Hospital Financing and the Development and Adoption of New Technologies

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Abstract

We study the influence of different reimbursement systems, namely Prospective Payment System, Cost Based Reimbursement System and Mixed Reimbursement System on the development and adoption of different technologies with an endogenous supply of these technologies. We focus our analysis on technology development and adoption under two models: private R&D and R&D within the hospital. One of the major findings is that the optimal reimbursement system is a pure Prospective Payment System independently of the market structure.

Keywords: R&D, technology adoption, process and product innovation, optimal reimbursement

JEL Classifications: I18,H51,O31,O38

1 Introduction

Technological progress has been identified 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)). Given the preponderance of technology on total health care expenditure it urges the study of mechanisms behind the development, adoption and diffusion of technology. One of the possible factors that might affect the technology market is the health regulatory policy. If the regulation on the health care market can stimulate innovation, this has profound implications for the health policy targets and the choice of instruments to pursue them.

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The idea that different reimbursement systems lead to the adoption of different types of technology has been widely defended in the existing literature. Nonetheless, there has been some tendency to treat technology development as a black box. Indeed, although much of the existing literature targeted the effects of alternative policy instruments on technology innovation, the focus was constrained to the effects of policy on technology adoption and diffusion. In reality, this body of literature shows 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. 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 empirically the effect of prospective reimbursement on the diffusion of technologies. The authors have shown that Prospective Reimbursement affects the diffusion of new medical technologies and that a strong Prospective Reimbursement System might enhance the attractiveness of cost saving technologies.

Gelijns and Rosenberg (1994) describe two examples that back up the hypothesis that the rate of innovation is sensitive to changes in the financial regulatory environment within which hospitals act. The hypothesis inherent to both examples consists of the impact of the differential between the DRG tariff and the actual cost of the procedure on the development of technologies. In this way, the first example presented concerns the percutaneous transluminal coronary angiosplasty (PTCA). The author asserts that given that this procedure was assigned to a "profitable" surgical DRG, that is a DRG which had associated reimbursement tariff much higher than the actual cost of providing the procedure, it stimulated a rapid adoption of PCTA and high level of incremental innovation in PCTA catheters. The opposite effect is illustrated with the case of cochlear implants. By being classified under a "un-profitable" DRG, that is, a DRG for which the associated reimbursement did not cover the whole actual costs, there was not only a reduction in the diffusion but also a reduction in the R&D investment on this kind of procedure.

In the same line, Cutler and McClellan (1996), state some institutional factors as the major determinants of the pattern technology diffusion. These factors are the insurance mechanism, public policy regulating technologies, malpractice concerns, competition degree between providers and demographic change. The authors conclude by identifying the insurance levels, technology regulation and the relation between providers as the more influent factors on the pattern of technology diffusion.

Even though these studies contribute to the study of the effect of health financing policies on technology adoption, we believe that the way in which the R&D sector is affected by these policies is an important issue and has not been explored by the existing literature. Indeed, beyond such case studies, just a limited literature (partly) documents how recent changes in the financial flows taking place in the health care
market are affecting the rate and pattern of innovation. Nevertheless, the above described studies seem to open the door to the conjecture on the relation between the R&D market and the underlying health care institutional set up, by allowing to further infer on the relation between the patterns of technological change and the health care financial flows.

The diffusion process of existing technologies may feed back into the R&D sector since the incentives to create new technologies depend on the propensity to apply them. If different reimbursement schemes create different demands for innovation then it must be the case that they also influence the R&D sector decisions. In fact, some early studies (Weisbrod (1991) and Palmeri (2001)) already point in this direction. Weisbrod (1991) states that fee for service insurance biases 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 average cost, making hospitals reducing the use of its supply.

On another study by McClellan and Kessler (2001) analyze the incentives behind technological change. Namely the author analyses to which extent the patterns of technological change are somehow correlated with the underlying incentive mechanisms that regulate the provision of health care. The factors identified as being responsible for technological change are mostly supply side incentives having as target hospitals.

Furthermore, another study by Weisbrod and LaMay: (1999) show some evidence on the fact prospective payment system being favorable to costly technologies. By comparing the prices of 468 original DRG categories established in 1983 with the prices of the twenty categories added in the following decade, the authors conclude that after the implementation of the DRG system almost all the new DRGs, such as liver transplantation, were associated to higher payment levels.

Still on the same article, the authors present a study on the role of mixed signals from public policy and the future of health care R&D. The study focus on the impact of the U.S. health insurance system on the incentives facing the R&D sector. By examining the Medicare DRG system, the authors state that even though such a regulatory system could, potentially, have a negative impact on the adoption of costly innovations as it happened for the cochlear implant technology for the deaf, there is still some evidence suggesting that quality enhancing innovations consisting of major medical advances will keep on being adopted and developed despite of, to some extent, its cost implications.

Behind these studies resides the belief that the survival of an innovation depends on whether it is perceived as worthwhile by the organizations that will directly determine whether it is adopted and the scale of use. If the innovation is to persist and expand in use, it must be the case that the market perceives it as being profitable to adopt and employ, meaning that, in our context, the hospital must view the treatment as efficacious.

From the R&D firm perspective, the two main elements ruling the expected profitability of a particular new technology are the size of the market and the price at which it will be sold at, meaning, in our context, the rate of use by the
hospital and the reimbursement levels. Together these factors determine the revenue side of the market.

In other words, given that the development of new technologies is influenced by the potential demand for particular innovation, the preferences, rules and behavior of these various actors exert an important influence on not only on the path but also on the rate of development and adoption of new technologies.

Despite of constituting a starting point to the study of the relation between health care and R&D markets, the studies above described lack of a theoretical base able to allow the generalization of such findings. Indeed, the only theoretical paper focusing on the effect of reimbursement policies on the development of new technologies with endogenous supply of this technologies is the one by Goddeeris (1984). The author finds that insurance biases technological change in the direction of innovations that increase medical expenditure.

Hence, our goal in this paper is to build a theoretical setting which allows the analysis of the influence of prospective, cost based and mixed reimbursement on the development and adoption of new technologies with an endogenous supply of these technologies. Incorporating, both, the demand and supply side of the innovation market we can examine the full welfare effects of reimbursement policies. The main difference with the existing literature is that we endogeneize the technology supply.

The paper presents 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 illustrates cases where the technology to be used in medical treatment represents a variation of a technology originally developed in another market (ex. laser) while the latter illustrates those technologies that are specifically developed for the health market.

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.

We find that there is space for a Pure Prospective Payment System being more efficient in creating cost decreasing and quality increasing incentives than a Pure Cost Based Reimbursement system.

Finally, it is always optimal for the government to implement prospective reimbursement.

The 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 analyze the model when R&D is carried out within the hospital and, finally, section 6 draws the conclusions.
2 The model

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

The number of agents varies with the 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. 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 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.

Prior to technology development and adoption, treatment with quality \( x_0 > 0 \) may be provided at an original marginal cost of \( k_0 > 0 \) and this treatment is processed by the use of a single 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 characterized by two parameters: \( \tau \) and \( k \). The first, \( \tau \), is a treatment quality parameter that is composed by two elements, the existing quality level \( x_0 \) and the quality innovation parameter \( x \) that represents the product innovation. The second, \( k \), a cost decreasing parameter. Increasing \( x \) decreases treatment quality and, increasing \( k \), decreases treatment marginal cost.

Developing technology is assumed to involve "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 latter are negligible and thus set to zero.

Each patient demands one unit of treatment. And the number of patients demanding treatment is increasing with the level of quality and given by: \( q \tau \), with \( q \tau \leq 1 \) and \( q \in [0, 1] \).

Patients are assumed to have a reservation price \(- p^*\) that states their willingness to pay for quality. Assuming a reservation price equal for all patients, for a treatment price \( p \leq p^* \) patients demand \( q \tau \) units of treatment. If \( p > p^* \) patients’ demand is zero. Therefore, demand is given by,

\[
d = \begin{cases} 
q \tau & \text{if } p \leq p^* \\
0 & \text{if } p > p^*
\end{cases}
\]  

(1)

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

\[
CS = (p^* - p)q \tau
\]

(2)
Without loss of generality, we normalize the reservation price $p^* = 1$. Therefore, consumer surplus is equal to $q\pi$.

## 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 maximize a social welfare function that is composed by patient surplus $-q\pi$ minus the cost of developing technology increased by the cost of public funds $\lambda$.

$$\max_{x,k} q\pi - (1 + \lambda) \left[ (k_0 - k)q\pi + \frac{x^2}{2} + \frac{k^2}{2} \right]$$

s.t. $\pi \geq 0$, $k \leq k_0$

Before stating the results one comment is useful. The constraint on the quality parameter will never bind otherwise the welfare would become negative. Hence, we have that a maximum exists for $k_0 \in \left[0, \frac{x_0}{q} + \frac{1}{1+\lambda} \right]$.

Solving the first order conditions for $x$ and $k$ the optimal solution is described by the following proposition.

**Proposition 1** For $k_0 < \frac{q^2}{1+\lambda} + qx_0$ the constraint on $k$ is slack and the optimum is characterized by,

$$x_{FB} = q \frac{1 - (1 + \lambda) [qx_0 - k_0]}{(1 + \lambda)(q^2 - 1)}$$

$$k_{FB} = q \frac{(1 + \lambda) [qk_0 - x_0] - q}{(1 + \lambda)(q^2 - 1)}$$

Otherwise, for $k_0 \in \left[\frac{q^2}{1+\lambda} + qx_0, \frac{x_0}{q} + \frac{1}{1+\lambda} \right]$ we have that the constraint is binding, hence, the optimum is,

$$k_{FB} = k_0$$

$$x_{FB} = -\frac{q}{1+\lambda}$$

For low values of the initial marginal cost, $k_0 < \frac{q^2}{1+\lambda} + qx_0$, technology is cost decreasing and quality increasing. For intermediate values of the status quo

\footnote{Second order conditions are satisfied for $1 - q^2 > 0$ and $\lambda > 0$}
marginal cost \( k_0 \in \left[ \frac{x^2}{1+x} + qx_0, x_0 + \frac{k^2}{1+x} \right] \), technology not only increases quality but also decreases the initial marginal costs to zero \((x^{FB} < 0 \text{ and } k^{FB} = k_0)\). Finally, for high marginal costs, high \( k_0 \), technology still decreases the marginal costs to zero but also decreases quality \((x^{FB} > 0 \text{ and } k^{FB} = k_0)\).

These results suggest that cost reduction appears as a priority for technology adoption, i.e., even though there is space for the development and adoption of quality increasing technology it only occurs once the marginal cost achieves a specific (low) threshold. More importantly, if the initial marginal costs are high it becomes optimal to decrease technology quality. INTUITION

4 Private R&D

4.1 The Model

In this set-up we have three agents: one hospital, one R&D firm and the government. The hospital supplies treatment to patients and buys technology from the R&D firm at a price \( t \). This price paid can be thought as a royalty, i.e. the hospital pays an amount \( t \) for each utilization of technology. Alternatively, one can think that each patient requires one unit of technology. This situation can be illustrated with the example of drugs. In this case for each patient to be treated, the hospital will need to buy one pack of drugs 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.

We will assume that the feature \( k \) will be developed if and only if \( x \) is developed. This assumption is justified by the fact that the hospital demands some technology with a specific level of quality and the R&D firm decides if this technology with such a quality will be cost increasing or decreasing. Hence we cannot have a technology that is neutral concerning quality \((x = 0)\) but affects the marginal cost of treatment \((k \neq 0)\). At the status-quo, i.e. prior to technology adoption, the hospital provides treatment with quality \( x_0 \) at a marginal cost \( k_0 \).

The cost structure remains the same as the one defined previously under the benchmark set up, that is, developing technology is assumed to evolve "design" costs\(-\frac{x^2}{1+x}, \frac{k^2}{1+x}\) 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, \( \frac{x^2}{1+x} \), is borne by the hospital. This cost can be thought as the costs inherent to the basic research aimed at deriving the fundamental knowledge behind the development of new technologies. The assumption that these costs are borne by the hospital, 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 \( \frac{k^2}{1+x} \) will be paid by the R&D firm.

As patients’ demand for treatment only depends on quality, the hospital decides on the quality level that will provide \( x \).
The R&D firm decides on the price $t$- and on the level of cost decreasing parameter $k$.

Finally, the government decides on the reimbursement scheme. As instruments the government will use $R$ (prospective payment system fee) and $r$ (cost based reimbursement rate). Therefore, we are in the presence of a pure Prospective Payment System when $R > 0$ but $r = 0$. A pure Cost Based reimbursement system is characterized by $R = 0$, $r > 0$. Finally, a reimbursement scheme is classified as being mixed for $R > 0$, $r > 0$.

### 4.2 Timing

The game will be developed in three stages as described in the following diagram,

![Diagram](image)

**Figure 1:**

In the first stage the reimbursement system will be decided, that is, the government, optimally, decides between the implementation of one of three regimes: Cost Based Reimbursement System (CBR), Prospective Payment System (PPS) and mixed system (MRS).

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. We 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 incur when treatment is provided. Throughout the 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).

Finally a Mixed Reimbursement System (MRS) is just a combination of PPS and CBR, i.e., a scheme where $r > 0$ and $R > 0$.

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 quality $x$ provided. The model will be solved backwards.

### 4.3 The hospital

For a patients’ treatment demand $D = q\overline{x}$ the hospital profit function is as follows:

$$\Pi_H = Rq\overline{x} + (r - 1)(k_0 - k + t)q\overline{x} - \frac{x^2}{2}$$  \hspace{1cm} (3)

With $\overline{x} = x_0 - x$

Being a profit maximizer agent the hospital problem is given by,

$$\max_x Rq\overline{x} + (r - 1)(k_0 - k + t)q\overline{x} - \frac{x^2}{2}$$

$$\text{s.t. } \overline{x} \geq 0$$

Maximizing with respect to $x$, the optimum is characterized by the first order condition,

$$\frac{x}{q} - (1 - r)(k_0 - k + t) + R = 0$$

Solving the first order condition the optimum is given by,

$$x^* = q \left[ (1 - r)(k_0 - k + t) - R \right]$$  \hspace{1cm} (4)

The quality level demanded by the hospital, and hence supplied to patients, is always increasing in the reimbursement fee $R$ and reimbursement rate $r$. Indeed, by increasing quality, the hospital boosts demand and, consequently, revenues. The profitability of this demand increase will be higher the higher the marginal revenue for each patient, i.e., the reimbursement rate either $R$ or $r$ (or both).

It will never be optimal for the hospital to demand technology that reduces completely the level of quality, i.e., $x = x_0$. Indeed, this would imply zero demand and, consequently, negative profits. Therefore, we can focus our analysis on a range of parameters such that $x < x_0$, i.e., by manipulating (4) the analysis will be carried out for $k_0 < \frac{R}{k} + \frac{R}{r(1 - r)}$.

### 4.4 The R&D firm

The R&D firm will, through a profit maximizing problem and anticipating the hospital behavior, choose the level of $k$ and the technology price $t$ ensuring that the hospital makes non negative profits, that is, its objective will be defined by,
\[
\max_{k,t} \quad tq\pi - \frac{k^2}{2} \\
\text{s.t.} \quad \pi_H \geq 0, \quad k \leq k_0, \quad x^* = q[R + (r - 1)(k_0 - k + t)]
\]

with the first condition ensuring that the hospital makes non-negative profits, the second imposing an upper bound on the amount of the cost decreasing factor and, finally, the third representing the optimal choice by the hospital.

Solving the maximization problem we can summarize the results in the following propositions,

**Proposition 2** Let

\[
k_0 \geq \frac{q^2 R + q x_0}{2}, \quad R > (1 - r)k_0 - qx_0^2
\]  \(5\)

Then, the constraint \(k \leq k_0\) is slack. At the optimum, technology developed and adopted is cost decreasing \(^3\) and for \(k_0 > \frac{qR+x_0[q^2(1-r)-1]}{q(1-r)}\) is quality decreasing, for \(k_0 < \frac{qR+x_0[q^2(1-r)-1]}{q(1-r)}\) increases quality and for \(k_0 = \frac{qR+x_0[q^2(1-r)-1]}{q(1-r)}\) is quality neutral. This optima are characterized by,

\[
k^* = \frac{[R + (r - 1) k_0] q + x_0}{q^2 (r - 1) + 2} \\
t^* = \frac{q [(1 - r) k_0 - R] - x_0}{q \left[ q^2 (r - 1)^2 + 2 (r - 1) \right]} \\
x^* = \frac{q [(1 - r) k_0 - R] + x_0 [1 + q^2 (r - 1)]}{q^2 (r - 1) + 2}
\]  \(6\)

Intuitively, ceteris paribus the higher the initial marginal costs \(k_0\) the lower the demand by the hospital to the R&D firm. Consequently, in order to make profits the latter needs to supply technology that decreases costs and, consequently, as a second order effect, increases the demand for quality increasing technology by the hospital.\(^4\)

Given this optimum configuration we can further infer on the relation between the reimbursement variables and the type of technology developed.

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\(^{2}\)Where the first inequality arises from the constraint \(k \leq k_0\), and the second from \(x \leq x_0\)

\(^{3}\)Indeed as \(x < x_0\), i.e, \(k_0 < \frac{R}{1-r} + \frac{x_0}{q(1-r)}\) for this parameters range \(k\) is always positive, i.e, technology is always cost decreasing.

\(^{4}\)This applies only for \(r < 1\)
Corollary 3  For a low reimbursement fee \( R \) technology decreases costs but also the quality level. For intermediate reimbursement fees technology is cost decreasing and quality increasing but the latter effect is stronger. Finally for sufficiently high reimbursement fees technology decreases costs and increases quality but the former effect is stronger.

Proof. Defining \( I \) as an index of units of quality per cost decreasing parameter,

\[
I = \left\| \frac{x^*}{k^*} \right\|
\]

From (6) we have that at the optimum \( I = \left\| \frac{q(1-r)k_0 + q^2(1-r)x_0 + x_0 - Rq}{q[x_0 + Rq + qk_0(1-r)]} \right\| \). Denote \( R' \) the reimbursement fee above which technology increases the quality level and below which technology decreases the quality level. \( R' \) is the solution for \( x^* = 0 \). Then, for \( R < R' \) we have that \( x^* > 0 \) and \( k^* > 0 \), i.e., technology decreases both costs and the level of quality. For \( R > R' \) technology increases quality and decreases costs. Let \( \overline{R} \) be the solution for \( I = \left\| \frac{x^*}{k^*} \right\| = 1 \),

\[
\overline{R} = k_0 (1 - r) + \frac{x_0}{q} \left[ q^2 (1 - r) - 1 \right]
\]

Then we have that for \( R \in (R', \overline{R}] \), the effect of technology is higher in quality than in costs, i.e., \( I > 1 \). Finally, for \( R > \overline{R} \) technology increases quality and decreases costs but the latter effect is higher, \( I < 1 \).  

Also here results are quite intuitive. Indeed, for low reimbursement levels it does not pay to invest in quality. Increasing the reimbursement level increases the hospital payoff for providing quality and, consequently, demand for quality increasing technologies increases while the incentive for the development of cost decreasing technologies is weakened.

Proposition 4  For

\[
k_0 < \min \left\{ \frac{q^2 R + qx_0}{2} \cdot \frac{R}{1 - r} + \frac{x_0}{q (1 - r)} \right\}
\]

the constraint \( k \leq k_0 \) is binding and the technology developed decreases initial marginal costs while its impact on quality level is ambiguous. This technology is characterized by,

\[
t^* = \frac{qR + x_0}{2q (1 - r)}, \quad k^* = k_0, \quad x^* = \frac{1}{2} (x_0 - qR)
\]

The demand for quality increasing technology will depend on the trade-off between the reimbursement level and the status quo marginal cost, i.e., the demand for quality varies positively with the reimbursement level and negatively with the initial marginal cost. Anticipating this reaction by the hospital, the
R&D firm is better off by supplying cost decreasing quality such that the negative impact of \( k_0 \) is decreased and, therefore, the demand for quality simply depends on the reimbursement level and the technology price. For sufficiently high reimbursement fees the hospital will demand quality increasing technology, while, if the reimbursement fee is high enough, precisely for \( R > \frac{2k_0}{q} \) then the technology adopted and developed will be quality increasing.

These results are further developed in the following corollary,

**Corollary 5** For low values of the reimbursement fee \( R \) technology decreases costs but also decreases quality. For intermediate values of the reimbursement fee \( R \) technology decreases costs but increases quality but the effect on costs is higher than on quality. Finally for sufficiently high reimbursement rates technology is both cost decreasing and quality increasing but the latter effect is stronger.

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

\[
I = \left| \frac{q^*}{k^*} \right|
\]

We have that at the optimum (from (7)) \( I = \frac{x_0+qR}{k_0} \) for \( x^* < 0 \) and \( I = \frac{x_0-qR}{2k_0} \) for \( x^* > 0 \) and Hence, for cost decreasing \((k^* > 0)\) quality increasing \((x^* < 0)\) technology we have

\[
\begin{align*}
  I &> 1 & \text{if } R > \frac{2k_0+x_0}{q} \\
  I &< 1 & \text{if } R \in \left[ \frac{2k_0+x_0}{q}, \frac{2k_0-x_0}{q} \right]
\end{align*}
\]

For \( R < \frac{x_0}{q} \) technology decreases costs and quality.\( \blacksquare \)

**Comparative Statics** We now proceed with a comparative statics analysis.

**Proposition 6** For \( k_0 \geq \frac{2kR}{q} \)

\[
\begin{align*}
  \frac{\partial t}{\partial R} &= \frac{1}{2(q^2 (r-1)^2 + 2(r-1)^2)} \frac{\partial t}{\partial r} = \frac{q^2 (r-1) (k_0 + 2R) + 2R}{q^2 (r-1)^2 + 2(r-1)^2} \\
  \frac{\partial k}{\partial R} &= \frac{q^2}{q^2 (r-1) + 2} \\
  \frac{\partial x}{\partial R} &= \frac{q}{q^2 (1-r) - 2} \\
  \frac{\partial x}{\partial t} &= q (r-1)
\end{align*}
\]

While for

\[
\begin{align*}
  \frac{\partial t}{\partial R} &= \frac{1}{2(1-r)} \\
  \frac{\partial k}{\partial R} &= \frac{\partial k}{\partial r} = \frac{\partial x}{\partial r} = 0 \\
  \frac{\partial x}{\partial R} &= -\frac{q}{2} \\
  \frac{\partial x}{\partial t} &= q (r-1)
\end{align*}
\]

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Given the results above we can state the following,

**Corollary 7** For \( \forall k_0 \) quality is strictly increasing with the reimbursement fee \( R \), increasing in the reimbursement rate \( r \) and increasing in the technology price. Technology price is strictly increasing in both reimbursement variables and marginal costs are decreasing in both reimbursement parameters. That is,

\[
\frac{\partial t}{\partial R} > 0, \quad \frac{\partial t}{\partial r} > 0, \quad \frac{\partial x}{\partial R} < 0, \quad \frac{\partial x}{\partial t} < 0, \quad \frac{\partial k}{\partial r} \leq 0, \quad \frac{\partial k}{\partial R} \geq 0
\]

**Proof.** For \( k_0 \geq \frac{q^2}{2} R^2 \) given that the conditions for the existence of this optimum require that \( k_0 \geq \frac{q^2}{2} R^2 + q x_0^2 \) and \( q^2 < \frac{2}{(1-r)^2} \) we have that in (8) \( \frac{\partial t}{\partial R} > 0, \frac{\partial t}{\partial r} > 0, \frac{\partial x}{\partial R} < 0, \frac{\partial x}{\partial t} < 0, \frac{\partial x}{\partial r} < 0, \frac{\partial k}{\partial r} > 0, \frac{\partial k}{\partial R} > 0 \).

4.5 Pure Prospective Payment System

We can now analyze the characteristics of technology at the optimum as well as its price for a pure Prospective Payment system, i.e., for \( r = 0 \) and \( R > 0 \). Plugging \( r = 0 \), on (6) under a pure PPS, at the optimum, the technology developed and adopted will be cost decreasing and quality increasing. This

\[
(r - 1)[q (x^* - x_0) - 2t^*] - t^*(r - 1)^2 q^2 + 2 \frac{x^* - x_0}{q} = 0
\]

Solving for \( x^* \) we obtain \( x^* \) as a function of \( t \), i.e., \( x^* = t q (r - 1) + x_0 \). Therefore \( \frac{dx^*}{dt} = q (r - 1) < 0 \) for \( r \in [0,1[ \).

\[
2q (1-r) t^* - 2x_0 = -2x^*
\]

Solving for \( x^* \) we obtain \( x^* \) as a function of \( t \), i.e., \( x^* = x_0 - q (1-r) t \). Therefore \( \frac{dx^*}{dt} = q (r - 1) < 0 \) for \( r \in [0,1[ \).

\[
\text{With the first condition arising from the constraint } k \leq k_0 \text{ being slack and the second by concavity of the profit function}
\]

\[
\text{Note that } \frac{\partial}{\partial x} < 0 \Rightarrow \frac{\partial}{\partial x} > 0 \text{ and } \frac{\partial}{\partial x} < 0 \Rightarrow \frac{\partial}{\partial x} > 0
\]
optimum is characterized by

\[
\begin{align*}
  k^{PPS^*} &= q \left[ R - k_0 \right] q + x_0 \frac{2 - q^2}{2 - q^2}, \\
  t^{PPS^*} &= q \left[ k_0 - R \right] + x_0 \frac{q^2}{q^2 - 2}, \\
  x^{PPS^*} &= q \left[ k_0 - R \right] + x_0 \frac{1 - q^2}{2 - q^2}
\end{align*}
\]

From (5) we have that \( R > k_0 - \frac{x_0}{q} \) and . Hence, technology adopted and developed will decrease costs. Concerning the effect of technology on quality, it depends on the reimbursement fee \( R \), i.e., for a sufficiently high reimbursement fee, technology will be quality increasing\(^9\).

Both, the cost decreasing parameter and the level of quality are increasing in the reimbursement fee\(^10\). Nevertheless, increasing the level of reimbursement drives the technology price up.

Instead, when (7) holds as an optimum, and for \( r = 0 \), the technology developed and adopted will be cost decreasing and quality increasing. This optimum is characterized by,

\[
\begin{align*}
  t^{PPS^*} &= \frac{x_0 + qR}{2q}, \\
  k^{PPS^*} &= k_0, \\
  x^{PPS^*} &= \frac{1}{2} \left( x_0 - qR \right)
\end{align*}
\]

In this case we have that the higher the reimbursement fee \( R \) the higher the level of quality and the higher the technology price. The cost decreasing parameter is not affected by the reimbursement level.

### 4.6 Pure Cost Based Reimbursement System

In a pure CBR we have that \( R = 0 \). Hence, plugging \( R \) on (6), the optimum is characterized by:

For \( k \in \left[ \frac{x_0}{2 - q^2}, \frac{k_0}{q(1 - r)} \right] \)

\[
\begin{align*}
  t^{CBR} &= \frac{q \left( 1 - r \right) k_0 - x_0}{q^2 \left( r - 1 \right)^2 + 2 \left( r - 1 \right)} \\
  k^{CBR} &= q \left[ \left( r - 1 \right) k_0 \right] q + x_0 \\
  x^{CBR} &= q \left( 1 - r \right) k_0 + x_0 \frac{1 + q^2 \left( r - 1 \right)}{q^2 \left( r - 1 \right) + 2}
\end{align*}
\]

Technology, in equilibrium will decrease costs. The impact of technology on quality will depend on the reimbursement rate. For a sufficiently low reimburse-

\(^9\)This threshold is given by \( R > k_0 + x_0 \frac{1 - q^2}{q} \)

\(^{10}\)Indeed, \( \frac{\partial x^*}{\partial r} < 0 \Rightarrow \frac{\partial t^*}{\partial r} > 0 \)
ment rate \( r \) technology will decrease the level of quality. Otherwise, i.e. for high reimbursement rates, technology will increase the level of quality\(^{11}\).

For \( k < \frac{q x_0}{2} \),

\[
t^{PPS*} = \frac{x_0}{2q(1-r)}, \quad k^{PPS*} = k_0, \quad x^{PPS*} = \frac{1}{2} x_0
\]

Technology is cost decreasing but also quality decreasing. Moreover, the reimbursement rate can not be used as a regulatory instrument to control the level of quality and cost decreasing parameter. Nevertheless, as \( \frac{\partial t}{\partial r} > 0 \), price can be controlled through the reimbursement rate \( r \).

### 4.7 Some remarks

Before proceeding with the optimal reimbursement it is useful to make a comment on the possible values of the reimbursement rate \( r \).

The existence of the optima found above require an \( r < 1 \). Nonetheless, one could ask what happens in the other possible values of \( r \).

For \( r = 1 \), in a mixed reimbursement system, the hospital demand for quality will not depend neither on the technology price nor on the cost decreasing parameter \( t \). Hence, the R&D firm will produce quality increasing technology but at an infinite price and this technology will not contribute for the decrease of the marginal cost of treatment.

Indeed, for \( r = 1 \) the hospital problem becomes

\[
\max_x \Pi_H = Rq x - \frac{x^2}{2}
\]

Solving the first order conditions the maximum is given by \( x^* = -Rq \).

Plugging into the R&D firm profit function and maximizing with respect to \( t \) and \( k \),

\[
\max_{t,k} \Pi_{R&D} = tq (x_0 + Rq) - \frac{k^2}{2}
\]

Differentiation with respect to \( t \) and \( k \),

\[
\frac{\partial \Pi_{R&D}}{\partial t} = q (x_0 + Rq) > 0
\]

\[
\frac{\partial \Pi_{R&D}}{\partial k} = -k < 0
\]

Therefore, having that \( \frac{\partial \Pi_{R&D}}{\partial t} > 0 \) and \( \frac{\partial \Pi_{R&D}}{\partial k} < 0 \) in equilibrium \( t^* \to +\infty \) and \( k^* \to -\infty \).

Under this scenario, in a pure CBR (\( R = 0 \)) with full cost reimbursement, \( r = 1 \), one can see that, as the design costs are financial responsibility of the hospital, its best strategy is to supply no additional quality in order to avoid negative profits.

\(^{11}\) This threshold is given by \( r = \frac{q x_0}{q x_0 + x_0} \)
Instead, an $r > 1$ means that the hospital is reimbursed for more than the incurred marginal costs. This means that the government is left with the whole responsibility of these costs. In such a case, in a mixed reimbursement system and in a pure CBR, one can easily see that the hospital and the R&D firm strategies result in that the technology developed and adopted is traded, at the optimum, at an infinite price. Moreover, this technology will be infinitely quality increasing and will not contribute for the decrease of the marginal cost of treatment.

In this case, our results match the existing literature. In a pure Cost Based Reimbursement System quality is provided but at very high costs. Furthermore, a pure Cost Based Reimbursement System provides more quality than a pure Prospective Payment System.

### 4.8 Optimal reimbursement

Finally, on the first stage, accounting for the hospital and the R&D firm behavior, the government will decide on the reimbursement variables: $r$ and $R$.

The government will then maximize an utilitarian social welfare function $W$ by deciding on the reimbursement system to be implemented having as instruments the reimbursement variables $r$ and $R$:

$$
\max_{r, R} W = CS + \Pi_H + \Pi_{R&D} - (1 + \lambda) \left[Rq\overline{x} + r(k_0 - k + t)q\overline{x}\right]
$$

Where the first term $CS$ is patient’s surplus is given by $q\overline{x}$, the second term $\Pi_H$ stands for the hospital profit and is given by $Rq\overline{x} + (r - 1)(k_0 - k + t)q\overline{x} - \frac{k^2}{\overline{x}^2}$, $\Pi_{R&D} = tq\overline{x} - \frac{k^2}{\overline{x}^2}$ is the R&D firm profit and $(1 + \lambda)Rq\overline{x} + (1 + \lambda)r(k_0 - k + t)q\overline{x}$ is the government reimbursement to the hospital weighed by the cost of public funds $\lambda$.

**Proposition 8** 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 $W = \Pi_H + \Pi_{R&D} + q\overline{x}\{1 - (1 + \lambda)[R + r(k_0 - k + t)]\}$ 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

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

$$
= \frac{d\Pi_{R&D}}{dk} + q\overline{x}(1 + \lambda r)
$$

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 $k = k_0$.
Proposition 9 For $k_0 < \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ a Pure Prospective Payment System is socially optimal and is characterized by:

$$r^* = 0, \quad R^* = \frac{x_0(1-2\lambda) + 2q}{q(1+4\lambda)}$$

Proof. For $k_0 < \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ 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 that the welfare function is always decreasing in $t$ and decreasing in $r$. As $t$ is increasing in both $r$ and $R$ and quality does not depend on $r$, the government to use $r$ to induce a low value of $t$. Hence it is always optimal to set $r = 0$. The optimal level of $R$ will depend on the trade-off between the positive effect of increasing quality level relatively to its costs and the negative effect of increasing $t$.

Analytically, the government objective is:

$$\max_{r,R} W = q\bar{x} + Rq\bar{x} + (r-1)(k_0 - k + t)q\bar{x} - \frac{x^2}{2} + tq\bar{x} - \frac{k^2}{2}$$

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

$$t^* = \frac{qR + x_0}{2q(1-r)}, \quad k^* = k_0, \quad x^* = \frac{x_0 - qR}{2}$$

Plugging in $W$ and solving the first order conditions it can be easily shown that the optimum is:

$$r^* = 0, \quad R^* = \frac{x_0(1-2\lambda) + 2q}{q(1+4\lambda)}$$

As the R&D optimum above stated is defined for $k_0 < \min \left\{ \frac{q^2}{4\lambda + 1}, \frac{R}{1-r} + \frac{x_0}{q(1-r)} \right\}$ we have that this solution is valid for $k_0 < \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$.

Proposition 10 For $k_0 \geq \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ the government will choose to be on the constraint $k_0 \geq \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ meaning that at the optimum $R^* = \frac{2k_0 - qx_0}{q^2}$

Proof. For $k_0 \geq \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ we have that $k_0 < \frac{q^2 + qx_0(1+\lambda)}{4\lambda + 1}$ no longer holds.
and so we fall in the second case of the R&D problem,

\[
\begin{align*}
    k^* &= q \left[ R + (r - 1) k_0 \right] q + x_0 \\
    t^* &= \frac{q \left[ (1 - r) k_0 - R \right] - x_0}{q \left[ q^2 (r - 1)^2 + 2 (r - 1) \right]} \\
    x^* &= \frac{q \left[ (1 - r) k_0 - R \right] + x_0 \left[ 1 + q^2 (r - 1) \right]}{q^2 (r - 1) + 2}
\end{align*}
\]

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

\[
k_0 \geq \frac{q^2 R + qx_0}{2}
\]

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., \( R = \frac{2k_0 - qx_0}{q^2} \).

**Proposition 11** For \( R = \frac{2k_0 - qx_0}{q^2} \) 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 \( R = \frac{2k_0 - qx_0}{q^2} \) and \( r^* = 0 \). Moreover, at the optimum, the technology developed and adopted will be cost decreasing and quality increasing. It is characterized by

\[
\begin{align*}
    x^* &= \frac{qx_0 - k_0}{q}, \quad k^* = k_0, \quad t^* = \frac{k_0}{q^2}
\end{align*}
\]

**Proof.** Given \( k = k_0, R = \frac{2k_0 - qx_0}{q^2} \) we can easily see that the Welfare function is always decreasing in \( t \). Plugging \( r, R = \frac{2k_0 - qx_0}{q^2} \) and \( k = k_0 \) on \( k^*, t^* \) and \( x^* \) from (6) we get

\[
\begin{align*}
    x^* &= \frac{qx_0 - k_0}{q}, \quad k^* = k_0, \quad t^* = \frac{k_0}{q^2 (1 - r)}
\end{align*}
\]

The Welfare function can then be rewritten as:

\[
W = \Pi_H + \Pi_{R&D} + q\tau \left\{ 1 - (1 + \lambda) [R + rt] \right\}
\]

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

\[
\frac{dW}{dt} = \frac{d\Pi_H}{dt} + \frac{d\Pi_{R&D}}{dt} = q\tau (1 + \lambda) r
\]

With \( \frac{d\Pi_H}{dt} = (r - 1)q\tau \) and, by the envelope theorem, \( \frac{d\Pi_{R&D}}{dt} = 0 \) we have that:
\[
\frac{dW}{dt} = -q(1 + \lambda r) < 0
\]

Hence it is always optimal 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., \( r^* = 0 \). Substituting \((R^*, r^*)\) in \( x^*, k^* \) and \( t^* \) we have \( x^* = \frac{q \tau q - k_0}{q}, k^* = k_0, t^* = \frac{k_0}{q} \).

5 R&D within the Hospital

5.1 The model

We will now consider a different set-up where we assume that the R&D process is carried out by the hospital. Thus, the development of technology is carried out by the hospital.

The model has then only two agents: the government and the hospital. The demand for treatment remains as described in the previous set-ups.

The government decides on the reimbursement scheme: \( R \) (Prospective Payment system Fee) and \( r \) (Cost Based reimbursement rate), while 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 \( x \) decreases treatment quality and increasing \( k \) decreases treatment marginal cost.

Developing technology is assumed to evolve "design" costs \( x^2, k^2 \) 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

The game will then be developed in a two stage game described in the following diagram.

In the first stage, the government decides on the optimal way to finance the hospital by (optimally) deciding on the reimbursement instruments \( R \) and \( r \) and on the second stage the hospital decides on the characteristics of the technology to be developed and adopted \((x, k)\).

As usual, the model will be solved backwards.
5.3 The hospital problem

The hospital objective function is thus:

$$\max_{x,k} Rq\Phi + (r - 1)(k_0 - k)q\Phi - \frac{x^2}{2} - \frac{k^2}{2}$$

s.t. \( k \leq k_0, \Phi \geq 0 \)

Solving the first order conditions for \( x \) and \( k \) the optima are characterized by two cases described in the following sub sections.

5.3.1 Case 1: \( k = k_0 \)

For \( k \leq k_0 \) binding, that is, for \( k \in [0, q(1 - r)] [qR + x_0] \) we have that at the optimum the hospital will set:

$$k^* = k_0, \quad x^* = -qR$$

(13)

For concavity we need \( k_0 < q^2 (1 - r) R \). Furthermore, as \( k_0 \) is, by definition, positive we have that \( r < 1^{12} \).

In this case technology, at the optimum, will increase quality and decrease costs. Quality level does, and the cost decreasing parameter does not, vary with the reimbursement rate \( r \). Moreover, the reimbursement fee \( R \) has a positive impact on quality and a null impact on costs.

**Corollary 12** Under a pure PPS technology is cost decreasing and quality increasing

$$k^* = k_0, \quad x^* = -qR$$

Furthermore, for a sufficiently high reimbursement fee \( R > \frac{k_0}{q} \) a Prospective Payment System favours more quality than costs. While for a pure CBR technology is quality neutral but cost decreasing and is characterized by,

$$k^* = k_0, \quad x^* = 0$$

\(^{12}\)In fact, even allowing for a subsidy such that \( r \geq 1 \) we have that the hospital profit is decreasing on \( k \), thus the constraint never binds.
Proof. Indeed, in a pure PPS we have that $r = 0$ and $R > 0$. Hence, the technology developed and adopted is characterized by:

$$x^{PPS} = -qR, \quad k^{PPS} = k_0$$

Therefore, we have that $I^{PPS} = \frac{x^{PPS}}{k^{PPS}} = \frac{qR}{k_0}$. Consequently, $I > 1$ iff $R > \frac{k_0}{q}$.

Comparing the two reimbursement systems, Prospective Payment and Cost Based Reimbursement, in a pure PPS the level of quality is higher than under a pure Cost Based Reimbursement system. Nevertheless, both systems are equally efficient in cost control incentives.\(^\text{13}\)

5.3.2 Case 2: $k \leq k_0$

When the constraint $k \leq k_0$ is slack the optimal solution will depend qualitatively on the level of the initial marginal cost. Algebraically,

$$x^* = q \left[ \frac{R + (r - 1) k_0 + qx_0 (r - 1)^2}{q^2 (r - 1)^2 - 1} \right]$$

$$k^* = \frac{q (r - 1) [R + (r - 1) k_0] + (r - 1) x_0}{q^2 (r - 1)^2 - 1}$$

This optimum holds for $k_0 \in \left[ q (1 - r) [qR + x_0], \frac{x_0}{q^{(1-r)}} + \frac{R}{q^{(1-r)}} \right]$ where $k_0 < \frac{x^*}{q^{(1-r)}},$ and $k_0 > q (1 - r) [qR + x_0]$ assure $x \leq x_0$ and $k \leq k_0$, respectively. Even though the technology adoption is always cost decreasing its impact on the quality level will depend on the initial marginal costs. For $k_0 \in \left[ q (1 - r) [qR + x_0], q x_0 (1 - r) + \frac{R}{q^{(1-r)}} \right]$ the level of quality will be increased by technology. For $k_0 \in \left[ q x_0 (1 - r) + \frac{R}{q^{(1-r)}}, \frac{x_0}{q^{(1-r)}} + \frac{R}{q^{(1-r)}} \right]$ technology is quality decreasing.

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

\(^{13}\)In a pure PPS we have that $r = 0$ and $R > 0$ hence the technology developed and adopted is characterized by:

$$x^{PPS} = -qR < 0, \quad k^{PPS} = k_0$$

With quality level given by $x = x_0 - x$ we have that in the optimum $x = x_0 + Rq$.

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

$$x^{CBR} = 0, \quad k^{CBR} = k_0$$

With $q > 0, R > 0$ and the quality level given by $x = x_0 - x$, the result follows $x^{PPS} > x^{CBR}$ and $k^{PPS} = k^{CBR}$.

\(^{14}\)Note that an equilibrium will never arise for $k_0 > \frac{x_0}{q^{(1-r)}},$ and $\frac{R}{q^{(1-r)}}$. Indeed, for such range of the initial marginal cost $x^* = x$ makes the hospital earn negative profits.
Proposition 13 A pure Cost Based Reimbursement system leads to the development and adoption of quality and cost decreasing technologies. While in a pure PPS, technology, at the optimum, will be cost decreasing. Its impact on quality level depends on the reimbursement fee $R$. For highly enough reimbursement levels technology is quality increasing.

Corollary 14 Comparing the two systems, the effectiveness in cost control depends on the reimbursement schedule. In what concerns quality, for a sufficiently high reimbursement fee, i.e. $R > k_0 - qx_0$, technology developed under a PPS increases quality while within a CBR system it decreases the level of quality. For low reimbursement fees both systems decrease quality. The relative magnitude of this effect will depend on the relation between the two reimbursement instruments $r$ and $R$.

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

$$x^{CBR} = \frac{q(r - 1)k_0 + x_0(r - 1)^2}{q^2(r - 1)^2 - 1}, \quad k^{CBR} = \frac{q^2(r - 1)^2k_0 + qx_0(r - 1)}{q^2(r - 1)^2 - 1}$$

As, by concavity, $q^2(r - 1)^2 - 1 < 0$ for $k \in \left[\frac{x_0}{q(1-r)} + \frac{R}{(1-r)}q(1-r)[qR + x_0]\right]$ implies $x^{CBR} > 0$ and $k^{CBR} < 0$.

Under a PPS $r = 0$. Hence, the optimum is given by

$$x^{PPS} = \frac{R - k_0 + qx_0}{q^2 - 1}, \quad k^{PPS} = \frac{q^2[k_0 - R] - qx_0}{q^2 - 1}$$

Furthermore under a pure PPS we have that, by concavity $q^2 - 1 < 0$. Moreover this optimum is defined for $k_0 \in [qR^2 + qx_0, \frac{x_0}{q(1-r)} + \frac{R}{(1-r)}q(1-r)]^{15}$. Hence we have that $R > k_0 - qx_0 \Rightarrow x^* < 0$, technology increases the quality level. While for $R < k_0 - qx_0 \Rightarrow x^* > 0$, technology is quality decreasing. Concerning $k$ we have that $k_0 < \frac{x_0}{q(1-r)} + \frac{R}{(1-r)}q(1-r)$.

Proposition 15 For a pure PPS we can further state that for low reimbursement values quality is quality decreasing, for intermediate values technology decreases costs and increases quality but the former is stronger. Finally for sufficiently high reimbursement fees, technology developed and adopted is quality increasing and cost decreasing but the latter effect dominates.

Proof. Under PPS, define $I = \left\|x^{PPS}\right\| = \left\|\frac{R - k_0 + qx_0}{q^2[k_0 - R] - qx_0}\right\|$. Let $R'$ be the reimbursement fee above which technology increases the quality level and below which technology decreases the level of quality. $R'$ is the solution for $x^* = 0$

$$R' = k_0 - qx_0$$

\(^{15}\)Condition that states $x \leq x_0$ and $k \leq k_0$
Then, for $R < R'$ we have that $x^* > 0$ and $k^* > 0$, i.e., technology decreases both costs and the level of quality. For $R > R'$ technology increases quality and decreases costs. Let $\overline{R} = k_0$ be the solution for $I = \left\| x^* \right\| = 1$, then for $R \in ]R', \overline{R}[$, the effect of technology is higher in quality than in costs, i.e., $I > 1$. Finally, for $R > \overline{R}$ technology increases quality and decreases costs but the latter effect is higher, $I < 1$. ■

5.4 Optimal reimbursement

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

The government objective will be to decide on the reimbursement policy by, optimally, choosing the reimbursement instruments in order to maximize social welfare $W$,

$$\max_{r,R} W = CS + \Pi_H - (1 + \lambda) [Rq\overline{x} + r(k_0 - k)q\overline{x}]$$

Where the first term $CS$ is patient’s surplus is given by $q\overline{x}$, the second term $\Pi_H$ stands for the hospital profit and is given by $Rq\overline{x} + (r - 1)(k_0 - k)q\overline{x} - \frac{q^2}{2} - \frac{k^2}{2}$, $(1 + \lambda) [Rq\overline{x} + r(k_0 - k)q\overline{x}]$ is the government reimbursement to the hospital weighed by the cost of public funds $\lambda$.

Proposition 16 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 $W = \Pi_H + q\overline{x}(1 - (1 + \lambda)[R + r(k_0 - k)])$ with $\Pi_H$ standing for the hospital profit. The socially optimal level of $k$ is given by

$$\frac{dW}{dk} = \frac{d\Pi_H}{dk} + q\overline{x}(1 + \lambda)r$$

From the envelope theorem $\frac{d\Pi_H}{dk} = 0$ in case 2, while $\frac{d\Pi_H}{dk} > 0$ in case 1. This implies that the social welfare is always increasing in $k$. Hence, it is always socially optimal to have $k = k_0$. ■

Proposition 17 The optimal reimbursement is characterized by a pure prospective payment system

Indeed, for $k_0 < q(1 - r)[qR + x_0]$ the hospital, at the optimum, chooses the socially optimal level of the cost decreasing parameter, $k = k_0$. Therefore, the government can use the reimbursement scheme to induce the socially optimal level of quality. Having $\frac{\partial r}{\partial R} = 0$ and $\frac{\partial r}{\partial x} > 0$, the optimal reimbursement system is a Pure Prospective defined by,

$$r^* = 0, \quad R^* = \frac{q - x_0\lambda}{2\lambda + 1}$$
Given the reimbursement levels, at the optimum, the technology developed will be characterized by,

\[ x^* = \frac{x_0\lambda - q}{1 + 2\lambda}, \ k^* = k_0 \]

Hence, at the optimum, technology increases the level of quality and decreases costs.

And this solution is valid for \( k_0 < q \left( \frac{q^2}{2\lambda + 1} + x_0 \left( 1 - \frac{\lambda q}{2\lambda + 1} \right) \right) \).

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. Plugging the value of \( k^* \) this constraint can be re-written as,

\[ k_0 \geq q \left( \frac{q^2}{2\lambda + 1} + x_0 \left( 1 - \frac{\lambda q}{2\lambda + 1} \right) \right) \]

In this case, by inducing the optimal level of the cost decreasing parameter \( k \), the government would need to tax the hospital \( (r < 0) \) in order to implement the optimal amount of quality. However, as in our set up \( r \in [0, 1] \) in the optimum the maximum level of cost decreasing parameter \( k \) that the government can induce is the level attained for a null reimbursement rate \( (r = 0) \) and is lower than \( k \leq k_0 \). The reimbursement fee will then be used to regulate the level of quality\(^{16}\).

The reimbursement schedule is given by

\[ r^* = 0 \quad R^* = \frac{q - x_0\lambda}{q (1 + 2\lambda)} \]

And the technology at the optimum characterized by

\[ x^* = \frac{x_0}{q^2 - 1} \left[ \frac{q^2 - \lambda}{2(2\lambda + 1)} \right] - qk_0 \left[ \frac{1 + \lambda}{2(2\lambda + 1)(q^2 - 1)} \right] \]
\[ k^* = \frac{q}{(2\lambda + 1)} \left[ \frac{(1 + \lambda)[qk_0 - x_0] - q}{(2\lambda + 1)(q^2 - 1)} \right] \]

The effect of technology on costs and quality will depend on the relation between the initial marginal cost \( k_0 \) and the initial level of quality \( x_0 \).

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\(^{16}\)Algebraically, the welfare function in the reimbursement variables

\[
\max_{r, R} W = q\pi + Rq\pi + (r - 1)(k_0 - k)q\pi - \frac{x^2}{2} - \frac{k^2}{2} \]
\[ - (1 + \lambda)(Rq\pi + r(k_0 - k)q\pi) \]

s.t. \( \pi \geq 0 \)

The first order condition on the reimbursement rate \( r \), given that the hospital earns non negative profits, is always negative.
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 set-ups: private R&D and R&D within the hospital.

The first best technology, for low values of the initial marginal cost, is cost decreasing and quality increasing. For intermediate values of the status quo marginal cost technology not only increases quality but also drives marginal costs to zero. Finally, for high marginal costs, technology still decreases the marginal costs to zero but also decreases quality.

In the former set up results depend on the value of the reimbursement rate $r$. We have been able to show that, for $r < 1$, under a mixed reimbursement system there is space for the development and adoption of cost decreasing/quality increasing technologies. By first treating the reimbursement as exogenous, we have shown that under both reimbursement systems, Cost Based Reimbursement System and Prospective Payment System, technology developed and adopted is cost decreasing. In what concerns quality, under a MRS, for sufficiently high reimbursement fees technology developed and adopted will increase quality. Under a PPS, results remain qualitatively the same. For a sufficiently high reimbursement fee, technology increases the initial level of quality. Nonetheless, the higher the reimbursement fee the more expensive technology will be. Under CBR for medium initial marginal costs the impact of technology on quality depends on the reimbursement rate $r$, for a sufficiently high reimbursement rate technology increases the level of quality. However, for sufficiently low initial marginal costs, technology decreases quality. Moreover, as this quality level does not depend on the reimbursement variable, the latter can not be used as a quality level regulatory instrument.

For $r = 1$, in a mixed reimbursement system, the hospital demand for quality will not depend neither on the technology price nor on the cost decreasing parameter $t$. Hence, the R&D firm will produce quality increasing technology but at an infinite price and this technology will not contribute for the decrease of the marginal cost of treatment. Under this scenario, in a pure CBR ($R = 0$) with full cost reimbursement, $r = 1$, one can see that, as the design costs are financial responsibility of the hospital, its best strategy is to supply no quality in order to avoid negative profits.

Instead, for a reimbursement rate $r > 1$, our results match the existing literature. In a pure Cost Based Reimbursement System quality is provided but at very high costs. Furthermore, a pure Cost Based Reimbursement System provides more quality than a pure Prospective Payment System. Finally, going one step further and endogeneizing the reimbursement, 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, for high initial marginal costs, a pure prospective payment system leads to the adoption of cost decreasing technologies. The impact of technology on quality will depend on the level of the reimbursement fee. For high reimbursement fees technology will increase quality. On the other hand, under a pure Cost Based Reimbursement system, after technology development and adoption quality will be higher but also the marginal costs.

For low initial marginal costs, PPS is efficient in cost control and quality improvement. Indeed, technology adopted is cost decreasing and quality increasing. On the other hand, under CBR the type of technology developed and adopted has no impact on quality even though it decreases costs.

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 endogenizing the reimbursement policy, we found that, it is optimal for the government to reimburse the hospital on a prospective basis.

Finally, we use a simple setup, allowing us to obtain clear-cut results and to highlight the effects driving the technology choices under each financing scheme and R&D sector. Nevertheless, the model could be extended in a number of directions, enriching the set of results. One could have considered asymmetric information and heterogeneous patients. With heterogeneity in patients' severity, the treatment costs are not contractible, making it profitable for the hospital to misreport the costs incurred. In this case, the technology developed and adopted could assume different characteristics from the ones that arise from our optima.

Another possible extension to our model would be the differentiation between services which quality is perfectly perceived by the patients from services where patients are not enough informed to detect its quality. For example, a patient might be sensitive to the type of technology used on his treatment but then not aware of the right number of sessions needed before discharge. In such a context one can expect that the hospital would only supply quality in the type of treatment where the patients can detect quality.

A third aspect is that we consider that patients' demand for treatment is sensitive to quality. In the real world this is not always true. For instance we have that in emergency treatment, even if this assumption holds, in the end the demand that the hospital faces is not affected by this sensitivity.

Finally, one could also introduce competition between hospitals and, maybe more crucial, in the R&D sector.
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