Technological adoption in health care*

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Abstract

This paper addresses the impact of payment systems on the rate of technology adoption. We present a model where technological shift is driven by demand uncertainty, increased patients' benefit, financial variables, and the reimbursement system to providers. Two payment systems are studied: cost reimbursement and (two variants of) DRG. According to the system considered, adoption occurs either when patients' benefits are large enough or when the differential reimbursement across technologies offsets the cost of adoption. Cost reimbursement leads to higher adoption of the new technology if the rate of reimbursement is high relative to the margin of new vs. old technology reimbursement under DRG. Having larger patient benefits favors more adoption under the cost reimbursement payment system, provided that adoption occurs initially under both payment systems.

Keywords: Health care, technology adoption, payment systems.

JEL numbers: I11, I12, Q33

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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 27-48% of growth in the US health spending (1960-2007) is due to medical technology. Despite the relatively large literature documenting empirically the innovation in health care, theory has not been fully developed. In this paper we address a particular issue: the role of payment systems to the rate of technology adoption.

We contribute to the theoretical literature by setting up a model of uncertain demand, where the technological shift is driven by 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 contemplates a higher reimbursement for new technology, sufficiently large patient benefits are a sufficient condition for technology adoption to exist. In the absence of patient benefits, the margin gained with the new DRG associated with treatment with the new technology must be sufficiently high to compensate the cost of adoption. Finally, to compare the levels of technological adoption, we identify the values of the relevant parameters that for a given investment level, yield to the provider the same marginal return of investment in new capacity across regimes. Cost 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.

The following paragraphs provide a brief overview of the literature addressing the impact of technological progress on health care expenditures from a number of different perspectives.

In general, the main findings can be grouped in three related items: (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 technology (or both). Some of the main conclusions of this mainly empirical literature stress the fact that (i) prospective payment systems encourage cost efficient new technologies but have perverse effects on quality improvement, and (ii) 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.

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 technology 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 analyse 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 catherization 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.

Goddeeris (1984b) develops a framework for analysing 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), analysing 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.

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 an 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.

The structure of the paper is as follows. Section 2 introduces the model and behavioural assumptions. Sections 3 and 4 deal with the adoption decision of a new technology under the different payment regimes. Section 5 compares the levels of adoption across payment schemes. Section 6 studies how technology diffuses across the health care sector. A section with conclusions and a technical appendix closes the paper.

2 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 patients q^* in need of treatment. 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 capacity of a new technology that allows it to treat $\bar{q}$ patients. If demand for hospital services exceeds the newly installed capacity, then patients are treated using an older technology. We assume that within the set of patients needing treatment no prioritization is made across patients.[1] Uncertainty about demand for hospital services is modeled simply as distribution $F(q)$, with density $f(q)$, in the domain $[0, q^*]$.

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

The new technology has a cost per unit of capacity built of p (a unit allows to treat one patient).[2] There is also a constant marginal cost per patient treated, given by θ in the new technology and by c in the old technology. We assume that the total average/marginal cost of the new technology is higher than the corresponding average/marginal cost of the old technology.

Assumption 1.

$$p + \theta - c > 0. \tag{1}$$

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

[2] 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.

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.

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.

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,*

$$\Delta = b - \hat{b} > p + \theta - c > 0 \tag{2}$$

Later on, we will allow this requisite for formal adoption of new technologies to play a role. For the time being, this condition is not imposed. 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).

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.

$$W = \int_0^{\bar{q}} V(R - p\bar{q} - \theta q) f(q) dq + \int_{\bar{q}}^{q^*} V(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q})) f(q) dq$$
$$+ \int_0^{\bar{q}} bq f(q) dq + \int_{\bar{q}}^{q^*} \Big((q - \bar{q})\hat{b} + \bar{q}b \Big) f(q) dq \tag{3}$$

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 building capacity $\bar{q}$. 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 (3).

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 (3). Note also that in the computation on the expected welfare we are summing over probabilities, not over patients.

The (adoption) decision problem of the hospital is to choose its capacity under the new technology $\bar{q}$. Naturally, such decision is contingent on the system of reimbursement to the hospital. We will study and compare a (partial) cost reimbursement system and a DRG payment system.[3]

3 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 demand is in excess of the capacity provided by the new technology ($\bar{q}$). Implicitly, we assume that the new technology is used until capac-

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

ity 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,

$$TC = \begin{cases} p\bar{q} + \theta q & \text{if } q \leq \bar{q} \\ p\bar{q} + \theta\bar{q} + c(q - \bar{q}) & \text{if } q > \bar{q} \end{cases} \tag{4}$$

A cost reimbursement system that the transfer to the hospital is composed of a fixed part 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.

Substituting (5) into (3) the hospital's welfare function becomes

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

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:

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

Proposition 1. *Under a cost reimbursement system, full adoption is never optimal for the provider. Patient 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,

$$\frac{\partial W}{\partial \bar{q}} = \Delta \int_{\bar{q}}^{q^*} f(q)dq - (1-\beta)p \int_0^{\bar{q}} V'(R_1(q))f(q)dq$$
$$- (1-\beta)(p+\theta-c) \int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq = 0. \tag{7}$$

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, $\Delta - (1-\beta)(p + \theta - c) \int_0^{q^*} V'(R_2(q))f(q)dq > 0$ for β sufficiently high. Or equivalently, for each β there is a critical Δ such that $\bar{q} > 0$. $\square$

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 ($V'(\cdot) = 1$), and a uniform distribution. Also normalize $q^* = 1$ without loss of generality. Then, the first-order condition (7) reduces to

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

or

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

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

Remark 1. *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)*. In other words, given that* $p + \theta - c > 0$*, if* $\Delta = 0$*, the first order condition* (7) *is always negative and accordingly* $\bar{q} = 0$.

Note that, in general, 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.

Under risk neutrality and uniform distribution, the use of economic evaluation criteria implies that adoption desired by the provider occurs more often, as long as $\beta < 1$.[4]

3.1 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 level of technology adoption.

Let us thus compute,

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

Given the concavity of $V(\cdot)$ and using (1), it follows that increasing cost sharing leads to more adoption, because a higher fraction of the cost is automatically covered. The sign of expression (9) is sufficient to sign the effect of interest, $d\bar{q}/d\beta$, which will carry the same sign.

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 (1), it follows that this expression is positive. Higher values of α mean lower marginal cost of investing more in terms of utility. Thus, for the same benefit more investment will result. As before, the sign of

[4]This can be seen from direct inspection of equation (8) against Assumption 2.

$d\bar{q}/d\alpha$ is the same as the sign of expression (10). A special 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.

3.2 Further comparative statics

The previous comparative statics exercise, although informative, was incomplete. In a way it says that in general, higher transfers lead to higher levels of technology adoption by the hospital, because of the increased patients' benefits. Next, we want to complete the study of the comparative static properties of the optimal technology adoption decision. In particular, the impact on the optimal technology adoption of redefining the parameters of the payment system, keeping expected payment constant or expected hospital surplus constant. In this way, we have a well-defined reference point to base the study of the impact of a variation of the parameters of the payment function.

3.2.1 Constant expected payment

Consider keeping payment constant in expected terms, that is, $dR = 0$. Recalling (4) 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

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

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

$$
\begin{aligned}
&\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} + \Big(p\int_0^{\bar{q}} V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq \\
&- (1-\beta)\Big(p\int_0^{\bar{q}} V''(R_1(q))(p\bar{q}+\theta q)f(q)dq \\
&\qquad + (p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))(p\bar{q}+\theta\bar{q}+c(q-\bar{q}))f(q)dq\Big)d\beta \\
&- (1-\beta)\Big(p\int_0^{\bar{q}} V''(R_1(q))f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))f(q)dq\Big)d\alpha = 0 \qquad (12)
\end{aligned}
$$

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

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

where we use the following notation:

$$
\begin{aligned}
\Gamma \equiv& \beta\Big(p\int_0^{\bar{q}} f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} f(q)dq\Big) > 0 \\
\Lambda \equiv& \int_0^{\bar{q}} (p\bar{q}+\theta q)f(q)dq + \int_{\bar{q}}^{q^*} (p\bar{q}+\theta q+c(q-\bar{q}))f(q)dq > 0 \\
\Phi \equiv& -(1-\beta)\Big(p\int_0^{\bar{q}} V''(R_1(q))f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))f(q)dq\Big) > 0 \\
\Psi \equiv& -\frac{\partial^2 W}{\partial \bar{q}^2} > 0 \\
\Upsilon \equiv& p\int_0^{\bar{q}} V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\bar{q}}^{q^*} V'(R_2(q))f(q)dq \\
&\qquad - (1-\beta)\Big(p\int_0^{\bar{q}} V''(R_1(q))(p\bar{q}+\theta q)f(q)dq \\
&\qquad + (p+\theta-c)\int_{\bar{q}}^{q^*} V''(R_2(q))(p\bar{q}+\theta\bar{q}+c(q-\bar{q}))f(q)dq\Big) > 0
\end{aligned}
$$

To obtain some clear intuition of the content of the system (12) let us simplify the analysis by assuming risk neutrality. Then, the system (13) becomes,

$$d\alpha + \Gamma d\bar{q} + \Lambda d\beta = 0 \tag{14}$$

$$-\Psi' d\bar{q} + \Upsilon' d\beta = 0. \tag{15}$$

where Ψ' and Υ' 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,[5]

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

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

Note that the numerators in (16) have an ambiguous sign, or alternatively it is positive iff $\frac{\Upsilon}{\Psi} > \Lambda$, 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 $V(\cdot)$ function are such that the ratio Υ/Ψ is above the threshold given by Λ). The properties of the utility function $V(\cdot)$ will vary across hospitals. 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 welfare, while maintaining $dR = 0$, let us compute

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

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

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

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 favours 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.

3.2.2 Constant hospital surplus

Let us assess the comparative statics while maintaining the expected surplus of the hospital constant. Denote such surplus as S. It is defined as,

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

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

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

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

$$\begin{aligned} \Phi d\alpha - \Psi d\bar{q} + \Upsilon d\beta = 0 \\ d\alpha + \Omega d\bar{q} + \Pi d\beta = 0 \end{aligned} \quad (20)$$

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,

$$\begin{aligned} -\Psi d\bar{q} + \Upsilon' d\beta &= 0 \\ d\alpha + \Omega d\bar{q} + \Pi d\beta &= 0 \end{aligned} \tag{21}$$

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

Finally, note that

$$dW = \Big(\int_0^{\bar{q}} V'(R_1(q)) f(q) dq + \int_{\bar{q}}^{q^*} V'(R_2(q)) f(q) dq\Big) d\alpha +$$
$$\Big(\int_0^{\bar{q}} V'(R_1(q))(p\bar{q} + \theta q) f(q) dq + \int_{\bar{q}}^{q^*} V'(R_2(q))(p\bar{q} + \theta\bar{q} + c(q - \bar{q})) f(q) dq\Big) d\beta \tag{22}$$

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 comes from patients' benefits due to more adoption and given the absence of costs to raising money for the payment to be made.*

4 Technology adoption under DRG payment

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 approaches. The first one pays the hospital the same amount regardless of the technology used. 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. The second approach will condition the level of reimbursement 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.

4.1 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 (3) the hospital's welfare function becomes,

$$\begin{aligned} W = U(b)\int_0^{\bar{q}} qf(q)dq + \int_{\bar{q}}^{q^*}\Big((q-\bar{q})U(\hat{b}) + \bar{q}U(b)\Big)f(q)dq \\ + \int_0^{\bar{q}} V\Big(Kq - p\bar{q} - \theta q\Big)f(q)dq \\ + \int_{\bar{q}}^{q^*} V\Big(Kq - p\bar{q} - \theta\bar{q} - c(q-\bar{q})\Big)f(q)dq \end{aligned} \tag{24}$$

Let us define the reimbursement received when the capacity installed of 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,

$$\begin{aligned} R_3(q) &\equiv Kq - p\bar{q} - \theta q \\ R_4(q) &\equiv Kq - p\bar{q} - \theta\bar{q} - c(q-\bar{q}) \end{aligned}$$

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,

$$\begin{aligned} \frac{\partial W}{\partial \bar{q}} = \Delta\int_{\bar{q}}^{q^*} f(q)dq + \Big(V(R_3(\bar{q})) - V(R_4(\bar{q}))\Big)f(\bar{q}) \\ - p\int_0^{\bar{q}} V'(R_3(q))f(q)dq - (p+\theta-c)\int_{\bar{q}}^{q^*} V'(R_4(q))f(q)dq = 0. \end{aligned} \tag{25}$$

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

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, and without loss of generality $q^* = 1$. Then, the first-order condition (25) reduces to,

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

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

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

The denominator of equation (27) is positive from the second-order condition. Clearly, $\bar{q} < 1$. Finally, the optimal value of adoption given by (27) trades off patients' benefits and the differential marginal cost of the two technologies.

Now, under the DRG payment systems, adoption by the health care provider occurs if and only if the economic evaluation criterion is satisfied (compare equation (27) with Assumption 2).

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

4.2 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

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

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. Note that K_1 must be greater than K_2. Otherwise, hospitals would not even consider the possibility of investing in the new technology.

Note that we can rewrite $R_6(q)$ as $\bar{q}(K_1 - K_2 - p - \theta + c) + q(K_2 - c)$. We assume that 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, $(K_2 - c)$, or equivalently,

Assumption 3.

$$K_1 - K_2 - (p + \theta - c) > 0.$$

This assumption is necessary for adoption to occur. Otherwise, the hospital would have no incentive whatsoever to invest in the adoption of the new technology.

Now the utility function of the hospital is given by,

$$\begin{aligned} W = b\int_0^{\bar{q}} qf(q)dq &+ \int_{\bar{q}}^{q^*} \Big((q - \bar{q})\hat{b} + \bar{q}b\Big) f(q)dq \\ &+ \int_0^{\bar{q}} V(R_5(q))f(q)dq + \int_{\bar{q}}^{q^*} V(R_6(q))f(q)dq \end{aligned} \tag{28}$$

Proposition 3. *Under a heterogeneous DRG payment system, full adoption is never optimal. Under Assumption 3, a positive adoption level exists even in the absence of positive patient benefits.*

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

$$\begin{aligned}\frac{\partial W}{\partial \bar{q}} &= \Delta \int_{\bar{q}}^{q^*} f(q)dq + V(R_5(\bar{q}))f(\bar{q}) - V(R_6(\bar{q}))f(\bar{q}) \\ &- p\int_0^{\bar{q}} V'(R_5(q))f(q)dq \\ &+ (K_1 - K_2 - p - \theta + c)\int_{\bar{q}}^{q^*} V'(R_6(q))f(q)dq = 0. \qquad (29)\end{aligned}$$

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

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

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

so that,

$$\bar{q} = \Big(1 - \frac{p}{\Delta + K_1 - K_2 - \theta + c}\Big). \qquad (30)$$

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 is reimbursed sufficiently higher than the old technology ($K_1 > K_2$) (in other words, 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 does prefer a strictly positive level of technology adoption.

5 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) and (30) respectively, and let $\lambda \equiv K_1 - K_2$:

$$\begin{aligned}\bar{q}^{cr} &= \Big(1 - \frac{p(1-\beta)}{\Delta - (1-\beta)(\theta - c)}\Big),\\ \bar{q}^{drg}_{hom} &= \Big(1 - \frac{p}{\Delta - (\theta - c)}\Big),\\ \bar{q}^{dgr}_{het} &= \Big(1 - \frac{p}{\Delta + \lambda - (\theta - c)}\Big).\end{aligned}$$

The difference in adoption levels is given by:

$$\bar{q}^{drg}_{hom} - \bar{q}^{dgr}_{het} = p\Big(\frac{1}{\Delta + \lambda - (\theta - c)} - \frac{1}{\Delta - (\theta - c)}\Big) < 0, \tag{31}$$

$$\bar{q}^{cr} - \bar{q}^{drg}_{het} = p\Big(\frac{1}{\Delta + \lambda - (\theta - c)} - \frac{1}{\frac{\Delta}{1-\beta} - (\theta - c)}\Big), \tag{32}$$

$$\bar{q}^{cr} - \bar{q}^{drg}_{hom} = p\Big(\frac{1}{\Delta - (\theta - c)} - \frac{1}{\frac{\Delta}{1-\beta} - (\theta - c)}\Big) > 0 \tag{33}$$

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.

The comparison of technology adoption under cost reimbursement and under a DRG payment system with a new DRG to pay for the new technology is less clear cut.

To interpret expression (32), suppose the provider decides to invest an amount p in the new technology under the DRG system. Such investment generates one

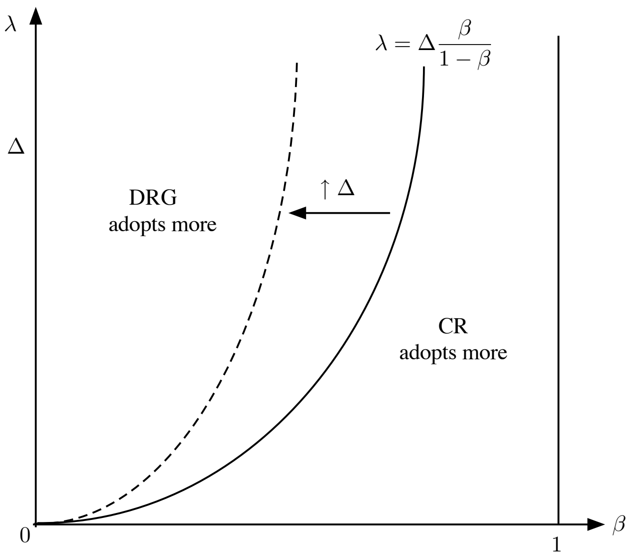

Figure 1: Optimal adoption: CR vs. heterogenous DRG.

extra unit of capacity of 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 ($\theta - c$), whenever the additional capacity is used. Summarizing the net gains to the provider of an additional unit of the new technology under a heterogenous DRG reimbursement scheme are $\Delta + K_1 - K_2 - (\theta - c)$. This is the denominator of the left-hand fraction in (32).

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 $1/1 - \beta$ units of capacity for treatment with the new technology. Each of these additional units generate patients' benefits (Δ), and an operating marginal cost change of $(1 - \beta)(\theta - c)$. Summarizing, the investment of p monetary units results in a return of $(1/1 - \beta)(\Delta - (1 - \beta)(\theta - c))$. This corresponds to the denominator of the right-hand fraction in (32).

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 new capacity 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.

A similar argument can be put forward to analyse expression (33). The net gains to the provider of an additional unit of the new technology under a homogenous DRG reimbursement scheme are $\Delta - (\theta - c)$. This is the denominator of the left-hand fraction in (33). Under cost reimbursement, the investment of p monetary units results in a return of $(1/1-\beta)(\Delta - (1-\beta)(\theta - c))$. This corresponds to the denominator of the right-hand fraction in (33). The return of the investment is thus larger under cost reimbursement, yielding the higher level of adoption.

6 The diffusion of technology

We can link our model to existing literature on technological diffusion. Consider as a reference point the well-known "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.[6]

Let N be the total number of hospitals, and let $M(t)$ be the number of hospitals that have adopted the new technology up to time period t. Assume that each of the present users contacts a non-user with probability ϕ. The probability of contacting one of the $(N - M(t))$ non-users is $\beta M(t)$, so that the number of new adopters over an interval dt increases in $dM(t) = \phi M(t)(N - M(t))dt$. Assume that at $t = 0$ there are $M(0)$ users of the new technology, so that the initial adoption rate η is given by $\eta = (N - M(0))/M(0)$. Taking the limit as $dt \to 0$ and solving for $M(t)$ we obtain,

$$M(t) = \frac{N}{1 + \eta\ exp[-\phi N t]}$$

Next we propose to link our results on adoption to the diffusion process just presented. To do so, we endogenize the "infection" rate ϕ by assuming it to be

[6]Our purpose in this section is mainly illustrative. Thus we neglect here both the weaknesses of this approach and the alternatives proposed to overcome them. See Geroski (2000) for a non-technical introduction.

determined by $\bar{q}$ and $\phi'(\bar{q}) > 0$. The total number of patients using the new technology is $\bar{q}M$, while the potential size of adopters, given the extent of installed capacity is $N\bar{q}$. From this expression, the number of adopters at each moment is given by,

$$M(t) = \frac{\bar{q}N}{1 + \eta \; exp[-\phi(\bar{q})Nt]}.$$

This expression allows us to see that variables that increase $\bar{q}$ will also increase the total number of patients treated under the new technology and the diffusion speed. Thus, the way payment systems influence $\bar{q}$ translates into an impact on the speed of diffusion carrying the same sign. This implication is relevant for empirical works looking at the speed and level of diffusion of new technologies.

7 Final remarks

Adoption of new technologies is usually considered a main driver of growth of health care costs.[7]. Many discussions about it exist. Arguments in favour of cost-benefit analysis (health technology assessment) before the introduction of new 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.

Our model allows for an integrated treatment of incentives for adoption of new technology. 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. The

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

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.

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 DRG. A larger patient benefit favours 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).

Our model and results are the first to theoretically address the role of payment systems in the adoption of new technologies. 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, capacity building in the new technology is perfectly lumpy. It is invested once and it cannot be adjusted further within the same time frame of uncertain demand.

Appendix

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

$$\begin{aligned}\frac{\partial W}{\partial \bar{q}} &= f(\bar{q}) \bigtriangleup U(b) - p\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q)f(q)dq \\ -(p+\theta-c)&\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq = 0.\end{aligned} \tag{34}$$

To obtain the impact of the policy change on technology adoption (that is, on $\bar{q}$), we totally differentiate (34) with respect to $\bar{q}, p$, and θ, and impose $d\theta = -\lambda dp$, where $\lambda = \bar{q}/\int_0^{\bar{q}} qf(q)dq$.

Total differentiation of the first-order condition yields,

$$\begin{aligned}\frac{\partial^2 W}{\partial \bar{q}^2}d\bar{q} - \Big(\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q)f(q)dq\Big)dp \\ +\Big(p\bar{q}\int_0^{\bar{q}} V''(R - p\bar{q} - \theta q)f(q)dq\Big)dp \\ +\Big(\Big(p\bar{q}\int_0^{\bar{q}} V''(R - p\bar{q} - \theta q)f(q)dq\theta \\ -\Big(\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big)dp \\ +\Big((p+\theta-c)\bar{q}\int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big)dp \\ -\Big(\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big)d\theta \\ +\Big((p+\theta-c)\bar{q}\int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big)d\theta = 0\end{aligned} \tag{35}$$

Substituting $d\theta = \lambda dp$ and collecting terms we can rewrite (35) as

$$\begin{aligned}\frac{\partial^2 W}{\partial \bar{q}^2}d\bar{q} = \Big[\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q)f(q)dq\Big]dp \\ -\Big[p\bar{q}\int_0^{\bar{q}} V''(R - p\bar{q} - \theta q)f(q)dq - p\int_0^{\bar{q}} V''(R - p\bar{q} - \theta q)qf(q)dq\lambda\Big]dp \\ +\Big[(1-\lambda)\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big]dp \\ +\Big[(\lambda-1)\bar{q}(p+\theta-c)\bar{q}\int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q}))f(q)dq\Big]dp,\end{aligned} \tag{36}$$

and further collecting terms, equation (36) becomes,

$$\begin{aligned}
\frac{\partial^2 W}{\partial \bar{q}^2} d\bar{q} = \Big[\int_0^{\bar{q}} V'(R - p\bar{q} - \theta q) f(q) dq\Big] dp \\
-\Big[p\bar{q}\int_0^{\bar{q}} V''(R - p\bar{q} - \theta q)\Big(1 - \frac{q}{\int_0^{\bar{q}} q f(q) dq}\Big) f(q) dq\Big] dp \\
+\Big[(1-\lambda)\int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q})) f(q) dq\Big] dp \\
+\Big[(\lambda - 1)\bar{q}(p + \theta - c)\bar{q}\int_{\bar{q}}^{q^*} V''(R - p\bar{q} - \theta\bar{q} - c(q-\bar{q})) f(q) dq\Big] dp
\end{aligned} \tag{37}$$

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 (37) can be rewritten as,

$$\begin{aligned}
&\int_0^{\bar{q}} (R - p\bar{q} - \theta q) f(q) dq + (1-\lambda)\int_{\bar{q}}^{q^*} (R - p\bar{q} - \theta\bar{q} - c(q-\bar{q})) f(q) dq \\
&= R - p\bar{q} - \theta\int_{\bar{q}}^{q^*} q f(q) dq - (1-\lambda)\int_{\bar{q}}^{q^*} c(q-\bar{q})) f(q) dq \\
&\qquad - \lambda\int_{\bar{q}}^{q^*} (R - p\bar{q} - \theta\bar{q}) f(q) dq - \theta\int_{\bar{q}}^{q^*} \bar{q} f(q) dq \\
&= R - p\bar{q} - \theta\int_{\bar{q}}^{q^*} q f(q) dq + (\lambda - 1)\int_{\bar{q}}^{q^*} c(q-\bar{q})) f(q) dq \\
&\qquad - \frac{\bar{q}}{\int_0^{\bar{q}} q f(q) dq}(1 - F(\bar{q}))(R - p\bar{q} - \theta\bar{q}) \\
&= (\lambda - 1)\int_{\bar{q}}^{q^*} c(q-\bar{q})) f(q) dq + (R - p\bar{q})\Big(1 - F(\bar{q}))\lambda\Big) + \theta\Big(\lambda\bar{q} - \int_0^{\bar{q}} q f(q) dq\Big) \\
&= (\lambda - 1)\int_{\bar{q}}^{q^*} c(q-\bar{q})) f(q) dq + \theta(\lambda^2 - 1)\int_0^{\bar{q}} q f(q) dq + (R - p\bar{q})\big(1 - \lambda(1 - F(\bar{q}))\big).
\end{aligned} \tag{38}$$

The first two terms of equation (38) 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,

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

In this case, a decrease in the price of capacity, 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 capacity price retards diffusion in anticipation of the high costs associated with consumables.[8]

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

$$\begin{aligned} \frac{dW}{dp}\Big|_{dE(\pi)=0} &= \int_0^{\bar{q}} V'(R - p\bar{q} - \theta q)[-\bar{q}dp + q\lambda dp]f(q)dq \\ &+ \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))[-\bar{q}dp + \bar{q}\lambda dp]f(q)dq. \end{aligned} \tag{39}$$

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 (39) can be rewritten as

$$\begin{aligned} &V'(R - p\bar{q}) \int_0^{\bar{q}} (-\bar{q} + \lambda q)f(q)dq + (\lambda - 1) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))f(q)dq \\ &= V'(R - p\bar{q})(1 - F(\bar{q}))\bar{q} + (\lambda - 1)) \int_{\bar{q}}^{q^*} V'(R - p\bar{q} - \theta\bar{q} - c(q - \bar{q}))f(q)dq > 0, \end{aligned} \tag{40}$$

implying

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

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

[8]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.

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