}\right)}{\left(2c+2t\gamma\Delta^{*C}\right)} - \gamma\left(\frac{P^C - ct\Delta^{*C}}{c+2t\gamma\Delta^{*C}}\right)^2$$

Thus, profits are positive if and only if

$$t\left(2\gamma P + c^2\right)^2 \frac{\left(3c+2t\gamma\Delta^*\right)}{\left(2c+2t\gamma\Delta^*\right)} \geq \gamma\left(P - ct\Delta^*\right)^2. \tag{28}$$

Since $\left(3c+2t\gamma\Delta^*\right)/\left(2c+2t\gamma\Delta^*\right) > 1$ and $\Delta^* > 0$, a sufficient condition for (28) to hold is that

$$\begin{aligned} & t\left(2\gamma P + c^2\right)^2 > \gamma P \\ \iff\ & \gamma(4t\gamma - 1)P^2 + c^4 + 2t\gamma P c^2 > 0, \end{aligned}$$

wich is always true if $t > \bar{t}$. In fact $\bar{t} > \left[(2-3c)+(c+2)\right]/2\gamma = 2 - c/\gamma > 1/\gamma$, so that $t\gamma > 1$ and $4t\gamma > 1$.

(iii) When $t < \underline{t}$, equation (22) says that the constraint $\hat{c} \geq 0$ is binding so that $\mu > 0$ and $\hat{c} = 0$. One can then repeat the proof of proposition 2 where $\hat{c} = 0$ and $t < \underline{t} < \bar{t}$ to show that the optimum is such that there is underprovision of quality and overdifferentiation. It remains to be checked that the regulatory parameters ensure positive profits in a symmetric equilibrium. In this regime, the profit can be rewritten as

$$\pi(P^A, 0) = \frac{1}{2}P^A - \frac{\gamma}{2}\left((P^A)^{2/3}(2\gamma)^{-2/3}t^{-1/3}\right)^2.$$

This expression is positive if and only if

$$P^A < 16t^2\gamma,$$

which can be shown to be satisfied for any $t \geq (1-c)/2\gamma$.

E Proof of lemma 2

Substituting (1), (2) , (5) and (6), the first order condition (23) can be rewritten as:

$$\left[(1-c)\left(\frac{S}{2}+\frac{q_1-q_2}{t\Delta}\right)-\gamma q_1\right]\frac{\partial q_1}{\partial \hat{c}}+\left[(1-c)\left(1-\frac{S}{2}-\frac{q_1-q_2}{t\Delta}\right)-\gamma q_2\right]\frac{\partial q_2}{\partial \hat{c}}=0 \tag{29}$$

where

$$\begin{aligned}\frac{\partial q_1}{\partial \hat{c}} &= -\frac{P}{(\hat{c}+2t\gamma\Delta)^2}-\frac{4t^2\gamma\Delta^2\hat{c}(1-S)}{(\hat{c}+2t\gamma\Delta)(3\hat{c}+2t\gamma\Delta)^2}-\frac{2t^2\gamma\Delta^2\left((2+S)\hat{c}+2St\gamma\Delta\right)}{(\hat{c}+2t\gamma\Delta)^2(3\hat{c}+2t\gamma\Delta)}\\ \frac{\partial q_2}{\partial \hat{c}} &= -\frac{P}{(c'+2t\gamma\Delta)^2}-\frac{4t^2\gamma\Delta^2\hat{c}(S-1)}{(\hat{c}+2t\gamma\Delta)(3c'+2t\gamma\Delta)^2}-\frac{2t^2\gamma\Delta^2\left((4-S)\hat{c}+2(2-S)t\gamma\Delta\right)}{(\hat{c}+2t\gamma\Delta)^2(3c'+2t\gamma\Delta)}\end{aligned}$$

Applying the implicit function theorem to (29), one can write

$$\frac{\partial \hat{c}}{\partial x_1}(P,X)=-\frac{\Omega}{\Upsilon}$$

where

$$\begin{aligned}\Omega &= \left[(1-c)\left(\frac{1}{2}+\frac{q_1-q_2}{t\Delta^2}\right)\right]\frac{\partial q_1}{\partial \hat{c}}+\left[(1-c)\left(-\frac{1}{2}-\frac{q_1-q_2}{t\Delta^2}\right)\right]\frac{\partial q_2}{\partial \hat{c}}\\ &+ \left[\frac{1-c}{t\Delta}-\gamma\right]\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_1}{\partial x_1}+\left[\frac{1-c}{t\Delta}-\gamma\right]\frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_2}{\partial x_1}\\ &- \left[\frac{1-c}{t\Delta}\right]\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_2}{\partial x_1}-\left[\frac{1-c}{t\Delta}\right]\frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_1}{\partial x_1}\\ &+ \left[(1-c)\left(\frac{S}{2}+\frac{q_1-q_2}{t\Delta}\right)-\gamma q_1\right]\frac{\partial^2 q_1}{\partial \hat{c}\partial x_1}+\left[(1-c)\left(1-\frac{S}{2}-\frac{q_1-q_2}{t\Delta}\right)-\gamma q_2\right]\frac{\partial^2 q_2}{\partial \hat{c}\partial x_1},\end{aligned}$$

and

$$\begin{aligned}\Upsilon &= \left[\frac{1-c}{t\Delta}-\gamma\right]\left(\frac{\partial q_1}{\partial \hat{c}}\right)^2+\left[\frac{1-c}{t\Delta}-\gamma\right]\left(\frac{\partial q_2}{\partial \hat{c}}\right)^2\\ &- \left[\frac{1-c}{t\Delta}\right]\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_2}{\partial \hat{c}}-\left[\frac{1-c}{t\Delta}\right]\frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_1}{\partial \hat{c}}\\ &+ \left[(1-c)\left(\frac{S}{2}+\frac{q_1-q_2}{t\Delta}\right)-\gamma q_1\right]\frac{\partial^2 q_1}{\partial \hat{c}^2}+\left[(1-c)\left(1-\frac{S}{2}-\frac{q_1-q_2}{t\Delta}\right)-\gamma q_2\right]\frac{\partial^2 q_2}{\partial \hat{c}^2}\end{aligned}$$

In a symmetric equilibrium, this yields

$$\begin{aligned}\Omega_s &= \left(\frac{1-c}{2}\right)\left[\frac{\partial q_1}{\partial \hat{c}}-\frac{\partial q_2}{\partial \hat{c}}\right]-\gamma\left(\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_1}{\partial x_1}+\frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_2}{\partial x_1}\right)\\ &+ \left[\frac{1-c}{2}-\gamma q^*\right]\left(\frac{\partial^2 q_1}{\partial \hat{c}\partial x_1}+\frac{\partial^2 q_2}{\partial \hat{c}\partial x_1}\right),\end{aligned}$$

and

$$
\begin{aligned}
\Upsilon_s &= \left[\frac{1-c}{t\Delta} - \gamma\right]\left[\left(\frac{\partial q_1}{\partial \hat{c}}\right)^2 + \left(\frac{\partial q_2}{\partial \hat{c}}\right)^2\right] \\
&- \left[\frac{1-c}{t\Delta}\right]\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_2}{\partial \hat{c}} - \left[\frac{1-c}{t\Delta}\right]\frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_1}{\partial \hat{c}} \\
&+ \left[\frac{1-c}{2} - \gamma q^*\right]\left(\frac{\partial^2 q_1}{\partial \hat{c}^2} + \frac{\partial^2 q_2}{\partial \hat{c}^2}\right).
\end{aligned}
$$

Furthermore, at a symmetric equilibrium

$$
\frac{\partial q_1}{\partial \hat{c}} = \frac{\partial q_2}{\partial \hat{c}} = -\frac{P + 2t^2\gamma\Delta^2}{(\hat{c} + 2t\gamma\Delta)^2}
$$

and $\hat{c} = \tilde{c}$, so that $(1-c)/2 - \gamma q = 0$. Thus, using the comparative statics of $q_1$and q_2 with respect to x_1(given in section 2.2.1), we can rewrite Ω_s and Υ_S as

$$
\begin{aligned}
\Omega_s &= -\gamma\left(\frac{\partial q_1}{\partial \hat{c}}\frac{\partial q_1}{\partial x_1} + \frac{\partial q_2}{\partial \hat{c}}\frac{\partial q_2}{\partial x_1}\right) \\
&= \gamma\left(\frac{P + 2t^2\gamma\Delta^2}{(\hat{c} + 2t\gamma\Delta)^2}\right)\frac{2t\left(\hat{c}^2 + 2\gamma P\right)}{(\hat{c} + 2t\gamma\Delta)^2}
\end{aligned}
$$

and

$$
\begin{aligned}
\Upsilon_s &= -\gamma\left[\left(\frac{\partial q_1}{\partial \hat{c}}\right)^2 + \left(\frac{\partial q_2}{\partial \hat{c}}\right)^2\right] \\
&= -2\gamma\left(\frac{P + 2t^2\gamma\Delta^2}{(\hat{c} + 2t\gamma\Delta)^2}\right)^2.
\end{aligned}
$$

Consequently, at a symmetric equilibrium

$$
\left.\frac{\partial \hat{c}(P,X)}{\partial x_1}\right|_{X=X_s} = -\frac{\Omega_s}{\Upsilon_s} = \frac{t\left(\hat{c}^2 + 2\gamma P\right)}{P + 2t^2\gamma\Delta^2} \geq 0
$$

F Proof of lemma3

The proofs of points (i) and (ii) are direct implications of proposition 3.

In regime B, the problem of the regulator can be written as

$$
\begin{aligned}
&\max_P \frac{t(3\left(\Delta^B(P) - \Delta^B(P)\right) - 1)}{12} \\
\text{s.t} \quad &(\varsigma)\ \ P \geq (1-c)t\Delta^B(P) \\
&(\varrho)\ P \leq (1-c)c/2\gamma + t\Delta^B(P)
\end{aligned}
$$

where ς and ϱ are (positive) Lagrange multipliers respectively associated with minimal and maximal constraint on P. Assume first that $\varsigma = \varrho = 0$. The interior first order condition with respect to P simply involves $\Delta^B = 1/2$. Substituting $\Delta^B = 1/2$ in (26), it yields

$$P = \frac{t\left(3(1-c)^2 - 2t\gamma(1-c) + t^2\gamma^2\right)}{4\left(2(1-c) - t\gamma\right)} \tag{30}$$

$\varsigma = \varrho = 0$ is thus satisfied if and only if:

$$\frac{t(1-c)}{2} \leq P \leq \frac{(1-c)c + t\gamma}{2\gamma}.$$

which using (30) reduces to $\underline{\underline{t}} \leq t \leq \overline{\overline{t}}$.

If $t < \underline{\underline{t}}$, then $\varsigma > 0$, the price is constrained and $P = (1-c)t\Delta^B(P)$. Substituting $P^B = (1-c)t\Delta^B(P, 0)$ in (26) yields

$$\Delta^B - \frac{(1-c)}{(1-c) + 2t\gamma\Delta^B} = 0 \tag{31}$$

It is easy to show that Δ^B is decreasing in t and equal to 1/2 if and only if $t = \underline{\underline{t}}$. Thus, this solution is characterized by overderdifferentiation.

Conversely, if $t > \overline{\overline{t}}$, the price is constrained and $P^B = (1-c)c/2\gamma + t\Delta^B(P)$. The level of differentiation is implicitly defined by

$$\Delta^B - \frac{(1-c)}{(1-c) + 2t\gamma\Delta^B}\frac{3c + 2t\gamma\Delta^B}{2c + 2t\gamma\Delta^B} = 0. \tag{32}$$

Straightforward calculations show that Δ^B is decreasing in t and is equal to 1/2 if and only if $t = \overline{\overline{t}}$. Thus, this solution is characterized by underdifferentiation.

G Proof of proposition 5

In regime A, $R^A = \left\{P^A, 0\right\}$ where

$$P^A = \arg\max_P \; W = (1-c)q^{A*} - \gamma\left(q^{A*}\right)^2 + \frac{t\left[3\left(\Delta^{*A} - \left(\Delta^{*A}\right)^2\right) - 1\right]}{12}.$$

which can be shown to yield:

$$P^A = (1-c)\,t\Delta^{A*} + \frac{t}{8} - \frac{1}{4}t\Delta^A \tag{33}$$

Substituting equation (33) in (12) yields:

$$\Delta^{A*} = \frac{(1-c)}{2t\gamma\Delta^{A*}} - \frac{1 - 2\Delta^{A*}}{16t\gamma(\Delta^{A*})^2} \tag{34}$$

with

$$q^{A*} = \left(\frac{P^A}{2\gamma}\right)^{2/3} t^{-1/3} \tag{35}$$

This defines:

$$W^A(t) = (1-c)q^{A*}(t) - \gamma q^{A*}(t) + \frac{t\left[3\left(\Delta^{A*}(t) - \left(\Delta^{A*}(t)\right)^2\right) - 1\right]}{12},$$

Differentiating $W^A(t)$ with respect to t and using the envelop theorem yields:

$$\begin{aligned}\frac{\partial W^A}{\partial t} &= (1-c-2\gamma q^{A*})\frac{\partial q^{A*}}{\partial t} + \frac{t}{4}(1-2\Delta^{A*})\frac{\partial \Delta^{A*}}{\partial t} \\ &\quad + \frac{1}{12}\left[3\left(\Delta^{A*} - \left(\Delta^{A*}\right)^2\right) - 1\right],\end{aligned}$$

which using $(33), (34)$ and (35) can be shown to yield:

$$\frac{dW^A}{dt} = \frac{\Delta^A}{8} - \frac{1}{12}.$$

Differentiating $W^B(t)$ with respect to t and using the envelop theorem yields:

$$\frac{\partial W^B}{\partial t} = \frac{t}{4}(1-2\Delta^B)\frac{\partial \Delta^B}{\partial t} + \frac{1}{12}\left[3\left(\Delta^B - \left(\Delta^B\right)^2\right) - 1\right].$$

One can thus write

$$\frac{dW^A}{dt} - \frac{dW^B}{dt} = \frac{\Delta^A}{8} - \frac{t}{4}(1-2\Delta^B)\frac{\partial \Delta^B}{\partial t} - \frac{\left(\Delta^B - \left(\Delta^B\right)^2\right)}{4}.$$

Since $\Delta^B < 1/2$ and $\partial \Delta^B / \partial t < 0$ in this range of parameters, $-(t/4)(1-2\Delta^B)\left(\partial \Delta^B/\partial t\right) > 0$. Furthermore,

$$\frac{\Delta^A}{8} - \frac{\left(\Delta^B - \left(\Delta^B\right)^2\right)}{4} = \frac{1}{8}\left[\Delta^A - 2\Delta^B(1-\Delta^B)\right] > 0,$$

since $\Delta^A > 1/2$ and $2\Delta^B(1-\Delta^B) < 1/2$. Thus $dW^A/dt - dW^B/dt > 0$ and $W^A - W^B$ is monotonically increasing. Consequently, there exists a unique threshold $\underset{\cdot}{t} \in \left]\bar{\bar{t}}, \underline{t}\right[$ such that regime B dominates for any $t < \underset{\cdot}{t}$, and regime A dominates for any $t \geq \underset{\cdot}{t}$.