Quality and Investment Decisions in Hospital Care when Physicians are Devoted Workers

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Summary

This paper analyses the decision to invest in quality by a hospital in an environment where doctors are devoted workers, i.e. they care for specific aspects of the output they produce. We assume that quality is the result of both an investment in new technology and the effort of the medical staff. Hospital services are paid on the basis of their marginal cost of production while the number of patients treated depends on a purchasing rule which discriminates for the level and timing of the investment. We show that the presence of devoted doctors affects the trade-off between investment and the purchasing rule so that for the hospital it is not always optimal to anticipate the investment decision.

Keywords: Hospital technology, Devoted worker, Quality, Irreversible investment, Real options

JEL Classification: I11, D81

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1 Introduction

All advanced health care systems have to cope with the need to control growth expenditure without over-reducing investments in new technology, in order to guarantee patients adequate quality (Bokhari, 2001; Baker, 2001; Propper, 2004; HTC 2003). In this context, it is important to overcome the traditional (and somehow misleading) trade-off between cost and quality, where the latter is simply seen as a running cost[1].

In this paper, we argue that the quality of hospital care is determined by two main factors: the capital invested (i.e. adoption of new technologies) which is usually irreversible, and the effort of the personnel employed which has a more complex objective function than standard workers. Therefore, hospital care needs a more comprehensive modelling approach which considers the particular features of the production process as regards investment decisions on medical equipment and human capital. Following Chalkley and Malcomson (2000), we define quality as a multivariable vector that includes all the aspects of medical care such as the appropriateness of the treatment, the investment in technology that benefits the recipients, and other aspects that are not strictly medical but that can improve hospital output, such as patient accessibility (proper information by hospital staff, short waiting times before treatment etc.) and hotel quality.

In this respect, the paper analyses a Nash game between a hospital and its medical staff to determine the quality level of health care within an intertemporal model where the investment implemented by the hospital is irreversible, because of physical or economic reasons. In this game, the quality of hospital care and doctors' efforts are non-contractable variables (i.e. they cannot be enforced before a court). In modelling the behaviour of the medical staff and the related choice of doctors' efforts, we follow the literature on the "devoted workers" which has pointed out the differences in the choice of the effort by a worker (in our case, a doctor) who is interested in both the outcome and the technology content of the productive process adopted (Francois, 2000, 2003; Glazer, 2004)[2].

Furthermore, we analyse how a purchaser (e.g. an insurance company, an HMO or a public health authority) who pursues its patients' welfare may influence the hospital's quality choice through strategic setting of the parameters of a purchasing rule that relates the volume of hospital care to be reimbursed to the timing of the hospital's investment decision.

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[1] See Harris (1979), Ellis and Mc Guire (1986), Newhouse (1996), Ma (1994), Chalkley and Malcomson (1998, 2000 and 2002), Bigliaser and Ma (2003).

[2] Interesting examples are firemen, university professors and medical staff.

In order to analyse hospital investment in health care technology, we use a real option approach[3]. Essentially this approach posits that the opportunity to invest in a project is analogous to an American call option on the investment opportunity. Since the future value of the project is uncertain, there is an opportunity cost to investing today. Another example of option game between a purchaser and a hospital over the investment in quality can be traced in Levaggi and Moretto (2004). In that model, however, the medical staff did not play any role in the investment in quality[4].

We show that the strategic behaviour between the doctors and the hospital affects the hospital's decision both on the level and the timing of investment. Since the investment decision is the result of the Nash game between the medical staff and the hospital, the latter can use the devoted characteristic of the physician to substitute investment with effort in order to maximise its intertemporal surplus. In particular, our model provides a surprising result as regards the timing of the investment: if the purchaser aims at maximising the current level of quality (i.e. the earlier adoption of a new technology by the hospital), the adoption of a purchasing rule linking the volume of current hospital admissions to be reimbursed to the investment made in the past periods may not be optimal. That is, in contrast with the real option theory, we show that it is not necessary to drive to zero the firm's option to wait for more information to convince it to invest soon[5].

The paper is organized as follows. Section two presents the basic model. In section three, the Nash equilibrium of the game between the hospital and the medical staff is presented. In section four, the relationship between the Nash equilibrium and the purchasing rule is analysed. Lastly, section five concludes.

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[3] See Abel et al. (1996), Dixit and Pindyck (1994).

[4] Also Bös and Fraja (2002) study a game between a health care authority and a hospital over the investment in quality. However, they do not consider the intertemporal aspect of the investment in health care and the specific effort of the medical staff in determining the level of quality. Furthermore, they allow the purchaser to rely on outside providers to induce the hospital to increase its investment.

[5] This contrasts also with the result obtained by Levaggi and Moretto (2004) who showed that the problem of non-verifiability of quality could usually be avoided by a purchasing rule linking the volume of current care to be reimbursed to the investment made in the past periods, which induces the hospital to anticipate the investment.

2 The model

The model deals with the investment choices of a representative hospital and the effort decision made by its medical staff in a two-period framework. To simplify the analysis, we assume that patients admitted to the hospital can be affected only by one disease that requires a standard treatment. The total quality of hospital care is determined by its clinical effectiveness and by perceived quality, as explained in the next section. A new technology for producing hospital care is available at time 1 and the hospital may decide the level of investment (i.e. the number of technology units) in each period. The effort of medical staff is set at time 1 and is kept constant over time. Both capital and doctors' efforts contribute to determining the total quality q_t, $t = 1, 2$. We also assume that, once the investment in the new technology is undertaken, it cannot be diverted and depreciation is absent[6].

2.1 Quality and its aspects

The outcome of hospital care depends on several variables, some of which cannot be controlled by any of the parts involved in the hospital production process. The main determinants of hospital care outcome are: the quality of the treatment, patient's compliance with therapy and his ability to recover. These elements interact: a high level of quality makes the patient confident of recovering his health and motivates him to comply and, sometimes, might enhance the placebo effect of the treatment. In this process the perceived quality is equally (sometimes more) important than the clinical quality of health care. However, the patient cannot fully perceive clinical outcome because of his ignorance of health care. In his assessment of quality he might sometimes be biased towards elements that he can readily observe and measure, even if they are not the most important ones.

In our analysis we define total quality as:

$$q = F(q^p, q^c) \tag{1}$$

where $q^p \geq 0$ represents the quality perceived by patients, $q^c \geq 0$ is the clinical quality, with $F(0, q^c) \geq 0$ and $F(q^p, 0) \geq 0$. Perceived and clinical quality can be interpreted as two intermediate outcomes in the process leading to total quality. The term q^p captures important aspects relating to the

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[6] Together with irreversibility of investment, this assumption avoids the need to consider operating options for the hospital such as reducing output or even shutting down, and thereby considering reducing variable costs. For further details on this issue see e.g. Dixit and Pindyck (1994).

quality as perceived by patients: access to hospital services, level of comfort in hospital care (hotel quality measured by number of beds per room, visiting times, private telephones, nurses per ward, etc.) and relationship with the medical staff (appropriate information on the therapy and its likely effectiveness, shared motivation with doctors and other personnel as regards the therapy, establishing a satisfactory human relationship with staff, etc.)[7]. Perceived quality can be assumed to be a function of the ancillary services s (which the literature often defines "hotel-related quality services") and the effort of the medical staff devoted to patient-centered care e (Stewart, 1995, 2000). That is:

$$q^p = h(s, e; \varepsilon) \tag{2}$$

where ε is a random variable which is related to unknown patients' characteristics and their prior beliefs *concerning* health outcomes. This specification corresponds to the way most of the traditional literature models health care quality: a running cost that depends on some inputs and the effort of the medical staff[8]. This definition, however, and especially its specification, are not sufficient to define the overall quality of hospital care. Another important element is clinical quality which, we believe, has to be treated separately from the previous term since it also depends on investment decisions concerning medical technology.

The clinical quality of hospital care can be written as an increasing function of three inputs:

$$q^c = g(k, e, a; \theta)$$

where: k represents the level of capital invested in medical technology, e is the effort of the medical staff, a is the appropriateness of the care offered to the patient and θ is a random parameter that captures the unknown characteristics of each patient (which can influence the health outcome) as well as all the other uncertain determinants influencing clinical quality (e.g. shocks on input productivity etc.). Appropriateness a measures the use of hospital resources in order to respond (according to clinical standards and existing medical evidence) to a specific health care demand. We assume

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[7] q^p represents the quality as perceived by patients when they actually use hospital care services and experience a relationship with hospital staff. Under this perspective, the concept of perceived quality we adopt here is very close to relational quality and should be considered distinct from the concept of reputation which can drive competition between hospitals and which depends not only on patients' experience of hospital care (i.e. perceived quality) but also on people's beliefs *concerning* hospital technology and staff before their actual experience of hospital services.

[8] See Chalckley and Malcomson (2000).

that the appropriateness of the care delivered is an increasing function of medical effort, i.e.:

$$a = a(e;\zeta) \tag{3}$$

The underlying assumption is that the effort of the medical staff permits precise diagnosis and appropriate treatment for the patient[9]. The effort of the medical staff provides the patient with personalised treatment which, due to the presence of ζ, cannot be standardised (e.g. through protocols or guidelines). The effort of the medical staff enhances the productivity of the capital invested in health care. Medical technology is per se important to improve medical care, but it is the effort of the medical staff that determines the appropriateness of the treatment. Using (3), clinical quality can be written as:

$$q^c = g(k,e;\beta) \tag{4}$$

where $\beta = (\theta, \zeta)$. Substituting (4) and (2) into (1), and assuming, without any loss of generality, that s is fixed[10] (so that q^p depends only on e), we obtain the following functional form for total quality:

$$q = F\left(h(e;\varepsilon), g(k,e;\beta)\right) \tag{5}$$

For the perceived and clinical quality the usual marginal properties hold: $h_e > 0, h_{ee} < 0$ and $g_e > 0, g_k > 0$, $g_{ee} < 0, g_{kk} < 0$ respectively. We complete these properties by assuming that capital and effort are substitutes, i.e. $g_{ke} < 0$ and $g_{k\beta} > 0$[11].

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[9] Therefore, we assume that appropriateness does not depend on k However, the real effect of k on the appropriateness of hospital care is controversial. Sometimes appropriateness is determined by the ability of doctors to keep themselves abreast of technical developments which are often more "capital intensive" and are considered really effective according to Evidence Based Medicine (e.g. the adoption of laparoscopy instead of traditional surgery in cholecystectomy); in this case, appropriateness could be positively related to k. In other cases, however, the relationship between a and k could assume a negative sign. For instance, to accomplish a first diagnosis of bronchopneumonia or to ascertain the existence of particular orthopaedic diseases, the use of traditional X-ray diagnostics could be sometimes equally (or even more) effective than using CAT (Computed Axial Tomography) scan. Therefore, the relationship between a and k is rather ambiguous, depending on the particular health care problem considered.

[10] For the sake of simplicity, we assume that hotel-related quality is set at a standard level. In this way, we focus on the perceived quality determined by the effort of medical staff devoted to the relationship with patients. Moreover, we do not consider a hospital's investment in hotel services but only in new clinical technology. Anyway, our main results hold even with a variable s.

[11] Although not strictly necessary for the results we may add that $g(0,e;\beta) = g(k,0;\beta) = 0$.

Finally, we assume that (5) is additive and separable in q^p and q^c, i.e.:[12]

$$q = (1-\lambda)q^p + \lambda q^c \equiv (1-\lambda)h(e;\varepsilon) + \lambda g(k,e;\beta) \tag{6}$$

where $0 \le \lambda \le 1$ parameterizes the marginal rate of substitution between k and e.

2.2 The actors

In this paper we model the behaviour of three main actors: an agency purchasing hospital care (the purchaser), a hospital (the provider) and its medical staff.

2.2.1 The purchaser

We do not assume a specific objective function for the purchaser. However, even if this actor limits itself to setting the parameters of a purchasing rule in order to maximise total quality on behalf of its patients[13], its role is not marginal as will be shown in this paper[14]. The maximisation of total quality can be pursued by supporting hospital investment in new technologies and stimulating a high level of effort by the medical staff. The purchaser pursues its objective by rewarding the hospital a fixed price p for each treatment and setting a quality-contingent long-term contract with the hospital[15]. In particular, we assume that the number of patients needing treatment is independent of quality, but the purchaser reimburses the hospital for the treatment of a number of patients which is fixed in the first period, $x_1 \equiv x \ge 0$, and may increase in the second period if the hospital increases its total quality. In other words, we assume that the purchaser is committed to linking the number of patients to be treated in the second period to the quality provided by the hospital using the following linear rule:

$$x_2(q_1,q_2) \equiv x + \gamma q_1 + \alpha(q_2 - q_1) \quad \text{with } \gamma, \alpha \ge 0 \text{ and } \gamma \ge \alpha \tag{7}$$

where x is fixed, q_1 and q_2 are the level of total quality in the first period and in the second period respectively, and γ and α represent the relative

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[12] This is like assuming a Cobb-Douglas representation of total quality with q^p and q^c as inputs.

[13] In this respect, it can be considered a perfect agent of the patients.

[14] A vast empirical literature has studied the effect of different reimbursement setting on the adoption of new technology. See HTC (2003) for a review.

[15] Price p can be either a DRG tariff or any other form of prospective price for a specific treatment.

weights attached by the purchaser to the quality in the two periods. Since investment is irreversible, if $\gamma = 0$, the hospital is allowed to increase its (reimbursed) activity level only if it increases the total quality in the second period; if $\alpha = 0$, x_2 depends only on the quality level at time $t = 1$ while, if $\gamma = \alpha$, x_2 depends on the quality level at time $t = 2$.

The purchasing rule (7) can be interpreted in this way: each hospital, by increasing total quality (in both periods) can increase the number of admitted (and rewarded) patients. Therefore, rule (7) represents either a situation in which higher quality hospitals attract more patients who are free to choose their preferred provider (and the purchaser pays for the increased admissions to higher quality hospitals), or a situation in which the purchaser buys more treatments from higher quality hospitals on behalf of the patients it represents. For example, in the US an HMO could set the number of patients to be treated in each hospital according to some quality indices; in the Italian NHS, an ASL (Azienda Sanitaria Locale: the purchaser) could remove (reduce) part of the yearly ceiling set on the number of treatments if the hospital increases the quality of treatments[16].

2.2.2 The medical staff

Doctors are "devoted workers", i.e. they receive utility from increasing their patients' health and therefore they prefer an earlier adoption of new technologies by the hospital that enables a rapid achievement of health outcomes on behalf of their patients. The "devoted worker" assumption can be justified on several grounds: the doctor could be considered a benevolent agent that truly believes that better health outcomes for patients can be achieved through progress in medical technology; he might even be biased in his evaluation of the effectiveness of the new technology since he wants early adoption for the benefit of his principal (the patient). On the other hand, the doctor might also be motivated by selfish interests and might wish to use the new technology to quicken his career and enhance his reputation. In any case, the technology of production enters the doctor's utility function with a positive sign and he is interested in earlier adoption of new medical equipment. He provides the effort that determines the level of total quality as defined by (6). In particular, the doctor's effort input consists of two components. The first is a minimum level of effort e_l, which can be defined as "monitored effort of the doctor", and is delivered independently

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[16] It must be pointed out that, following rule (7), higher quality hospitals are rewarded with more bought admissions at a given price p; however, the results hold even if the number of admissions were set constant, while the price varies according to quality levels.

of the adoption of the new technology by the hospital (we assume without losing in generality that $e_l = 0$). The second component is a level of effort e, which cannot be observed or verified by the other actors. Following the literature on the devoted worker (Francois, 2000, 2003; Glazer, 2004), we assume that the doctor is not paid for the unverifiable effort, though this assumption can be relaxed without substantially changing the results. The hospital hires doctors at the constant exogenous wage w; the private cost for the unverifiable effort e is defined by $m(e)$, with $m' > 0$ and $m'' > 0$. Finally, since doctors are interested in earlier adoption of the new technology, we can assume, without losing in generality, that $e_1 = e_2 = e$.

2.2.3 The hospital

The hospital is a surplus maximiser and in this respect it is interested in cost minimisation. In our model the hospital becomes interested in the quality of the care provided through the purchasing rule (7).

It stipulates a contract with the purchaser that foresees the payment of a prospective price p for each treatment. In each period, the hospital can invest in a new technology at unit cost r[17]. Then capital accumulation is given by $k_2 = k_1 + i_2$, where i_2 denotes investment in period 2. Both the investment and the effort made by the medical staff determine the level of total quality according to (6).

In addition to investment costs, the hospital faces some operating costs in running the new technology. Operating costs differ from period to period due to our assumption concerning the nature of the investment decision. In general, these costs are higher in the first period due to set-up costs, such as learning cost and human capital formation, and lower in the subsequent periods[18]. Again, to simplify we set $c_1 = c < p$ and $c_2 = 0$.

By the above arguments, the hospital net surplus in the first period is:

$$R^1(k_1, e) \equiv (p - c)x \ , \tag{8}$$

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[17] In this article, we assume that the investment cost does not change over time. However, the results would not change if we assume that the investment cost at time 2 is lower than at time 1, i.e. $r_2 < r_1$ (Levaggi and Moretto, 2004) or decreases with the dimension of the project, i.e. $r(k)$ with $r'(k) < 0$ (Dixit, 1993).

[18] As an example, we might think about introducing laser therapy to treat patients with specific diseases. In the first period, we will have to bear the cost of the equipment and the cost related to teaching the staff how to use the new technology. In the second period, the purchase of another laser to treat the same ailment simply increases the cost due to the higher number of treated patients.

and in the second period is:

$$
\begin{aligned}
R^2(k_1, k_2, e; \varepsilon; \beta) &\equiv px_2(q_1, q_2) \qquad (9)\\
&\equiv p[x + \gamma q_1(k_1, e; \varepsilon_1; \beta_1) + \alpha(q_2(k_2, e; \varepsilon_2; \beta_2) - q_1(k_1, e; \varepsilon_1, \beta_1))]
\end{aligned}
$$

2.2.4 Information structure and timing

Since the quality of hospital care and the doctors' efforts are non-contractable variables (i.e. even though the parties of a contract can observe or measure them, they cannot be enforced before a court), our model may present several forms of asymmetry of infomation among the three actors considered here. In particular, we assume that in each period:

- No one of the three actors is able to verify the current level of total quality q_t;
- The purchaser and the hospital cannot directly verify the doctors' efforts e_t.

Yet, since quality is a function of both the investment by the hospital and the effort of the medical staff, which is not observable by a third party, we also get:

- The contribution of the capital to the current quality level is not fully verifiable by both the purchaser and the doctors[19].

However, since in our two-period model the purchaser may observe ex-post the hospital capital k_1 and the doctors' efforts e, we introduce a time-gap in observing and verifying the main elements of the contract, that is:

- The purchaser may always verify ex post q_1 before a court (or a health care authority).

3 Effort and investment decision

Given the purchasing rule (7) and the information set, at time 1 the hospital and the doctors choose their state variables k_1 and e simultaneously and non-cooperatively.

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[19] Intuitively, given that quality is not verifiable, even if the medical staff can observe the level of investment in new technology, it cannot claim a high result in quality by the provision of its effort.

Since doctors keep the level of effort constant over time, q^p differs from period 1 to period 2 only for the realisation of the patients' characteristics ε. Without any loss in generality, we simplify the model by setting ε constant over time[20].

Therefore, uncertainty in the production process derives only from shocks affecting the clinical quality β. As for β, we assume that, in the first period, β_1 is known and normalised to 1 while, in the second period, $\beta_2 \equiv \beta$ is stochastic and its realisation is characterised by the cumulative distribution $\Phi(\beta)$ with density $\Phi'(\beta) > 0$ on $\beta \in [0, \infty)$, which is known by all the actors[21].

By the above assumptions, the timing of the model can be summarised as follows. At the beginning of period 1, the purchaser announces the purchasing rule (7) and the price p. The hospital and the medical staff, knowing β_1, and the purchasing rule, decide non-cooperatively k_1 and e respectively. At the beginning of period 2, q_1 becomes verifiable, nature reveals β_2 and, conditional on k_1 and e (i.e. q_1), the hospital chooses k_2.

Before proceeding with the medical staff and hospital decisions, we need to consider the ex-ante objective function of both these actors.

3.1 The medical staff's ex-ante objective function

The medical staff are paid an exogenous wage w and their effort is constant over time; their objective function can be written as:

$$B(k_1, e) \equiv w + vq_1(k_1, e) - m(e) = w + v[(1-\lambda)h(e) + \lambda g(k_1, e)] - m(e) \quad (10)$$

where v is the doctor's evaluation of each unit of quality.

3.2 The hospital's ex-ante objective function

The hospital decision to invest in health care technology is intertemporal. In particular, if in period 1 the hospital makes an investment that it cannot resell in period 2 and future capital returns are uncertain, this investment decision involves the exercise of an option. Because of this uncertainty, the opportunity of waiting to learn more about the future productivity level has a timing premium (i.e. a holding value).

We start by describing the hospital action in the second period, given the stock of investment k_1 inherited from period 1. We then step back and

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[20] ε can be the mean value of the shocks affecting the perceived quality.

[21] As in Bös and De Fraja (2002), we assume that there is symmetry of information about the technology.

show how the marginal profit in the first period depends on the hospital's expected action in the second period.

Second period

By (9), (7) and (6) the hospital's surplus at time 2 can be written as:

$$\begin{aligned} R^2(k_1,k_2,e;\beta) &\equiv p[x+\gamma q_1(k_1,e)+\alpha(q_2(k_2,e;\beta)-q_1(k_1,e))] \qquad (11)\\ &\equiv p[x+\gamma(1-\lambda)h(e)+(\gamma-\alpha)\lambda g(k_1,e)+\alpha\lambda g(k_2,e;\beta)] \end{aligned}$$

The assumptions on q^c guarantee that $R^2_{k_2}(k_1,k_2,e;\beta)) \geq 0$ is continuous and strictly decreasing in k_2 and continuous and strictly increasing in β (see Appendix A). Then, for a given stock of k_1 inherited from period 1 and effort e, we can define a critical value of β such that:[22]

$$R^2_{k_2}(k_1,e;\tilde{\beta}) \equiv p\alpha\lambda g_{k_2}(k_1,e;\tilde{\beta}) = r \qquad (12)$$

At the beginning of period 2, nature reveals β and the hospital adjusts its stock of capital to the new optimal level that we identify as $k_2(\beta)$. The stock of capital must satisfy the constraint:

$$k_2(\beta) \geq k_1 \qquad (13)$$

Thus, depending on the inherited stock k_1 and e, from (12) it emerges that when $\beta > \tilde{\beta}(k_1,e)$, it is optimal for the hospital to invest in extra units of technology up to the point where the marginal return equals the marginal investment cost r. On the other hand, when $\beta < \tilde{\beta}(k_1,e)$ the profit is so low that the hospital finds it convenient not to invest, so $k_2(\beta) = k_1$.

First period

By using the option decomposition proposed by Abel et al.(1996), we can show that:

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[22] By assumptions on (4) we get:

$$\frac{\partial\tilde{\beta}}{\partial r} = \frac{1}{p\alpha\lambda g_{k\beta}} > 0 \qquad \frac{\partial\tilde{\beta}}{\partial k} = -\frac{g_{kk}}{g_{k\beta}} > 0$$

and

$$\frac{\partial\tilde{\beta}}{\partial e} = -\frac{g_{ke}}{g_{k\beta}} > 0$$

Lemma 1 *The value of the hospital's investment can be written as:*

$$V(k_1, e) \equiv G(k_1, e) - \delta O(k_1, e) \tag{14}$$

where:

$$G(k_1, e) \equiv (p-c)x + \delta p[x + \gamma(1-\lambda)h(e) + (\gamma - \alpha)\lambda g(k_1, e) + \int_0^\infty \alpha\lambda g(k_1, e; \beta) d\Phi(\beta)]$$

$$O(k_1, e) \equiv \int_{\tilde{\beta}}^{+\infty} \{-[p\alpha\lambda g(k_2(\beta), e; \beta) - rk_2(\beta)] + [p\alpha\lambda g(k_1, e; \beta) - rk_1]\} \, d\Phi(\beta)$$

and δ is the discount factor.

Proof. See Appendix A ■

The term $G(k_1, e)$ is the hospital's expected present value of returns, keeping the stock of capital fixed at k_1. This can be interpreted as the hospital's value when it does not expand its investment in the second period. The term $O(k_1, e)$ indicates the value of the (*call*) option to expand the capital in the second period if β rises above $\tilde{\beta}$. Equation (14) then has an interesting and immediate interpretation: when the hospital invests in period 1 it gets the value $G(k_1, e)$ but gives up the opportunity or option to invest in the future, valued at $O(k_1, e)$.

The non-contractability of k_1 and e in the first period implies that the investment decisions by both actors are taken non-cooperatively. In this respect, equations (10) and (14) constitute a two-person normal form game. Therefore, we need to derive the best reply functions of the two actors.

3.3 The best reply function of the doctor

The doctor's reaction curve is derived from his first-order condition on (10), that is:

$$B_e(k_1, e) \equiv v[(1-\lambda)h'(e) + \lambda g_e(k_1, e)] - m'(e) = 0 \tag{15}$$

Moreover, since:

$$B_{ee}(k_1, e) \equiv v[(1-\lambda)h''(e) + \lambda g_{ee}(k_1, e)] - m''(e) < 0$$

for any given value of k_1 a unique value of e^* exists satisfying equation (15). The total differential of (15) yields:

$$\begin{aligned} \frac{de}{dk_1}_{|e=e^*} &= -\frac{B_{ek_1}(k_1,e)}{B_{ee}(k_1,e)} \qquad (16) \\ &\equiv -\frac{v\lambda g_{ek}(k_1,e)}{v[(1-\lambda)h''(e)+\lambda g_{ee}(k_1,e)]-m''(e)} \end{aligned}$$

Since the two inputs are substitutes, i.e. $g_{ek}(k_1,e) < 0$, the doctor's reaction curve slopes downwards. This assumption appears plausible: an increase in the doctor's effort somehow reduces hospital investment in capital, and vice versa. This is represented by the curve DD in Figure 1.

Figure 1 about here

3.4 The best reply function of the hospital

Similarly, the hospital reaction function is obtained by the first-order condition on (14). The optimal amount of capital in period 1 depends on a comparison between marginal benefits and marginal costs:

$$V_{k_1}(k_1,e) \equiv G_{k_1}(k_1,e) - \delta O_{k_1}(k_1,e) = r \qquad (17)$$

where:

$$\begin{aligned} G_{k_1}(k_1,e) &\equiv \delta p[(\gamma-\alpha)\lambda g_{k_1}(k_1,e) + \int_0^{+\infty} \alpha\lambda g_{k_1}(k_1,e;\beta)]d\Phi(\beta)] \\ &= \delta p\gamma\lambda g_{k_1}(k_1,e) + \int_0^{+\infty} \delta p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta)] \end{aligned}$$

$$O_{k_1}(k_1,e) \equiv \int_{\tilde{\beta}}^{+\infty} [p\alpha\lambda g_{k_1}(k_1,e;\beta) - r]d\Phi(\beta) \geq 0$$

Equation (17) emphasises the role played by the option pricing approach in determining the stock of capital in period 1. The hospital optimal behaviour does not simply require the equalisation of the expected present value of marginal returns in the first period, i.e. $G_{k_1}(k_1,e)$ and the marginal cost of the investment r. In fact, costs are represented by the price of the investment, r, plus the value of the marginal call option, $O_{k_1}(k_1,e)$, as investing in period 1 means giving up the opportunity of delaying the investment. Moreover, since:

$$\begin{aligned}
V_{k_1k_1}(k_1,e) &\equiv G_{k_1k_1}(k_1,e)-\delta O_{k_1k_1}(k_1,e)\\
&\equiv \delta p(\gamma-\alpha)\lambda g_{k_1k_1}(k_1,e)+\delta\int_0^{+\infty} p\alpha\lambda g_{k_1k_1}(k_1,e;\beta))d\Phi(\beta)\\
&\quad -\delta\int_{\tilde{\beta}}^{+\infty} p\alpha\lambda g_{k_1k_1}(k_1,e;\beta)d\Phi(\beta)\\
&\equiv \delta p(\gamma-\alpha)\lambda g_{k_1k_1}(k_1,e)+\delta\int_0^{\tilde{\beta}} p\alpha\lambda g_{k_1k_1}(k_1,e;\beta))d\Phi(\beta)<0
\end{aligned}$$

for any given value of r and e, a unique value of k_1^* exists satisfying equation (17).

The total differential of (17) can be written as:

$$\frac{dk_1}{de}_{|k_1=k_1^*}=-\frac{V_{k_1e}(k_1,e)}{V_{k_1k_1}(k_1,e)} \tag{18}$$

where:

$$V_{k_1e}(k_1,e)=\delta p(\gamma-\alpha)\lambda g_{k_1e}(k_1,e)+\delta\int_0^{\tilde{\beta}} p\alpha\lambda g_{k_1e}(k_1,e;\beta))d\Phi(\beta)<0$$

Since the two inputs are substitutes we get $V_{k_1e}(k_1,e)<0$ and then (18) is downward-sloping. This is represented by the curve HH in Figure 1.

3.5 The equilibrium

The intersection of the two best reply functions is the Nash equilibrium, denoted by N in Figure 1. We also assume that the doctor's reaction function is steeper than the hospital reaction function[23]. This guarantees that the Nash equilibrium is unique and stable (Vives 1999, p. 49-52). Therefore, the following proposition holds (see Figure 1):

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[23] This assumption seems reasonable since in most cases the rate of substitution between capital and effort is higher for doctors than for the hospital.

Proposition 1 *1) The presence of devoted doctors implies underinvestment at time $t = 1$.*

2) The Nash equilibrium is not optimal since it usually implies a lower level of effort and investment than the First Best.

Proof. See Appendix B ■

The first part of proposition 1 is a straightforward application of the geometric solution of the Nash equilibrium. In Figure 1, the point $(\hat{k}_1, 0)$ represents the benchmark solution for the case of a doctor that is not a devoted worker. In this case, the level of capital is higher than in our Nash solution $N = (k_1^*, e^*)$.

To compare the Nash solution with the First Best, we need to depict the hospital iso-profit and the doctor's iso-utility curves. In Figure 1, PP represents the hospital iso-profit curve and UU the doctor iso-utility curve going through point N. The First Best is the set of points where the iso-profit and iso-utility curves are tangent. From Figure 1, it can be seen that these points are characterized by a higher level of effort and investment.

4 Purchasing rule and Nash equilibrium

Let's now investigate how the purchaser can influence the investment/effort mix by changing the parameters of the purchasing rule (7). In particular we compare the Nash equilibria for the following alternative values of the parameters of the purchasing rule:

- $\alpha = 0$,so that the number of patients whose treatment is reimbursed in the second period depends only on the quality level at time $t = 1$;
- $\gamma = \alpha$,so that the number of patients whose treatment is reimbursed in the second period depends only on the quality level at time $t = 2$;
- $\gamma = 0$, and the hospital can increase the number of patients treated in the second period (and its rewards) only if the quality increases in the second period.

This comparison has important policy implications as in the first case the option to delay the investment held by the hospital is neutralized. That is, even if the level of quality can be observed only ex post, asymmetry of information is ruled out of the system. When the contract is signed, the purchaser cannot observe both the level of investment in health technology and the doctor's effort, but he will be able to do so before implementing the relevant part of the contract. In our model this is a sufficient deterrent to prevent the hospital and doctor cheating on their decision variables in the first period. In the second period the issue becomes irrelevant since the new investment is not considered in the decision of how many patients to send to the hospital.

Since the purchasing rule affects only the hospital objective function, in order to analyse how the Nash solutions change varying the parameters of (7), we need to compare the different hospital best reaction functions. Defining $k_1^{*\alpha=0}$, $k_1^{*\gamma=\alpha}$ and $k_1^{*\gamma=0}$ the level of capital that the hospital would obtain under the three cases examined, we can prove the following proposition.

Proposition 2 *1) For α sufficiently low, the level of capital and effort in period 1 can be ranked as follows:*

$$k_1^* > k_1^{*\gamma=\alpha} > \begin{array}{l} k_1^{*\gamma=0} > 0 \\ k_1^{*\alpha=0} > 0 \end{array} \qquad \textit{and} \quad 0 < e^* < e^{*\gamma=\alpha} < \begin{array}{l} e^{*\gamma=0} \\ e^{*\alpha=0} \end{array}$$

2) For α sufficiently high the level of capital and effort in period 1 can be ranked as follows:

$$k_1^{*\alpha=0} > k_1^* > k_1^{*\gamma=\alpha} \qquad \textit{and} \quad e^{*\alpha=0} < e^* < e^{*\gamma=\alpha}$$

while a Nash equilibrium for $\gamma = 0$ does not exist.

Proof. See Appendix C ■

A first important result follows from Proposition 2: the purchaser can induce the substitution of capital with effort by reducing the weight γ of the first period quality q_1 in the rule (7). That is, an increase in the ratio α/γ shifts down the hospital's best reply function (17) with respect to (18), and we obtain $k_1^* > k_1^{*\gamma=\alpha} > k_1^{*\gamma=0}$, and $e^* < e^{*\gamma=\alpha} < e^{*\gamma=0}$ as depicted in Figure 2.

As the real option theory predicts, an increase in the ratio α/γ (i.e in the weight of the option to wait α compared to the weight of investing today γ) delays the investment decision. This is a consequence of the "bad news principle of irreversible investment": a variance in health quality makes the investment return volatile with positive effect on the value of the investment. However, the net marginal benefit of waiting, arising from the avoidance of an investment in the bad state, increases. This induces delay (Bernanke, 1983).

A second important result that follows from Proposition 2 is the impossibility of a global ranking in terms of substitution between capital and effort. In fact, the optimal level of investment is not maximised for $\alpha = 0$, which contradicts the real option theory. That is, despite the disappearance of the option effect, we do not obtain a clear increase in the investment in the first period compared with k_1^* (and/or $k_1^{*\gamma=\alpha}$).

The parameter α influences both the expected marginal returns of the investment $G_{k_1}(k_1, e)$ and the marginal call option, $O_{k_1}(k_1, e)$. This means that its effect is countervailing since it incentivates delaying the investment, but it increases its expected marginal return in the first period. The overall effect may lead to $V_{k_1}(k_1, e) > V_{k_1}^{\alpha=0}(k_1, e)$ and then $k_1^* > k_1^{*\alpha=0}$. This leads indeed to the second important result of proposition 2. For any given γ, a threshold $\tilde{\alpha}$ may exist such that:

$$\begin{array}{rclll} V_{k_1}(k_1, e) & \geq & V_{k_1}^{\alpha=0}(k_1, e) & \text{for} & \alpha \leq \tilde{\alpha} \\ V_{k_1}(k_1, e) & < & V_{k_1}^{\alpha=0}(k_1, e) & \text{for} & \alpha > \tilde{\alpha} \end{array}$$

If the option effect (i.e. α) is sufficiently high, the disequality may be reverted and we get $k_1^* < k_1^{*\alpha=0}$ (Appendix C).

Figure 2 about here

5 Purchasing rule and total quality

As argued, the purchaser wants to maximise total quality in order to make the best treatment available for its patients. Although it cannot control hospital care quality, it can pursue its goal by influencing both the hospital investment in new technologies and the level of effort by the medical staff in the first period. This can be done by setting the parameters of the purchasing rule. In particular the following proposition holds :

Proposition 3 *Within the long-term contract between the hospital and the purchaser, the latter is able to rank the total quality at $t = 1$ as follows:*

1) For α sufficiently low, we get:

$$q_1^* > q_1^{*\gamma=\alpha} > \begin{array}{l} q_1^{*\gamma=0} > 0 \\ q_1^{*\alpha=0} > 0 \end{array}$$

2) For α sufficiently high, the rank becomes:

$$q_1^{*\alpha=0} > q_1^* > q_1^{*\gamma=\alpha} > q_1^{*\gamma=0} = 0$$

Proof. See Appendix D ■

The intuition for this result relies on the properties of the doctor's best reply function DD. For example, we can compare the total quality at N with the one at $N^{\gamma=\alpha}$(see Figure 3). Let's consider the "isoqual" QQ that goes through N and depicts all the values of k_1 and e compatible with a given quality level. As k_1 decreases, the doctor increases e along the curve DD, but if the marginal cost of the effort increases with e, this is not sufficient to keep the quality constant. Therefore, to the right of the point N, the isoqual QQ lies above the doctor's reply function DD, while to the left of N, it lies below DD. This implies that point $N^{\gamma=\alpha}$, which represents the Nash solution for $\gamma = \alpha$, lies on an isoqual lower than the one through N, with a reduction in the total quality. Similar results apply for the cases of $\gamma = 0$ and $\alpha = 0$.

These results have important implications both in theoretical and policy terms. In our model - as stated by the first part of Proposition 3 - for α below a specific threshold $\widetilde{\alpha}$, total quality is higher than when the purchasing rule is based only on past investment ($\alpha = 0$). This implies that, for α sufficiently low but positive, the purchaser can increase total quality in the first period without eliminating the hospital option value of investing in the second period. This is possible because of the existence of a substitution effect between capital and devoted physicians' efforts. If $\alpha = 0$, there should be no substitution between capital and effort[24].

Figure 3 about here

From proposition 3, we can also determine whether total quality is higher at the Nash solution, where the doctor values the quality, than at the solution where the doctor does not.

Corollary 1 *The total quality is higher when the doctor values it, i.e.*

$$q_1^* > q_1(\hat{k}_1, 0)$$

Proof. See Appendix E ■

If the doctor is not devoted, he sets $e = 0$ (i.e. his effort is only e_l) and the hospital sets the investment at $(\hat{k}_1, 0)$, where the reply function intersects the vertical axis. To compare the total quality at N with the one at $(\hat{k}_1, 0)$

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[24] Differently in Moretto and Levaggi (2004) the investment was higher when the option value to invest in the second period was set to zero (i.e. α was made equal to zero); in fact, the purchasing rule is backward looking (since the hospital receives more patients only if it has invested in past periods) and the current level of investment i_2 is never considered.

we consider the *isoqual* that goes through $(\hat{k}_1, 0)$, i.e. the curve $\hat{Q}\hat{Q}$ in Figure 3. Since the marginal rate of transformation between k_1 and e is decreasing, the isoqual through point $(\hat{k}_1, 0)$ lies below the curve of the hospital's reply function HH. That is, the hospital may respond optimally to an increase in the effort made by the doctor by reducing the investment less than the reduction required by the isoqual through point $(\hat{k}_1, 0)$. Therefore, point N lies on an isoqual higher than the one through $(\hat{k}_1, 0)$.

If the medical staff are not devoted, the purchaser is not able to influence the trade-off between effort and capital, hence it is indifferent between a purchasing rule defined on quality or on the level of capital. Its purchasing rule can be written as:

$$x_2(k_1, k_2) \equiv x + \gamma k_1 + \alpha(k_2 - k_1) \quad \text{with } \gamma, \alpha \geq 0 \text{ and } \gamma \geq \alpha$$

In this case, it is possible to show that the only possible rank is: $k_1^{*\alpha=0} > k_1^* > k_1^{*\gamma=\alpha} > k_1^{*\gamma=0}$as in Levaggi and Moretto (2004).

In a context where the medical staff are not devoted, the purchaser faces an intertemporal trade-off in deciding the level of investment, i.e. it might decide to delay hospital investment in new technology either for policy reasons or due to the existence of a budget constraint, but by doing so it faces the cost of verifying hospital care quality (i.e. it can verify quality only ex-post). In this case the problem in itself offers a simple solution: setting $\alpha = 0$ in the purchasing rule permits maximisation of the level of investment at $t = 1$ and rules out any verifiability problem.

On the contrary, with the presence of devoted doctors, a true trade-off exists between the level and verifiability of quality. The devoted worker adds an important dimension to the set of choices of the purchaser. Besides the intertemporal substitution between present and future investment, it becomes possible to substitute capital with doctor's effort to increase total quality. In this way, it is possible to get a higher quality even with a lower investment in new technology, but now $\alpha = 0$ is no longer sufficient to rule out the verifiability problem.

6 Conclusions

The model presented in this paper adds important new dimensions to the debate on quality and investment in new technology in hospital care.

Considering the interaction between three actors (a purchaser, a hospital and a hospital's medical staff), we explicitly model two fundamental determinants of hospital care quality: the effort of the medical staff and the investment in hospital technology which has the characteristic of being irreversible. The latter had been introduced by Levaggi and Moretto (2004); in this paper the "devoted worker" characteristics of the effort produced by the medical staff - an aspect so far neglected in the traditional literature - is modelled explicitly. The utility of the hospital medical staff depends both on the salary received and on the outcome of care. In this respect, doctors can be considered devoted workers. This assumption has important consequences both on the level of investment decided by the hospital and then on final quality of in-patient care. We show that in the game developed between the hospital and the medical staff the presence of devoted doctors allows the hospital to reduce its investment while increasing the level of quality.

We then show that, when investment in new technology is irreversible, a purchasing rule that cancels out the option to delay (i.e. $\alpha = 0$, where the purchaser reimburses the hospital only on the current level of quality) is never optimal. From a policy perspective, this result has an important implication: in the definition of the long-term contract between the purchaser and the hospital there is a trade-off between the level and the verifiability of quality. The purchaser could use the substitutability between capital and doctors' efforts to increase quality, but this reduces its ability to verify it.

The model presented in this paper is a first step in modelling quality in a devoted workers setting and our approach can be extended in several directions.

First of all, we could consider, as in Levaggi and Moretto (2004), that the technology is innovative only at the beginning (first period) of its adoption when learning costs (related to the size of the investment) are higher and future operating costs of running the technology are not known. However, it should be considered that in the second period (in general, in subsequent periods) the technology is consolidated and the hospital investing in the first period produces a positive externality to the whole system.

The assumption of the devoted worker also adds new dimensions to the quality setting of hospital care. In this paper we have in fact assumed that all the actors care about the same type of quality, but this assumption might be relaxed. In particular, it could be considered that the type of hospital care quality depends on the type of treatment. For surgical treatment, for example, clinical quality is probably very important, but for rehabilitation or for palliative care, perceived (relational) quality might be considered more relevant. In the latter cases, the relatively higher importance of perceived quality might mitigate the effect of the devoted physician on the investment decision, hence on the optimal purchasing rule. Another important extension could be the explicit consideration within the model of hospital competition on quality ruled by patients' choices. This would add another important actor (the patient) to the model and in this case the hospital's reputation would become an essential ingredient of perceived quality.

A Proof of Lemma 1

At $t = 2$, the hospital's surplus is given by (11), i.e:

$$\begin{aligned} R^2(k_1, k_2, e; \beta) &\equiv p[x + (\gamma - \alpha)q_1(k_1, e) + \alpha q_2(k_2, e; \beta)] \\ &\equiv p[x + \gamma(1 - \lambda)h(e) + (\gamma - \alpha)\lambda g(k_1, e) + \alpha\lambda g(k_2, e; \beta)] \end{aligned}$$

with the properties:

$$R^2_{k_2} \equiv p\alpha \frac{\partial q_2}{\partial k_2} \equiv p\alpha\lambda g_{k_2}(k_2, e; \beta) > 0, \tag{19}$$

$$R^2_{k_2k_2} \equiv p\alpha \frac{\partial^2 q_2}{\partial k_2^2} \equiv p\alpha\lambda g_{k_2k_2}(k_2, e; \beta) < 0, \tag{20}$$

If the hospital does not invest in the second period, i.e. $k_2 = k_1$, its surplus (11) reduces to:

$$\begin{aligned} R^2(k_1, e; \beta) &\equiv p[x + (\gamma - \alpha)q_1(k_1, e) + \alpha q_2(k_1, e; \beta)] \\ &\equiv p[x + \gamma(1 - \lambda)h(e) + (\gamma - \alpha)\lambda g(k_1, e) + \alpha\lambda g(k_1, e; \beta)] \end{aligned}$$

which still depends on both q_1 and q_2[25]. Finally:

$$R^2_{k_2\beta} \equiv p\alpha \frac{\partial^2 q_2}{\partial k_2 \partial \beta} \equiv p\alpha\lambda g_{k_2\beta}(k_2, e; \beta) > 0 \tag{21}$$

Since the value of the hospital at $t = 1$ is:

$$V(k_1, e) \equiv R^1(k_1, e) + \delta \left\{ \int_0^{\tilde{\beta}} R^2(k_1, e; \beta) d\Phi(\beta) \right. \tag{22}$$

$$\left. + \int_{\tilde{\beta}}^{+\infty} \{R^2(k_1, k_2(\beta), e; \beta) - r[k_2(\beta) - k_1] \} d\Phi(\beta) \right\},$$

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[25] Only if $\beta = 1$ we get $q_2 = q_1$ and

$$R^2(k_1, e; \beta) \equiv p[x + \gamma q_1(k_1, e)]$$

easy computation shows that (22) can be written as:

$$V(k_1,e) \equiv R^1(k_1,e) + \delta \int_0^{+\infty} R^2(k_1,e;\beta)d\Phi(\beta) \tag{23}$$

$$+\delta \int_{\tilde{\beta}}^{+\infty} \{-[R^2(k_1,k_2(\beta),e;\beta) - rk_2(\beta)] + [R^2(k_1,e;\beta) - rk_1]\}d\Phi(\beta).$$

where δ is the discount factor. Then, defining:

$$G(k_1,e) \equiv R^1(k_1,e) + \delta \int_0^{+\infty} R^2(k_1,e;\beta)d\Phi(\beta),$$

$$O(k_1,e) \equiv \int_{\tilde{\beta}}^{+\infty} \{-[R^2(k_1,k_2(\beta),e;\beta) - rk_2(\beta)] + [R^2(k_1,e;\beta) - rk_1]\}d\Phi(\beta),$$

by direct substitution of (8) and (11), we obtain:

$$V(k_1,e) = G(k_1,e) - \delta O(k_1,e)$$

where:

$$\begin{aligned}
G(k_1,e) &\equiv (p-c)x + \delta \int_0^{\infty} p[x + (\gamma-\alpha)q_1(k_1,e) + \alpha q_2(k_1,e;\beta)]d\Phi(\beta) \\
&\equiv (p-c)x + \delta \int_0^{\infty} p[x + \gamma(1-\lambda)h(e) + (\gamma-\alpha)\lambda g(k_1,e) + \alpha\lambda g(k_1,e;\beta)]d\Phi(\beta) \\
&\equiv (p-c)x + \delta p[x + \gamma(1-\lambda)h(e) + (\gamma-\alpha)\lambda g(k_1,e) + \int_0^{\infty} \alpha\lambda g(k_1,e;\beta)d\Phi(\beta)]
\end{aligned}$$

$$\begin{aligned}
O(k_1,e) \equiv \int_{\tilde{\beta}}^{+\infty} &\{-[p(x + (\gamma-\alpha)q_1(k_1,e) + \alpha q_2(k_2(\beta),e;\beta)) - rk_2(\beta)] \\
&+ [p(x + (\gamma-\alpha)q_1(k_1,e) + \alpha q_2(k_1,e;\beta)) - rk_1]\}\, d\Phi(\beta)
\end{aligned}$$

$$\equiv \int_{\tilde{\beta}}^{+\infty} \left\{-[p\alpha q_2(k_2(\beta),e;\beta)) - rk_2(\beta)] + [p\alpha q_2(k_1,e;\beta)) - rk_1]\right\} d\Phi(\beta)$$

$$\equiv \int_{\tilde{\beta}}^{+\infty} \{-[p(\alpha((1-\lambda)h(e) + \lambda g(k_2(\beta),e;\beta))) - rk_2(\beta)]$$
$$+ [p(\alpha((1-\lambda)h(e) + \lambda g(k_1,e;\beta))) - rk_1]\} d\Phi(\beta)$$

$$\equiv \int_{\tilde{\beta}}^{+\infty} \left\{-[p\alpha\lambda g(k_2(\beta),e;\beta) - rk_2(\beta)] + [p\alpha\lambda g(k_1,e;\beta) - rk_1]\right\} d\Phi(\beta)$$

This concludes the proof.

B Proof of Proposition 1

The first part of the proposition is a straightforward application of the geometric solution of the Nash equilibrium. For the second part, we need to draw the hospital's iso-profit curve and the doctor's iso-utility curve in the (k_1, e) plane.

Let's start with the doctor's iso-utility curve. Totally differentiating (10) we get:

$$B_{k_1}(k_1,e)dk_1 + B_e(k_1,e)de = dB$$

and, setting $dB = 0$, we *can* evaluate the sign of:

$$\frac{dk_1}{de} = -\frac{B_e(k_1,e)}{B_{k_1}(k_1,e)} \tag{24}$$

The numerator is simply given by (15) while the denominator is:

$$B_{k_1}(k_1,e) \equiv v\lambda g_{k_1}(k_1,e) > 0$$

Then the slope of the iso-utility curve is simply determined by (15). For a fixed value of k_1,(24) is decreasing up to e^* and increasing for a higher value of e. The same procedure determines the hospital's iso-profit curve. By totally differentiating (14) we get

$$V_{k_1}(k_1, e)dk_1 + V_e(k_1, e)de = dV$$

and, then:

$$\frac{dk_1}{de} = -\frac{V_e(k_1, e)}{V_{k_1}(k_1, e)} \tag{25}$$

The numerator of (25) is simply (17) and the denumerator is given by:

$$\begin{aligned}
V_e(k_1, e) &\equiv G_e(k_1, e) - \delta O_e(k_1, e) \\
&\equiv \delta p[\gamma(1-\lambda)h'(e) + (\gamma - \alpha)\lambda g_e(k_1, e) + \int\limits_0^{\infty} \alpha\lambda g_e(k_1, e; \beta) d\Phi(\beta)] \\
&\quad -\delta \int\limits_{\tilde{\beta}}^{+\infty} \{-[p\alpha\lambda g_e(k_2(\beta), e; \beta)] + [p\alpha\lambda g_e(k_1, e; \beta)]\} \, d\Phi(\beta) \\
&\equiv \delta p[\gamma(1-\lambda)h'(e) + (\gamma - \alpha)\lambda g_e(k_1, e) + \int\limits_0^{\tilde{\beta}} \alpha\lambda g_e(k_1, e; \beta) d\Phi(\beta)] \\
&\quad +\delta \int\limits_{\tilde{\beta}}^{+\infty} \{p\alpha\lambda g_e(k_2(\beta), e; \beta)\} \, d\Phi(\beta)
\end{aligned}$$

Since the above expression is always positive the slope of the iso-profit curve is, for a fixed value of e,decreasing up to k_1^* and increasing for a higher value of k_1. This concludes the proof.

C Proof of Proposition 2

Since the purchasing rule affects only the hospital's objective function, to compare the Nash solutions varying the parameters of (7) we need to compare the different hospital best reaction functions.

Firstly, if $\gamma = \alpha$ the purchasing rule becomes $x_2 = x + \alpha q_2$. The necessary condition for a maximum (17) becomes:

$$V_{k_1}^{\gamma=\alpha}(k_1, e) \equiv G_{k_1}^{\gamma=\alpha}(k_1, e) - \delta O_{k_1}(k_1, e) = r \tag{26}$$

where:

$$G_{k_1}^{\gamma=\alpha}(k_1,e) \equiv \delta \int_0^{+\infty} p\alpha\lambda g_{k_1}(k_1,e;\beta))d\Phi(\beta)$$

$$O_{k_1}(k_1,e) \equiv \int_{\tilde{\beta}}^{+\infty} [p\alpha\lambda g_{k_1}(k_1,e;\beta) - r]d\Phi(\beta) \geq 0$$

and $\tilde{\beta}$ is given by (12). Since $G_{k_1}^{\gamma=\alpha}(k_1,e) < G_{k_1}(k_1,e)$ the hospital's reaction function shifts down and to the left as depicted in Figure 2.

Secondly, if $\gamma = 0$ the purchasing rule becomes $x_2 = x + \alpha(q_2 - q_1)$, which makes the surplus $R^2(k_2,k_1,e;\beta)$ independent from q at $q_2 = q_1$. The necessary condition for a maximum (17) becomes:

$$V_{k_1}^{\gamma=0}(k_1,e) \equiv G_{k_1}^{\gamma=0}(k_1,e) - \delta O_{k_1}(k_1,e) = r \tag{27}$$

where:

$$G_{k_1}^{\gamma=0}(k_1,e) \equiv \delta \int_0^{+\infty} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e;1)]d\Phi(\beta)]$$

$$O_{k_1}(k_1,e) \equiv \int_{\tilde{\beta}}^{+\infty} [p\alpha\lambda g_{k_1}(k_1,e;\beta) - r]d\Phi(\beta) \geq 0$$

and $\tilde{\beta}$ is still given by (12). Since $G_{k_1}^{\gamma=0}(k_1,e) < G_{k_1}^{\gamma=\alpha}(k_1,e)$ we have another shift to the left of the hospital's reply curve as in Figure 2.

Finally, if $\alpha = 0$ the purchasing rule reduces to $x_2 = x + \gamma q_1$. For any given stock of q_1 inherited from period 1, the surplus at $t = 2$ is always constant, which makes $q_2(\beta) = q_1$ for all β. Then, condition (17) reduces to:

$$V_{k_1}^{\alpha=0}(k_1,e) \equiv G_{k_1}^{\alpha=0}(k_1,e) = r \tag{28}$$

where:

$$G_{k_1}^{\alpha=0}(k_1,e) \equiv \delta p\gamma\lambda g_{k_1}(k_1,e)$$

$$O_{k_1}^{\alpha=0}(k_1,e) \equiv 0$$

To compare (28) with (17), we can first rewrite $G_{k_1}(k_1,e)$ in the following form:

$$\begin{aligned} G_{k_1}(k_1,e) &\equiv \delta p[(\gamma-\alpha)\lambda g_{k_1}(k_1,e)+\int\limits_0^{+\infty}\alpha\lambda g_{k_1}(k_1,e;\beta))d\Phi(\beta)] \\ &= \delta p\gamma\lambda g_{k_1}(k_1,e)+\delta\int\limits_0^{+\infty}p\alpha\lambda[g_{k_1}(k_1,e;\beta)-g_{k_1}(k_1,e)]d\Phi(\beta) \\ &= G_{k_1}^{\alpha=0}(k_1,e)+G_{k_1}^{\gamma=0}(k_1,e) \end{aligned}$$

and:

$$\begin{aligned} V_{k_1}(k_1,e) &\equiv V_{k_1}^{\alpha=0}(k_1,e)+G_{k_1}^{\gamma=0}(k_1,e)-\delta O_{k_1}^{\gamma=0}(k_1,e) \\ &\equiv V_{k_1}^{\alpha=0}(k_1,e)+V_{k_1}^{\gamma=0}(k_1,e) \end{aligned} \tag{29}$$

Therefore, if $V_{k_1}^{\gamma=0}(k_1,e)>0$, $k_1^{\alpha=0}$ cannot be greater than k_1.Furthermore, if we specify (29) for the case in which $\alpha=\gamma$ it is easy to show that:

$$V_{k_1}^{\gamma=\alpha}(k_1,e)\equiv V_{k_1}^{\alpha=0}(k_1,e)+V_{k_1}^{\gamma=0}(k_1,e) \tag{30}$$

hence, if $V_{k_1}^{\gamma=0}(k_1,e)>0$ we get $V_{k_1}^{\gamma=\alpha}(k_1,e)-V_{k_1}^{\alpha=0}(k_1,e)>0$ and the first part of the proposition follows.

Let's now consider the second part of the proposition. By (29) (and (30)), a necessary condition for having $k_1^{\alpha=0}>k_1^*$ is $V_{k_1}^{\gamma=0}(k_1,e)\equiv G_{k_1}^{\gamma=0}(k_1,e)-\delta O_{k_1}(k_1,e)<0$, which in turn implies $k_1^{\gamma=0}=0$. After some simple algebraical manipulations we obtain:

$$\begin{aligned}
& G_{k_1}^{\gamma=0}(k_1,e) - \delta O_{k_1}(k_1,e)\ddot{y} \qquad (31) \\
= \; & \delta[\int_0^{+\infty} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) - \int_{\tilde{\beta}}^{+\infty}[p\alpha\lambda g_{k_1}(k_1,e;\beta) - r]d\Phi(\beta)] \\
= \; & \delta[\int_0^{\tilde{\beta}} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) + \int_{\tilde{\beta}}^{+\infty} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) \\
& - \int_{\tilde{\beta}}^{+\infty}[p\alpha\lambda g_{k_1}(k_1,e;\beta) - r]d\Phi(\beta)] \\
= \; & \delta[\int_0^{\tilde{\beta}} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) + \int_{\tilde{\beta}}^{+\infty}[r - p\alpha\lambda g_{k_1}(k_1,e)]d\Phi(\beta)] \\
= \; & \delta[\int_0^{\tilde{\beta}} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) + [r - p\alpha\lambda g_{k_1}(k_1,e)](1 - \Phi(\tilde{\beta})] \\
= \; & \delta[\int_0^{\tilde{\beta}} p\alpha\lambda[g_{k_1}(k_1,e;\beta) - g_{k_1}(k_1,e)]d\Phi(\beta) + p\alpha\lambda[g_{k_1}(k_1,e;\tilde{\beta}) - g_{k_1}(k_1,e)](1 - \Phi(\tilde{\beta})]
\end{aligned}$$

If $\tilde{\beta} < 1$, the first and second terms of (31) are both negative which yields $G_{k_1}^{\gamma=0}(k_1,e) - \delta O_{k_1}(k_1,e) < 0$. On the contrary if $\tilde{\beta} > 1$ the second term is positive while the sign of the first term is ambiguous, and becomes positive if $\tilde{\beta} \gg 1$. Therefore, since:

$$\frac{\partial\tilde{\beta}}{\partial\alpha} = -\frac{g_k(k_1,e;\tilde{\beta})}{\alpha g_{k\beta}} < 0$$

a trigger value $\tilde{\alpha}$ may exist such that:

$$\begin{array}{rcll}
V_{k_1}(k_1,e) & < & V_{k_1}^{\alpha=0}(k_1,e) & \text{for } \alpha > \tilde{\alpha} \\
V_{k_1}(k_1,e) & \geq & V_{k_1}^{\alpha=0}(k_1,e) & \text{for } \alpha \leq \tilde{\alpha}
\end{array}$$

This concludes the proof.

D Proof of Proposition 3

To prove the proposition it is sufficient to show that the isoquals that pass through the Nash equilibrium can be ranked.

Lemma 2 *The isoqual that passes through a Nash equilibrium, say N, lies above the hospital's reply function HH and below DD to the left of N and below HH and above DD to the right.*

Proof. To do this we compare the slope of the isoqual with the slope of the hospital's reply function and the slope of the doctor's reply function respectively. Let's first recall the MRT between k and e and the slope of the hospital's reaction function, i.e.:

$$MRT_{k,e} \equiv \frac{dk_1}{de}_{\ q=\bar{q}} = -\frac{(1-\lambda)h'(e)+\lambda g_e}{\lambda g_k} < 0, \tag{32}$$

$$\frac{dk_1}{de}_{\ |k_1=k_1^*} = -\frac{V_{k_1 e}}{V_{k_1 k_1}} < 0 \tag{33}$$

By (32) and (33), the slope of the isoqual is greater than the slope of the hospital's reaction function if:

$$\frac{(1-\lambda)h'(e)+\lambda g_e}{\lambda g_k} > \frac{V_{k_1 e}}{V_{k_1 k_1}} \tag{34}$$

Secondly, the condition that guarantees that the MRT is decreasing in e is:

$$\frac{\partial MRT_{k,e}}{\partial e} = -\frac{[(1-\lambda)h''(e)+\lambda g_{ee}]\lambda g_k - [(1-\lambda)h'(e)+\lambda g_e]\lambda g_{ke}}{(\lambda g_k)^2} > 0$$

or:

$$\frac{(1-\lambda)h''(e)+\lambda g_{ee}}{\lambda g_{ke}} > \frac{(1-\lambda)h'(e)+\lambda g_e}{\lambda g_k} \tag{35}$$

Putting together (34) and (35), with an MRT decreasing in e, the condition (34) becomes:

$$\frac{(1-\lambda)h''(e)+\lambda g_{ee}}{\lambda g_{ke}} > \frac{V_{k_1 e}}{V_{k_1 k_1}} \tag{36}$$

Thirdly, the condition that guarantees the stability of the Nash equilibrium (Vives 1999, p. 49-52) requires:

$$V_{k_1 k_1} B_{ee} > V_{k_1 e} B_{e k_1}$$

or:

$$\frac{B_{ee}}{B_{ek_1}} \equiv \frac{v[(1-\lambda)h''(e)+\lambda g_{ee}]-m''(e)}{v\lambda g_{ek}} > \frac{V_{k_1 e}}{V_{k_1 k_1}} \tag{37}$$

which is equivalent to (36) if $m'' = 0$. Therefore, if (37) holds for $m'' < 0$ also (36) holds. Finally,

$$\frac{de}{dk_1}_{|e=e^*} = -\frac{B_{ek_1}}{B_{ee}} \equiv -\frac{v\lambda g_{ek}}{v[(1-\lambda)h''(e)+\lambda g_{ee}]-m''(e)}$$

is also the inverse of the doctor's best reply function. ■

Let's consider the isoqual that passes through N. As HH shifts down (i.e. k_1 decreases) the doctor increases e along the curve DD and a new equilibrium N' is reached. By Lemma 2, however, N' lies on an isoqual lower than the one through N, with a reduction in the total quality. On the contrary if HH shifts up (i.e. k_1 increases) the doctor decreases e along the curve DD and by Lemma 2, the new Nash solution N'' lies on an isoqual higher than the one through N, with an increase in the total quality. This concludes the proof.

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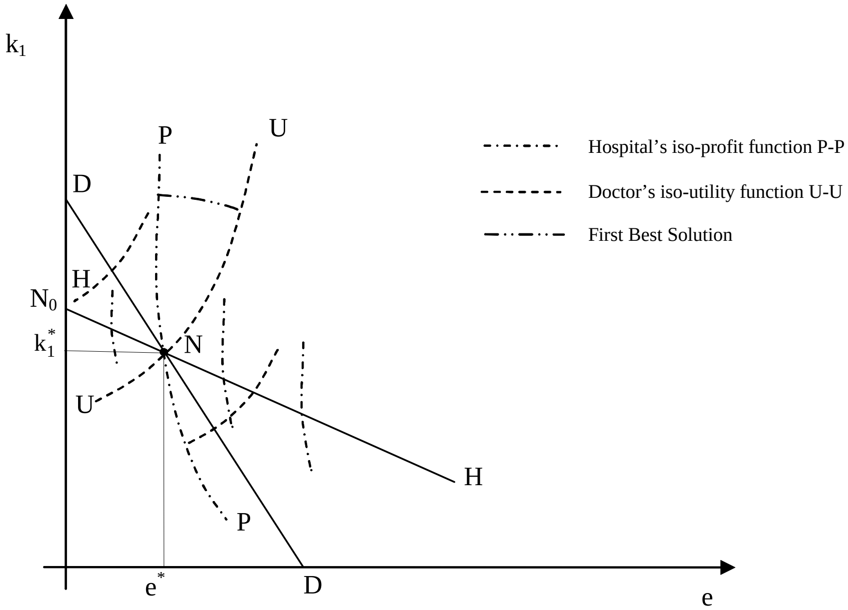
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Hospital's iso-profit function P-P
Doctor's iso-utility function U-U
First Best Solution

Figure 1

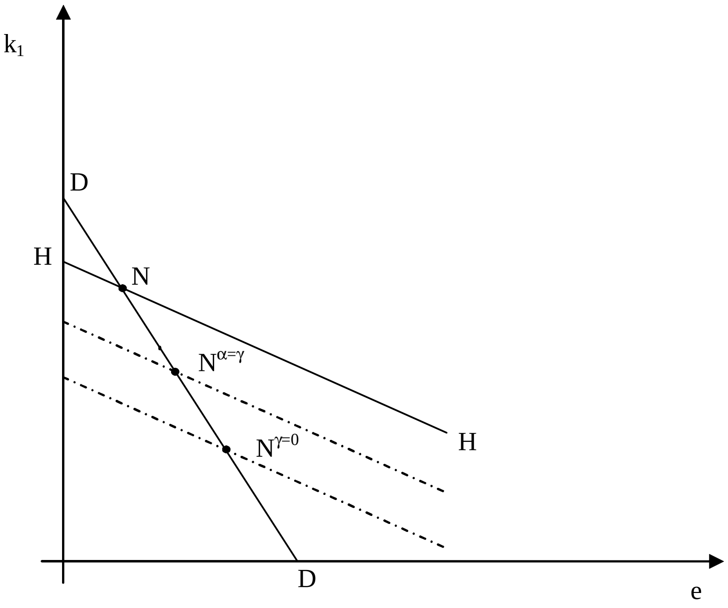

Figure 2

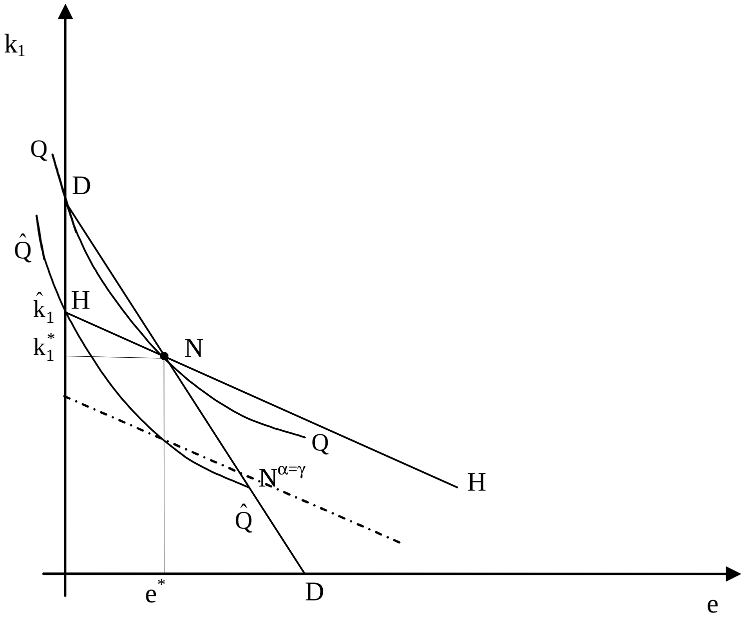

Figure 3

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