Contributions

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Technological Adoption in Health Care – The Role of Payment Systems

Abstract: This paper examines the incentive to adopt a new technology resulting from common payment systems, namely mixed 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-linked payment, adoption may arise in the absence of patients benefits when the differential reimbursement for the old vs new technology is large enough. Also, mixed cost reimbursement leads to higher adoption under conditions on the differential reimbursement levels and patient benefits. In policy terms, mixed cost reimbursement system may be more effective than a DRG payment system to induce technology adoption. Our analysis also shows that current economic evaluation criteria for new technologies do not capture the different ways payment systems influence technology adoption. 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.

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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, 2005b). There is a general

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consensus that technological development (and diffusion) is a prime driver of this phenomenon. The recent account by Smith, Newhouse, and Freeland (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 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. Neither we consider the issue of diffusion of a new technology. Our departing point is that a new way to provide some treatment has become available, and thus providers must decide whether to acquire it. An illustrative example of the situation we have in mind is the adoption of the laser technology in ophthalmology.

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 mixed 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 different payment regimes, we take as reference an investment level yielding to the provider the same marginal return of investment in new technology across regimes. Mixed 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 mixed 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 mixed 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.

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).

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. Illustrative references include Di Tommaso and Schweitzer (2005), OECD (2005c), Bodenheimer (2005), Duggan and Evans (2005), and Bokhari (2009).

Sorenson et al. (2014) report on the use of separate payments, supplementary payments, and cost-outlier funding to compensate the short-run lack of information in the initial stages of the adoption of a new technology. These payments are either additional funds or retrospective reimbursement of reported costs beyond the DRG system. New technologies adopted must satisfy a set of criteria for the hospital to receive the additional funds. Among them, (i) costs exceeding standard deviation of the respective DRGs; (ii) apply the new technology to a sufficiently large base of patients; and (iii) being more cost effective compared with existing services. The review of experiences in Sorenson et al. (2014) reveals that diversity exists, with different approaches being adopted within the DRG-like payment framework. In some cases, a new DRG is created, while in others extra payments are negotiated. The use of (negotiated) supplemental payments on top of DRG value to pay for innovation is close to what we term below as mixed payment systems. These supplemental payments pay cover fully or partially the cost of the innovation (for a review of the UK NHS experience, see Sorenson, Drummond, and Wilkinson 2013). An illustration of this diversity is provided by the diffusion of drug eluting stents in Italy during the early 2000s, as described in Capellaro, Ghislandi, and Anessi-Pessina (2011): the Italian health system is decentralized to the regional level and it introduced an ad hoc DRG to accommodate the new technology in some regions while in others different extra payments in existing DRGs were adopted. They find that hospitals funded by DRG had higher technology adoption than hospitals paid by global budget (linked to the region's capitation and not paying explicitly for innovation).

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, 1984b), Baumgardner (1991), and Selder (2005), who examine the effects of technical innovation on the insurance market, and Miraldo (2007) who studies the feedback effects between the health care and the R&D sectors, Grebel and Wilfer (2010) who study the diffusion of two competing technologies, and Levaggi, Moretto, and Pertile (2010) who consider how the uncertainty on patients' benefits affects the incentives to invest in new technologies.

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 McCellan (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 adoption 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.

At this point of the analysis, we do not include strategic aspects related to the adoption decision. Rather, we focus in the decision making of an isolated hospital trading off costs and benefits given some popular reimbursement schemes.

The structure of the paper is as follows. Section 2 introduces the model and behavioral 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 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 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 $V''(\cdot) \leq 0$) and patients' health gains. We will refer to the hospital as an example of a relevant provider throughout the text.

The potential population of patients is known (from say, epidemiological studies). It is represented by q^m. Also, these patients are homogeneous, i.e. they all suffer from the same illness and with the same severity.[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 $\hat{q}$ patients. If demand for hospital services exceeds the newly installed 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 in a simple way as distribution $F(q)$, with density $f(q)$, in the domain $[0, q^m]$.

The uncertainty on demand gives content to the problem. Should demand be deterministic the hospital would know before hand the capacity to be used

1 Allowing for heterogeneous 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.

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.

with the new technology, and thus the decision to adopt would become trivial. Also, the endogenous character of $\hat{q}$ leads us to assume that $\hat{q}$ is not contractible (as in the literature). The specific way the hospital will use the new technology 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.

Adoption of a new technology is an investment decision in capacity to treat patients, represented by a continuous endogenous variable $\hat{q}$. 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.

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

Note that uncertainty over the actual number of patients induces uncertainty over the use of the new technology (even though we assume it is used prior to the old one, up to capacity), and thus over the financial result of the investment. We capture this uncertainty by assuming a risk adverse behavior on the part of the hospital. Also note that risk neutrality would imply that the marginal valuation of the financial results of the hospital is independent of its level of activity.

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, we will study a mixed cost reimbursement scheme flexible enough to accommodate total mixed cost reimbursement, fixed fee/capitation, and partial mixed 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 $\hat{q}$ patients given by $p\hat{q}$, 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, $\hat{q}$ patients are treated with the new technology at marginal cost θ, and $(q - \hat{q})$ patients are treated under the old technology with marginal cost c. Formally, the total cost function of the hospital is given by,

$$TC = \begin{cases} p\hat{q} + \theta q & \text{if } q \leq \hat{q} \\ p\hat{q} + \theta\hat{q} + c(q - \hat{q}) & \text{if } q > \hat{q} \end{cases} \qquad [1]$$

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

$$p + \theta - c > 0. \qquad [2]$$

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. Of course, a technology with more benefits and lower costs poses no trade-off to adoption decisions, in particular if the condition in Assumption 1 is reversed. Note that the assumption allows marginal cost of treatment-only in the new technology to be lower that in the old one ($\theta < c$) without violating the assumption.

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.

We abstract from explicitly considering fixed costs. As the optimal adoption decision is made of marginal arguments, they do not play a role. Implicitly, we are assuming that demand is large enough to cover for the fixed cost.

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

$$\Delta > p + \theta - c > 0 \qquad [3]$$

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

The expected utility 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.

$$\begin{aligned} U = & \int_0^{\hat{q}} V(R - p\hat{q} - \theta q) f(q) dq + \int_{\hat{q}}^{q^m} V(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q})) f(q) dq \\ & + \eta \int_0^{\hat{q}} \hat{b} q f(q) dq + \eta \int_{\hat{q}}^{q^m} ((q - \hat{q}) b + \hat{q}\hat{b}) f(q) dq \end{aligned} \qquad [4]$$

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

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.

allowing to treat up to $\hat{q}$ patients. This is given by $p\hat{q}$, 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, $\hat{q}$ patients are treated with the new technology at marginal cost θ, and $(q - \hat{q})$ 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 utility function of the hospital is made up of benefits to patients. These are $\hat{b}$ and 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 $\hat{b}q$ is generated for each level of realized demand. In the case of realized demand above the capacity level for the new technology, $\hat{q}$ patients have utility $\hat{b}$ and $(q - \hat{q})$ patients have utility 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 utility 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 $\hat{q}$ 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 mixed cost reimbursement system and a DRG payment system.[7]

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 Le Grand 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 $f(q) = 1$. These are referred to in the text as remarks.

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

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 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.

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^m patients, and the new technology allows to provide treatment to a maximum of $q^M > q^m$ patients. Therefore we would have a population of two groups of patients where $(q^M - q^m)$ 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 $\overline{b}$. Then we can redefine patients' benefits as $b = \tau\overline{b} + (1 - \tau)\underline{b}$ and the analysis goes through integrating over q^M instead of q^m.

3 Technology adoption under mixed 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 $\hat{q}$ 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 ($p\hat{q}$) 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 ($\hat{q}$). Whenever the installed capacity of the new technology allows to treat all patients ($\hat{q} = q^*$), 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 eq. [1].

We propose a mixed cost reimbursement system flexible enough to accommodate a total cost reimbursement, a partial cost reimbursement, and a fixed fee/capitation payment system. The system is described by (Ellis and McGuire 1986):

$$R = \alpha + \beta TC \qquad [5]$$

where TC stands for total cost and $\alpha \geq 0$ and $\beta \in [0, 1]$ are parameters allowing for different variations of the payment system. In particular, if $\beta = 0$, 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; if $\alpha = 0$ and

$\beta = 1$ we obtain a full reimbursement system; if $\alpha = 0$ and $\beta \in (0,1)$ we obtain a partial reimbursement system; finally, if $\alpha > 0$ and $\beta \in (0,1)$, we obtain a mixed payment system with a prospective component and a retrospective element.

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 eqs [5] into [4] the hospital's utility function becomes

$$\begin{aligned} U = \hat{b}\eta \int_0^{\hat{q}} qf(q)dq + \eta \int_{\hat{q}}^{q^m} ((q - \hat{q})b + \hat{q}\hat{b})f(q)dq \\ + \int_0^{\hat{q}} V(\alpha - (1-\beta)(p\hat{q} + \theta q))f(q)dq \\ + \int_{\hat{q}}^{q^m} V(\alpha - (1-\beta)(p\hat{q} + \theta\hat{q} + c(q - \hat{q})))f(q)dq \end{aligned} \qquad [6]$$

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

$$\eta\Delta \equiv \eta(\hat{b} - b)$$

$$R_1(q) \equiv \alpha - (1-\beta)(p\hat{q} + \theta q)$$

$$R_2(q) \equiv \alpha - (1-\beta)(p\hat{q} + \theta\hat{q} + c(q - \hat{q}))$$

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 ($q < \hat{q}$), 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 ($q > \hat{q}$), and some of patients are treated with the old technology.

Proposition 1 *Under a mixed 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 $\hat{q}$ is the solution of first-order condition of the optimization problem [6]. That is, the solution of,

$$\frac{\partial U}{\partial \hat{q}} = \eta\Delta \int_{\hat{q}}^{q^m} f(q)dq - (1-\beta)p \int_0^{\hat{q}} V'(R_1(q))f(q)dq$$
$$- (1-\beta)(p+\theta-c) \int_{\hat{q}}^{q^m} V'(R_2(q))f(q)dq = 0. \quad [7]$$

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

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

$$\eta\Delta - (1-\beta)V'(R(\hat{q}))(\theta - c) > 0. \quad [8]$$

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.

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 eq. [7] represents the marginal gain from treating one additional patient with the new technology when the realized demand is greater than $\hat{q}$. 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 to

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

or

$$\hat{q}^{cr} = 1 - \frac{p(1-\beta)}{\eta\Delta - (1-\beta)(\theta - c)}. \quad [9]$$

8 As we commented previously, 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 utility is constant.

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 eq. [9] as,

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

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 eq. [9] 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 (2015) and Liu and Ma (2013).

Remark 2 *Interestingly enough, the usual cost–benefit rule does not capture the mechanism through which payments systems induce adoption.*

We introduced the cost–benefit assessment rule in assumption 2. It can be rewritten as

$$\Delta-p-(\theta-c)>0$$

On the other hand, the rule governing the optimal level of adoption is given by eq. [8], that can be rewritten as

$$\Delta-\kappa(\theta-c)>0$$

where $\kappa\equiv\frac{1-\beta}{\eta}V'(R(\hat{q}))$. Thus, cost–benefit analysis does not substitute for a proper analysis of incentives to adopt a new technology.

3.1 Cost-sharing and optimal technology adoption

We are interested in assessing how adoption changes with the level of mixed 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 $d\hat{q}/d\beta$ and of $d\hat{q}/d\alpha$, where $\hat{q}$ is given by the solution of eq. [7]. Thus, we capture the impact of a variation of β and α on the level of adoption $\hat{q}$ by computing $\partial^2 U/\partial\hat{q}\partial\beta$ and $\partial^2 U/\partial\hat{q}\partial\beta$.

Let us thus compute,

$$\begin{aligned}\frac{\partial^2 U}{\partial\hat{q}\partial\beta} = p\int_0^{\hat{q}} V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m} V'(R_2(q))f(q)dq \\ -(1-\beta)\left[p\int_0^{\hat{q}} V''(R_1(q))(p\hat{q}+\theta q)f(q)dq\right. \\ \left.+(p+\theta-c)\int_{\hat{q}}^{q^m} V''(R_2(q))(p\hat{q}+\theta\hat{q}+c(q-\hat{q}))f(q)dq\right]\end{aligned} \quad [10]$$

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 eq. [10] is positive, and so is the expression of $d\hat{q}/d\beta$. 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,

$$\frac{\partial^2 U}{\partial\hat{q}\partial\alpha} = -(1-\beta)\left(p\int_0^{\hat{q}} V''(R_1(q))f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m} V''(R_2(q))f(q)dq\right) \quad [11]$$

Given the concavity of $V(\cdot)$ and using eq. [2], it follows that this expression is positive. As before, the sign of $d\hat{q}/d\alpha$ is the same as the sign of expression [11]. 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 3 *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 mixed 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 utility obtained by the hospital.

3.2 Technological adoption under an exogenous 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 (assumption 2). A full analysis of the impact 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 either of them. Accordingly, we propose two alternatives. 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 eqs [1] and [5], the expression of the monetary transfer to the hospital is given by,

$$R = \alpha + \beta\left(\int_0^{\hat{q}}(p\hat{q} + \theta q)f(q)dq + \int_{\hat{q}}^{q^m}(p\hat{q} + \theta q + c(q - \hat{q}))f(q)dq\right),$$

To assess the impact on the level of adoption, besides adjusting the parameters (α,β) of the payment function to maintain payment constant, $dR = 0$, we also need to look at the adjustment of (α,β) in the first-order condition [7] characterizing the optimal value of $\hat{q}$. The detailed computation of this system of equations is to be found in Appendix A. To obtain some clear intuition of its content let us assuming risk neutrality. Then,

Remark 4 *Under risk neutrality, moving to more mixed 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 [38] is given by (see Appendix B),

$$\frac{d\hat{q}}{d\beta} = \frac{\Upsilon - \Lambda\Phi}{\Psi + \Gamma\Phi} \quad \text{and} \quad \frac{d\hat{q}}{d\alpha} = -\frac{\Upsilon - \Lambda\Phi}{\Lambda\Psi + \Gamma\Upsilon} \qquad [12]$$

Note that the numerators in eq. [12] 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 eq. [12]. 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 utility, while maintaining $dR = 0$, let us compute

$$dU = \frac{\partial U}{\partial R} dR + \frac{\partial U}{\partial \hat{q}} d\hat{q} \qquad [13]$$

The first term of eq. [13] is zero because we are evaluating the impact on hospital utility 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 utility 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 utility.

Remark 5 *Keeping the expected payment constant implies no change in the objective function when changing the parameters of the mixed cost reimbursement system.*

Remark 4 and remark 5 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.

3.3 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,

$$S = \alpha - (1-\beta)\left(\int_0^{\hat{q}} (p\hat{q} + \theta q) f(q)dq + \int_{\hat{q}}^{q^m} (p\hat{q} + \theta\hat{q} + c(q-\hat{q}) f(q)dq\right). \quad [14]$$

Similarly as in the previous case, we have a system of two equations given by the adjustment of parameters (α, β) to maintain surplus constant $dS = 0$ and the adjustment of (α, β) in the first-order condition [7] characterizing the optimal value of $\hat{q}$ (see Appendix C). As before let us assume risk neutrality. The following remark summarizes the main intuitions.

Remark 6 *Under risk neutrality and constant trade-off of surplus against patient benefits, an increase in the mixed 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.*

4 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 *heterogeneous DRG reimbursement*. As before, we assume that R will always suffice to guarantee a non-negative surplus for the provider.

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,

$$R = Kq. \quad [15]$$

Substituting eqs [15] into [4] the hospital's utility function becomes,

$$\begin{aligned} U = \eta \int_0^{\hat{q}} \hat{b} q f(q) dq + \eta \int_{\hat{q}}^{q^m} ((q - \hat{q}) b + \hat{q} \hat{b}) f(q) dq \\ + \int_0^{\hat{q}} V(Kq - p\hat{q} - \theta q) f(q) dq \\ + \int_{\hat{q}}^{q^m} V(Kq - p\hat{q} - \theta \hat{q} - c(q - \hat{q})) f(q) dq \end{aligned} \qquad [16]$$

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,

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

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,

$$\begin{aligned} \frac{\partial U}{\partial \hat{q}} = \eta \Delta \int_{\hat{q}}^{q^m} f(q) dq + (V(R_3(\hat{q})) - V(R_4(\hat{q}))) f(\hat{q}) \\ - p \int_0^{\hat{q}} V'(R_3(q)) f(q) dq - (p + \theta - c) \int_{\hat{q}}^{q^m} V'(R_4(q)) f(q) dq = 0. \end{aligned} \qquad [17]$$

For $\hat{q} \to q^m$, the first-order condition [17] is negative. Thus, the optimal value satisfying eq. [17] must be less than q^m.

Remark 7 *Note that sufficiently large patients' benefits are necessary for the first-order condition [17] 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 $q^m = 1$. Then, the first-order condition [17] reduces to,

$$\eta \Delta (1 - \hat{q}) - p\hat{q} - (p + \theta - c)(1 - \hat{q}) = 0 \qquad [18]$$

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

$$\hat{q} = 1 - \frac{p}{\eta\Delta - \theta + c}. \qquad [19]$$

The denominator of eq. [19] is positive from the second-order condition. Thus, $\hat{q} < 1$, and full adoption is never optimal. The optimal value of adoption given by eq. [19] 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. $\hat{q} > 0$) if and only if the economic evaluation criterion is satisfied (compare eq. [19] with Assumption 2).

Remark 8 *Note that $\hat{q}$ 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,

$$\frac{\partial^2 U}{\partial \hat{q} \partial K} = -p \int_0^{\hat{q}} V''(R_3(q)) q f(q) dq - (p + \theta - c) \int_{\hat{q}}^{q^m} V''(R_4(q)) q f(q) dq > 0$$

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 9 *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

$$R_5(q) \equiv K_1 q - p\hat{q} - \theta q$$

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

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,

$$U = \eta \int_0^{\hat{q}} \hat{b} q f(q) dq + \eta \int_{\hat{q}}^{q^m} ((q - \hat{q}) b + \hat{q} \hat{b}) f(q) dq + \int_0^{\hat{q}} V(R_5(q)) f(q) dq + \int_{\hat{q}}^{q^m} V(R_6(q)) f(q) dq \qquad [20]$$

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

$$\frac{\partial U}{\partial \hat{q}} = \eta \Delta \int_{\hat{q}}^{q^m} f(q) dq + V(R_5(\hat{q})) f(\hat{q}) - V(R_6(\hat{q})) f(\hat{q}) - p \int_0^{\hat{q}} V'(R_5(q)) f(q) dq + (K_1 - K_2 - p - \theta + c) \int_{\hat{q}}^{q^m} V'(R_6(q)) f(q) dq = 0. \qquad [21]$$

For $\hat{q} \to q^m$, the first-order condition [21] is negative. Thus, the optimal value satisfying eq. [17] must be less than q^m.

Remark 10 *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 $q^m = 1$ without loss of generality. Then, expression [21] reduces to,

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

so that,

$$\hat{q} = 1 - \frac{p}{\eta \Delta + K_1 - K_2 - \theta + c}. \qquad [22]$$

and second-order conditions guarantee that the denominator of the fraction is positive. Note that $\hat{q} < 1$. The optimal value of $\hat{q}$ given by eq. [22] reflects the trade-off between incurring an idle capacity cost for high $\hat{q}$ 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.

5 Comparing payment regimes

We have presented the adoption decision under two payment regimes, mixed 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 mixed cost reimbursement and DRG payment systems, given by eqs [9], [19] and [22] respectively, and let $\lambda \equiv K_1 - K_2$:

$$\hat{q}^{cr} = 1 - \frac{p(1-\beta)}{\eta\Delta - (1-\beta)(\theta - c)}, \qquad [23]$$

$$\hat{q}^{hom} = 1 - \frac{p}{\eta\Delta - (\theta - c)}, \qquad [24]$$

$$\hat{q}^{het} = 1 - \frac{p}{\eta\Delta + \lambda - (\theta - c)}, \qquad [25]$$

where the superscripts *cr, hom* and *het* refer to the mixed cost reimbursement, homogeneous DGR, and heterogeneous DRG respectively. Direct comparison of the difference in adoption levels yields:

$$\hat{q}^{hom} - \hat{q}^{het} < 0, \quad [26]$$

$$\hat{q}^{cr} - \hat{q}^{het} \lesseqgtr 0, \quad [27]$$

$$\hat{q}^{cr} - \hat{q}^{hom} > 0 \quad [28]$$

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 [27], 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 heterogeneous DRG reimbursement scheme are $\eta\Delta + K_1 - K_2 - (\theta - c)$. This is the denominator of the left-hand fraction in eq. [27].

Consider now the same investment under the mixed 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 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 eq. [27].

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

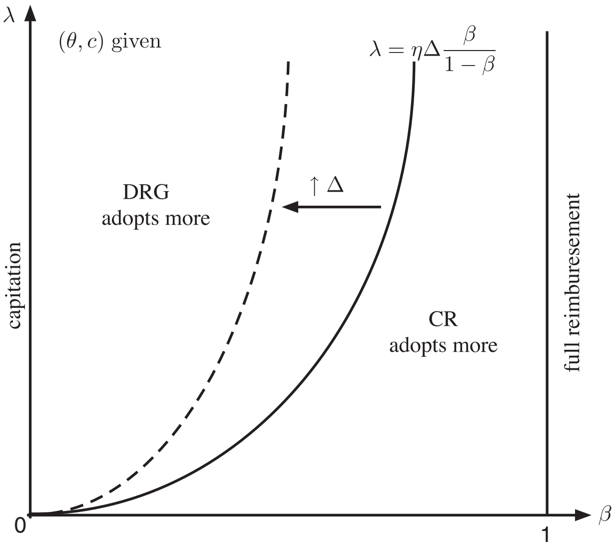

Figure 1: Optimal adoption: CR vs heterogeneous DRG

willing to adopt under mixed cost reimbursement increases. This is a direct consequence of the retrospective character of the mixed 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 $K_2, \alpha,$ and β that are not directly related.

A similar argument can be put forward to analyze expression [28]. 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 eq. [28]. Under mixed 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 eq. [28]. The return of the investment is thus larger under mixed cost reimbursement, yielding the higher level of adoption.

6 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, Moretto, and Pertile (2010)) 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 eqs [23], [24] and [25], we shall assume again risk neutrality and a uniform distribution and also normalize $q^m = 1$. Then,

$$SW(\hat{q}) = \int_0^{\hat{q}} \hat{b}qf(q)dq + \int_{\hat{q}}^{q^m} ((q-\hat{q})b + \hat{q}\hat{b})f(q)dq \\ - \int_0^{\hat{q}} (p\hat{q} + \theta q)f(q)dq - \int_{\hat{q}}^{q^m} (p\hat{q} + \theta\hat{q} + c(q-\hat{q}))f(q)dq - \xi E(R^j) \tag{29}$$

where ξ represents the social cost of public funds à la Laffont and Tirole (1986)[9] and $E(R^j)$ denote expected revenues under reimbursement rule *j*.

The expected revenues under the different reimbursements rules are given by

$$E(R^{cr}) = \alpha + \beta\left[\int_0^{\hat{q}} (p\hat{q} + \theta q)f(q)dq + \int_{\hat{q}}^{q^m} (p\hat{q} + \theta\hat{q} + c(q-\hat{q}))f(q)dq\right] \tag{30}$$

$$E(R^{hom}) = \int_0^{q^m} Kqf(q)dq = KE(q) \tag{31}$$

$$E(R^{het}) = \int_0^{\hat{q}} K_1qf(q)dq + \int_{\hat{q}}^{q^m} (K_1\hat{q} + K_2(q-\hat{q}))f(q)dq \tag{32}$$

6.1 Mixed cost reimbursement rule

After substituting eqs [30] into [29] we compute the first-order condition:

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

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

$$\hat{q}^{swcr} = 1 - \frac{p(1+\xi\beta)}{\Delta - (1+\xi\beta)(\theta - c)}. \tag{33}$$

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

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

A direct comparison of eqs [23] and [33] yields

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

Accordingly, under mixed 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.

6.2 Homogeneous DRG reimbursement rule

Substituting eqs [31] into [29] we compute the first-order condition,

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

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

$$\hat{q}^{swhom} = 1 - \frac{p}{\Delta - (\theta - c)}. \qquad [34]$$

Now, comparing eqs [24] and [34] we obtain

$$\hat{q}^{hom} - \hat{q}^{swhom} \geq 0.$$

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.

6.3 Heterogeneous DRG reimbursement rule

Substituting eqs [32] into [29] we compute the first-order condition,

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

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

$$\hat{q}^{swhet} = 1 - \frac{p}{\Delta - (\theta - c) - \xi\lambda} \qquad [35]$$

A direct comparison of eqs [25] and [35] yields

$$\hat{q}^{het} - \hat{q}^{swhet} > 0.$$

Again, as under mixed 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).

7 Final remarks

Adoption of new technologies is usually considered a main driver of growth of health care costs.[10] Arguments in favor 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.

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

Under a mixed 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

10 See Smith, Newhouse, and Freeland (2009) for a recent account.

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 mixed cost reimbursement allows for the extreme cases of full mixed cost reimbursement and capitation (a fixed fee is paid, regardless of actual costs).

The other payment system we have considered is 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 mixed cost reimbursement, full adoption is not optimal either with prospective reimbursements schemes, regardless of whether the reimbursement rate differs 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, mixed 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 mixed cost reimbursement payment system, provided adoption occurs initially under both payment systems (i.e. 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 mixed 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 toward adoption of a new technology after a decade where the debate between cost containment versus quality issues has favored prospective reimbursement over mixed 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 mixed 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.

In our analysis we assume that the new technology does not convey any demand expansion. We can accommodate the popular argument 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. Simply we need to assume that the old technology can treat a maximum of q^m patients, and the new technology allows to provide treatment to a maximum of $q^M > q^m$ patients. Therefore we would have a population of two groups of patients where $(q^M - q^m)$ would denote the increased demand induced by the new technology. Redefining in a suitable way patients' benefits, the analysis goes through integrating over q^M instead of q^m.

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 analysis also shows that standard health technology assessment (economic evaluation studies) does not capture the channels by which payment mechanisms may lead to more (or less) adoption.

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 contributions 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 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.[11] 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 $\hat{q}$. In this way we would obtain the number of adopters at each moment, so that the way payment systems influence $\hat{q}$ 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.

11 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.

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Appendix

Appendix A

A.1 Welfare analysis under an exogenous budget

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

$$dR = d\alpha + d\beta\left(\int_0^{\hat{q}}(p\hat{q}+\theta q)f(q)dq + \int_{\hat{q}}^{q^m}(p\hat{q}+\theta q + c(q-\hat{q}))f(q)dq\right) + \beta\left(p\int_0^{\hat{q}}f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m}f(q)dq\right)d\hat{q} = 0. \quad [36]$$

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

$$\frac{\partial^2 W}{\partial \hat{q}^2}d\hat{q} + \left(p\int_0^{\hat{q}}V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m}V'(R_2(q))f(q)dq\right.$$
$$-(1-\beta)\left(p\int_0^{\hat{q}}V''(R_1(q))(p\hat{q}+\theta q)f(q)dq\right.$$
$$\left.2cm + (p+\theta-c)\int_{\hat{q}}^{q^m}V''(R_2(q))(p\hat{q}+\theta\hat{q}+c(q-\hat{q}))f(q)dq\right)d\beta$$
$$-(1-\beta)\left(p\int_0^{\hat{q}}V''(R_1(q))f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m}V''(R_2(q))f(q)dq\right)d\alpha = 0 \quad [37]$$

Thus, we have a system of equations given by eqs [36] and [37], that we can write in a compact form as

$$\begin{aligned} d\alpha + \Gamma d\hat{q} + \Lambda d\beta &= 0 \\ \Phi d\alpha - \Psi d\hat{q} + \Upsilon d\beta &= 0. \end{aligned} \qquad [38]$$

where we use the following notation:

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

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

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

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

$$\begin{aligned} \Upsilon \equiv\ & p\int_0^{\hat{q}} V'(R_1(q))f(q)dq + (p+\theta-c)\int_{\hat{q}}^{q^m} V'(R_2(q))f(q)dq \\ & -(1-\beta)\left(p\int_0^{\hat{q}} V''(R_1(q))(p\hat{q}+\theta q)f(q)dq\right. \\ & \left. +(p+\theta-c)\int_{\hat{q}}^{q^m} V''(R_2(q))(p\hat{q}+\theta\hat{q}+c(q-\hat{q}))f(q)dq\right) > 0 \end{aligned}$$

Note that if we assume risk neutrality, the system simplifies to

$$d\alpha + \Gamma d\hat{q} + \Lambda d\beta = 0 \qquad [39]$$

$$-\widehat{\Psi} d\hat{q} + \widehat{\Upsilon} d\beta = 0. \qquad [40]$$

where $\widehat{\Psi}$ and $\widehat{\Upsilon}$ represent the corresponding values Ψ and Υ when $V''(\cdot) = 0$. Note that eq. [40] tells us that $d\hat{q}/d\beta > 0$, and eq. [39] tells us that α adjusts accordingly to satisfy the equation.

Appendix B

B.1 Technical analysis of Remark 4

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

$$\frac{\partial W}{\partial \hat{q}} = f(\hat{q})\Delta U(b) - p\int_0^{\hat{q}} V'(R - p\hat{q} - \theta q)f(q)dq$$
$$-(p+\theta-c)\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq = 0. \quad [41]$$

To obtain the impact of the policy change on technology adoption (that is, on $\hat{q}$), we totally differentiate eq. [41] with respect to $\hat{q}, p$, and θ, and impose $d\theta = -\lambda dp$, where $\lambda = \hat{q}/\int_0^{\hat{q}} qf(q)dq$.

Total differentiation of the first-order condition yields,

$$\begin{aligned}
&\frac{\partial^2 W}{\partial \hat{q}^2}d\hat{q} - \left(\int_0^{\hat{q}} V'(R - p\hat{q} - \theta q)f(q)dq\right)dp \\
&+\left(p\hat{q}\int_0^{\hat{q}} V''(R - p\hat{q} - \theta q)f(q)dq\right)dp \\
&+\left(\left(p\hat{q}\int_0^{\hat{q}} V''(R - p\hat{q} - \theta q)f(q)dq\theta\right.\right. \\
&-\left(\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right)dp \\
&+\left((p+\theta-c)\hat{q}\int_{\hat{q}}^{q^m} V''(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right)dp \\
&-\left(\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right)d\theta \\
&+\left((p+\theta-c)\hat{q}\int_{\hat{q}}^{q^m} V''(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right)d\theta = 0
\end{aligned} \quad [42]$$

Substituting $d\theta = \lambda dp$ and collecting terms we can rewrite eq. [42] as

$$\begin{aligned}
\frac{\partial^2 W}{\partial \hat{q}^2}d\hat{q} = &\left[\int_0^{\hat{q}} V'(R - p\hat{q} - \theta q)f(q)dq\right]dp \\
&-\left[p\hat{q}\int_0^{\hat{q}} V''(R - p\hat{q} - \theta q)f(q)dq - p\int_0^{\hat{q}} V''(R - p\hat{q} - \theta q)qf(q)dq\lambda\right]dp \\
&+\left[(1-\lambda)\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right]dp \\
&+\left[(\lambda-1)\hat{q}(p+\theta-c)\bar{q}\int_{\hat{q}}^{q^m} V''(R - p\hat{q} - \theta\hat{q} - c(q-\hat{q}))f(q)dq\right]dp,
\end{aligned} \quad [43]$$

and further collecting terms, eq. [43] becomes,

$$\frac{\partial^2 W}{\partial \hat{q}^2} d\hat{q} = \left[\int_0^{\hat{q}} V'(R - p\hat{q} - \theta q) f(q) dq \right] dp$$
$$- \left[p\hat{q} \int_0^{\hat{q}} V''(R - p\hat{q} - \theta q) \left(1 - \frac{q}{\int_0^{\hat{q}} q f(q) dq} \right) f(q) dq \right] dp$$
$$+ \left[(1-\lambda) \int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q})) f(q) dq \right] dp$$
$$+ \left[(\lambda - 1)\hat{q}(p + \theta - c)\hat{q} \int_{\hat{q}}^{q^m} V''(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q})) f(q) dq \right] dp \quad [44]$$

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 $\hat{q}$ 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 eq. [44] can be rewritten as,

$$\int_0^{\hat{q}} (R - p\hat{q} - \theta q) f(q) dq + (1-\lambda) \int_{\hat{q}}^{q^m} (R - p\hat{q} - \theta\hat{q} - c(q - \hat{q})) f(q) dq$$
$$= R - p\hat{q} - \theta \int_{\hat{q}}^{q^m} q f(q) dq - (1-\lambda) \int_{\hat{q}}^{q^m} c(q - \hat{q})) f(q) dq$$
$$- \lambda \int_{\hat{q}}^{q^m} (R - p\hat{q} - \theta\hat{q}) f(q) dq - \theta \int_{\hat{q}}^{q^m} \hat{q} f(q) dq$$
$$= R - p\hat{q} - \theta \int_{\hat{q}}^{q^m} q f(q) dq + (\lambda - 1) \int_{\hat{q}}^{q^m} c(q - \hat{q})) f(q) dq$$
$$- \frac{\hat{q}}{\int_0^{\hat{q}} q f(q) dq} (1 - F(\hat{q}))(R - p\hat{q} - \theta\hat{q})$$
$$= (\lambda - 1) \int_{\hat{q}}^{q^m} c(q - \hat{q})) f(q) dq + (R - p\hat{q})(1 - F(\hat{q}))\lambda) + \theta \left(\lambda\hat{q} - \int_0^{\hat{q}} q f(q) dq \right)$$
$$= (\lambda - 1) \int_{\hat{q}}^{q^m} c(q - \hat{q})) f(q) dq + \theta(\lambda^2 - 1) \int_0^{\hat{q}} q f(q) dq + (R - p\hat{q})(1 - \lambda(1 - F(\hat{q}))). \quad [45]$$

The first two terms of eq. [45] are positive, whilst the last one is positive if $1 > \lambda(1 - F(\hat{q}))$. This occurs for a high value of $\hat{q}$.

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

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

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 $\hat{q}$ in equilibrium.

Also, $\hat{q}$ 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.[12]

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

$$\begin{aligned}\frac{dW}{dp}|_{dE(\pi)=0} &= \int_0^{\hat{q}} V'(R - p\hat{q} - \theta q)[-\hat{q}dp + q\lambda dp]f(q)dq \\ &+ \int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q}))[-\hat{q}dp + \hat{q}\lambda dp]f(q)dq.\end{aligned} \quad [46]$$

Noting that,

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

expression [46] can be rewritten as

$$\begin{aligned}&V'(R - p\hat{q})\int_0^{\hat{q}}(-\hat{q} + \lambda q)f(q)dq + (\lambda - 1)\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q}))f(q)dq \\ &= V'(R - p\hat{q})(1 - F(\hat{q}))\hat{q} + (\lambda - 1))\int_{\hat{q}}^{q^m} V'(R - p\hat{q} - \theta\hat{q} - c(q - \hat{q}))f(q)dq > 0,\end{aligned} \quad [47]$$

implying

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

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

12 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.

Appendix C

C.1 Welfare analysis under constant hospital surplus

Totally differentiating eq. [14] allows us to introduce the restriction of keeping the hospital surplus constant as,

$$dS = d\alpha - (1-\beta)(p + (\theta - c)(1 - F(\hat{q})))d\hat{q} + \left(\int_0^{\hat{q}} (p\hat{q} + \theta q)f(q)dq + \int_{\hat{q}}^{q^m} (p\hat{q} + \theta\hat{q} + c(q - \hat{q})f(q)dq\right)d\beta = 0 \qquad [48]$$

As before, we have a system of two equations given by eqs [37] and [48], which in compact form are

$$\begin{aligned} \Phi d\alpha - \Psi d\hat{q} + \Upsilon d\beta &= 0 \\ d\alpha + \Omega d\hat{q} + \Pi d\beta &= 0 \end{aligned} \qquad [49]$$

where we use the following notation:

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

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

Imposing risk neutrality to better assess its content, the system [49] simplifies to,

$$\begin{aligned} -\Psi d\hat{q} + \Upsilon' d\beta &= 0 \\ d\alpha + \Omega d\hat{q} + \Pi d\beta &= 0 \end{aligned} \qquad [50]$$

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

Finally, note that

$$dW = \left(\int_0^{\hat{q}} V'(R_1(q))f(q)dq + \int_{\hat{q}}^{q^m} V'(R_2(q))f(q)dq\right)d\alpha + \left(\int_0^{\hat{q}} V'(R_1(q))(p\hat{q} + \theta q)f(q)dq + \int_{\hat{q}}^{q^m} V'(R_2(q))(p\hat{q} + \theta\hat{q} + c(q - \hat{q}))f(q)dq\right)d\beta \qquad [51]$$

Assume under risk neutrality that $V'(\cdot) = 1$ without loss of generality. Then, substituting eq. [48] in eq. [51], it follows that $dW > 0$.

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