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# HOSPITAL FINANCING AND THE DEVELOPMENT AND ADOPTION OF NEW TECHNOLOGIES

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# Hospital Financing and the development and adoption of new technologies

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**Abstract**

We study the influence of different reimbursement systems (PPS and CBR) on the development and adoption of different technologies with an endogenous supply of these technologies.With private R&D we found that under a mixed reimbursement system we there is space for the development and adoption of cost decreasing/quality increasing technologies. In a pure CBR no new technology is developed while in a pure PPS the technology developed and adopted is quality increasing and cost decresing.Endogeneizing the reimburesement, it is always optimal for the government to implement a pure PPS.When the R&D is carried out within the hospital a pure prospective payment system leads to the adoption of quality increasing/cost decreasing technologies. At the contrary, in a pure CBR, the type of technology developed and adopted depends on the reimbursement rate.Comparing the two reimbursement systems we may conclude that, if the reimbursement rate $r$ is less than unity then a pure Prospective payment system provides more incentives for the development of quality increasing/cost decreasing technologies. For an $r$ greater than unity we found that a pure PPS is more efficient in reducing the costs. For a sufficiently high prospective reimbursement fee $R$, the technologies developed under a PPS provide more quality than the ones developed under a pure CBR.If demand is sufficiently sensitive to quality it is optimal for the government to reimburse the hospital on a prospective basis. Otherwise a mixed reimbursement system will prevail.

## 1 Introduction

Technological progress has been indentified as one of the major contributors to the rising health care expenditure (Newhouse,1992).

This contribution is a product of two processes: the development and the adoption of technologies, both of fundamental importance for the development of both health benefits and costs.

Furthermore, changes in treatment account for most of the growth in spending on specific diseases (Cutler McClellan & Newhouse (1998), McClellan Newhouse and Remler(1998) ).

The idea that different reimbursement systems lead to the adoption of different types of technology has been widely defended in the existing literature. While Cost Based Reimbursement is believed to create incentives for the provision of quality for any cost level, hospitals that are reimbursed through a Prospective Payment System (PPS) scheme focus on short-run cost savings rather than on treatment quality.

Romeo *et al* (1984) test emprically the effect of prospective reimbursement on the diffusion of technologies. The authors have shown that Prospective Reimbursement affect the diffusion of new medical technologies and that the attractiveness of cost saving technologies might be enhanced by a strong Prospective Reimbursement System.

Even though this idea has been widely covered by health economics literature a better theoretical understanding of the factors influencing the development and adoption of new technologies is crucial to explain which type of innovation will actually be used in the medical market.

Several early studies showed that the technology adopted by hospitals is sensitive to reimbursement policies but little attention has been paid on the externality of these policies on the supply side of the R&D process.

The diffusion process of existing technologies may feed back into the R&D sector since the incentives to create new technologies are dependent on the propensity to apply them.

If different reimbursement systems create different demands for innovation then it must be the case that they also influence the R&D sector decisions.

Weisbrod (1991) states that fee for service insurance bias the innovation/adoption process toward higher quality but higher cost technologies.

Palmeri (2001) describes an example of how payment systems can affect technological innovations. For cochlear implants the Medicaid payment was below its the average cost, making hospitals to reducing the use of its supply. As a consequence, the device turned out being unprofitable for the manufacturer that ended up its production.

The only theoretical paper focusing on the effect of reimbursement policies on the development of new technologies with endogeneous supply of this technologies is the one by Goddeeris (1984). The author finds that insurance biases technological change in the direction of innovations that icrease medical expenditure.

Our goal in this paper is to build a theoretical setting where we can analyse the influence of prospective, cost based and mixed reimbursement on the development and adoption of new technologies.

Incorporating, both, the demand and supply side of the innovation market we can examine the full welfare effects of reimbursement policies.

We study the influence of different reimbursement systems (prospective, cost based and mixed system) on the development and adoption of different technologies (cost decreasing/increasing and quality increasing) with an endogenous

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supply of these technologies.

The paper consists of two models, one where the R&D and the hospital are two separate agents and a second where the R&D process is done within the hospital

The former consists of a three agents model: a hospital, a private R&D firm and the government. Given the reimbursement system, from the hospital problem we derive a demand for different technologies to be incorporated in the R&D firm problem that will decide on the type of technology to be developed.

In the second model, given the reimbursement schedule, the hospital decides on the technology that will be developed and adopted.

The paper structure of the paper is as follows: in section 2 we describe briefly the common features of the three model settings, in section 3 we develop the benchmark, in section 4 we study the private R&D case, in the following section we analyse the model when R&D is carried out withinn the hospital and, finally, section 6 draws the conclusions.

## 2 The model:

We will now describe some features common to the three settings that we analyse.

We study an economy with a continuum of identical patients of mass standardized to one.

The number of agents varies with th setting up of the model. In the first best (section 3) we will have that the R&D firm and the hospital are run by the government. Thus the government allocates treatment and develops new technology.one single hospital, one R&D firm and the government. In the model of private R&D (section 4) the R&D firm and the hospital are two separate agents .In this case the economy has three agents: the government, the R&D firm and the hospital.Given the reimbursement schedule decided by the government, the hospital decides on the the level of quality to be provided and buys the technology from the R&D firm at a price $t$.

Finally, in the last model, R&D within the hospital, the economy has two agents: the hospital and the government. Also here the government decides on the optimal reimbursement to the hospital and the hospital decides on the technology to be developed.

We study an economy with a continuum of identical patients of mass standardized to one.

The treatment may be provided at an original marginal cost of $k_0 > 0$ and this treatment is processed by the use of technology.

We assume that exists only one type of technology. One can think about the development of a new technology as, on one hand, a product innovation and, on the other hand, a process innovation. Our technology covers both aspects. It is characterised by two parameters: $x$ and $k$ . The first, $x$, is a treatment quality parameter that represents the product innovation. The second, $k$, a cost

decreasing parameter. Increasing $x$ increases treatment quality and increasing $k$ decreases treatment marginal cost.

Developing technology is assumed to envolves "design" costs- $\frac{x^2}{2}, \frac{k^2}{2}$ and other production costs. For simplicity we will assume that, as the design costs are so big when compared with the production ones, the latest are negligible and thus set to zero.

Patients are assumed to have a reservation price- $p^*-$ that states their willingness to pay for quality. For a treatment price $p \leq p^*$ the patients demand $qx$ units of treatment. If $p > p^*$ the patient's demand is zero. Therefore, demand is given by,

$$d = \begin{cases} qx & \text{if} & p \leq p^* \\ 0 & \text{if} & p > p^* \end{cases} \tag{1}$$

By assumption, patients receive treatment free of charge, i.e., $p = 0$. Consumer surplus is then defined by:

$$CS = (p^* - p)qx \tag{2}$$

For sake of simplicity, we will normalise the reservation price $p^* = 1$. Therefore, consumer surplus is equal to $qx$.

# 3 First best:

We will first describe the first best solution as a benchmark

In the first best the R&D firm and the hospital are run by the government. Thus the government allocates treatment and develops new technology. Its objective will be to maximise a social welfare utility function that is composed by patient surplus$-qx-$ minus the cost of developing technology increased by the cost of public funds $\lambda$.

$$\max_{x,k} qx - (1 + \lambda) \left[ (k0 - k)qx + \frac{x^2}{2} + \frac{k^2}{2} \right]$$
$$s.t.\ x \geq 0,\ k \leq k_0$$

Solving the first order conditions for $x$ and $k$ the optimal solution will be described by the two following propositions.

**Proposition 1** *For $k_0 \leq \frac{q^2}{1+\lambda}$ the constraint on $k$ is slack and the optimum is*

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$$x^{FB} = q\frac{(1+\lambda)k0 - 1}{(1+\lambda)(q^2 - 1)}$$
$$k^{FB} = q^2\frac{(1+\lambda)k0 - 1}{(1+\lambda)(q^2 - 1)}$$

*Otherwise we have that the constraint is binding, hence, the optimum is,*

$$k = k_0$$
$$x = \frac{q}{1+\lambda}$$

# 4 Private R&D

## 4.1 The Model

In this model we have three agents: one hospital and one R&D firm and the government. The hospital supplies treatment to patients and buys technology from the R&D firm at a price $t$.

Technology is characterized by two parameters: $x$ and $k$ where $x$ is a treatment quality parameter and $k$ a cost decreasing parameter, i.e., increasing x increases treatment quality and increasing k decreases treatment marginal cost.

Developing technology is assumed to evolve "design" costs- $\frac{x^2}{2}, \frac{k^2}{2}$ and other production costs. For simplicity we will assume that, as the design costs are so big when compared with the production ones, the latest are negligible and thus set to zero. The cost associated with quality, $\frac{x^2}{2}$, will be bear by the hospital. These costs can be thought as the costs inherent to the basic research aimed at deriving the fundamental knowledge behind the development of new technologies. This assumption can be justified by the fact that the hospital is the agent with more information concerning the different diseases and the different treatments' efficacy in treating those diseases. The design cost $\frac{k^2}{2}$ will be paid by the R&D firm.

As patient's demand for treatment only depends on quality, the hospital decides on the demand for quality $x$.

The R&D firm decides on the price- $t$- and on the level of cost decreasing technology $k$.

The government decides on the reimbursement scheme: $R$ (Prospective Payment system Fee) and $r$ (Cost based reimbursement rate). We are in the presence of a pure Prospective Payment system when $R > 0$ but $r = 0$. A pure Cost Based reimbursement system is characterised by $R = 0$, $r > 0$. Finally a reimbursement scheme is classified as mixed for $R > 0$, $r > 0$ .

## 4.2 Timing:
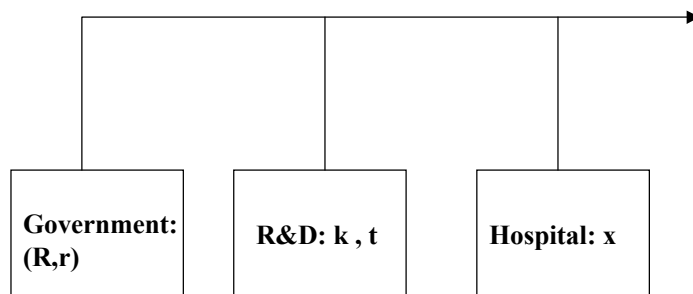


In the first stage the government decides on the reimbursement system. The reimbursement system can be of three types types: Cost Based Reimbursement System (CBR) and Prospective Payment System (PPS) and mixed system.

In a Cost based reimbursement system the hospital costs are fully or partly reimbursed *ex-post*. In this system, reimbursement is based on the incurred costs.

Wel assume that hospitals are reimbursed on its costs through a reimbursement rate $r \geq 0$. For $r < 1$ the hospital is partly reimbursed on its costs, $r = 1$ we are in the presence of full reimbursement and $r > 1$ could be interpreted as a subsidy.

Under a prospective reimbursement system (PPS) the hospital payment is determined *ex ante* and the reimbursement is independent of the real costs that the hospital will icurr when treatment is provided.

Finally a mixed system is a combination of the previous two systems.

In this paper we will assume that the prospective reimbursement consists of a per case payment, that is, the hospital is paid a fee $R > 0$ for each patient treated. This reimbursement could be thought as a Diagnostic Related Groups System (DRG-system) where, for sake of simplicity, only one group is considered for our analysis (patients are homogeneous on illness type as well as on severity).

In the second stage we have that the R&D firm will decide on the technology price to charge to the hospital as well on the technology parameter $k$ that will be developed.

And, finally, on the last stage, the hospital will decide on the demand for quality $x$.

The model will be solved backwards.

## 4.3 The hospital

The hospital is reimbursed by the government on its treatment costs. The reimbursement system is characterised by a cost based reimbursement parameter

$r$ and a prospective reimbursement parameter $R$. The hospital is paid, by the government, a fee per service $R$ and is reimbursed a share $r$ of its total costs.

For a patients'treatment demand $D = qx$ the hospital profit function is as follows:

$$\Pi_H = Rqx + (r-1)(k0 - k + t)qx - \frac{x^2}{2} \tag{3}$$

Being a profit maximizer agent the hospital problem will then be,

$$\max_x Rqx + (r-1)(k0 - k + t)qx - \frac{x^2}{2}$$
$$s.t.\ x \ \geq \ 0$$

Solving the first order condition for $x$:

$$x^* = q\left[R + (r-1)(k0 - k + t)\right] \tag{4}$$

## 4.4 The R&D firm

The R&D firm will, through a profit maximizing problem and anticipating the hospital behaviour, choose the level of k and on the technology price $t$ ensuring that the hospital makes non negative profits:

$$\max_{k,t} tqx - \frac{k^2}{2}$$
$$s.t.\pi_H \ \geq \ 0, k \leq k_0,\ x^* = q\left[R + (r-1)(k0 - k + t)\right]$$

Solving the maximization problem we can state the following results.

**Proposition 2** *For*

$$k_0 \geq \frac{q^2 R}{2}$$

*the constraint $k \leq k_0$ is slack and the optimum is given by*

$$
\begin{aligned}
t &= -\frac{R + (r-1)\,k_0}{q^2\,(r-1)^2 + 2\,(r-1)} \\
k &= q^2 \frac{R + (r-1)\,k_0}{q^2\,(r-1) + 2} \\
x &= q \frac{R + (r-1)\,k_0}{q^2\,(r-1) + 2}
\end{aligned}
\tag{5}
$$

This configuration of optimum is feasible for

$$r < 1, \ k_0 \geq \frac{q^2 R}{2}, \ q^2 (r - 1) + 2 > 0, R > (1 - r)k_0 \qquad (6)$$

Where the first inequality comes from the fact that $t > 0$. The second arises from $k \leq k_0$. The third is a second order condition. Finally the fourth ensures a positive $x$.

Given this optimum configuration we can further state that:

**Proposition 3** *For a low demand responsiveness to quality* $- q < 1-$ *we have the technology developed and adopted favours more quality than costs, i.e., the level of quality-x- per unit of the cost decreasing parameter-k is greater than one. If the demand is very sensitive to quality* $- q > 1-$ *the technology developed and adopted favours more cost reduction than quality.*

*Proof. Defining I as an index of units of quality per cost decreasing parameter,*

$$I = \frac{x}{k}$$

*From (5) we have that at the optimum* $I = \frac{1}{q}$. *Hence,*

$$\begin{cases} I > 1 & if \ q < 1 \\ I < 1 & if \ q > 1 \end{cases}$$

∎

**Proposition 4** *For*

$$k_0 < \frac{q^2 R}{2}$$

*the constraint* $k \leq k_0$ *is binding and the optimum is,*

$$\begin{aligned} t &= \frac{R}{2(1-r)} \\ k &= k_0 \\ x &= q\frac{R}{2} \end{aligned} \qquad (7)$$

This solution is valid for $r < 1$. Indeed for a higher $r$ the price would become negative meaning that the R&D firm would be incurring into losses, perferring then not to operate.

**Proposition 5** *For a suficiently high reimbursement fee, i.e.,* $R > \frac{2k_0}{q}$ *the technology developed and adopted favours more quality than costs, i.e., the units of*

*quality x per cost decreasing parameter k is greater than one . Otherwise, the technology developed and adopted favours more cost reduction than quality.*

**Proof.** *Defining I as an index of units of quality per cost decreasing parameter,*

$$I = \frac{x}{k}$$

*We have that at the optimum (from (7)) $I = \frac{qR}{2k_0}$. Hence,*

$$\begin{cases} I > 1 & if \ R > \frac{2k_0}{q} \\ I < 1 & if \ R < \frac{2k_0}{q} \end{cases}$$

∎

## Comparative Statics:

**Proposition 6** *For $k_0 \geq \frac{q^2 R}{2}$ quality the cost saving parameter and the technology price are always increasing in the reimbursement fee R .Moreover quality and the cost decreasing parameter are both increasing in r.*

**Proof.**

$$\frac{\partial t}{\partial R} = -\frac{1}{q^2 (r-1)^2 + 2 (r-1)}$$

$$\frac{\partial k}{\partial R} = \frac{q^2}{q^2 (1-r) + 2}$$

$$\frac{\partial k}{\partial r} = \frac{q^2 (2k_0 - q^2 R)}{[q^2 (1-r) + 2]^2}$$

$$\frac{\partial x}{\partial R} = \frac{q}{q^2 (1-r) + 2}$$

$$\frac{\partial x}{\partial r} = \frac{q (2k_0 - q^2 R)}{[q^2 (1-r) + 2]^2}$$

As the conditions for the existence of this optimum require that $k_0 \geq \frac{q^2 R}{2}$ , $r < 1$ and $q^2 < \frac{2}{(1-r)}$ we have that $\frac{\partial t}{\partial R} > 0$, $\frac{\partial k}{\partial R} > 0$, $\frac{\partial x}{\partial R} > 0$, $\frac{\partial k}{\partial r} > 0$, $\frac{\partial x}{\partial r} > 0$. ∎

**Proposition 7** *For $k_0 < \frac{q^2 R}{2}$ the price for technology, t, is increasing on both the reimbursement fee R and reimbursement rate r.The cost decreasing parameter is not affected by neither R nor r. Finally the level of quality is increasing in the reimbursement fee R.*

## 4.5 Pure Prospective Payment System:

We can now analyse the optimal technology and technology price for a pure Prospective Payment system. In a pure PPS we have that $r = 0$ hence the optimum is characterized by:

**Proposition 8** *For $k_0 \geq \frac{q^2 R}{2}$ at the optimum the technology developed and adopted will be cost decreasing and quality increasing. This optimum is characterised by*

$$
\begin{aligned}
t^{PPS} &= \frac{R - k_0}{2 - q^2} \\
k^{PPS} &= q^2 \frac{R - k_0}{2 - q^2} \\
x^{PPS} &= q \frac{R - k_0}{2 - q^2}
\end{aligned}
\tag{8}
$$

**Proof.** Being in a pure Prospective Payment System $r = 0$. Plugging $r = 0$ on (5) we find the above solution. From (6) and for $r = 0$ we have that $R - k_0 > 0$ and $q^2 < 2$. Hence $x^{PPS} > 0$, $k^{PPS} > 0$ ∎

In this case we have that the higher the reimbursement fee $R$ the higher the level of cost decreasing/ quality increasing technology developed and adopted.

**Proposition 9** *For $k_0 < \frac{q^2 R}{2}$, at the optimum the technology developed and adopted will be cost decreasing and quality increasing. This optimum is characterised by,*

$$
\begin{aligned}
t^{PPS} &= \frac{R}{2} \\
k^{PPS} &= k_0 \\
x^{PPS} &= q \frac{R}{2}
\end{aligned}
\tag{9}
$$

In this case we have that the higher the reimbursement fee $R$ the higher the level of quality and the higher the technology price.

## 4.6 Pure Cost Based Reimbursement System:

**Proposition 10** *In a pure Cost based reimbursement system no technology will be developed.*

**Proof.** In a pure CBR we have that $R = 0$. Hence plugging $R$ on (5) the optimum is characterised by:

$$t^{CBR} = \frac{(1-r)\,k_0}{q^2\,(r-1)^2 + 2\,(r-1)} \tag{10}$$

$$k^{CBR} = q^2 \frac{(r-1)\,k_0}{q^2\,(r-1)+2}$$

$$x^{CBR} = q \frac{(r-1)\,k_0}{q^2\,(r-1)+2}$$

One has to pay attention to the fact that as $k_0 > 0$, in a pure cost based reimbursement system we fall always in the first solution of the R&D problem.

As this optimum is defined for $r < 1$ and $q^2(r-1) + 2 > 0$ the hospital will demand zero quality. Hence, to not incur into negative profits, the best strategy for the R&D firm is not to produce. ∎

## 4.7 Optimal reimbursement:

Finally, given the hospital and the R&D firm behaviour the government will decide on the reimbursement variables: $r$ and $R$.

The government will then maximise an utilitarian social welfare function $W$,

$$\max_{r,R} W = qx + Rqx + (r-1)(k_0 - k + t)qx - \frac{x^2}{2} + tqx - \frac{k^2}{2}$$
$$-(1+\lambda)\left[Rqx + r(k_0 - k + t)qx\right]$$

Where the first term is patient's surplus, $Rqx + (r-1)(k_0 - k + t)qx - \frac{x^2}{2}$ is the hospital profit, $tqx - \frac{k^2}{2}$ is the R&D firm profit and $(1+\lambda)Rqx+$
$+(1+\lambda)r(k_0 - k + t)qx$ is the government reimbursement to the hospital weighed by the cost of public funds $\lambda$.

**Proposition 11** *As the social welfare function is always increasing in $k$ the reimbursement schedule will be chosen such that at the optimum $k$ is at its maximum, i.e, $k = k_0$.*

**Proof.** Indeed the welfare function $W$ can be re-written as $W = \Pi_H + \Pi_{R\&D} + qx\{1 - (1+\lambda)[R + r(k0 - k + t)]\}$ with $\Pi_H$ being the hospital profit and $\Pi_{R\&D}$ the R&D firm profit. The socially optimal level of $k$ is given by

$$\frac{dW}{dk} = \frac{d\Pi_H}{dk} + \frac{d\Pi_{R\&D}}{dk} + qx(1+\lambda)r$$
$$= \frac{d\Pi_{R\&D}}{dk} + qx(1+\lambda r)$$

From the envelope theorem $\frac{d\Pi_{R\&D}}{dk} = 0$ in case 2 $\frac{d\Pi_{R\&D}}{dk} > 0$ in case 1 of the R&D problem, what implies that $\frac{dW}{dk} > 0$ i.e. the social welfare is always increasing in $k$. Hence, it is always socially optimal to have $k = k0$

**Proposition 12** *For $k_0 < \frac{2}{4\lambda+1}$ a Pure Prospective Payment System is optimal and is characterised by:*

$$r = 0 \qquad\qquad (11)$$
$$R = \frac{2}{1+4\lambda}$$

**Proof.** For

$$k_0 < \frac{q^2 R}{2}$$

We have that in this case the R&D firm will always choose the social optimal level of $k$, i.e., $k = k_0$.

Having also that the welfare function is always decreasing in $t$ and always increasing in $x$. As $t$ is increasing in both $r$ and $R$, but $x$ is not affected by $r$ and is increasing in $R$, it is always optimal for the government to use $r$ to induce a low value of $t$. Hence it is always optimal to set $r = 0$. Finally, it is desirable from a welfare point of view to increase quality. The only instrument that the government has to control the level of quality is $R$. However, this reimbursement fee also affects positively $t$. Hence, the optimal level of $R$ will depend on the tradeoff between the positive effect of increasing $x$ and the negative effect of increasing $t$.

Analitically, the government objective is:

$$\max_{r,R} W = qx + Rqx + (r-1)(k_0 - k + t)qx - \frac{x^2}{2} + tqx - \frac{k^2}{2}$$
$$- (1+\lambda)\left[Rqx + r(k_0 - k + t)qx\right]$$

From the R&D problem we know that from (7):

$$t = \frac{R}{2(1-r)}$$
$$k = k_0$$
$$x = q\frac{R}{2}$$

Plugging in $W$ and solving the first order conditions one can easily find that the optimum is:

$$r = 0$$
$$R = \frac{2}{1+4\lambda}$$

As the R&D optimum above stated is defined for $k_0 < \frac{q^2 R}{2}$ we have that this solution is valid for $k_0 < \frac{q^2}{4\lambda+1}$ ■ ■

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**Proposition 13** *For $k_0 \geq \frac{2}{4\lambda+1}$ the government will choose to be on the constraint $k_0 \geq \frac{q^2 R}{2}$ meaning that at the optimum $R = \frac{2k_0}{q^2}$*

**Proof.** For $k_0 \geq \frac{2}{4\lambda+1}$ we have that $k_0 < \frac{q^2 R}{2}$ no longer holds and so we fall in the second case of the R&D problem:

$$t^* = -\frac{R + (r-1)k_0}{q^2(r-1)^2 + 2(r-1)}$$

$$k^* = q^2 \frac{R + (r-1)k_0}{q^2(r-1) + 2}$$

$$x^* = q\frac{R + (r-1)k_0}{q^2(r-1) + 2}$$

That is an optimum for the constraint $k \leqslant k_0$ not binding. Plugging in $k^*$ this constraint can be rewritten as,

$$k_0 \geq \frac{q^2 R}{2}$$

As it is, from a social welfare point of view, desirable to have $k = k_0$ the optimal reimbursement schedule will lie on the boundary of this constraint, i.e., $R = \frac{2k_0}{q^2}$ ∎

**Proposition 14** *For $R = \frac{2k_0}{q^2}$ and $k = k_0$ the social welfare function is always decreasing in $t$ and $t$ is an increasing function of the reimbursement rate $r$. Therefore, we have that the optimal reimbursement system is always a pure PPS, that is $R = \frac{2k_0}{q^2}$ and $r = 0$. Moreover, at the optimum the technology developed and adopted will be cost decreasing and quality increasing.*

**Proof.** Given $k = k_0$, $R = \frac{2k_0}{q^2}$ we can easily see that the Welfare function is always decreasing in $t$. Plugging $r, R = \frac{2k_0}{q^2}$ and $k = k_0$ on $k^*, t^*$ and $x^*$ from (5) we get

$$x^* = \frac{k_0}{q}$$

$$k^* = k_0$$

$$t^* = \frac{k_0}{q^2(1-r)}$$

The Welfare function can then be rewritten as:

$$W = \Pi_H + \Pi_{R\&D} + qx\{1 - (1+\lambda)[R + rt]\}$$

Where $\Pi_H$ and $\Pi_{R\&D}$ stand for the hospital's and R&D firm's profits. The social optimal level of $t$ is given by

$$\frac{dW}{dt} = \frac{d\Pi_H}{dt} + \frac{d\Pi_{R\&D}}{dt} - qx(1 + \lambda)r$$

With $\frac{d\Pi_H}{dt} = (r-1)qx$ and, by the envelope theorem, $\frac{d\Pi_{R\&D}}{dt} = 0$ we have that:

$$\frac{dW}{dt} = -qx(1 + \lambda r) < 0$$

Hence it is always social optimum to set the reimbursement such that $t$ at the optimum is as low as possible.

With

$$t^* = \frac{k_0}{q^2(1-r)}$$

We have that $\frac{dt}{dr} > 0$, i.e., $t$ is increasing in $r$. Consequently, the government will use $r$ as an instrument to induce a low $t$, i.e., $r = 0$.

This optimum is valid for: $q^2 < 2$ that comes from the second order conditions of the R&D problem and for $k_0 > \frac{q^2}{1+4\lambda-\lambda q^2}$ that is the constrain that must hold for a positive lagrangean multiplier. ∎

# 5 R&D within the Hospital:

## 5.1 The model:

In this model we assume that the R&D process is carried out by the hospital. Thus, the development of technology is done by the hospital.

The model has then only two agents: the government and the hospital. The demand for treatment is the same as the one described before.

Government decides on the reimbursement scheme: $R$ (Prospective Payment system Fee) and $r$ (Cost based reimbursement rate). The hospital decides on the technology to be developed and adopted.

Technology is characterized by two parameters: $x$ and $k$ where $x$ is a treatment quality parameter and $k$ a cost decreasing parameter, i.e., increasing $x$ increases treatment quality and increasing $k$ decreases treatment marginal cost.

Developing technology is assumed to envolves "design" costs- $\frac{x^2}{2}, \frac{k^2}{2}$ and other production costs. For simplicity we will assume that, as the design costs are so big when compared with the production ones, the latest are negligible and thus set to zero.

## 5.2 Timing:
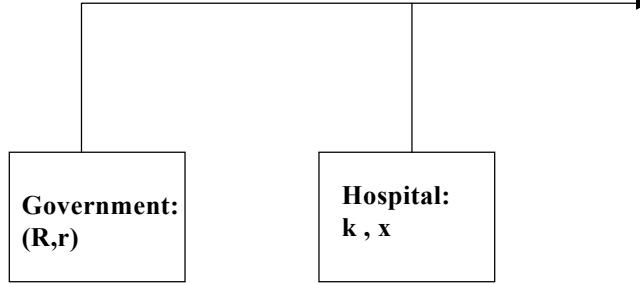


In the first stage the government decides on the optimal way to finance the hospital and on the second stage the hospital decides on thecharacteristics of the technology to be developed and adopted.

As usual, the model will be solved backwards.

## 5.3 The hospital problem:

The hospital objective function is thus:

$$\max_{x,k} Rqx + (r-1)(k0-k)qx - \frac{x^2}{2} - \frac{k^2}{2}$$
$$s.t \quad k \quad \leq \quad k_0, \ x \geq 0$$

Solving the first order conditions for $x$ and $k$ we get:

### 5.3.1 Case 1: $k = k_0$

If the constraint $k \leq k_0$ is binding we have that at the optimum the hospital will set:

$$k = k_0 \qquad (12)$$
$$x = qR$$

To ensure a positive lagrangean multiplier we have that this optimum holds for $k_0 < q^2 (1-r) R$.. Furthermore, as $k_0$ is by definition positive we have that $r < 1$.

**Proposition 15** *For $R > \frac{k_0}{q}$ in pure Prospective Payment System the level of quality per unit of the cost decreasing paraeter is higher than one.Otherwise, for $R < \frac{k_0}{q}$ it is lower than one.*

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**Proof.** The proof is straightforward. In a pure PPS we have that $r = 0$ and $R > 0$. Hence, the technology developed and adopted is characterized by:

$$
\begin{aligned}
x^{PPS} &= qR \\
k^{PPS} &= k_0
\end{aligned}
$$

Hence, we have that $\frac{x^{PPS}}{k^{PPS}} = \frac{qR}{k_0}$. Consequently, $\frac{x^{PPS}}{k^{PPS}} > 1$ $iff$ $R > \frac{k_0}{q}$, i.e., $R > \frac{k_0}{q}$. $\blacksquare$

**Proposition 16** *In a pure Cost Based Reimbursement system no new technology is developed.*

**Proof.** *Indeed analysing the profit function of the hospital we can easily see that for $r < 1$ the profit is always decreasing in quality being optimal to produce no technology ($x = 0, k = 0$)* $\blacksquare$

**Proposition 17** *In a pure Prospective Payment system the level of quality and of the cost decreasing parameter of the technology developed and adopted is always higher than those of a pure cost based reimbursement system.*

**Proof.** The proof is straightforward. In a pure PPS we have that $r = 0$ and $R > 0$ hence the technology developed and adopted is characterized by:

$$
\begin{aligned}
x^{PPS} &= qR \\
k^{PPS} &= k_0
\end{aligned}
$$

In a pure CBR $R = 0$ and $r > 0$. Thus, the technology developed and adopted in this case is characterised by:

$$
\begin{aligned}
x^{CBR} &= 0 \\
k^{CBR} &= 0
\end{aligned}
$$

A $q > 0$ clearly implies the proposition $x^{PPS} > x^{CBR}$ and $k^{PPS} > k^{CBR}$ $\blacksquare$

### 5.3.2 Case 2: $k \leq k_0$

When the constraint $k \leq k_0$ is slack the optimal solution is in accordance with the following proposition:

**Proposition 18** *For $k \leq k_0$ the optimum is*

$$
\begin{aligned}
x &= -\frac{q\left[R + (r-1)\,k_0\right]}{q^2\,(r-1)^2 - 1} \\
k &= q^2\frac{(r-1)\left[R + (r-1)\,k_0\right]}{q^2\,(r-1)^2 - 1}
\end{aligned}
\tag{13}
$$

*This optimum holds for : $R > (1-r)k_0$ for a positive $x$, $q^2(r-1)^2 - 1 < 0$ that comes from the second order conditions and for $k_0 \geq q^2(1-r)R$ that ensures that $k \leq k_0$*

It is now useful to analyse the optima of a pure Prospective Payment System and of a pure Cost Based Reimbursement System.

**Proposition 19** *For $r > 1$ we have that a pure cost based reimbursement system leads to the development and adoption of quality increasing/cost increasing technologies. Instead, if $r \leq 1$ no technology will be developed.*

**Proof.** In a pure CBR system we have that at the optimum the hospital will set $(x, k)$ such that:

$$x^{CBR} = q\frac{(1-r)k_0}{q^2(r-1)^2 - 1}$$

$$k^{CBR} = \frac{q^2(r-1)^2 k_0}{q^2(r-1)^2 - 1}$$

For the second order conditions to hold we have that $q^2(r-1)^2 - 1 < 0$. Consequently, for $r < 1$ the optimal level of quality and cost decreasing parameter is zero. On the other hand, for $r > 1$ technology will be quality increasing but cost increasing that is $x^{CBR} > 0$, $k^{CBR} > 0$. ∎

**Proposition 20** *A pure PPS is more effective in inducing quality than decreasing the costs.*

**Proof.** In a pure PPS system we have that at the optimum the hospital will set $(x, k)$ such that::

$$x^{PPS} = q\frac{R - k_0}{1 - q^2}$$

$$k^{PPS} = q^2\frac{R - k_0}{1 - q^2}$$

Having $\frac{x^{PPS}}{k^{PPS}} = \frac{1}{q}$ we can state the following:

$$If \quad \begin{cases} q > 1 & \Rightarrow & \frac{x^{PPS}}{k^{PPS}} < 1 \\ q < 1 & \Rightarrow & \frac{x^{PPS}}{k^{PPS}} > 1 \\ q = 1 & \Rightarrow & \frac{x^{PPS}}{k^{PPS}} = 1 \end{cases}$$

As this optimum is defined for $R > (1-r)k_0$ and for $q^2 < \frac{1}{(1-r)^2}$. Furthermore, as in a pure PPS $r = 0$ and as $q > 0$ these conditions can be rewritten as $R > k_0$ and $q < 1$. Hence, $\frac{x^{PPS}}{k^{PPS}} > 1$ ∎

Comparing the two reimbursement systems we can say that,

**Proposition 21** *For $r < 1$ a pure Prospective Payment System leads always to the development of technologies that are more quality increasing and cost decreasing than a pure Cost Based Reimbursement system*

    **Proof.** *Having seen that for $r < 1$ $x^{CBR} = k^{CBR} = 0$ and $x$ $x^{PPS} > 0$, $k^{PPS} > 0$ it comes straightforward that $x^{PPS} > x^{CBR}$ and $k^{PPS} > k^{CBR}$* ∎

**Proposition 22** *For $r > 1$ and $R > k_0 r$ a pure Prospective Payment system leads to a higher level of quality and a lower level of costs when compared with a pure Cost Based Reimbursement System.*

    **Proof.** The result immediatly follows from solving the following inequalities:

$$x^{PPS} = q\frac{R - k_0}{1 - q^2} > x^{CBR} = q\frac{(1 - r)k_0}{q^2(r-1)^2 - 1}$$

$$k^{PPS} = q^2\frac{R - k_0}{1 - q^2} > k^{CBR} = \frac{q^2(r-1)^2 k_0}{q^2(r-1)^2 - 1}$$

∎

## 5.4   Optimal reimbursement:

Finally, given the hospital behaviour the government will decide on the reimbursement variables.

    The government will then maximise an utilitarian social welfare function:

$$\max_{r,R} W = qx + Rqx + (r-1)(k_0 - k)qx - \frac{x^2}{2} - \frac{k^2}{2}$$
$$- (1 + \lambda)\left[Rqx + r(k_0 - k)qx\right]$$

    Where the first term is patient's surplus, $Rqx + (r-1)(k_0 - k)qx - \frac{x^2}{2} - \frac{k^2}{2}$ is the hospital profit, $(1+\lambda)\left[Rqx + r(k_0 - k)qx\right]$ is the government reimbursement to the hospital weighed by the cost of public funds $\lambda$.

**Proposition 23** *As the social welfare function is always increasing in $k$ the reimbursement schedule will be chosen such that at the optimum the hospital sets $k$ at its maximum, i.e, $k = k_0$.*

    **Proof.** *Indeed $W = H + qx\{1 - (1 + \lambda)[R + r(k0 - k)]\}$ with $H$ being the hospital profit. The socially optimal level of $k$ is given by*

$$\frac{dW}{dk} = \frac{dH}{dk} + qx(1 + \lambda)r$$

    *From the envelope theorem $\frac{dH}{dk} = 0$ in case 2, while $\frac{dH}{dk} > 0$ in case 1. This implies that the social welfare is always increasing in $k$. Hence, it is always socially optimal to have $k = k0$.* ∎

In the first case of the Hospital's problem, i.e., for $k_0 < q^2 R(1-r)$ the hospital at the optimum sets $k = k_0$. Hence, the government, knowing that the hospital's decision on $k$ doesn't depend on the reimbursement schedule $(R, r)$ and that quality only depends on $R$ the government can easily set $r = 0$ and choose an $R$ that maximises the Social Welfare function.

From the maximisation problem we find that at the optimum the government will set:

$$r = 0 \tag{14}$$
$$R = \frac{1}{2\lambda + 1}$$

In this case we have that at the optimum the technology developed will be characterized by:

$$x = \frac{q}{1 + 2\lambda}$$
$$k = k_0$$

And this solution is valid for $k_0 < \frac{q^2}{2\lambda+1}$, $q < 1$.

In the second solution of the hospital's problem the optimal level of the cost decreasing parameter $k$ is such that $k \leq k_0$, i.e., the constraint on $k$ is not binding.

$$k0 \geq (1-r)q^2 R$$

**Proposition 24** *If the demand for treatment is sufficiently sensitive to quality, i.e., $q^2 \geq \frac{k_0}{2\lambda+1}$, a pure Prospective Payment system is always optimal with $R = \frac{k_0}{q^2}$. Otherwise, if $q^2 < \frac{k_0}{2\lambda+1}$ the optimal reimbursement is characterised by a mixed reimbursement system with $R = \frac{1}{(1+2\lambda)}$ and $r = 1 - \frac{(2\lambda+1)}{q^2}$*

**Proof.** From proposition 23 we have that it is socially optimum to have $k0 = (1-r)q^2 R$. Rewriting this constraint,

$$r = 1 - \frac{k0}{q^2 R}$$

As $r \in [0, 1[$ we have that $r > 0$ is feasible if and only if

$$R > \frac{k0}{q^2}$$

In this case we get that at the optimum:

$$R = \frac{1}{(1 + 2\lambda)}$$
$$r = 1 - \frac{(2\lambda + 1)}{q^2}$$

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In such a case, the technology developed and adopted will be charecterised by:

$$x = \frac{q}{1 + 2\lambda}$$
$$k = k_0$$

This optimum is defined for $k_0 < \frac{q}{2\lambda+1}$. Instead if $R \leq \frac{k_0}{q^2}$ , $r = 1 - \frac{(2\lambda+1)}{q^2} < 0$. As $r \geq 0$ at the optimum this constraint will bind and we will have a corner solution:

$$r = 0$$
$$R = \frac{k_0}{q^2}$$

The technology developed and adopted will be characterised by:

$$x = \frac{k_0}{q}$$
$$k = k_0$$

This optimum is defined for
$k_0 > \frac{q^2}{2\lambda+1}$, $k_0 > \frac{q^2}{2\lambda+1-\lambda q^2}$, $q < 1$ ∎

# 6 Conclusions

Previous literature on the impact of reimbursement systems on quality and on cost decreasing efforts has mostly concluded that, while retrospective reimbursement encourages quality but lacks sensitivity towards cost decrease, PPS encourages cost efficiency but has perverse effects on quality improvement. Nevertheless, we have shown that, within the described set up, these results may not hold.

We focus our analysis on technology development and adoption under two models: private R&D and R&D within the hospital.

In the former set up we have been able to show that under a mixed reimbursement system we there is space for the development and adoption of cost decreasing/quality increasing technologies.By first treating the reimbursement as exogeneous, we have shown that under a pure Cost Based Reimbursement System no new technology is developed while in a pure Prospective Payment System the technology market is "active" and the technology developed and adopted allows for inreasing the quality of treatment and for savings in the marginal cost.

Going one step further and endogeneizing the reimburesement, we have also been able to show that it is always optimal for the government to implement a pure Prospective Reimbursement System.

In the latter case, when the R&D is carried out within the hospital a pure prospective payment system leads to the adoption of quality increasing/cost

decreasing technologies. At the contrary, in a pure Cost Based Reimbursement system, the type of technology developed and adopted depends on the reimbursement rate. In particular, when the hospital's costs are not fully covered, hence, in order to not incur into losses the hospital decides not to develop new technology. If instead the reimbursement rate is greater than unity the hospital is able to make positive profits by developing and adopting new technology. In this case the technology developed and adopted will be quality increasing but also cost increasing.

Comparing the two reimbursement systems we may conclude that, if the reimbursement rate $r$ is less than unity then a pure Prospective payment system provides more incentives for the development of quality increasing/cost decreasing technologies. For an $r$ greater than unity we found that, in what concerns costs savings, a pure Prospective Payment System is more efficient. Concerning quality we have been able to show that, for a sufficiently high prospective reimbursement fee $R$, the technologies developed under a pure prospective payment system provide more quality than the ones developed under a pure Cost Based Reimbursement system.

Finally, by endogeneizing the reimbursement, we found that,

if demand is sufficiently sensitive to quality it is optimal for the government to reimburse the hospital on a prospective basis. Otherwise a mixed reimbursement system will prevail.

fURTHER extensions:::

# 7    References

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