Technological adoption in health care - The role of payment systems*

Pedro Pita Barros
Universidade Nova de Lisboa
and CEPR (London)

Xavier Martinez-Giralt
Universitat Autònoma de Barcelona
and MOVE

October 2013

Abstract

This paper examines the incentive to adopt a new technology given by some popular reimbursement systems, namely cost reimbursement and DRG reimbursement. Adoption is based on a cost-benefit criterion. We find that retrospective payment systems require a large enough patient benefit to yield adoption, while under DRG, adoption may arise in the absence of patients benefits when the differential reimbursement for the old vs. new technology is large enough. Also, cost reimbursement leads to higher adoption under some conditions on the differential reimbursement levels and patient benefits. In policy terms, cost reimbursement system may be more effective than a DRG payment system. This gives a new dimension to the discussion of prospective vs. retrospective payment systems of the last decades centered on the debate of quality vs. cost containment.

Keywords:

JEL numbers: I11, I12

CORRESPONDENCE ADDRESSES:

Pedro Pita Barros, Nova School of Business and Economics, Universidade Nova de Lisboa, Campus de Campolide, PT-1099-032 Lisboa, Portugal; email: ppbarros@novasbe.pt

Xavier Martinez-Giralt, CODE, Edifici B, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain; email: xavier.martinez.giralt@uab.eu

1

1 Introduction.

Recent decades have witnessed an increasing share of the level of spending on health care relative to the GDP (see OECD, 2005a,b). There is a general consensus that technological development (and diffusion) is a prime driver of this phenomenon. The recent account by Smith *et al.* (2009) estimates that medical technology explains a fraction of between 27-48% (depending on different estimation techniques) of growth in the US health spending in the period 1960-2007. Despite the relatively large literature documenting empirically the impact of innovation in health care, a theoretical corpus has not been fully developed yet. In this paper we address a particular theoretical issue: the relationship between payment systems and the rate of technology adoption. To avoid unnecessary confusion, let us point out that we refer to adoption as the decision of a provider to acquire a piece of new technology available. We do not consider the process by which such a new technology has become available, nor the R&D involved in it, nor any other considerations. Our departing point is that a new way to provide some treatment has become available, and thus providers must decide whether to acquire it.

We contribute to the theoretical literature by setting up a model of uncertain demand, where the novelty lies in relating the technological shift to the increased benefit for patients, financial variables, and the reimbursement system to providers. We seek to assess the impact of the payment system to providers on the rate of technology adoption. We propose two payment schemes, a reimbursement according to the cost of treating patients, and a DRG payment system where the new technology may or may not be reimbursed differently from the old technology. We find that under a cost reimbursement system, large enough patient benefits are necessary for adoption to occur. However, when the DRG offers a higher reimbursement for new technology, adoption occurs even in the absence of patients' benefits. In this case, the new technology must be reimbursed sufficiently higher than the old one. Finally, to compare the levels of technological adoption in the differnt payment regimes, we take as reference an investment level yielding to the provider the same marginal return of investment in new technology across regimes. Cost

2

reimbursement leads to higher adoption of the new technology if the rate of reimbursement is high relative to the margin of new vs. old DRG. Having larger patient benefits favors more adoption under the cost reimbursement payment system, provided that adoption occurs initially under both payment systems. In policy terms, it may well be the case that for some objectives of the regulator regarding the level of technological adoption, a retrospective payment system to the providers is more effective than a prospective reimbursement system. This opens again the discussion of prospective versus retrospective payment systems in a wider framework than the debate of quality vs. cost containment developed along the last decade. To evaluate the impact of the adoption of new technology, we study how adjusting the parameters of the payment function affect adoption *for a given level of total expenditure*. We use this approach as a proxy for a welfare analysis of adoption, due to the inherent difficulties in our model to define a social welfare function for the health authority. We obtain that under risk neutrality, more cost reimbursement always increases adoption. More generally, risk aversion leads to ambiguity of how the level of adoption adjusts to changes in the payment system.

The structure of the paper is as follows. The following section provides a brief overview of the literature addressing the impact of technological progress on health care expenditures from a number of different perspectives. Section 3 introduces the model and behavioral assumptions. Sections 4 and 5 deal with the adoption decision of a new technology under the different payment regimes. Section 6 compares the levels of adoption across payment schemes. Section 7 studies whether the different reimbursement regimes induce over- or under adoption with respect to the first-best associated with the social welfare. A section with conclusions and a technical appendix close the paper.

2 Literature review

In general, the main findings in the empirical literature can be grouped in three related classes: (i) technological development induces an increase in health care expenditures, (ii) the reimbursement system in the health care sector has an impact

on the R&D effort, and (iii) the R&D effort determines the type of technological development, either brand new technology, or improvements in existing technologies (or both). In contrast, our analysis as mentioned above, links the reimbursement system to the adoption of a new technology. Some of the main conclusions of this mainly empirical literature stress the fact that (a) prospective payment systems encourage cost efficient new technologies but have perverse effects on quality improvement, and (b) retrospective payment systems encourage quality but dim sensitivity toward cost efficiency.

Di Tommaso and Schweitzer (2005) collect a series of papers to describe the benefits of promoting a country's health industry as a way to stimulate its high-technology industrial capacity. In particular, they stress the fact that the health system is a major generator of scientific knowledge leading not only to improvements in the health state of the country, but also produce positive externalities on other industries in the form of public goods, "national champions" industries producing new technological breakthroughs and high-technology start-ups that with adequate protection will turn into self-sustaining industries.

According to the OECD (2005c), to understand the economic consequences of technological change it is necessary to know "... whether the new technologies substitute for old or are add-ons to existing diagnostic and treatment approaches, (...) whether these technologies are cost reducing. cost neutral, or cost effective, [and] what the target population is" (p.28). As clear-cut as these questions may look, they do not always lead to a simple answer. It may well occur that a technological change allows for reducing the average cost, improving quality, and reducing risk to patients. However, such technology would also allow for an expansion of the population of patients suitable for such technology, thus inducing an increase in the overall health care budget. Key determinants of the technological change in health care systems (see OECD, 2005c: 31-38) are (i) the relationship between health care expenditures and GDP; (ii) the reimbursement arrangements in the insurance contracts, and (iii) the regulatory environment.

Bodenheimer (2005) finds evidence linking tight budget controls to slower

technological advance "... but eventually [technological advance] drives costs up. The imperative to innovate overcomes the effort to economize." (p. 936).

In a fascinating paper, Weisbrod (1991) explains the interaction between the R&D effort and the health care insurance system as the result of the combination of two arguments. The first one tells us that health care expenditures are driven by technical innovation, which in turn, is the result of the R&D processes, which are determined by the (expected future) financial mechanisms allowing for recovering the R&D expenses. These financial mechanisms are related to the expected utilization of the new technologies, which is defined by the insurance system. The second argument defines the present technological situation as a proxy for past R&D effort and determines the demand for health care insurance. In this respect, Weisbrod and LaMay (1999) elaborate on the increased uncertainty surrounding the R&D decision process, as private and public insurance decisions on the use of and payment for health care technology are under tighter control from the pressures for cost containment.

In studying the sources of increasing health care expenditures, Fox *et al.* (1993) point out three elements in the case of the United States. These are the view of health insurance as a tax subsidy, the presence of entry barriers into the medical profession, and the lack of competition in the insurance industry. Also, Chou and Liu (2000) look at Taiwan's National Health Insurance program to find evidence of causality from third party payment mechanism inducing higher patient volume that in turn, leads hospitals' adoption of new technologies.

Cutler *et al.* (1998) go into the debate of the impact of the increase in health care expenditures on health outcomes. In front of positions illustrated by Fuchs (1974) or Newhouse and the Insurance Experiment Group (1993) where the main conclusion is that medical care has little impact on health outcomes, Cutler *et al.* (1998) argue that in a "dynamic context, the evidence that the marginal value of medical care at a point in time is low does not imply that the average value of medical technology changes over several decades is low. To measure cost-of-living indexes accurately, however, one needs to know the average value of medical tech-

nology changes." (p. 133). So far there is no general agreement on how to construct such indexes. On the one hand, hedonic prices are difficult to apply given the widespread regulation of prices; on the other hand, there is no agreement on how to set up a model of medical decision-making. Without such indexes, Cutler *et al.* (1998) argue that no complete answer can be given to the question of the consequences of the increase of health care expenditures on the health status of the population.

In a somewhat similar perspective, Newhouse (1992) also calls for dynamic arguments to analyze the impact of the increasing costs of medical care when evaluating the welfare losses at a point in time as compared with those that may arise due to the increases of expenditures over time. "However, I will contend that economists have been too preoccupied with a one-period model of health care services that takes technology as given, and that we need to pay more attention to technological change." (p.5).

The most detailed analyses of the benefits vs. costs of medical advances have been performed on the basis of case studies. To mention some, the TECH team is exploring whether individuals living in countries that rapidly adopted new revascularization technologies and clot-dissolving drugs are more likely to survive heart attacks than individuals living in countries that adopted such interventions more slowly. McClellan and Kessler for the TECH group (1999) show the spread of health technology in 16 OECD nations with widely divergent health care systems, using treatment of heart attacks. TECH (2001) update the information and report that technological change has occurred in all 17 countries of the study, but its diffusion shows very different rates. For intensive procedures, countries can be classified into three patterns: early start and fast growth; late start/fast growth; and late start/slow growth. Those differences are attributed to economic and regulatory incentives in the health care systems.

Duggan and Evans (2005) estimate the impact of medical innovation in the case of HIV antiretroviral treatments in the period 1993-2003 from a sample of more than 10,000 Medicaid patients living in California who were diagnosed HIV/AIDS.

The authors evaluate the cost effectiveness of new drugs on spending. They conclude that those new drugs yield a three-fold increase in lifetime Medicaid spending due to their high cost and increase in life expectancy. Despite this, the authors conclude that the new treatments were cost effective based on the value of a year of life.

Cutler and Huckman (2003) study the diffusion of angioplasty in New York state to address the puzzling feature of many medical innovations that simultaneously reduce unit costs and increase total costs. The key elements of their analysis is the identification of the so-called treatment expansion (the provision of more intensive treatment to patients with low-grade symptoms) and treatment substitution (the shift of a patient from more- to less-intensive interventions), and the consideration of the costs and benefits of these effects not only at a point in time but also their change over time.

Bokhari (2008) studies the impact on adoption of cardiac cauterization laboratories according to HMO market penetration and HMO competition. In a related line, Baker (2001) analyses HMO market penetration and diffusion of MRI equipment, and Baker and Phibbs (2002) look at HMO market penetration and diffusion of neonatal intensive care units.

Finally, Cutler and McClellan (2001) look at treatments for heart attack, low birthweight infants, depression, and cataracts. Taking into account the treatment substitution and treatment expansion effects, they conclude that the estimated benefit of technological change is much greater than the cost.

The findings advanced in the empirical literature link health care expenditure and technology diffusion based on a number of factors, including (i) the degree of substitutability/complementarity between the old and new technologies, (ii) the efficiency of the innovation in terms of effort reduction and output improvement, (iii) the impact of expenses of the adoption of new technologies in accordance with the treatment expansion and treatment substitution effects, (iv) the presence of agents whose objective functions need not be profit maximization, and (v) the characteristics of the health care system, its financing and regulation.

These and other elements determine the incentives to develop and diffuse new medical technologies. However, there are very few theoretical models providing support to the empirical modeling, and allowing for addressing the incentives for technological development, the rate of its diffusion in the health care system, or the welfare effects of the adoption of such (expensive) medical innovations. Among those few contributions we find Goddeeris (1984a,b), Baumgardner (1991), and Selder (2005), who examine the effects of technical innovation on the insurance market, and Miraldo (2007) who studies the feed-back effects between the health care and the R&D sectors, Grebel and Wilfer (2010) who study the diffusion of two competing technologies, and Levaggi *et al.* (2012) who consider how the uncertainty on patients' benefits affects the incentives to invest in new technologies.

Goddeeris (1984b) develops a framework for analyzing the effects of medical insurance on the direction of technological change in medicine, where research is carried out by profit maximizing institutions. Goddeeris (1984a) sets up a dynamic model to look at the welfare effects of the adoption of endogenously supplied innovations in medical care financed through medical insurance, using as welfare criterion the expected utility of the typical individual. Baumgardner (1991) builds upon Godderis (1984a) and studies the relationship between different types of technical change, welfare and different types of insurance contracts, to conclude that the value of a specific development in technology depends on the type of insurance contract. Selder (2005) extends Baumgardner (1991), analyzing the incentives of health care providers driven by different reimbursement systems to adopt new technologies in a world with ex-post moral hazard and their impact on the rate of diffusion. In particular, he considers a model where "the physician chooses a technology and offers this technology to the patient. The patient then chooses the treatment intensity which maximizes his utility given the technology offered. Taking these actions into account, the insurer (or social planner) designs a remuneration scheme for the physician and an insurance contract for the patient. He cannot contract upon technology choice and treatment intensity" (p. 910). The welfare implications of the adoption of new technologies are also addressed.

Miraldo (2007) studies the impact of different payment systems on the adoption of endogenously supplied new technologies, by introducing a feed-back effect from the health care sector into the R&D sector. Her central claim is that "[t]he 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" (p.2). In turn, the expected profitability of a newly developed technology depends on the number of hospitals adopting (market size) and the reimbursement associated with it. R&D activities may be done in either in-house or externally. Both scenarios are solved for the technologies' optimal quality and cost decreasing levels and for the decision on optimal reimbursement by a central planner.

Grebel and Wilfer (2010) study the diffusion process of two competing technologies in the health care sector where network externalities and individual learning are the main decision drivers. In particular, the demand side of the market (physicians) learn by using the new technologies and generate network externalities that diffuse the information of the new technologies and thus affects the decision of adopting. On the supply side, firm size and the time to market play an important role. These forces, namely the willingness of potential technology users to adopt a new technology and the strategic behavior of the firm, subject to the network externalities, shape the resulting market structure.

Levaggi *et al.* (2012) is the closest contribution in spirit to our modeling approach. They analyze the interaction between different payments systems and the uncertainty of patients' benefits on the incentives for providers to invest in new technologies, both in terms of *static efficiency* (cost reduction) and *dynamic efficiency* (timing of adoption). It turns out that if lump-sum payments cannot be implemented (which often occurs in the real world health care systems), there appears a trade-off between both types of efficiency, because the incentive to adopt the new technology when the price equals the marginal cost (yielding static efficiency) yields a later-than-efficient adoption timing. In contrast, we focus in the impact of the design of the reimbursement system on the incentives to adopt a new technology.

There are several relevant topics that we do not address in our analysis. One is the role of the malpractice system, with extra tests and procedures ordered in response to the perceived threat of medical malpractice claims (Kessler and McClellan, 1996). On the effects of hospital competition on health care costs see Kessler and Mcclellan (2000). Another topic is the use of technology assessment criteria to measure the value of new health care technologies brought about by R&D investments. Economic evaluation (cost-benefit analysis) of new technologies is common in pharmaceutical innovation and has led to a wide body of literature, both on methodological principles and on application to specific products. For a recent view on the interaction between R&D and health technology assessment criteria, see Philipson and Jena (2006).

Most of our analysis is set in the context of a health care sector organized around a NHS. We do not explicitly account for a specific role of the private sector in the provision of health care services as a driver in the diffusion of new available technologies. Our analysis is applicable to both private and public sectors to the extent that they use the payment mechanisms we explore below.

3   The model

We consider a semi-altruistic provider, who values financial results (represented by an increasing and concave utility function, $V(\cdot), V'(\cdot) > 0$ and $V''(\cdot) < 0$) and patients' health gains. We will refer to the hospital as an example of a relevant provider throughout the text.

There is a potential total number of homogeneous patients (i.e. they all suffer from the same illness and with the same severity) q^* in need of treatment.[1] The actual number of patients treated by the hospital, q, is uncertain over the course of a time period (say, a year). The hospital can install a new technology that allows it to treat $\bar{q}$ patients. If demand for hospital services exceeds the newly installed

---

[1]Allowing for heterogenous patients in terms of severity levels should not alter the qualitative results as long as the increased benefits of the treatment offset the increased costs aggregately (see below). No clear cut conclusions are to be expected otherwise, In particular, the distribution of severities over the population of patients (and thus of patients' benefits) would be crucial to assess the incentives for adoption of the new technology.

capacity, then patients are treated using an older technology. In other words, the new technology is used prior to the old technology. We assume that within the set of patients needing treatment no prioritization is made across patients.[2] Uncertainty about demand for hospital services is modeled simply as distribution $F(q)$, with density $f(q)$, in the domain $[0, q^*]$.

Note that we model adoption of a new technology as an investment decision in capacity to treat patients. That is, adoption is represented by a continuous endogenous variable $\bar{q}$. In this sense we interpret the new technology in terms of the health care services it provides rather than as a discrete decision on whether to adopt or not. Accordingly, adoption in our context means an investment in capacity to treat patients with a different protocol yielding higher benefits to them. Alternatively, we can think of one decision, namely to adopt or not to adopt, and at the same time decide the scale of the adoption. In this case, the new technology can be a (scalable) equipment or training of health professionals in providing a new treatment.

We also assume that uncertainty is symmetric for the two technologies. In other words, we assume the the total number of patients is uncertain, not how many treatments will be required with the new technology. Implicitly, this implies the the new technology represents a step forward in the development of the treatment rather than a break through improvement.

Finally, we also consider the patients' benefits as the criterion for the use of the new technology. Patients are treated with the new technology up to capacity, and if there is demand left, it is treated with the old technology. This is a simple mechanism that in our context of homogeneous patients is meaningful. More general set-ups where patients are differentiated in severity allow for more sophisticated mechanisms (see Siciliani, 2006, and Hafsteinsdottir and Siciliani, 2010 for the analysis of treatment selection mechanisms when patients differ in severity).

Hospitals receive a payment transfer R. Such payment may be prospective, retrospective, or mixed. We will analyze two payment systems. On the one hand,

---

[2]This is assumed for expositional simplicity. The problem remains basically the same within each priority group if we allow for explicit prioritization of patients.

we will study a cost reimbursement scheme flexible enough to accommodate total cost reimbursement, fixed fee/capitation, and partial cost reimbursement. On the other hand, we look at the effects of a DRG-based payment system with payments by sickness episode.[3] We assume that the payer can commit to the rule announced. Otherwise, "hold-up" issues à la Bös and de Fraja (2002) could arise.

The new technology has an investment cost per patient treated of p.[4] There is also a constant marginal cost per patient treated, given by θ in the new technology and by c in the old technology. Accordingly, the total cost is composed of (i) the cost of installing the new technology allowing to treat up to $\bar{q}$ patients given by $p\bar{q}$, and (ii) the cost of treatments. This in turn, depends on whether realized demand is below capacity (in which case it is given by θq), or whether realized demand is above capacity. Then, $\bar{q}$ patients are treated with the new technology at marginal cost θ, and $(q - \bar{q})$ patients are treated under the old technology with marginal cost c. Formally, the total cost function of the hospital is given by,

$$TC = \begin{cases} p\bar{q} + \theta q & \text{if } q \leq \bar{q} \\ p\bar{q} + \theta\bar{q} + c(q - \bar{q}) & \text{if } q > \bar{q} \end{cases} \tag{1}$$

We assume that the average and marginal costs of the new technology is higher than the corresponding average and marginal costs of the old technology:

Assumption 1.

$$p + \theta - c > 0. \tag{2}$$

With this assumption we capture the generally accepted claim that new technologies are not cost savers relative to existing ones and are one of the main drivers of the cost inflation in the health care sectors in developed countries.

The endogenous character of $\bar{q}$ leads us to assume that $\bar{q}$ is not contractible (as in the literature). The specific way the hospital will use the new technology

---

[3]Implicitly we define DRGs as describing processes and procedures. We have chosen this approach instead of the alternative definition of DRGs capturing the casemix, as we find it more suitable for our analysis.

[4]This means that for the purposes of our main arguments we abstract from the potential lumpiness of technological investment. Lumpiness can be easily accommodated by redefining the units of measurement of patients.

depends on elements internal to the provider such as the clinical decision-making. In this sense, the model can be interpreted as conveying private information and the payer trying to induce socially optimal decisions through the choice of the reimbursement system.

Patient benefits measured in monetary units are given by b under the new technology and by $\hat{b}$ in the old technology. We assume $b > \hat{b}, b > p + \theta$ and $\hat{b} > c$, so that it is socially desirable to provide treatment to patients. To ease notation, hereafter let $\Delta \equiv b - \hat{b}$. That is Δ represents the incremental patients' benefits when treated with the new technology.

Economic evaluation criteria will often require that incremental benefits from the new technology exceed incremental costs, that is:

Assumption 2. *Economic evaluation criterion for approval of new technology requires incremental benefits greater than incremental costs from the new technology. That is,*

$$\Delta > p + \theta - c > 0 \tag{3}$$

Hereinafter, whenever we mention that economic evaluation criteria (or health technology assessment) is used, we mean that incremental benefits are greater than incremental costs (or equivalently Assumption 2 holds).[5]

The expected welfare for the hospital decision maker is given by the valuation of the financial results of the hospital and by valuation of patients' benefits from treatment.

$$W = \int_0^{\bar{q}} V(R - p\bar{q} - \theta q) f(q) dq + \int_{\bar{q}}^{q^*} V(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq$$

$$+\eta \int_0^{\bar{q}} bq f(q) dq + \eta \int_{\bar{q}}^{q^*} \left((q - \bar{q})\hat{b} + \bar{q}b \right) f(q) dq \tag{4}$$

---

[5]We assume new technologies that are both cost and benefit incremental. The relevant assumption for adoption is that the increased benefits offset the increased cost. This allows to extend in a parallel way new technologies that are both cost and benefit decreasing, under the equivalent assumption that the decrease in benefits is lower that the decrease in cost. Technologies associated to higher costs and lower benefits would never be adopted, while new technologies with lower cost and higher benefits for the patients would always be adopted regardless of the payment system.

This function captures a semi-altruistic provider who weights its private benefits and the social benefits implicitly through the function V and the parameter $\eta > 0$. In particular, the financial result of the hospital is given by revenues R (that will follow a pre-specified rule), minus the costs of treating patients. Costs of the hospital have two components. First, the cost of installing the new technology allowing to treat up to $\bar{q}$ patients. This is given by $p\bar{q}$, regardless of whether demand exceeds or not, the capacity level of the new technology. Second, there is the cost of actual treatments when realized demand is below the capacity built for the new technology. This cost is θq. On the other hand, when realized demand is above the capacity available for treatment under the new technology, $\bar{q}$ patients are treated with the new technology at marginal cost θ, and $(q - \bar{q})$ patients are treated under the old technology with marginal cost c. Financial results are assessed by the hospital with a utility function V. This valuation of financial results corresponds to the first line of equation (4).

The other element of the welfare function of the hospital is made up of benefits to patients. These are b and $\hat{b}$ in the event of treatment under the new and old technology respectively. When realized demand is below the capacity level of the new technology, then utility bq is generated for each level of realized demand. In the case of realized demand above the capacity level for the new technology, $\bar{q}$ patients have utility b and $(q - \bar{q})$ patients have utility $\hat{b}$. The expected utility over all possible levels of realized demand is the second line of equation (4). Note also that in the computation on the expected welfare we are summing over probabilities, not over patients. Finally, we assume that provider's altruism translates in a higher weight on patients' welfare than in the financial results.

The (adoption) decision problem of the hospital is to choose the level $\bar{q}$ of patients to be treated under the new technology. Naturally, such decision is contingent on the system of reimbursement to the hospital.[6] We will study and compare a (partial) cost reimbursement system and a DRG payment system.[7]

---

[6] Abbey (2009) presents a general appraisal of health care payment systems. See also Culyer and Newhouse (2000).

[7] A unified treatment encompassing all the payment systems studied would add elegance to the

Note that the question that we tackle is *not* the design of an optimal payment system to incentivate adoption, but the study the impact of some popular reimbursement systems (see Mossialos and LeGrand, 1999) on the level of adoption of new technology.

To clarify the intuition behind some of the results, we illustrate their content with a restricted version of the model characterized by risk-neutrality and a uniform distribution $q^* = 1$. These are referred to in the text as remarks.

4 Technology adoption under cost reimbursement

Let us assume that the hospital is reimbursed according to the cost of treating patients. We want to characterize the optimal choice of $\bar{q}$ by the hospital decision maker, taken as given the payment system.

The total cost depends on the level of realized demand and is defined as the fixed cost of investment in the new technology ($p\bar{q}$) and the variable cost given by the population of patients treated. We have to distinguish two situations according to whether or not realized demand is in excess of the capacity provided by the new technology ($\bar{q}$). Whenever the installed capacity of the new technology allows to treat all patients ($\bar{q} = q^*$), then we say that full adoption occurs. Recall that we assume that the new technology is used until capacity is exhausted. If there is demand left to serve, patients are treated with the old technology. Formally, the total cost function of the hospital is given by (1).

A cost reimbursement system that the transfer to the hospital is composed of a fixed part α and a cost sharing part $\beta \in [0, 1]$.

$$R = \alpha + \beta TC \tag{5}$$

Note incidentally, that by setting $\beta = 0$ we obtain a capitation system where only a fixed amount is transferred to the hospital regardless of the costs actually borne with treatment of patients.

analysis and would show explicitly the trade-offs among them. However, the addition of the extra set of parameters required would seriously interfere the study and comparison of results. Accordingly, we have opted for a separate analysis sacrificing analytical elegance.

To keep the model as simple as possible we do not introduce an explicit participation constraint for the provider. In turn, this implies that we assume that R will always suffice to guarantee a non-negative surplus for the provider. In other words, we implicitly assume that the regulator selects (α, β)-values so that the adoption of technology when it occurs does not generate losses to the provider.

Substituting (5) into (4) the hospital's welfare function becomes

$$
\begin{aligned}
W = b\eta \int_0^{\bar{q}} q f(q) dq + \eta \int_{\bar{q}}^{q^*} \left((q - \bar{q})\hat{b} + \bar{q}b \right) f(q) dq \\
+ \int_0^{\bar{q}} V\left(\alpha - (1 - \beta)(p\bar{q} + \theta q) \right) f(q) dq \\
+ \int_{\bar{q}}^{q^*} V\left(\alpha - (1 - \beta)(p\bar{q} + \theta\bar{q} + c(q - \bar{q})) \right) f(q) dq \quad (6)
\end{aligned}
$$

The problem of the hospital is to identify the value of $\bar{q}$ maximizing (6). To ease the reading of the mathematical expressions, let us introduce the following notation:

$$
\begin{aligned}
\eta\Delta &\equiv \eta(b - \hat{b}) \\
R_1(q) &\equiv \alpha - (1 - \beta)(p\bar{q} + \theta q) \\
R_2(q) &\equiv \alpha - (1 - \beta)(p\bar{q} + \theta\bar{q} + c(q - \bar{q}))
\end{aligned}
$$

In words, $R_1(q)$ denotes the net revenues of the hospital when the realized demand does not exhaust the capacity of the new technology ($q < \bar{q}$), and idle capacity of the new technology exists; and $R_2(q)$ denotes the net revenues of the hospital when the realized demand exceeds the capacity of the new technology ($q > \bar{q}$), and some of patients are treated with the old technology.

Proposition 1. *Under a cost reimbursement system, full adoption is never optimal (utility-maximizing) for the provider. Patients' benefits above a threshold ensure positive adoption for every level of reimbursement the payment system may define.*

Proof. The optimal level of adoption $\bar{q}$ is the solution of first-order condition of

the optimization problem (6). That is, the solution of,

$$\frac{\partial W}{\partial \bar{q}} = \eta \Delta \int_{\bar{q}}^{q^*} f(q)dq - (1-\beta)p \int_0^{\bar{q}} V'(R_1(q))f(q)dq$$

$$- (1-\beta)(p+\theta-c) \int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq = 0. \tag{7}$$

Note that for $\bar{q} \to q^*$, the first-order condition (7) is negative. Therefore, the value $\bar{q}$ solving (7) must be below q^*. Next, take $\bar{q} = 0$. Then, $\eta\Delta - (1-\beta)(p+\theta-c) \int_0^{q^*} V'(R_2(q))f(q)dq > 0$ for β sufficiently high. Or equivalently, for each $\eta\Delta$ there is a critical β such that $\bar{q} > 0$.

Looking at the second order condition, after noting that $R_1(\bar{q}) = R_2(\bar{q})$, it is satisfied if

$$\eta\Delta - (1-\beta)V'(R(\bar{q}))(\theta-c) > 0.$$

Given that by construction $\eta > 0$ (altruistic provider) and $\Delta > 0$ (incremental patients' benefits of the new technology), it follows that we require a value of β large enough, i.e. sufficiently large cost sharing component in the reimbursement system. $\square$

Remark 1. *Positive patients' benefits are a necessary condition for adoption given the assumption of no cost savings in treatment with the new technology and both technologies being reimbursed in the same way (β).*

To gain insight into the content of this proposition note that the first term in (7) represents the marginal gain from treating one additional patient with the new technology when the realized demand is greater than $\bar{q}$. The other terms represent the marginal cost of treating an extra patient with the new technology. To obtain an explicit solution to the optimal level of technology adoption, some further assumptions are required.

Assume now risk neutrality $(V'(\cdot) = 1)$[8], and a uniform distribution for the number of patients treated by the hospital in the relevant time period. Also normalize $q^* = 1$ without loss of generality. Then, the first-order condition (7) reduces

---

[8]This means that the marginal valuation of the financial results of the provider are independent of its level of activity. In other words, regardless of the realization of demand, the contribution of profits to the provider's welfare is constant.

to

$$\eta\Delta(1 - \bar{q}) - (1 - \beta)p\bar{q} - (1 - \beta)(p + \theta - c)(1 - \bar{q}) = 0,$$

or

$$\bar{q}^{cr} = 1 - \frac{p(1 - \beta)}{\eta\Delta - (1 - \beta)(\theta - c)}. \tag{8}$$

The second-order condition guarantees that the denominator of the fraction is positive.

Note that we cannot state whether, or not, passing a health technology assessment criterion (assumption 2) is restrictive over the desired adoption level by health care providers. To see it, rewrite equation (8) as,

$$(1 - \bar{q}^{cr})[\eta\Delta - (p + \theta - c)] - (1 - \beta)p\bar{q}^{cr} + \beta(1 - \bar{q}^{cr})(p + \theta - c) = 0.$$

The sign of the first term is given by assumption 2. If it is satisfied is positive, otherwise is non-positive. The second term is negative, and the last term is positive. Therefore, it may well be that for certain constellations of parameters, the optimal adoption level is achieved even without satisfying assumption 2. In other words, assumption 2 is sufficient but not necessary for adoption. Thus imposing that it must hold by law will clash in some cases with the decision of the semi-altruistic provider. For $\beta = 1$, full adoption occurs, as one would expect.

Under risk neutrality, uniform distribution, and $\eta > 1$, the use of economic evaluation criteria conveys a higher level of adoption, as long as $\beta < 1$, in the sense that rewriting the numerator of (8) as $\eta\Delta - (1 - \beta)(p + \theta - c)$, this expression is larger than the corresponding in assumption 2.

Note that the assumption $\eta > 1$ is only used as sufficient condition in comparing the level of adoption, not in the adoption decision *per se*. Two comments are in order regarding this assumption. One is technical. Having weight 1 for profits and η for patients can be rewritten in any suitable way with an appropriate transformation. For example, let $d \equiv \eta/(1 + \eta) < 1$. Then, by dividing the both weights by $1/(1 + \eta)$ we obtain weight $1 - d$ for profits and d for patients. The second relates to $\eta > 1$ is commonly used in the literature. Just with illustrative purposes, see Godager, Iversen and Ma (2012) and Liu and Ma (2013).

4.1 Cost-sharing and optimal technology adoption

We are interested in assessing how adoption changes with the level of cost reimbursement. In other words, we want to study the impacts of a variation of β and α on the level of adoption. This will give us the intuition of the role of the parameters of the payment system (α and β) in determining the optimal (utility-maximizing for the provider) level of technology adoption.

Technically, we want to compute the sign of $d\bar{q}/d\beta$ and of $d\bar{q}/d\alpha$, where $\bar{q}$ is given by the solution of (7). Thus, we capture the impact of a variation of β and α on the level of adoption $\bar{q}$ by computing $\partial^2 W/\partial\bar{q}\partial\beta$ and $\partial^2 W/\partial\bar{q}\partial\beta$.

Let us thus compute,

$$
\begin{aligned}
\frac{\partial^2 W}{\partial\bar{q}\partial\beta} &= p\int_0^{\bar{q}} V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq \\
&\quad - (1-\beta)\Big[p\int_0^{\bar{q}} V''(R_1(q))(p\bar{q}+\theta q)f(q)dq+ \\
&\quad (p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))(p\bar{q}+\theta\bar{q}+c(q-\bar{q}))f(q)dq\Big]
\end{aligned}
\tag{9}
$$

Recall that we have assumed a concave utility function V, that is $V'' < 0$. Also, assumption 1 tells us that $p+\theta-c > 0$. Thus, it follows that the sign of equation (9) is positive, and so is the expression of $d\bar{q}/d\beta$. In other words, increasing cost sharing leads to more adoption, because a higher fraction of the cost is automatically covered.

In a similar fashion, we study the impact of a variation of α by computing,

$$
\frac{\partial^2 W}{\partial\bar{q}\partial\alpha} = -(1-\beta)\Big(p\int_0^{\bar{q}} V''(R_1(q))f(q)dq+(p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))f(q)dq\Big)
\tag{10}
$$

Given the concavity of $V(\cdot)$ and using (2), it follows that this expression is positive. As before, the sign of $d\bar{q}/d\alpha$ is the same as the sign of expression (10). Hence, higher values of α mean lower marginal cost of investing more in terms of utility. Thus, for the same benefit more investment will result. A particular case occurs under risk neutrality.

Remark 2. *Under risk neutrality, the level of technology adoption is insensitive*

to α. Therefore, the only instrument of the payment system to affect technology adoption is the share of cost reimbursement.

Given that α monetary units are transferred regardless of the activity of the hospital, under risk neutrality it should not be surprising that the level of technology adoption will be linked exclusively to the (expected) number of patients treated with the new technology, as it is the only way to improve the welfare obtained by the hospital.

4.2 Technological adoption under a given budget

The previous comparative statics exercise says that in general, higher transfers lead to higher levels of technology adoption by the hospital, because the increased patients' benefits offset the increased marginal cost (assumption2). A full welfare analysis of the adoption of the new technology requires the definition of a reference point, or of a common threshold. In our case, it is not obvious how to define them. Accordingly, we propose two alternatives to approach the welfare analysis. One consists in assuming a given budget on the level of adoption; the alternative assumes that the hospital's expected surplus is constant. In this way, we have a well-defined reference point to evaluate the consequences of technological adoption. We consider first the case where the budget to invest in the adoption of the new technology is given.

Consider keeping payment constant in expected terms, that is, $dR = 0$. Recalling (1) and (5), the expression of the monetary transfer to the hospital is given by,

$$R = \alpha + \beta \Big(\int_0^{\bar{q}} (p\bar{q} + \theta q) f(q) dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta q + c(q - \bar{q})) f(q) dq \Big),$$

Assuming that the payment to the hospital remains constant after adjusting the parameters (α, β) of the payment function, a policy change in parameters will

satisfy

$$dR = d\alpha + d\beta \left(\int_0^{\bar{q}} (p\bar{q} + \theta q) f(q) dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta q + c(q - \bar{q})) f(q) dq \right)$$
$$+ \beta \left(p \int_0^{\bar{q}} f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} f(q) dq \right) d\bar{q} = 0. \qquad (11)$$

Finally, let us recall the first-order condition (7) characterizing the optimal value of $\bar{q}$. Total differentiation yields

$$\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} + \left(p \int_0^{\bar{q}} V'(R_1(q)) f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} V'(R_2(q)) f(q) dq \right.$$
$$- (1 - \beta) \left(p \int_0^{\bar{q}} V''(R_1(q))(p\bar{q} + \theta q) f(q) dq \right.$$
$$\left. + (p + \theta - c) \int_{\bar{q}}^{q^*} V''(R_2(q))(p\bar{q} + \theta\bar{q} + c(q - \bar{q})) f(q) dq \right) d\beta$$
$$- (1 - \beta) \left(p \int_0^{\bar{q}} V''(R_1(q)) f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} V''(R_2(q)) f(q) dq \right) d\alpha = 0$$
$$(12)$$

Thus, we have a system of equations given by (11) and (12), that we can write in a compact form as

$$d\alpha + \Gamma d\bar{q} + \Lambda d\beta = 0$$
$$\Phi d\alpha - \Psi d\bar{q} + \Upsilon d\beta = 0. \qquad (13)$$

where we use the following notation:

$$\Gamma \equiv \beta \left(p \int_0^{\bar{q}} f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} f(q) dq \right) > 0$$

$$\Lambda \equiv \int_0^{\bar{q}} (p\bar{q} + \theta q) f(q) dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta q + c(q - \bar{q})) f(q) dq > 0$$

$$\Phi \equiv - (1 - \beta) \left(p \int_0^{\bar{q}} V''(R_1(q)) f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} V''(R_2(q)) f(q) dq \right) > 0$$

$$\Psi \equiv - \frac{\partial^2 W}{\partial \bar{q}^2} > 0$$

$$\Upsilon \equiv p \int_0^{\bar{q}} V'(R_1(q)) f(q) dq + (p + \theta - c) \int_{\bar{q}}^{q^*} V'(R_2(q)) f(q) dq$$
$$- (1 - \beta) \left(p \int_0^{\bar{q}} V''(R_1(q))(p\bar{q} + \theta q) f(q) dq \right.$$
$$\left. + (p + \theta - c) \int_{\bar{q}}^{q^*} V''(R_2(q))(p\bar{q} + \theta\bar{q} + c(q - \bar{q})) f(q) dq \right) > 0$$

To obtain some clear intuition of the content of the system (13) let us simplify the analysis by assuming risk neutrality. Then, it becomes,

$$d\alpha + \Gamma d\bar{q} + \Lambda d\beta = 0 \qquad (14)$$

$$-\widehat{\Psi} d\bar{q} + \widehat{\Upsilon} d\beta = 0. \qquad (15)$$

where $\widehat{\Psi}$ and $\widehat{\Upsilon}$ represent the corresponding values Ψ and Υ when $V''(\cdot) = 0$. Note that equation (15) tells us that $d\bar{q}/d\beta > 0$, and equation (14) tells us that α adjusts accordingly to satisfy the equation. Therefore,[9]

Remark 3. *Under risk neutrality, moving to more cost reimbursement always increases adoption, even if (expected) payment is kept constant overall. Risk aversion leads to ambiguity of how the level of adoption adjusts to changes in the payment system.*

We can examine the ambiguity induced by the presence of risk aversion. The solution of the system (13) is given by

$$\frac{d\bar{q}}{d\beta} = \frac{\Upsilon - \Lambda\Phi}{\Psi + \Gamma\Phi} \quad \text{and} \quad \frac{d\bar{q}}{d\alpha} = -\frac{\Upsilon - \Lambda\Phi}{\Lambda\Psi + \Gamma\Upsilon} \qquad (16)$$

Note that the numerators in (16) have an ambiguous sign. They are positive iff $\frac{\Upsilon}{\Phi} > \Lambda$, where risk aversion appears only in the terms of the fraction. Therefore, an increase in the cost sharing (β) will induce more adoption if the properties of the utility function $V(\cdot)$ are such that the ratio Υ/Φ is above the threshold given by Λ. The properties of the utility function $V(\cdot)$ will vary across hospitals, because different providers will have different levels of activity, that is their values of V' and V'' will differ and so will the expressions in (16). Therefore, identifying them is an empirical exercise. This is precisely the issue behind the difficulties to interpret the empirical work on technological adoption as a function of the payment system.

To assess the impact on hospital welfare, while maintaining $dR = 0$, let us compute

$$dW = \frac{\partial W}{\partial R} dR + \frac{\partial W}{\partial \bar{q}} d\bar{q} \qquad (17)$$

---

[9]The last part of the remark is proved in the appendix.

The first term of (17) is zero because we are evaluating the impact on hospital welfare at $dR = 0$. The second term is also zero from the envelope theorem. Accordingly, $dW = 0$.

The intuition under risk aversion follows the same lines of reasoning as before. The hospital only improves its welfare through patients' benefits. Then, any increase in the cost sharing favors adoption because the new technology improves patients' benefits. Given that total payment remains constant, the increase in cost sharing is adjusted through a lower α to satisfy the restriction, thus offsetting the gain of welfare.

Remark 4. *Keeping the expected payment constant implies no change in the objective function when changing the parameters of the cost reimbursement system.*

Remark 3 and remark 4 together tell us that a move toward more reimbursement leads to more adoption. Thus, the extra benefits to patients are compensated with a lower surplus for the hospital to maintain the objective function constant.

4.3 Constant hospital surplus

A potential alternative to fixing the level of expenditure of the health care system, we could envisage a set-up where the expected surplus of the hospital is kept constant. Denote such surplus as S. It is defined as,

$$S = \alpha - (1 - \beta)\left(\int_0^{\bar{q}} (p\bar{q} + \theta q)f(q)dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta\bar{q} + c(q - \bar{q})f(q)dq\right). \quad (18)$$

Totally differentiating (18) allows us to introduce the restriction of keeping the hospital surplus constant as,

$$dS = d\alpha - (1 - \beta)\Big(p + (\theta - c)(1 - F(\bar{q}))\Big)d\bar{q} +$$
$$\left(\int_0^{\bar{q}} (p\bar{q} + \theta q)f(q)dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta\bar{q} + c(q - \bar{q})f(q)dq\right)d\beta = 0$$
$$(19)$$

As before, we have a system of two equations given by (12) and (19), which in compact form are

$$\Phi d\alpha - \Psi d\bar{q} + \Upsilon d\beta = 0$$

$$d\alpha + \Omega d\bar{q} + \Pi d\beta = 0 \qquad (20)$$

where we use the following notation:

$$\Omega \equiv -(1-\beta)\Big(p + (\theta - c)(1 - F(\bar{q}))\Big)$$

$$\Pi \equiv \int_0^{\bar{q}} (p\bar{q} + \theta q)f(q)dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta\bar{q} + c(q - \bar{q})f(q)dq$$

Imposing risk neutrality to better assess its content, the system (20) simplifies to,

$$-\Psi d\bar{q} + \Upsilon' d\beta = 0$$

$$d\alpha + \Omega d\bar{q} + \Pi d\beta = 0 \qquad (21)$$

so that $d\bar{q}/d\beta > 0$, but the sign of $d\alpha/d\beta$ is ambiguous.

Finally, note that

$$dW = \left(\int_0^{\bar{q}} V'(R_1(q))f(q)dq + \int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq\right)d\alpha +$$

$$\left(\int_0^{\bar{q}} V'(R_1(q))(p\bar{q} + \theta q)f(q)dq + \int_{\bar{q}}^{q^*} V'(R_2(q))(p\bar{q} + \theta\bar{q} + c(q - \bar{q}))f(q)dq\right)d\beta \qquad (22)$$

Assume under risk neutrality that $V'(\cdot) = 1$ without loss of generality. Then, substituting (19) in (22), it follows that $dW > 0$. Accordingly,

Remark 5. *Under risk neutrality and constant trade-off of surplus against patient benefits, an increase in the cost reimbursement adjusted in a way that total expected surplus of the hospital remains constant, results in an increase in the objective function. This results from patients' benefits due to more adoption given the absence of costs to raising money for the payment to be made.*

5 Technology adoption under DRG payment

Consider a health care system where the provision of services is reimbursed using a DRG catalog. A DRG payment system means that a fixed amount is paid for every type of disease. We are considering a single-disease model, where two technologies are available. We will distinguish two cases. The first one consists in paying the hospital the same amount regardless of the technology used. We term it as *homogenous DRG reimbursement*. It corresponds to a situation where each patient treated is an episode originating a payment through a given DRG and technology adoption will keep the DRG. Hence the payment received by the hospital remains constant. In the second case the level of reimbursement is conditional upon the choice of technology to provide treatment. It is interpreted as a situation where adoption of technology leads to the coding of the sickness episode in a different DRG, receiving a different payment. In this sense we refer to it as *heterogenous DRG reimbursement*. As before, we assume that R will always suffice to guarantee a non-negative surplus for the provider.

5.1 Homogeneous DRG reimbursement

Let us consider first that the adoption of a new technology does not convey a variation in the DRG classification. Then, the payment received by the hospital for patients treated is defined as,

$$R = Kq. \tag{23}$$

Substituting (23) into (4) the hospital's welfare function becomes,

$$
\begin{aligned}
W = &\ \eta \int_0^{\bar{q}} bq f(q) dq + \eta \int_{\bar{q}}^{q^*} \left((q - \bar{q})\hat{b} + \bar{q}b \right) f(q) dq \\
&+ \int_0^{\bar{q}} V\left(Kq - p\bar{q} - \theta q \right) f(q) dq \\
&+ \int_{\bar{q}}^{q^*} V\left(Kq - p\bar{q} - \theta\bar{q} - c(q - \bar{q}) \right) f(q) dq
\end{aligned}
\tag{24}
$$

Let us define the net revenues obtained when the new technology can cover all the demand ($R_3(q)$), and when there is excess demand so that a fraction of the

patients are treated with the old technology ($R_4(q)$) as,

$$R_3(q) \equiv Kq - p\bar{q} - \theta q$$

$$R_4(q) \equiv Kq - p\bar{q} - \theta\bar{q} - c(q - \bar{q})$$

Proposition 2. *Under homogeneous DRG payment system, full adoption is never optimal.*

Proof. The optimal level of adoption is given as before, by the solution of the first-order condition,

$$\frac{\partial W}{\partial \bar{q}} = \eta \Delta \int_{\bar{q}}^{q^*} f(q)dq + \Big(V(R_3(\bar{q})) - V(R_4(\bar{q}))\Big)f(\bar{q})$$

$$- p \int_0^{\bar{q}} V'(R_3(q))f(q)dq - (p + \theta - c)\int_{\bar{q}}^{q^*} V'(R_4(q))f(q)dq = 0. \quad (25)$$

For $\bar{q} \to q^*$, the first-order condition (25) is negative. Thus, the optimal value satisfying (25) must be less than q^*. $\qquad \square$

Remark 6. *Note that sufficiently large patients' benefits are necessary for the first-order condition* (25) *to have an interior solution. Otherwise, the hospital optimally does not adopt the new technology.*

Let us consider a simplified version of the model by assuming risk neutrality, a uniform distribution for the number of patients, and without loss of generality $q^* = 1$. Then, the first-order condition (25) reduces to,

$$\eta\Delta(1 - \bar{q}) - p\bar{q} - (p + \theta - c)(1 - \bar{q}) = 0 \quad (26)$$

This simplified version of the model allows us to obtain an explicit solution of the optimal level of technical adoption. It is given by,

$$\bar{q} = 1 - \frac{p}{\eta\Delta - \theta + c}. \quad (27)$$

The denominator of equation (27) is positive from the second-order condition. Thus, $\bar{q} < 1$, and full adoption is never optimal. The optimal value of adoption

given by (27) trades off patients' benefits and the differential marginal cost of the two technologies.

Note that under homogenous DRG payment systems, adoption by the health care provider occurs (i.e. $\bar{q} > 0$) if and only if the economic evaluation criterion is satisfied (compare equation (27) with Assumption 2).

Remark 7. *Note that $\bar{q}$ is independent of the price K. In other words, the price does not matter for the adoption decision. This is so because, given that the hospital receives the same payment for the patients regardless of the technology used, the adoption decision is driven by a cost-minimization rule (given Δ large enough).*

Next, we look at the comparative statics analysis of the impact of the level of reimbursement K on adoption. It follows from,

$$\frac{\partial^2 W}{\partial \bar{q} \partial K} = -p \int_0^{\bar{q}} V''(R_3(q))qf(q)dq - (p + \theta - c) \int_{\bar{q}}^{q^*} V''(R_4(q))qf(q)dq > 0$$

Given the concavity of $V(\cdot)$ and recalling that $p + \theta - c > 0$, it follows that this derivative is positive. Therefore, higher DRG payment means that in utility terms there is lower marginal cost of investment, and thus there is more investment in capacity.

Remark 8. *Risk aversion is a necessary condition for the DRG payment being able to affect the level of adoption.*

5.2 Heterogeneous DRG reimbursement

Assume now that the hospital is reimbursed conditionally upon the technology used in the treatments. This makes sense as long as the costs of the new and old technologies are sufficiently disperse so that each treatment falls in a different DRG, which typically elicits a different payment. With this framework in mind, let us define

$$R_5(q) \equiv K_1 q - p\bar{q} - \theta q$$
$$R_6(q) \equiv K_1 \bar{q} + K_2(q - \bar{q}) - p\bar{q} - \theta\bar{q} - c(q - \bar{q})$$

where K_1 is the payment associated with treating a patient with the new technology and K_2 is the payment associated with treating a patient with the old technology.

Now the utility function of the hospital is given by,

$$W = \eta \int_0^{\bar{q}} bq f(q)dq + \eta \int_{\bar{q}}^{q^*} \left((q - \bar{q})\hat{b} + \bar{q}b \right) f(q)dq$$

$$+ \int_0^{\bar{q}} V(R_5(q))f(q)dq + \int_{\bar{q}}^{q^*} V(R_6(q))f(q)dq \qquad (28)$$

Proposition 3. *Under a heterogeneous DRG payment system, full adoption is never optimal.*

Proof. The first-order condition characterizing the optimal level of adoption is

$$\frac{\partial W}{\partial \bar{q}} = \eta \Delta \int_{\bar{q}}^{q^*} f(q)dq + V(R_5(\bar{q}))f(\bar{q}) - V(R_6(\bar{q}))f(\bar{q})$$

$$- p \int_0^{\bar{q}} V'(R_5(q))f(q)dq$$

$$+ (K_1 - K_2 - p - \theta + c) \int_{\bar{q}}^{q^*} V'(R_6(q))f(q)dq = 0. \qquad (29)$$

For $\bar{q} \to q^*$, the first-order condition (29) is negative. Thus, the optimal value satisfying (25) must be less than q^*. $\qquad \square$

Remark 9. *Note that in contrast with the case of homogenous DRG, now patients' benefits may not be necessary for adoption to occur if the margin the hospital obtains with the new technology, $(K_1 - p - \theta)$, is larger than the margin that it obtains with the old technology, $(K_2 - c)$. In other words, the adoption decision is driven by the difference in reimbursement between the two technologies. Formally, if $K_1 - K_2 - (p + \theta - c) > 0$, then we can identify a constellation of parameters guaranteeing and interior solution, even without patients' benefits.*

To gain some intuition of the level of adoption, assume risk neutrality, and a uniform distribution once again. Also, normalize $q^* = 1$ without loss of generality. Then, expression (29) reduces to,

$$\eta \Delta (1 - \bar{q}) - p\bar{q} + (K_1 - K_2 - p - \theta + c)(1 - \bar{q}) = 0,$$

so that,

$$\bar{q} = 1 - \frac{p}{\eta\Delta + K_1 - K_2 - \theta + c}. \tag{30}$$

and second-order conditions guarantee that the denominator of the fraction is positive. Note that $\bar{q} < 1$. The optimal value of $\bar{q}$ given by (30) reflects the trade-off between incurring an idle capacity cost for high $\bar{q}$ and getting a better margin, i.e. $K_1 - (p + \theta) > K_2 - c$. Furthermore, the benefits of the patients are not a necessary condition for technology adoption as long as the new technology leads to a higher margin from payment. Adding patients' benefits naturally raises adoption rates.

In this case, technology adoption by the health care provider will always be greater than implied by application of the health technology assessment. That is, in cases where economic evaluation indicates no adoption of the new technology ($\Delta < p + \theta - c$), the health care provider will still prefer a strictly positive level of technology adoption for high enough differential reimbursement of the two technologies.

Summarizing we have obtained that assuming the hospital obtains a higher margin with the new technology than with the old one, is a sufficient condition for adoption (because the new technology produces no harm). However, it is not necessary. In particular, we will observe adoption when such assumption does not hold but patients' benefits are large enough. In other words, patients' benefits are a necessary condition for adoption but not sufficient.

6 Comparing payment regimes

We have presented the adoption decision under two payment regimes, cost reimbursement, and DRG payments. The respective optimal levels are difficult to compare. The very particular scenario of risk neutrality (under the form of $V'(\cdot) = 1$) and uniform distribution allows us to obtain some intuition on the relative impact of each of the payment systems on the level of adoption.

Let us recall the expressions for the respective levels of adoption under cost reimbursement and DRG payment systems, given by (8), (27) and (30) respectively,

and let $\lambda \equiv K_1 - K_2$:

$$\bar{q}^{cr} = 1 - \frac{p(1-\beta)}{\eta\Delta - (1-\beta)(\theta - c)}, \qquad (31)$$

$$\bar{q}^{hom} = 1 - \frac{p}{\eta\Delta - (\theta - c)}, \qquad (32)$$

$$\bar{q}^{het} = 1 - \frac{p}{\eta\Delta + \lambda - (\theta - c)}, \qquad (33)$$

where the superscripts *cr, hom* and *het* refer to the cost reimbursement, homogeneous DGR, and heterogeneous DRG respectively. The difference in adoption levels is given by:

$$\bar{q}^{hom} - \bar{q}^{het} = p\Big(\frac{1}{\eta\Delta + \lambda - (\theta - c)} - \frac{1}{\eta\Delta - (\theta - c)}\Big) < 0, \qquad (34)$$

$$\bar{q}^{cr} - \bar{q}^{het} = p\Big(\frac{1}{\eta\Delta + \lambda - (\theta - c)} - \frac{1}{\frac{\eta\Delta}{1-\beta} - (\theta - c)}\Big) \lessgtr 0, \qquad (35)$$

$$\bar{q}^{cr} - \bar{q}^{hom} = p\Big(\frac{1}{\eta\Delta - (\theta - c)} - \frac{1}{\frac{\eta\Delta}{1-\beta} - (\theta - c)}\Big) > 0 \qquad (36)$$

Comparison between the adoption levels across DRG regimes is clear cut. Under heterogeneous DRG reimbursement the optimal level of technical adoption is greater than under homogeneous DRG reimbursement. This is not surprising. The hospital has more incentive to invest in the new technology when the payment associated with it is larger than the payment for the old technology.

To interpret expression (35), suppose the provider decides to invest an amount p in the new technology under the DRG system. Such investment allows to treat one extra patient with the new technology. The benefits to the provider in our setting under additive utility and risk neutrality, are the gain in patients' benefits (Δ), plus the extra revenues associated with the new technology ($K_1 - K_2$), minus the marginal cost increase of treating one extra patient with the new technology ($\theta - c$). Summarizing the net gains to the provider of treating an additional patient with the new technology under a heterogenous DRG reimbursement scheme are $\eta\Delta + K_1 - K_2 - (\theta - c)$. This is the denominator of the left-hand fraction in (35).

Consider now the same investment under the cost reimbursement payment system. Since the provider knows that it will obtain a reimbursement β, from its perspective spending p from its free financial resources yields $1/(1 - \beta)$ patients
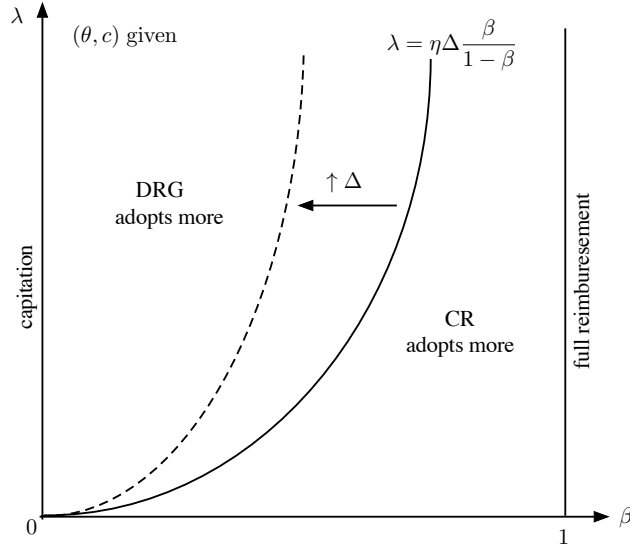
Figure 1: Optimal adoption: CR vs. heterogenous DRG.

to be treated with the new technology. Each of these additional patients generate benefits (Δ), and an operating marginal cost change of $(1 - \beta)(\theta - c)$. We can summarize this argument saying that the investment of p monetary units results in a return of $(\eta\Delta - (1 - \beta)(\theta - c))/(1 - \beta)$. This corresponds to the denominator of the right-hand fraction in (35).

We represent this comparison in Figure 1. The dividing line represents the locus of (λ, β) values yielding the same marginal return of investment in the new technology to the provider across regimes. The areas to the right and left of this line indicate the parameter configurations yielding more technology adoption under the payment scheme generating higher marginal net benefits to the provider.

Note that as the new technology embodies higher patients' benefits compared to the old one, the constellation of (λ, β)-values for which providers are willing to adopt under cost reimbursement increases. This is a direct consequence of the retrospective character of the cost reimbursement scheme. However, no clear-cut comparison on the level of reimbursement along the indifference line can be obtained. This is because such comparison involves comparing the values of K_2, α, and β that are not directly related.

31

A similar argument can be put forward to analyze expression (36). The net gains to the provider of an additional unit of the new technology under a homogenous DRG reimbursement scheme are $\eta\Delta - (\theta - c)$. This is the denominator of the left-hand fraction in (36). Under cost reimbursement, the investment of p monetary units results in a return of $(1/1 - \beta)(\eta\Delta - (1 - \beta)(\theta - c))$. This corresponds to the denominator of the right-hand fraction in (36). The return of the investment is thus larger under cost reimbursement, yielding the higher level of adoption.

7 Welfare analysis

So far we have identified the levels of technology adoption under different reimbursement rules and we have compared them as well, under some particular conditions. To complete the analysis we need to assess whether these payment rules induce over-adoption or under-adoption with respect to the first-best associated with the social welfare.

For our purpose, we define the social welfare, in line with Levaggi *et al.* (2012) and the literature in general, as the difference between benefits and costs. To obtain explicit solutions and compare them with the corresponding adoption levels in (31), (32) and (33), we shall assume again risk neutrality and a uniform distribution and also normalize $q^* = 1$. Then,

$$
SW(\bar{q}) = \int_0^{\bar{q}} bq f(q)dq + \int_{\bar{q}}^{q^*} \left((q - \bar{q})\hat{b} + \bar{q}b \right) f(q)dq -
$$
$$
\int_0^{\bar{q}} (p\bar{q} + \theta q) f(q)dq - \int_{\bar{q}}^{q^*} (p\bar{q} + \theta\bar{q} + c(q - \bar{q})) f(q)dq - \xi E(R^j) \quad (37)
$$

where ξ represents the social cost of public funds à la Laffont and Tirole (1986)[10] and $E(R^j)$ denote expected revenues under reimbursement rule j.

---

[10]See Armstrong and Sappington (2007) for a survey on the theory of regulation.

The expected revenues under the different reimbursements rules are given by

$$E(R^{cr}) = \alpha + \beta \left[\int_0^{\bar{q}} (p\bar{q} + \theta q) f(q) dq + \int_{\bar{q}}^{q^*} (p\bar{q} + \theta\bar{q} + c(q - \bar{q})) f(q) dq \right]$$
(38)

$$E(R^{hom}) = \int_0^{q^*} K q f(q) dq = K E(q)$$
(39)

$$E(R^{het}) = \int_0^{\bar{q}} K_1 q f(q) dq + \int_{\bar{q}}^{q^*} (K_1 \bar{q} + K_2 (q - \bar{q})) f(q) dq$$
(40)

7.1 Cost reimbursement rule

After substituting (38) into (37) we compute the first order condition:

$$\frac{\partial SW}{\partial \bar{q}} = (\Delta - (p + \theta - c))(1 - \bar{q}) - p\bar{q} - \xi\beta(p + (\theta - c)(1 - q)) = 0.$$

Solving for $\bar{q}$ we obtain,

$$\bar{q}^{swcr} = 1 - \frac{p(1 + \xi\beta)}{\Delta - (1 + \xi\beta)(\theta - c)}.$$
(41)

This is the welfare maximizing level of adoption under the cost reimbursement rule. We want to compare this level of adoption $\bar{q}^{swcr}$ with the corresponding level of adoption that maximizes provider's utility, namely $\bar{q}^{cr}$.

A direct comparison of (31) and (41) yields

$$\bar{q}^{cr} - \bar{q}^{swcr} = \frac{p(1 + \xi\beta)}{\Delta - (1 + \xi\beta)(\theta - c)} - \frac{p(1 - \beta)}{\eta\Delta - (1 - \beta)(\theta - c)} > 0.$$

Accordingly, under cost reimbursement the provider *over-adopts* the new technology with respect to a welfare maximizing policy. The intuition behind the result comes from the fact that the provider does not bear the full cost of the adoption.

7.2 Homogeneous DRG reimbursement rule

Substituting (39) into (37) we compute the first order condition,

$$\frac{\partial SW}{\partial \bar{q}} = (\Delta - (p + \theta - c))(1 - \bar{q}) - p\bar{q} = 0.$$

Solving for $\bar{q}$ we obtain,

$$\bar{q}^{swhom} = 1 - \frac{p}{\Delta - (\theta - c)}.$$
(42)

33

Now, comparing (32) and (42) we obtain

$$\bar{q}^{hom} - \bar{q}^{swhom} = \frac{p}{\Delta - (\theta - c)} - \frac{p}{\eta\Delta - (\theta - c)} \geq 0.$$

That is for $\eta > 1$, the provider *over-adopts* the new technology because patients are reimbursed at the same rate but patients' benefits are larger under the new technology. However, when $\eta = 1$, the level of adoption is optimal. This is so because given that both technologies are reimbursed at the same price, K, such price is irrelevant in the adoption decision. Recall, that $\eta = 1$ means that the semi-altruistic provider weights equally patients' benefits and its financial results.

7.3 Heterogeneous DRG reimbursement rule

Substituting (40) into (37) we compute the first order condition,

$$\frac{\partial SW}{\partial \bar{q}} = (\Delta - (p + \theta - c))(1 - \bar{q}) - p\bar{q} - \xi\lambda(1 - \bar{q}) = 0$$

Solving for $\bar{q}$ we obtain,

$$\bar{q}^{swhet} = 1 - \frac{p}{\Delta - (\theta - c) - \xi\lambda} \tag{43}$$

A direct comparison of (33) and (43) yields

$$\bar{q}^{het} - \bar{q}^{swhet} = \frac{p}{\Delta - (\theta - c) - \xi\lambda} - \frac{p}{\eta\Delta - (\theta - c) + \lambda} > 0.$$

Again, as under cost reimbursement, the provider *over-adopts* the new technology. The intuition now relies in the fact that the new technology has a higher reimbursement thus providing the incentives to over-invest in the new technology.

Note that the same (qualitative) results are obtained if we do not consider the social cost of public funds ($\xi = 0$) following the approach à la Baron and Myerson (1982).

8 Final remarks

Adoption of new technologies is usually considered a main driver of growth of health care costs.[11] Many discussions about it exist. Arguments in favor of cost-benefit analysis (health technology assessment) before the introduction of new

---

[11]See Smith et al. (2009) for a recent account

technologies has made its way into policy. We now observe in many countries the requirement of an "economic test" before payment for new technologies is accepted by third-party payers (either public or private). This is especially visible in the case of new pharmaceutical products and it has a growing trend in medical devices.

However, there is a paucity of theoretical work related to the determinants of adoption and diffusion of new technologies. We contribute toward filling this gap.

The novelty of our approach consists in allowing for an integrated treatment of incentives for adoption of new technology under demand uncertainty. We identify conditions for adoption under two different payment systems. Also, we compare technology adoption across reimbursement systems in a simplified set-up. We now summarize the main results.

Under a cost reimbursement system, large enough patient benefits are required for adoption to occur. As long as patient benefits are above a certain threshold, adoption of the new technology always occurs at strictly positive levels. However, it is never optimal to expand the level of adoption to cover all demand (full adoption). The threshold is given, in the case of risk neutrality and uniform distribution for patient benefits, by the cost of treating a patient under the new technology accounting for the savings resulting from not treating him under the old technology. The cost reimbursement allows for the extreme cases of full cost reimbursement and capitation (a fixed fee is paid, regardless of actual costs).

The other payment system we considered was prospective payments on a sickness episode basis (the DRG system). Two different regimes can be envisaged regarding the impact of using a new technology in the payment received by the provider. In the first one, the treatment performed with the new technology is classified into the same DRG (and payment made by the third-party payer) as the old technology. The second possibility is that the new technology leads to a payment in a different DRG. When the DRG is not adjusted by the use of a new technology, patients' benefits are necessary to induce adoption. Whenever the DRG for payment of the new technology has a higher price, adoption may occur even in the

absence of patients' benefits. However in that case, the margin gained with the new DRG associated with treatment must be sufficiently high to compensate the cost of adoption. As in the case of cost reimbursement, full adoption is not optimal either with prospective reimbursements schemes, regardless of whether the reimbursement rate difffers or not between the new and the old technology.

The role of patient benefits is a crucial one. The desired levels of technology adoption of health care providers can be compared with the implications of requiring technology adoption to pass a health technology assessment (incremental benefit above incremental cost). Except for the case of a new technology being paid in the same DRG of the old technology, private adoption levels are always higher than allowed by this criterion. This holds the testable prediction that health care providers will always find, in the other payment systems, regulation imposing health technology assessments to be actively constraining their decisions. Thus, they will voice the complaint that regulation reduces their desired level of adoption.

Under parameters for the payment systems in which adoption always occurs, cost reimbursement leads to greater adoption of the new technology if the rate of reimbursement is high relative to the margin of new vs. old technology under DRG. A larger patient benefit favors more adoption under the cost reimbursement payment system, provided adoption occurs initially under both payment systems (that is, in the case of uniform distribution of demand and risk neutrality, when patient benefits from the new technology are positive).

To evaluate the impact of technology adoption we keep fixed the level of total expenditure of the health system and study the impact on adoption of adjustments in the parameters of the payment function. Under risk neutrality the result is clear-cut: more cost reimbursement induces more adoption. However, results are ambiguous under risk aversion. Thus, in policy terms, our analysis also vindicates the virtues (under sufficiently large difference between the DRGs of the competing technologies) of retrospective payment systems as a driver towards adoption of a new technology after a decade where the debate between cost containment versus

quality issues has favored prospective reimbursement over cost reimbursement. A full assessment of this issue would require an investigation of the optimal definition of policy parameters within each reimbursement scheme. This is left for future research. Also, we compare adoption levels under the different reimbursement rules to its first-best level. We find that under homogeneous DRG reimbursement, given that both technologies are reimbursed at the same price the provider's decision is driven by cost minimization concerns allowing to adopt optimally. Under the other rules the provider always over-invests in the new technology although for different reasons. Under cost reimbursement the cost sharing between provider and payer induces the former with incentives to adopt the new technology beyond the optimal level. Under heterogeneous DRG reimbursement it is the price difference.

An assumption maintained throughout the analysis is the fact that the new technology does not convey any demand expansion. It is often argued that new technologies generate new protocols and treatments that can be applied to patients already under treatment but also opens the possibility to treat other patients for which the previous technology was not well-suited. In terms of our model, we can accommodate this feature by assuming that the old technology can treat a maximum of q^* patients, and the new technology allows to provide treatment to a maximum of $q^{**} > q^*$ patients. Therefore we would have a population of two groups of patients where $(q^{**} - q^*)$ would denote the increased demand induced by the new technology. Let us assume that the level of benefits to patients able to be treated with either technology is $\underline{b}$ and the benefits to patients only suited for the new technology is $\bar{b}$. Then we can redefine patients' benefits as $b = \alpha\bar{b} + (1 - \alpha)\underline{b}$ and the analysis goes through integrating over q^{**} instead of q^*.

We do not explicitly address the issue of uniqueness of the solutions. Our main concern lies in studying the adoption decision. Should multiple solutions exist, we would be forced to introduce more structure in the model to implement a selection criterion. However, qualitatively the intuitions would remain unaltered.

Our model and results are the first to theoretically address the role of payment systems in the adoption of new technologies. In contrast with the theoretical con-

tributions referenced in the introduction, our analysis does not look at adoption as the result of the interaction of the health care sector with other sectors of the economy, but as the strict consequence of the reimbursement system in place. The results obtained are to be used to interpret empirical evidence that addresses speed of diffusion of new technologies and payment systems. Some caveats are worth pointing out. First, we take a relationship between the provider and the third-party payer to take place without influence from other forces. In particular, there is no role for competition between hospitals in our model. Second, investment in the new technology is perfectly lumpy. It is done once and it cannot be adjusted further within the same time frame of uncertain demand. Third, we acknowledge the limitation of the analysis associated to not considering how the payment system will affect the number and type of new technologies available rather than simply whether existing technologies are adopted. Finally, we also acknowledge the difficulties both for patients and providers to assess the level of patient benefits. In the same vein, there may be substantial heterogeneity across patients with respect to the net health benefits. Both features will blur the distinction between the effect and/or desirability of one payment system versus another.

The model proposed in the analysis is static because we focus the attention in the decision of technological *adoption*. Closely related to adoption we find the diffusion of technology that is a dynamic phenomenon. Although beyond the scope of the present analysis, we can link our model to existing literature on technological diffusion by considering as a reference point the "epidemic" model, and assume information on the existence of the new technology follows a *word of mouth* diffusion process in which the main source of information is previous users.[12] In this context we can envisage hospitals that have already adopted the new technology until today and a (probabilistic) mechanism by which a hospital running the old technology contacts with a hospital that has adopted the new technology. Then, we propose to link our results on adoption to the diffusion process assuming that the "infection" is determined by $\bar{q}$. In this way we would obtain the number of

---

[12]This paragraph is purely illustrative. Thus, we neglect both the weaknesses of this approach and the alternatives proposed to overcome them. See Geroski (2000) for a non-technical introduction.

adopters at each moment, so that the way payment systems influence $\bar{q}$ translates into an impact on the speed of diffusion. This implication is relevant for empirical works looking at the speed and level of diffusion of new technologies.

Appendix

The first-order condition for the hospital is given by,

$$
\frac{\partial W}{\partial \bar{q}} = f(\bar{q}) \triangle U(b) - p \int_0^{\bar{q}} V'(R - p\bar{q} - \theta q) f(q) dq
$$
$$
-(p + \theta - c) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq = 0. \tag{44}
$$

To obtain the impact of the policy change on technology adoption (that is, on $\bar{q}$), we totally differentiate (44) with respect to $\bar{q}, p$, and θ, and impose $d\theta = -\lambda dp$, where $\lambda = \bar{q} / \int_0^{\bar{q}} q f(q) dq$.

Total differentiation of the first-order condition yields,

$$
\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} - \left(\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q) f(q) dq \right) dp
$$
$$
+ \left(p\bar{q} \int_0^{\bar{q}} V''(R - p\bar{q} - \theta q) f(q) dq \right) dp
$$
$$
+ \left(\left(p\bar{q} \int_0^{\bar{q}} V''(R - p\bar{q} - \theta q) f(q) dq \theta \right. \right.
$$
$$
- \left(\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right) dp \tag{45}
$$
$$
+ \left((p + \theta - c)\bar{q} \int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right) dp
$$
$$
- \left(\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right) d\theta
$$
$$
+ \left((p + \theta - c)\bar{q} \int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right) d\theta = 0
$$

Substituting $d\theta = \lambda dp$ and collecting terms we can rewrite (45) as

$$
\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} = \left[\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q) f(q) dq \right] dp
$$
$$
- \left[p\bar{q} \int_0^{\bar{q}} V''(R - p\bar{q} - \theta q) f(q) dq - p \int_0^{\bar{q}} V''(R - p\bar{q} - \theta q) q f(q) dq \lambda \right] dp
$$
$$
+ \left[(1 - \lambda) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right] dp
$$
$$
+ \left[(\lambda - 1)\bar{q}(p + \theta - c)\bar{q} \int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right] dp, \tag{46}
$$

and further collecting terms, equation (46) becomes,

$$\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} = \left[\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q) f(q) dq \right] dp$$

$$- \left[p\bar{q} \int_0^{\bar{q}} V''(R - p\bar{q} - \theta q) \left(1 - \frac{q}{\int_0^{\bar{q}} q f(q) dq} \right) f(q) dq \right] dp$$

$$+ \left[(1 - \lambda) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right] dp$$

$$+ \left[(\lambda - 1)\bar{q}(p + \theta - c)\bar{q} \int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq \right] dp$$

(47)

The first two terms in square brackets in the right-hand side are positive, while the third and fourth terms have negative signs. Therefore the impact on $\bar{q}$ will be ambiguous.

This can be made clearer in the special case of risk neutrality, that is $V' = 1$ and $V'' = 0$. Then hospital decision makers care about expected profits from hospital activity and patient health gains. Under these assumptions, the right-hand side of equation (47) can be rewritten as,

$$\int_0^{\bar{q}} (R - p\bar{q} - \theta q) f(q) dq + (1 - \lambda) \int_{\bar{q}}^{q^*} (R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq$$

$$= R - p\bar{q} - \theta \int_{\bar{q}}^{q^*} q f(q) dq - (1 - \lambda) \int_{\bar{q}}^{q^*} c(q - \bar{q})) f(q) dq$$

$$- \lambda \int_{\bar{q}}^{q^*} (R - p\bar{q} - \theta\bar{q}) f(q) dq - \theta \int_{\bar{q}}^{q^*} \bar{q} f(q) dq$$

$$= R - p\bar{q} - \theta \int_{\bar{q}}^{q^*} q f(q) dq + (\lambda - 1) \int_{\bar{q}}^{q^*} c(q - \bar{q})) f(q) dq$$

$$- \frac{\bar{q}}{\int_0^{\bar{q}} q f(q) dq} (1 - F(\bar{q}))(R - p\bar{q} - \theta\bar{q})$$

$$= (\lambda - 1) \int_{\bar{q}}^{q^*} c(q - \bar{q})) f(q) dq + (R - p\bar{q}) \left(1 - F(\bar{q}))\lambda \right) + \theta \left(\lambda\bar{q} - \int_0^{\bar{q}} q f(q) dq \right)$$

$$= (\lambda - 1) \int_{\bar{q}}^{q^*} c(q - \bar{q})) f(q) dq + \theta(\lambda^2 - 1) \int_0^{\bar{q}} q f(q) dq + (R - p\bar{q}) \left(1 - \lambda(1 - F(\bar{q})) \right).$$

(48)

The first two terms of equation (48) are positive, whilst the last one is positive if $1 > \lambda(1 - F(\bar{q}))$. This occurs for a high value of $\bar{q}$.

To better assess the meaning of this result, assume $1 > \lambda(1 - F(\bar{q}))$. Then it follows that,

$$\left.\frac{d\bar{q}}{dp}\right|_{dE(\pi)=0} > 0.$$

In this case, a decrease in the price of treating patients with the new technology, at the cost of increasing the price of consumables does result in a smaller adoption level (and consequently a lower diffusion rate) of the new technology. This result holds for a sufficiently high value of $\bar{q}$ in equilibrium.

Also, $\bar{q}$ will be higher when benefits to patients are higher. Thus, for technologies that would lead to extensive use on patients, the move toward a lower price p retards diffusion in anticipation of the high costs associated with consumables.[13]

To address the welfare effect to the hospital, the impact on the utility of the decision maker, by application of the envelope theorem, is given by

$$\left.\frac{dW}{dp}\right|_{dE(\pi)=0} = \int_0^{\bar{q}} V'(R - p\bar{q} - \theta q)[-\bar{q}dp + q\lambda dp]f(q)dq \tag{49}$$
$$+ \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))[-\bar{q}dp + \bar{q}\lambda dp]f(q)dq.$$

Noting that,

$$V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) > V'(R - p\bar{q} - \theta q) > V'(R - p\bar{q}),$$

expression (49) can be rewritten as

$$V'(R - p\bar{q}) \int_0^{\bar{q}} (-\bar{q} + \lambda q)f(q)dq + (\lambda - 1) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))f(q)dq$$
$$= V'(R - p\bar{q})(1 - F(\bar{q}))\bar{q} + (\lambda - 1)) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))f(q)dq > 0, \tag{50}$$

implying

$$\left.\frac{dW}{dp}\right|_{dE(\pi)=0} > 0.$$

Therefore, in general, the subsidization of equipment has a negative impact on a hospital's utility due to the extra costs associated with consumables.

---

[13]Note that we are not addressing the optimal pricing policy for the medical equipment company. This can be seen as the outcome of a previous stage in a larger game.

References

Abbey, D.C., 2009. Health care payment systems. An introduction. CRC Press, New York.

Armstrong, M., Sappington, D.E.M., 2007. Recent developments in the theory of regulation. in Handbook of Industrial Organization, vol 3, edited by M. Armstrong and R. Porter, Amsterdam, Elsevier North-Holland, chapter 27.

Baker, L.C., 2001. Managed care and technology adoption in health care: evidence from magnetic resonance imaging, Journal of Health Economics 20, 395–421.

Baker, L.C., Phibbs, C.S., 2002. Managed care, technology adoption, and health care: the adoption of neonatal intensive care. RAND Journal Economics 33, 524–548.

Baron, D., Myerson, R., 1982. Regulating a monopolist with unknown costs. Econometrica 50(4), 911–930.

Baumgardner, J.R., 1991. The interaction between forms of insurance contract and types of technical change in medical care. RAND Journal of Economics 22, 36–53.

Bodenheimer, T., 2005. High and Rising Health Care Costs. Part 2: Technologic Innovation. Annals of Internal Medicine 142, 932–937.

Bokhari, F.A.S., 2009. Managed care competition and the adoption of hospital technology: The case of cardiac catheterization. International Journal of Industrial Organization 27, 223–237.

Bös, D., and de Fraja, G., 2002, Contracts for Health Services: Quality versus Excess Capacity, *Journal of Public Economics*, **84**: 199–218.

Chou, S.-Y., Liu, J.-T., 2000. National health insurance and technology adoption: Evidence from Taiwan. HESG Working Paper E001, National Taiwan University.

Culyer, A.J., Newhouse, J.P., 2000. Handbook of Health Economics. Elsevier North-Holland, Amsterdam.

Cutler, D.M., Huckman, R.S., 2003. Technological development and medical productivity: the diffusion of angioplasty in New York state. Journal of Health Economics 22, 187–217.

Cutler, D.M., McClellan, M., 2001. Is technological change in medicine worth it?. Health Affairs 20(5), 11–29.

Cutler, D.M., McClellan, M., Newhouse, J.P., 1998. What has increased medical-care spending bought?. The American Economic Review 88(2), 132–136.

Di Tommaso, M., Schweitzer, S.O. (eds.), 2005. Health policy and high-tech industrial development, Edward Elgar.

Duggan, M.G., Evans, W.N., 2005. Estimating the impact of medical innovation: The case of HIV antiretroviral treatments. NBER, Working paper No. 11109.

Fox, B.J., Taylor, L.L., Yücel, M.K., 1993. America's health care problem: An economic perspective. Economic Review, Fed. Reserve Bank of Dallas, 21–31.

Godager, G., Iversen, T., and Ma, C. A., 2012, Competition, Gatekeeping, and Health Care Access, mimeo.

Goddeeris, J.H., 1984a, Medical insurance, technological change, and welfare, *Economic Enquiry*, **XXII**: 56–67.

Goddeeris, J.H., 1984b, Insurance and incentives for innovation in medical care, *Southern Economic Journal*, **51**(2): 530–539.

Grebel, T. and T. Wilfer, 2010, Innovative cardiological technologies: a model of technology adoption, diffusion, and competition. Economies of Innovation and New Technology, 19(4), 325–347.

Hafsteinsdottir, E.J.G., and Siciliani, L., 2010, DRG prospective payment systems: refine or not refine, *Health Economics*, **19**: 1226–1239.

Kessler, D.P., McClellan, M.B., 2000. Is hospital competition socially wasteful? The Quarterly Journal of Economics 115(2), 577–615.

Kessler, D.P., McClellan, M.B., 1996. Do doctors practice defensive medicine? The Quarterly Journal of Economics 111(2), 353–390.

Laffont, J.J., Tirole, J., 1986. Using cost observation to regulate firms. Journal of Political Economy 94(3), 614–641.

Levaggi, R., Moretto, M., Pertile, P., 2010. Static and dynamic efficiency of irreversible health care investments under alternative payment rules, Fondazione Eni Enrico Mattei, Nota di Lavoro 130.2010.

Liu, T., and Ma, A.C., 2013, Health Insurance, Treatment Plan, and Delegation to Altruistic Physician, *Journal of Economic Behavior & Organization*, **85**: 79–96.

McClellan, M., Kessler D. for the TECH Investigators, 1999. A global analysis of technological change in health care: The case of heart attacks. Health Affairs 18(3), 250–255.

Miraldo, M., 2007. Hospital financing and the development and adoption of new technologies. Center for Health Economics, University of York, CHErp 26.

Mossialos, E. and J. Le Grand, (eds), 1999, Health care and cost containment in the European Union, Ashgate.

Newhouse, J.P., 1992. Medical care costs: How much welfare loss. Journal of Economic Perspectives 6(3), 3–21.

OECD, 2005a. OECD health data 2005. OECD, Paris.

OECD, 2005b. Health at a glance: OECD indicators 2005. OECD, Paris.

OECD, 2005c. Health technologies and decision making. OECD, Paris.

Philipson, T.J., Jena, A.B., 2006. Surplus appropriation from R&D and health care technology assessment procedures. NBER Working paper No. 12016.

Satterthwaite, M.A., 1979. Consumer Information, Equilibrium Industry Price, and the Number of Sellers. The Bell Journal of Economics 10(2), 483–502.

Selder, A., 2005. Physician Reimbursement and Technology Adoption. Journal of Health Economics 24, 907–930.

Siciliani, L., 2006, Selection treatment under prospective payment systyems in the hospital sector, Journal of Health Economics 25, 479–499.

Smith, S., Newhouse, J.P., Freeland, M.S., 2009. Income, insurance, and technology: Why does health spending outpace economic growth. Health Affairs 28, 1276–1284.

TECH Research Network, 2001. Technological change around the world: Evidence from heart attack care. Health Affairs 20(3), 25–42.

Weisbrod, B.A., LaMay, C.L., 1999. Mixed signals: Public policy and the future of health care R&D, Health Affairs 18(2), 112–125.

Weisbrod, B.A., 1991. The health care quadrilemma: An essay on technological change, insurance, quality of care, and cost containment. Journal of Economic Literature XXIX, 523–552.