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Quality discrimination in healthcare markets*

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Abstract

Recent advances in healthcare information technologies allow healthcare providers to more accurately track patient characteristics and predict the future treatment costs of previously treated patients, which increases the scope for providers to quality discriminate across different patient types. We theoretically analyse the potential implications of such quality discrimination in a duopoly setting with profit-maximising hospitals, fixed prices and heterogeneous patients. Our analysis shows that the ability to quality discriminate tends to intensify competition and lead to higher quality provision, which benefits patients but makes the hospitals less profitable. Nevertheless, the effect on social welfare is *a priori* ambiguous, since quality discrimination also leads to an inefficient allocation of patients across hospitals.

Keywords: Quality discrimination; Hospital competition; Patient heterogeneity.

JEL Classification: I11, I14, L13.

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1 Introduction

Recent decades have witnessed an increasing use of prospective payment schemes by public and private insurers to pay for the provision of health services (Meng et al., 2020). In contrast to cost-based reimbursement, prospective payment schemes, such as payment based on Diagnoses Related Groups (DRGs), are advocated on the grounds that they lead to cost internalisation and therefore give incentives for cost-efficient provision of healthcare. However, such efficiency gains might come at a cost. One particular concern is that, in the presence of patient heterogeneity that is observable to healthcare providers but unobservable to the regulator, prospective payment schemes might lead to undesirable selection effects by giving healthcare providers an incentive for 'cream skimming' of low-cost patients, implying that a larger share of healthcare resources are directed towards patients that are more profitable to treat.[1]

Cream skimming can potentially occur via several different channels, such as transfer of high-cost patients to other hospitals (Yang et al., 2020) or specialising in procedures and treatments that disproportionately attract low-cost patients (Street et al., 2010). A more profitable patient mix can in principle also be obtained by providing different qualities to different patient types. If low-cost (high-cost) patients are offered higher (lower) quality of care, and if patient demand responds to quality, such quality discrimination across patient types might change a healthcare provider's patient composition in a profitable way. However, the presence of incentives for quality discrimination does not necessarily mean that profit-oriented healthcare providers are able to successfully discriminate across different patient types. With fixed prices, quality discrimination must be based on some patient characteristics that are observable to hospitals and that are

[1] See Ma and Mak (2019) for an overview and discussion of healthcare providers' incentives under different payment schemes.

also correlated with treatment costs (within a given DRG).[2] Thus, it is far from obvious that quality discrimination is feasible and the available empirical evidence of such discrimination is also sparse (Ma and Mak, 2019).

The point of departure for the present analysis is the observation that recent technological developments have the potential to greatly improve healthcare providers' ability to identify patients' cost types and therefore increase the scope for quality discrimination across different patient groups. The general rapid digitalisation process in modern societies has in the healthcare sector resulted in the adoption of Electronic Medical Records and Healthcare Information Systems, including wearable and smart devices. Furthermore, the use of Big Data analytics enables hospitals to run algorithms to analyse multiple types of data and incorporate them into predictions for disease risk, diagnosis, prognosis, and appropriate treatments (Ngiam and Khor, 2019). Such algorithms can be used for prediction of high-cost patients, readmissions, triage, decompensation, adverse events, and treatment optimisation for diseases affecting multiple organ systems (Bates et al., 2014; Ghani et al., 2014; Wang et al., 2018). Applications of these techniques include either machine learning to analyse the prediction of disease risks (Chen et al., 2017) or natural language processing to identify high-risk factors and for predictions of patients' future diseases (Martin-Sanchez et al., 2017). Our claim is that these technological advances enable healthcare providers to predict the future treatment costs of previously treated patients with some degree of precision, a process that we will henceforth refer to as *patient tracking*, and which in turn significantly increases the scope for healthcare providers to practice quality discrimination across different patient types.

The main aim of the present paper is to explore the potential implications of quality dis-

[2] With endogenous prices, healthcare providers could in principle offer a menu of contracts and let patients self-select into different price-quality combinations.

crimination in healthcare markets where providers compete on quality to attract patients. More specifically, we want to investigate how the ability to practice quality discrimination is likely to affect quality provision, patient utility, provider profits and social welfare. Should patients and policymakers be concerned about the prospect of increased quality-discriminating behaviour among competing healthcare providers? And will profit-oriented healthcare providers benefit from the ability to quality discriminate?

In order to answer these questions, we develop a theoretical model of quality competition between two profit-maximising healthcare providers (hospitals) facing regulated prices. As is common in the literature, we apply a spatial modelling framework where patients choose hospital based on quality and travelling (or mismatch) costs. Besides horizontal differentiation, patients also differ in terms of treatment costs, and each patient in the market has a treatment history at one of the hospitals. The novel feature of our model is that we allow for quality discrimination along two different dimensions. The hospitals are not only able to distinguish between new and returning patients, but can also determine the cost type of the latter category of patients with some degree of precision. Thus, we allow each hospital to quality-discriminate between new and returning patients, and also between high- and low-cost returning patients.

Our analysis produces a large and detailed set of results, but the main gist of these results is that, equity concerns apart, quality discrimination tends to benefit patients and harm profit-oriented healthcare providers. Although high-cost patients are offered lower quality than low-cost patients, the former category of patients still receive a higher quality of care than they would have done if quality discrimination was not possible. The reason for this (perhaps surprising) result is that quality competition is characterised by strategic complementarity. If each hospital uses quality discrimination to attract more profitable patients, this triggers positive strategic responses from the competing hospital that ultimately leads to higher quality for all patient types. Furthermore, we find that the average patient enjoys higher quality in equilibrium if quality discrimination is two-dimensional rather than one-dimensional. While these strategic effects benefit patients, the hospitals are caught in a Prisoners' Dilemma. Although each hospital has a unilateral incentive to quality discriminate, the business-stealing effect of quality discrimination implies that a larger share of their potential profits are competed away in equilibrium. This might suggest that quality discrimination also improves social welfare. However, this is not necessarily the case, even in a model where equilibrium quality is always below the first-best level. The reason is that quality discrimination also increases the share of patients who switch hospital, thus increasing total mismatch costs. The inefficiency related to excessive switching might outweigh the benefits of higher quality provision, implying that the effect of quality discrimination on social welfare is *a priori* ambiguous.

Our paper is related to what is now a sizeable theoretical literature on quality competition in healthcare markets. Our analysis shares many of the standard features of this literature, with profit-oriented providers competing for patients in a spatial setting with regulated prices.[3] With few exceptions, though, quality discrimination is not an issue.[4] These exceptions include Allen and Gertler (1991) and Glazer and McGuire (1993), but neither of these papers considers strategic interaction between healthcare providers, which is a key feature of the present analysis, and in the latter paper, quality discrimination is only enabled by price discrimination in the form of 'balance billing' by monopolistically competitive physicians.[5] The paper on quality

[3] Some key early contributions to this literature include Wolinsky (1997), Gravelle (1999), Beitia (2003), Karlsson (2007), Brekke et al. (2007) and Brekke et al. (2011).

[4] Siciliani and Straume (2019) address equity concerns related to unequal quality of care across othewise similar patients in a hospital market, but these inequalities are caused by quality differences across hospitals and not by quality discrimination within hospitals.

[5] Price and quality discrimination among competing general practitioners is also considered by Gravelle et al. (2016).

discrimination that is most closely related to ours is Ellis (1998). Like us, he considers a spatial model of quality competition between healthcare providers where patients are heterogeneous with respect to treatment costs (in a way that is unobservable to the regulator). However, the main focus in that paper is on the effect of different reimbursement schemes (prospective payment versus cost reimbursement) on providers' incentives for 'creaming', 'skimping' and 'dumping', and the analysis is carried out under the somewhat heroic assumption that perfect quality discrimination across a continuum of patient types is feasible. In contrast, we stress the importance of new versus returning patients and assume that quality discrimination based on cost types is only feasible for the latter category of patients, which has important implications for the strategic interaction between the hospitals in our model.

The scant theoretical literature on quality discrimination in healthcare markets probably reflects the limited feasibility of such practices. This is also reflected in the empirical evidence, which, as previously mentioned, finds relatively limited evidence of quality discrimination. Meltzer et al. (2002) study the effect of competition on the degree of quality discrimination under prospective payment in Californian hospital markets and find weak evidence of 'skimping' on high-cost patients as a result of more competition. Rosenman et al. (2005) test for quality discrimination among community clinics in California based on insurance types but find no evidence of such discrimination. Schwierz et al. (2011), on the other hand, find evidence from Germany on waiting time discrimination (which can be seen as a form of quality discrimination) by hospitals across patients according to insurance type, and Berta et al. (2021) find some evidence from Italy that hospitals use quality discrimination to attract extra-regional patients.[6] Despite the sparse empirical evidence, our assertion is that recent developments in patient tracking tech-

[6] Asplin et al. (2005) and Lungen et al. (2008) also find evidence of discrimination based on insurance type.

nologies considerably increase the scope for quality discrimination by healthcare providers. To which extent this will actually occur is of course an empirical question, but the present analysis explores some potential implications of such practices that can help guiding future empirical research.

Finally, our paper is also related to the vast literature on behaviour-based price discrimination (BBPD). In the early BBPD literature, price discrimination is usually purely based on the distinction between new and returning customers, and the analyses typically revolve around firms' unilateral incentives to attract profitable demand by offering a discount to new customers (see Fudenberg and Villas-Boas, 2006, for an overview of this literature). Although the institutional setting is quite different, the results in present paper mirror one of the key insights from the early BBPD literature, namely that price discrimination can be pro-competitive in an oligopolistic setting and thus harm firms' profits. The more recent BBPD literature has considered cases in which firms are also able to retain additional information about the characteristics of their consumers (e.g., Esteves, 2014; Colombo, 2018). One example of such information is consumers' cost-to-serve, which closely resembles the notion of treatment costs in the present study. In a context where consumers differ in how costly they are to serve, Shin et al. (2012) study cream-skimming of more profitable consumers through price discrimination (i.e., charging higher prices to consumers that are more costly to serve). A similar type of analysis is undertaken by Subramanian et al. (2014), who find that, due to strategic interaction, it can actually be profitable for a firm to retain unprofitable consumers.

None of the above mentioned papers considers quality discrimination, which is generally absent from the BBPD literature. One notable exception, however, is Li (2021), who analyses behaviour-based price and quality discrimination in a framework similar to standard BBPD models, but with quality as a second dimension of competition (and thus discrimination).[7] A main insight from this study is that the ability to quality discriminate reduces profits but increases consumers' surplus and welfare. Interestingly, these results have a strong resemblance to some of the main results from the present paper, although our study is cast in a very different institutional context, with price regulation and two-dimensional quality discrimination based on patient cost types.

The remainder of the paper is organised as follows. The model is presented in the next section, and in Section 3 we derive the Nash equilibrium of a game in which the hospitals do not (or cannot) engage in quality discrimination. This case will be used as a benchmark for comparison when considering the effects of quality discrimination. In Section 4 we analyse the effects of, respectively, one- and two-dimensional quality discrimination on the equilibrium quality provision to each patient group and to the 'average' patient. The resulting impacts on patient utility, profits and social welfare are analysed in Section 5, where we also derive the first-best outcome in terms of quality provision and patient allocation across the two hospitals. Two different extensions to the main analysis are presented in Section 6. First, we consider the asymmetric case in which patient tracking technologies are available only to one of the hospitals in the market. Second, we consider the (symmetric) case in which patient tracking is imperfect, so that the cost type of returning patients can only be determined with a certain probability. Finally, some concluding remarks are offered in Section 7.

[7] A somewhat related analysis is Zhang (2011), who studies the incentives for firms to offer personalised product variants based on consumers' purchase histories.

2 Model

Consider a market for elective hospital treatment offered by two hospitals, indexed by $i = A, B$, located at the opposite endpoints of the unit line segment $[0, 1]$. Let Hospital A be located at 0 and Hospital B at 1. Demand comes from a unit mass of patients whose preferences for hospitals are uniformly distributed on the line. A particular patient location on the line can be interpreted as a diagnosis in a disease space or as her residence in a geographical space. Therefore, hospitals can be differentiated with respect to their physical location or with respect to the treatments and services they offer.

We assume that patients are heterogeneous along two different dimensions. In addition to the spatial heterogeneity given by a uniform patient distribution along the unit line, we also assume that patients differ in their treatment costs because of how they react and behave in response to hospital treatment, in terms of medication adherence or individual healthcare behaviour. At each point on the unit line, a share $\alpha \in (0, 1)$ of the patients are low-cost patients, whereas the remaining share $1 - \alpha$ are high-cost patients. We denote these two patient types by L and H, respectively. Regardless of type, each patient demands a single unit of treatment either from Hospital A or from Hospital B. Consider a patient of type $s = L, H$ located at $x \in [0, 1]$. If this patient is offered a treatment with quality q_i^s by Hospital i, located at z_i, the patient's utility is given by

$$u^s\left(x, q_i^s\right) = v + q_i^s - t\left|x - z_i\right|, \tag{1}$$

where $v > 0$ is the patient's gross valuation of treatment, which we assume is high enough to guarantee that the market is always fully covered, and $t > 0$ is the patient's travelling (or mismatch) cost per unit of distance.

Whereas the utility parameters v and t are constant across patient types, we assume that the cost of treating a particular patient depends on the patient's cost type and on the quality of treatment offered to this patient. More specifically, if a patient of type s is offered a treatment by Hospital i with quality q_i^s, the cost of treating this patient is $c_s q_i^s$, with $i = A, B,\ s = L, H$ and $c_H > c_L$. We simplify this assumption by letting $c_H = 1$ and $c_L = \gamma$, where $\gamma \in (2/3, 1)$ is a parsimonious measure of patient heterogeneity with respect to treatment costs. The size of this cost heterogeneity is restricted to $c_H/c_L < 3/2$ in order to ensure the existence of interior-solution Nash equilibria in all games considered. We also assume that the treatment quality is bounded by an interval $[\underline{q}, \overline{q}]$, where the lower bound $\underline{q}$ might be interpreted as a malpractice threshold.

The hospitals are assumed to be profit maximisers. They are prospectively financed by a third-party payer offering a per-treatment price p (which can be interpreted as a DRG price) and potentially a lump-sum transfer T. As in Ellis (1998), we assume that patient heterogeneity with respect to treatment cost is unobservable to the regulator, so that the treatment price is the same for all treatments/patients (thus, we are considering within-DRG patient heterogeneity).[8] Suppose that all patients of type $s = L, H$ are offered a treatment with quality q_i^s by Hospital i. Assuming that the revenues do not depend on patient type (i.e., that p is constant across different patient types), the profits of Hospital i are then given by

$$\pi_i\left(q_i^s, q_j^s\right) = \sum_{s=L,H} \left[p - c_s q_i^s\right] D_i^s\left(q_i^s, q_j^s\right) + T, \quad i, j = A, B;\ i \neq j, \tag{2}$$

where $D_i^s\left(q_i^s, q_j^s\right)$ is the demand for treatments at Hospital i from patients of type s. This

[8] Notice that our assumption of $c_H/c_L < 3/2$ is qualitatively consistent with the notion of within-DRG heterogeneity, which naturally restricts the extent of treatment cost differences.

demand depends on the qualities of treatment offered by the two hospitals. In order to ensure that each hospital has an incentive to provide quality above the minimum level to each type of patient, we impose a lower bound on p given by $\underline{p} := t$. Thus, all of our results are derived under the condition $p > \underline{p}$.

Finally, we assume that each patient in the market has a treatment history at one of the two hospitals. More specifically, we assume that all patients (of both cost types) located between 0 and $\frac{1}{2}$ have previously been treated by Hospital A (but not by Hospital B), whereas the remaining patients (located between $\frac{1}{2}$ and 1) have previously been treated by Hospital B (but not by Hospital A). Thus, starting from a position of equal 'inherited' demand for each hospital, we consider a one-period model in which the hospitals simultaneously and independently choose quality levels to maximise their profits, and where each hospital's demand potentially consists of both returning and new patients.

3 Benchmark: Uniform quality

We start out by considering the benchmark case in which hospitals cannot offer quality-differentiated treatments to different types of patients. This means that Hospital i offers treatments with a uniform quality q_i^u to all the patients who seek treatment at this hospital. In this case, the patient (regardless of type) who is indifferent between seeking treatment at Hospital A and Hospital B is located at

$$x^u = \frac{1}{2} + \frac{q_A^u - q_B^u}{2t}. \tag{3}$$

If each patient in the market makes a utility-maximising choice, demand for each hospital is given by $D_A^u = x^u$ and $D_B^u = 1 - x^u$, respectively. The profits of Hospital i are consequently given by[9]

$$\pi_i^u = (p - \bar{c}q_i^u)\, D_i^u, \tag{4}$$

where $\bar{c} := 1 - \alpha(1-\gamma)$ is the treatment cost parameter for a randomly selected patient.

The first-order condition for the profit-maximising uniform quality provision by Hospital i is given by

$$\frac{\partial \pi_i^u}{\partial q_i^u} = (p - \bar{c}q_i^u)\,\frac{1}{2t} - \bar{c}D_i^u = 0 \tag{5}$$

and reflects a basic trade-off between attracting more patients and ensuring a higher profitability of each patient. The hospital can attract more demand by offering a higher quality, but this will make each treatment more expensive, thereby reducing the profitability of each patient. From (5) we can derive the best-response function of each hospital, yielding

$$q_i^u = \frac{1}{2}\left(q_j^u + \frac{p}{\bar{c}} - t\right), \quad i,j = A,B;\ i \neq j. \tag{6}$$

These best-response functions imply that qualities are strategic complements. If Hospital i offers a higher treatment quality, more patients will choose to be treated at this hospital. The competing Hospital j will therefore experience a drop in demand, and thus a corresponding reduction in the marginal cost of quality provision, which in turn implies that Hospital j optimally responds by increasing the quality of its treatments. Applying symmetry, the Nash equilibrium is characterised as follows:[10]

Proposition 1 *In case of no quality discrimination between different types of patients, each*

[9] To save notation, we henceforth set $T = 0$.

[10] It is easily verified that second-order and local stability conditions are satisfied for this and all subsequent Nash equilibria derived in the paper.

hospital chooses a uniform quality level given by

$$q^u = \frac{p}{\overline{c}} - t. \tag{7}$$

Intuitively, and in line with previous literature, quality provision is stimulated by higher treatment prices (p), lower treatment costs ($\overline{c}$) and more intense competition (inversely measured by t). In equilibrium, each hospital earns a profit of

$$\pi^u = \frac{\overline{c}t}{2}. \tag{8}$$

Notice that these profits are increasing in the average treatment cost parameter $\overline{c}$. This reflects the Prisoners' Dilemma nature of the game. Due to the assumption of fixed total demand, each hospital's quality provision is purely motivated by a business-stealing incentive. Since this business-stealing effect is completely neutralised in a symmetric Nash equilibrium, quality provision is wasteful from the perspective of profit-maximising hospitals. Even if a higher exogenous treatment cost ($\overline{c}$) reduces profits for a given quality level, this effect is more than outweighed by a dampening-of-competition effect, leading to an overall increase in profits due to less resources being 'wasted' on costly quality provision.

4 Quality discrimination

In this section we consider the case in which hospitals are able to offer different treatment qualities to different types of patients. From the viewpoint of each hospital, there are two types of patients along each of two different dimensions. Firstly, patients differ with respect to whether or not they have been treated by the hospital before; in other words, there is a distinction between new and returning patients. Secondly, both new and returning patients differ with respect to their treatment costs. We assume that the former distinction is always observable to the hospitals, whereas the second distinction might be observable, but only for returning patients. The existence of electronic health records enables access to the data of previously treated patients and might thereby enable each hospital to distinguish low- and high-cost types among the returning patients. Let $\beta_i \in [0,1]$ denote the precision of Hospital i's tracking technology and let S_s, $s = L, H$, denote the patient cost type identified by the hospital based on this technology. Consider now a high-cost patient who returns to Hospital i for treatment. Given β_i, the conditional probability that the cost type of this patient is correctly identified by the hospital is given by

$$\Pr(S_H \mid H) = \beta_i + (1-\beta_i)(1-\alpha). \tag{9}$$

If $\beta_i = 1$, the precision of the tracking technology is perfect and $\Pr(S_H \mid H) = 1$. On the other hand, if $\beta_i = 0$, patient tracking is not informative and $\Pr(S_H \mid H) = 1 - \alpha$. In the following, we will consider each of these two polar cases.

4.1 Quality discrimination with no patient type tracking

Suppose first that hospitals do not track returning patients' types (i.e., $\beta_i = 0$), either because the information technology is unavailable or because such patient type tracking is not permitted (due to legal restrictions or because patients take actions to preserve their anonymity). In this case, quality discrimination can only be based on whether patients are new or returning. We will intermittently refer to this case as *one-dimensional quality discrimination.*

Suppose that Hospital i offers treatments with quality q_i^N and q_i^R to new and returning patients, respectively, where $i = A, B$. Due to the symmetry of the model, we can restrict attention to competition for patients who were previously treated by Hospital A, which we henceforth refer to as patients in Hospital A's 'turf'. Suppose that one of these patients is now indifferent between seeking treatment at the same hospital or switching to Hospital B. Since a returning patient for Hospital A is a new patient for Hospital B, the location of such a patient, denoted by $\widehat{k}_A$, must be given by

$$\widehat{k}_A = \frac{q_A^R - q_B^N + t}{2t}. \tag{10}$$

Notice that $\widehat{k}_A \in \left[0, \frac{1}{2}\right)$ if $q_A^R < q_A^N$, which implies that some of Hospital A's previous patients switch to Hospital B. Below we confirm that this holds indeed in equilibrium. In this case, the profits that Hospital A makes from its returning patients are given by

$$\pi_A^R = \left(p - \overline{c} q_A^R\right) \left(\frac{q_A^R - q_B^N + t}{2t}\right), \tag{11}$$

whereas the profits that Hospital B makes from its new patients are given by

$$\pi_B^N = \left(p - \overline{c} q_B^N\right) \left(\frac{1}{2} - \widehat{k}_A\right). \tag{12}$$

By maximising (11) and (12) with respect to q_A^R and q_B^N, respectively, and applying symmetry, we derive the following best-response functions:

$$q_i^R(q_j^N) = \frac{1}{2}\left(\frac{p}{\overline{c}} - t + q_j^N\right), \tag{13}$$

$$q_j^N(q_i^R) = \frac{1}{2}\left(\frac{p}{\overline{c}} + q_i^R\right), \tag{14}$$

where $i, j = A, B$; $i \neq j$. As in the benchmark case of no quality discrimination, and for the exact same reason, qualities offered by competing hospitals are strategic complements. In the symmetric Nash equilibrium, each hospital offers a different treatment quality to new and returning patients, given by

$$q^R|_{\beta=0} = \frac{p}{\bar{c}} - \frac{2}{3}t \tag{15}$$

and

$$q^N|_{\beta=0} = \frac{p}{\bar{c}} - \frac{1}{3}t, \tag{16}$$

which implies that the quality offered to the *average patient* is given by

$$q^{av}|_{\beta=0} = \frac{p}{\bar{c}} - \frac{5}{9}t. \tag{17}$$

The resulting total profits of each hospital are given by

$$\pi|_{\beta=0} = \frac{5}{18}\bar{c}t. \tag{18}$$

The next proposition offers a characterisation of this equilibrium and a comparison with the benchmark case of no quality discrimination.[11]

Proposition 2 *Suppose that hospitals can discriminate between new and returning patients but cannot track their cost types. In the symmetric Nash equilibrium, (i) each hospital offers a higher quality to new than to returning patients and (ii) all patients receive higher quality than under no discrimination (i.e.,* $q^N > q^R > q^u$*).*

In order to explain the intuition behind these results, take the no-discrimination equilib-

[11] The proof involves a straightforward comparison of equilibrium expressions and is therefore omitted.

rium, q^u, as a starting point. If quality discrimination is not possible, the cost of attracting more patients by offering a higher treatment quality is a reduction in the profits earned on inframarginal patients due to a lower price-cost margin. Thus, in equilibrium each hospital offers a treatment quality (to all patients) at a level where the profit earned from one additional patient is equal to the aggregate reduction in the profitability of inframarginal patients. However, if the hospitals can discriminate between new and returning patients, the cost of generating higher demand through higher treatment quality is reduced, since the quality increase can be offered only to new patients, thus reducing the profit loss on inframarginal patients. This intensifies quality competition and gives each hospital an incentive to offer a higher quality level to new patients than in the benchmark case (i.e., $q_i^N > q_i^u$). Interestingly, this also benefits returning patients. All else equal, if Hospital i offers a higher quality to new patients, this reduces the number of returning patients, and thus the marginal cost of quality provision for these patients, for Hospital j. This means that, if Hospital i increases its quality to new patients, Hospital j optimally responds by increasing its quality to returning patients. Thus, because of strategic complementarity, higher quality to new patients also implies higher quality to returning patients. In sum, quality discrimination leads to higher quality provision for all patients, compared with the benchmark case of no discrimination.

4.2 Quality discrimination with perfect patient tracking

Suppose now that each hospital has access to a patient tracking technology that allows for perfect recognition of cost type for returning patients (i.e., $\beta_i = 1$). This allows each hospital to discriminate among patients along two different dimensions. In addition to offering different treatment qualities to new and returning patients, the hospitals can also discriminate among patients in the latter category based on cost type. We will thus refer to this case as *two-dimensional quality discrimination.*

Let q_i^H and q_i^L denote Hospital i's quality offered to its returning patients of type H and L, respectively. As before, the quality offered to new patients is denoted by q_i^N. In the following, we derive the Nash equilibrium under the assumption that some (but not all) patients of both cost types end up choosing a different hospital than what they have done previously. We will subsequently provide the parameter conditions for this to hold in equilibrium.

Consider the patients who were previously treated by Hospital A. Among these, a patient of cost type s will be indifferent between returning to Hospital A or switching to Hospital B if she is located at k_A^s, given by

$$k_A^s = \frac{q_A^s - q_B^N + t}{2t}. \tag{19}$$

Similarly, a patient of type s who were previously treated by Hospital B and who is now indifferent between returning to the same hospital or switching to Hospital A is located at

$$k_B^s = \frac{q_A^N - q_B^s + t}{2t}. \tag{20}$$

Suppose that $k_A^s \in \left[0, \frac{1}{2}\right)$ and $k_B^s \in \left(\frac{1}{2}, 1\right]$ for $s = L, H$, which means that both types of patients can be induced to switch in equilibrium. This is illustrated by Figure 1, where Hospital A's demand is made up of αk_A^L returning and $\alpha \left(k_B^L - \frac{1}{2}\right)$ new low-cost patients, and $(1-\alpha)\, k_A^H$ returning and $(1-\alpha)\left(k_B^H - \frac{1}{2}\right)$ new high-cost patients. Whereas returning low- and high-cost patients are offered treatments with quality q_A^L and q_B^H, respectively, all the new patients are offered treatments with quality q_A^N. The demand for Hospital B is composed in a similar manner.

[Figure 1 here]

As before, the symmetric nature of the model allows us to concentrate on the competition for patients in Hospital A's turf. Hospital A's profits from returning H-type and L-type patients, respectively, are given by

$$\pi_A^H = (1-\alpha)k_A^H(p - q_A^H) \tag{21}$$

and

$$\pi_A^L = \alpha k_A^L(p - \gamma q_A^L). \tag{22}$$

The remaining patients in Hospital A's turf choose to switch provider, and Hospital B's profits from these (new) patients are given by

$$\pi_B^N = (1-\alpha)\left(\frac{1}{2} - k_A^H\right)(p - q_B^N) + \alpha\left(\frac{1}{2} - k_A^L\right)(p - \gamma q_B^N) \tag{23}$$

By maximizing (21), (22) and (23), with respect to q_A^H, q_A^L and q_B^N, and applying symmetry, the best response functions are given by

$$q_i^s(q_j^N) = \frac{p}{2c_s} + \frac{q_j^N - t}{2}, \quad s = L, H, \tag{24}$$

and

$$q_i^N(q_j^H, q_j^L) = \frac{p + (1-\alpha)q_j^H + \alpha\gamma q_j^L}{2\overline{c}}, \tag{25}$$

where $i, j = A, B$ and $i \neq j$.

As before, qualities are strategic complements. We can also observe from (24) that the quality offered to a returning patient is inversely proportional to the patient's cost type. In other words, returning low-cost patients will be offered higher quality than returning high-cost patients.

By solving the system of best-response functions given by (24)-(25), we derive the Nash equilibrium quality levels under two-dimensional quality discrimination with perfect tracking, which are given by

$$q^H|_{\beta=1} = \frac{p\left(1+\overline{c}\right)}{2\overline{c}} - \frac{2t}{3}, \tag{26}$$

$$q^L|_{\beta=1} = \frac{p\left(\gamma+\overline{c}\right)}{2\gamma\overline{c}} - \frac{2t}{3}, \tag{27}$$

$$q^N|_{\beta=1} = \frac{p}{\overline{c}} - \frac{t}{3}. \tag{28}$$

This implies that the quality offered to the average patient in equilibrium is given by

$$q^{av}|_{\beta=1} = \frac{p}{\overline{c}} - \frac{5}{9}t + \frac{\alpha\left(1-\alpha\right)\left(1-\gamma\right)^2\left(3p\left(1-\alpha+\alpha\gamma^2\right)+2t\gamma\overline{c}\right)p}{12t\gamma^2\overline{c}^2}, \tag{29}$$

and equilibrium total profits for each hospital are

$$\pi|_{\beta=1} = \frac{5}{18}\overline{c}t - \frac{\alpha\left(1-\alpha\right)\left(1-\gamma\right)^2 p^2}{8t\gamma\overline{c}}. \tag{30}$$

With perfect patient tracking, there are two distinctly different incentives for quality discrimination. First, as in the case of $\beta_i = 0$, each hospital has an incentive to offer higher quality to new patients in order to increase demand without losing profits on inframarginal patients. Second, each hospital also has an incentive to cream-skim low-cost types among its previous patients, thereby reducing the average treatment cost for returning patients. The latter incentive leads to hospitals offering higher treatment quality to those returning patients who are being identified as having low treatment costs. This will cause a larger share of the high-cost patient to switch hospital, thus increasing the share of low-cost types among the returning patients.

The two above described incentives for quality discrimination clearly imply that each hospital will offer higher quality to new patients than to returning high-cost patients; i.e., $q^N|_{\beta=1} > q^H|_{\beta=1}$, which is easily verified by a comparison of (26) and (28). However, it is not equally obvious that hospitals will provide higher quality to new patients than to returning low-cost patients. The equilibrium given by (26)-(28) has been derived under the assumption that the patients who switch hospital consists of both cost types, which requires that $q^N|_{\beta=1}$ is strictly larger than $q^L|_{\beta=1}$. Comparing (27) and (28), it is straightforward to verify that $q^N|_{\beta=1} > q^L|_{\beta=1}$ if p is not too large. In this case, each hospital's incentive for cream skimming is sufficiently low to make each hospital offer lower quality to returning low-cost patients than to new patients.[12]

Alternatively, if the incentives for cream skimming are very strong, the equilibrium quality provision is a corner solution with $q^N|_{\beta=1} = q^L|_{\beta=1} > q^H|_{\beta=1}$, where only (some of the) high-cost patients switch hospital.[13] The exact condition for the existence of an interior solution Nash equilibrium, in which (some but not all) patients of both types switch hospital, are presented in the next proposition.[14]

Proposition 3 *Suppose that hospitals can discriminate between new and returning patients and also discriminate among the latter based on cost type. In this case, there exists a parameter set defined by*

$$\underline{p} < p < \min\left\{\frac{2t\gamma\overline{c}}{3\left(1-\alpha\right)\left(1-\gamma\right)}, \frac{4t\overline{c}}{3\alpha\left(1-\gamma\right)}\right\} \tag{31}$$

[12] The parameter set for which this is true is larger the smaller the cost difference between the two patient types and the larger the share of low-cost types in the patient population.

[13] Notice that all of Hospital i's previous low-cost patients prefer Hospital i over Hospital j if $q_i^L = q_j^N$, implying that, in a symmetric equilibrium, neither hospital has any incentive to offer higher quality to returning low-cost patients than to new patients.

[14] A formal proof is given in the Appendix.

for which the Nash equilibrium is characterised by

$$q^N|_{\beta=1} > q^L|_{\beta=1} > q^H|_{\beta=1}. \tag{32}$$

For the remainder of the analysis, we will assume that the parameter condition given by (31) holds. In other words, we assume that the hospitals' cream-skimming incentives are relatively moderate.

We have already shown (cf. Proposition 2) that all patients benefit from quality discrimination when such discrimination is only based on the observation of new versus returning patients. The next proposition confirms that this is also true under two-dimensional quality discrimination based on perfect tracking of patients' cost types.[15]

Proposition 4 *Suppose that the Nash equilibrium under two-dimensional quality discrimination with perfect patient tracking is an interior solution equilibrium. (i) The ranking of equilibrium treatment qualities across the different quality setting regimes is given by*

$$q^N|_{\beta=1} = q^N|_{\beta=0} > q^L|_{\beta=1} > q^R|_{\beta=0} > q^H|_{\beta=1} > q^u. \tag{33}$$

(ii) The equilibrium treatment quality offered to the average patient is highest under two-dimensional quality discrimination and lowest under no quality discrimination; i.e.,

$$q^{av}|_{\beta=1} > q^{av}|_{\beta=0} > q^u. \tag{34}$$

If we compare the two different discriminatory equilibria, low-cost patients benefit from dis-

[15] The proof involves a straightforward comparison of already reported equilibrium expressions and is therefore omitted.

crimination based on cost types whereas high-cost patients are better off when patient tracking is not possible, which is quite intuitive. However, compared to the case of uniform quality provision, all patients are better off if hospitals engage in some kind of quality discrimination. This is also true for returning high-cost patients. Even if they are offered a lower treatment quality than other patients due to patient tracking, the quality they are offered in the discriminatory equilibrium with cream skimming is still higher than the quality they would be offered if quality discrimination is not possible. This is once more explained by strategic complementarity. Each hospital's incentive to attract more demand by offering higher quality to new patients creates a positive strategic response for the competing hospital to offer higher quality to its returning patients, including the ones that are more costly to treat.

If we consider the equilibrium quality offered to the average patient, it also turns out that this is higher when quality discrimination is based on perfect tracking of patient types than when it is only based on identifying new versus returning patients. In other words, the higher quality offered to low-cost types more than outweighs the lower quality offered to high-cost types, in terms of average quality.

5 Welfare analysis

In this section we explore the welfare implications of quality discrimination. We define social welfare as the sum of hospital profits and patients' surplus net of total payment for hospital treatments. Under the simplifying assumption that the third-party payer can raise funds to pay for hospital treatments in a non-distortionary way, social welfare is simply given by patients' surplus net of treatment costs. Since the total patient mass is normalised to one, patients' surplus is given by

$$\Omega = v + q^{av} - \Delta, \tag{35}$$

where Δ is total (and average) transportation/mismatch costs, and social welfare is thus given by

$$W = \Omega - \overline{c}q^{av} = v + (1 - \overline{c})\, q^{av} - \Delta. \tag{36}$$

5.1 The first-best solution

As a reference point for the subsequent welfare comparisons, consider first the outcome that would be chosen by a welfare-maximsing social planner. Since $\overline{c} < 1$, it follows directly from (36) that social welfare is monotonically increasing in the average quality level. Furthermore, transportation costs are minimised if every patient attends the nearest hospital, which implies no switching. Since no patient has any incentive to switch hospital under uniform quality provision, the first-best solution can be implemented by setting a uniform treatment quality at the upper bound $\overline{q}$ to all patients, which yields a social welfare of

$$W^{fb} = (1 - \overline{c})\, \overline{q} - \frac{t}{4}. \tag{37}$$

Before making a complete welfare comparison of the three different equilibria considered, let us first summarise how quality discrimination affects hospital profits and patient's surplus.

5.2 Hospital profits

As we have shown in the previous section, any type of quality discrimination increases the average quality provision, compared with the case of uniform quality setting, and two-dimensional quality discrimination yields a higher average quality provision than one-dimensional quality discrimination. Since, in a symmetric equilibrium, both demand and patient composition are the same for each hospital regardless of whether they engage in quality discrimination or not, there is a monotonic negative relationship between average quality and hospital profits. In other words, since quality discrimination leads to higher average quality without affecting equilibrium demand, the corresponding increase in treatment costs is unambiguously negative for hospital profits.[16] Whereas each hospital clearly has a unilateral incentive to quality discriminate between new and returning patients, and, if possible, to use tracking technologies to cream-skim low-cost types from the pool of former patients, they are caught in a Prisoners' Dilemma that ultimately leads to lower equilibrium profits when such strategies are used by both hospitals. Thus, profit-maximising hospitals would benefit from being able to commit to a non-discriminatory treatment policy.

Proposition 5 *In a symmetric game, hospital profits are lower under any type of quality discrimination than under uniform quality setting, and they are lowest under two-dimensional quality discrimination with perfect tracking of patients' cost types (i.e.,* $\pi^u > \pi|_{\beta=0} > \pi|_{\beta=1}$*).*

5.3 Patients' surplus

While discrimination leads to higher average quality provision, which, all else equal, is beneficial for the average patient, the overall surplus of patients also depends on transportation or mismatch costs. In the case of uniform quality provision, which gives no incentives for switching,

[16] It is straightforward to verify this claim by comparing the equilibrium profits in (8), (18) and (30).

these costs are minimised at $\Delta^u = t/4$, and patients' surplus is given by

$$\Omega^u = v + \frac{p}{\bar{c}} - \frac{45}{36}t. \tag{38}$$

On the other hand, transportation costs are not minimised in equilibria with quality discrimination, which induces some patients to switch hospital. In the case of one-dimensional quality discrimination, equilibrium transportation costs are given by

$$\Delta|_{\beta=0} = 2t \left(\int_0^{\frac{q^R|_{\beta=0} - q^N|_{\beta=0} + t}{2t}} x dx + \int_{\frac{q^R|_{\beta=0} - q^N|_{\beta=0} + t}{2t}}^{\frac{1}{2}} (1-x)\, dx \right) = \frac{11}{36}t, \tag{39}$$

which implies that patients' surplus, using (17) and (39), is given by

$$\Omega|_{\beta=0} = v + \frac{p}{\bar{c}} - \frac{31}{36}t. \tag{40}$$

We can immediately verify that $\Omega|_{\beta=0} > \Omega^u$. This is entirely obvious. Since quality provision is higher for *all* patients under one-dimensional quality provision, the extra cost incurred by a patient who voluntarily switches hospital cannot result in lower patient utility.

The same revealed-preference argument cannot automatically be applied in the case of two-dimensional quality discrimination, since high-cost patients receive lower treatment quality under perfect patient tracking. In this case, equilibrium transportation costs are given by

$$\begin{aligned}
\Delta|_{\beta=1} &= 2\alpha t\left(\int_0^{\frac{q^L|_{\beta=1}-q^N|_{\beta=1}+t}{2t}} x dx + \int_{\frac{q^L|_{\beta=1}-q^N|_{\beta=1}+t}{2t}}^{\frac{1}{2}} (1-x)\, dx\right) \\
&\quad +2(1-\alpha)t\left(\int_0^{\frac{q^H|_{\beta=1}-q^N|_{\beta=1}+t}{2t}} x dx + \int_{\frac{q^H|_{\beta=1}-q^N|_{\beta=1}+t}{2t}}^{\frac{1}{2}} (1-x)\, dx\right) \\
&= \frac{11}{36}t + \frac{\alpha(1-\alpha)(1-\gamma)^2\left(3p\left(1-\alpha+\alpha\gamma^2\right)-4t\gamma\overline{c}\right)p}{24t\gamma^2\overline{c}^2}.
\end{aligned} \tag{41}$$

A comparison of (39) and (41) reveals that $\Delta|_{\beta=1}$ is larger (smaller) than $\Delta|_{\beta=0}$ if p is large (small) relative to t. This ambiguity is caused by two counteracting forces. On the one hand, it can easily be confirmed that the number of switchers is lower under two-dimensional quality discrimination, which contributes to lower transportation costs, all else equal.[17] On the other hand, for a given number of switchers, transportation costs are minimised under one-dimensional quality discrimination, since both patient types (high- and low-cost) receive the same treatment quality. The latter effect dominates if p is sufficiently high. In this case, the hospitals' incentives for cream-skimming are sufficiently strong to produce a difference in the qualities offered to high- and low-cost patients that is large enough to make aggregate transportation costs higher under two-dimensional discrimination.

Using (29) and (41), patients' surplus under two-dimensional quality discrimination is given by

$$\Omega|_{\beta=1} = v + \frac{p}{\overline{c}} - \frac{31}{36}t + \frac{\alpha(1-\alpha)(1-\gamma)^2\left(3p\left(1-\alpha+\alpha\gamma^2\right)+8t\gamma\overline{c}\right)p}{24t\gamma^2\overline{c}^2}. \tag{42}$$

[17] In the equilibrium with one-dimensional quality discrimination, the number of switchers is 1/3, while under two-dimensional quality discrimination, the number of switchers in equilibrium is

$$\frac{1}{3} - \frac{\alpha(1-\alpha)(1-\gamma)^2 p}{2t\gamma\overline{c}}.$$

Comparing (38), (40) and (42), it is straightforward to verify that

$$\Omega|_{\beta=1} > \Omega|_{\beta=0} > \Omega^u. \tag{43}$$

Thus, patients' surplus is always higher under two-dimensional discrimination, even if it leads to higher aggregate transportation costs. Notice, however, that this surplus is unevenly shared among the patients, with low-cost patients benefitting at the expense of high-cost patients.

Proposition 6 *In a symmetric game, patients' surplus is higher under any type of quality discrimination than under uniform quality setting, and it is highest under two-dimensional quality discrimination with perfect tracking of patients' cost types.*

5.4 Social welfare

The expressions for equilibrium social welfare in each of the three cases considered are given by

$$W^u = v - \frac{(1 + 4\alpha(1-\gamma))\,t}{4} + \frac{\alpha(1-\gamma)\,p}{\overline{c}}, \tag{44}$$

$$W|_{\beta=0} = v - \frac{(11 + 20\alpha(1-\gamma))\,t}{36} + \frac{\alpha(1-\gamma)\,p}{\overline{c}} \tag{45}$$

and

$$\begin{aligned} W|_{\beta=1} \quad = \quad & v - \frac{(20\alpha(1-\gamma) + 11)\,t}{36} + \frac{\alpha(1-\gamma)(1 + 5\gamma - \alpha(1-\gamma)(\alpha + (1-\alpha)\gamma))\,p}{6\gamma\overline{c}} \\ & - \frac{\alpha(1-\alpha)(1-\gamma)^2\left(1 - \alpha + \alpha\gamma^2\right)(1 - 2(1-\gamma)\alpha)\,p^2}{8t\gamma^2\overline{c}^2}. \end{aligned} \tag{46}$$

A comparison of (44), (45) and (46) reveals that the welfare implications of quality discrimination are generally ambiguous and can be characterised as follows:[18]

Proposition 7 *(i) If α is sufficiently low or γ is sufficiently high, social welfare is higher under uniform quality setting than under any type of quality discrimination. (ii) If α is sufficiently high and γ is sufficiently low, social welfare is higher when hospitals engage in some type of quality discrimination. In this case, two-dimensional quality discrimination is welfare superior if p is sufficiently low, whereas the welfare ranking of the two discriminatory equilibria is generally ambiguous when p is sufficiently high.*

The welfare effects of quality discrimination are explained by a trade-off that can be seen directly from (36). On the one hand, discrimination intensifies competition for patients and leads to higher quality provision for the average patient, which unambiguously increases social welfare, all else equal. However, this welfare gain comes at the expense of an efficiency loss caused by excessive patient switching. Thus, even if quality discrimination leads to a higher patient surplus, this surplus increase might not be large enough to outweigh the increase in treatment costs associated with a higher average quality level. Indeed, if the share of low-cost patients is sufficiently low *or* if the cost difference between high- and low-cost patients is sufficiently small, quality discrimination reduces social welfare even if average quality increases. The reason is that a lower α or a higher γ increases the average treatment cost for a given quality level and thus reduces the net marginal welfare gain of higher average quality, which is given by $1 - \overline{c}$. If this welfare gain is sufficiently small, the efficiency loss caused by patient switching is large enough to make any type of quality discrimination detrimental to social welfare.

[18] A formal proof is given in the Appendix.

On the other hand, if $\overline{c}$ is sufficiently low (which requires that α is sufficiently high *and* γ is sufficiently low), welfare is higher if the hospitals engage in some type of quality discrimination. In this case, whether social welfare is higher under one-dimensional or two-dimensional quality discrimination depends on the strength of the hospitals' cream-skimming incentives, which in turn is related to the magnitude of the treatment price p. If p is sufficiently small, the hospitals have relatively moderate incentives to cream-skim low-cost patients, and the difference in the qualities offered to returning high- and low-cost patients is therefore relatively small. This implies that the increase in aggregate transportation costs under two-dimensional (instead of one-dimensional) quality discrimination is outweighed by the welfare gain of higher average quality provision. Thus, in this case social welfare is higher when discrimination is based on the tracking of patients' cost type. However, the reverse might be true if p is sufficiently high.

6 Extensions

In this section we extend our main analysis in two different directions. First, we consider two different versions of an asymmetric game in which one of the hospitals has more information about individual patient characteristics than the competing hospital. Second, we relax the assumption of perfect patient tracking and consider the more general case in which the cost type of returning patients can only be determined with a certain probability. In both cases, we explore the implications for equilibrium quality provision.

6.1 Quality provision under asymmetric information technologies

Until now we have assumed that both hospitals have access to a similar technology to recognise new and returning patients and to track returning patients' types. We now relax this assumption by considering the asymmetric case where only one of the hospitals has access to such a technology. With no loss of generality, suppose that Hospital A is endowed with the information technology required to track new and returning patients and learns perfectly the returning patients' cost types ($\beta_A = 1$), thus allowing for two-dimensional quality discrimination. We will consider two different cases. In the first one, Hospital B learns nothing about its returning patients ($\beta_B = 0$), although it can distinguish them from new patients, thus allowing for one-dimensional quality discrimination. In the second one, we assume that Hospital B's information is even more limited, in the sense that it is not able to recognise any patient, new or returning. In this situation, quality discrimination is not feasible and Hospital B offers all patients the same quality of treatment.

6.1.1 Two-dimensional versus one-dimensional quality discrimination

Suppose that $\beta_A = 1$ and $\beta_B = 0$, which implies that Hospital A can perfectly track the cost types of returning patients, whereas Hospital B can only distinguish between new and returning patients without observing their cost types. Let $\widetilde{q}_A^N$ and $\widetilde{q}_A^s$ be the quality offered by Hospital A to new patients and returning patients of type s, respectively, where $s = L, H$. Hospital B, on the other hand, offers treatments of qualities $\widetilde{q}_B^N$ and $\widetilde{q}_B^R$ to its new and returning patients, respectively, regardless of cost type. As before, we derive a Nash equilibrium in which some (but not all) patients of both types end up choosing a different hospital than what they have done before.

Consider first the patients that were previously treated by Hospital A. Since Hospital A offers treatments of quality $\widetilde{q}_A^L$ and $\widetilde{q}_A^H$ to returning L- and H-type patients, respectively, while Hospital B provides these patients a treatment of quality $\widetilde{q}_B^N$, competition for patients in Hospital

A's turf is identical to the game with perfect tracking analysed in Section 4.2, which implies

$$\widetilde{q}_A^H = q_A^H|_{\beta=1}, \tag{47}$$

$$\widetilde{q}_A^L = q_A^L|_{\beta=1}, \tag{48}$$

$$\widetilde{q}_B^N = q_B^N|_{\beta=0} = q_B^N|_{\beta=1}. \tag{49}$$

Consider now the competition for patients that were previously treated by Hospital B. These patients will be offered a treatment of quality $\widetilde{q}_B^R$ by Hospital B and a treatment of quality $\widetilde{q}_A^N$ by Hospital A. This means that competition for patients in Hospital B's turf is identical to the game with no patient type tracking, which we analysed in Section 4.1. The equilibrium qualities offered to these patients are thus given by

$$\widetilde{q}_B^R = q_B^R|_{\beta=0}, \tag{50}$$

$$\widetilde{q}_A^N = q_A^N|_{\beta=0} = q_A^N|_{\beta=1} \tag{51}$$

Based on (47)-(51), the following characterisation of the Nash equilibrium is straightforward:

Proposition 8 *Suppose that Hospital A can perfectly track the cost type of returning patients, while Hospital B can only distinguish between new and returning patients without knowing their cost type. In this case, (i) Hospital A chooses the same qualities as in a symmetric game with two-dimensional quality discrimination, while Hospital B chooses the same qualities as* *in a symmetric game with one-dimensional quality discrimination, which implies that (ii) the ranking of equilibrium qualities offered by the two hospitals is given by (33) in Proposition 4, and (iii) this equilibrium exists for the parameter set given by (31) in Proposition 3.*

Thus, Hospital A, which by assumption has an informational advantage in the ability to track returning patients' cost types, chooses the same qualities as it would have done if Hospital B were also able to track cost types. And Hospital B, which by assumption has no access to a patient tracking technology, chooses the same qualities as it would have done if Hospital A were not able to track cost types either. In other words, each hospital's quality choices do not depend of whether the competing hospital has access to a perfect tracking technology or not. This rather striking result occurs because the hospitals compete for patients in two strategically separate segments with no informational externalities between them.

What are the unilateral hospital incentives for acquiring an information technology that allows for the tracking of patients' cost types? By inserting (47)-(51) into the hospitals' profit functions, equilibrium hospital profits are found to be given by

$$\widetilde{\pi}_A = \frac{5}{18}\bar{c}t + \frac{\alpha(1-\alpha)(1-\gamma)^2 p^2}{8t\gamma\bar{c}} \tag{52}$$

and

$$\widetilde{\pi}_B = \frac{5}{18}\bar{c}t - \frac{\alpha(1-\alpha)(1-\gamma)^2 p^2}{4t\gamma\bar{c}}. \tag{53}$$

A straightforward comparison of (52)-(53) and (18) allows us to reach the following conclusion:

Proposition 9 *If one hospital is able to track returning patients' cost types, while the competing hospital is only able to distinguish between new and returning patients without knowing their cost types, the former (latter) hospital earns higher (lower) profits than in the equilibrium of a* *symmetric game with one-dimensional quality discrimination.*

Thus, given that one of the hospitals is only able to discriminate between new and returning patients, the competing hospital has clearly a unilateral incentive to also discriminate based on patients' cost types. This is unsurprising, given the strategic nature of the asymmetric game considered here. Since the hospital that practices one-dimensional discrimination offers the same qualities regardless of whether the competing hospital practices one- or two-dimensional discrimination, the only effect of unilateral cream skimming is that the patient composition at the two hospitals changes such that average treatment costs go down for the hospital that practices two-dimensional quality discrimination, while the competing hospital suffers higher treatment costs on average.

6.1.2 Two-dimensional quality discrimination versus uniform quality

Consider now the case in which Hospital A practices two-dimensional quality discrimination, as before, whereas Hospital B has no information about individual patient characteristics and therefore offers a uniform quality to all patients. Thus, Hospital A offers quality levels $\widehat{q}_A^N$ and $\widehat{q}_A^s$ to new and returning patients of type s, respectively, where $s = L, H$, whereas Hospital B offers $\widehat{q}_B^u$ to all patients.

Consider the patients who were previously treated by Hospital A. Among these, a patient of cost type s will be indifferent between returning to Hospital A or switching to Hospital B if she is located at $\widehat{k}_A^s$, given by

$$\widehat{k}_A^s = \frac{\widehat{q}_A^s - \widehat{q}_B^u + t}{2t}. \tag{54}$$

Differently, a patient who was previously treated by Hospital B and who is now indifferent between returning to the same hospital or switching to Hospital A is located at

$$\widehat{k}_B = \frac{\widehat{q}_A^N - q_B^u + t}{2t}. \tag{55}$$

The profits of Hospital A from returning L- and H-type patients, respectively, are thus

$$\widehat{\pi}_A^L = \alpha \left(p - \gamma \widehat{q}_A^L\right) \widehat{k}_A^L \tag{56}$$

and

$$\widehat{\pi}_A^H = (1-\alpha) \left(p - \widehat{q}_A^H\right) \widehat{k}_A^H, \tag{57}$$

whereas Hospital A's profits from new patients are given by

$$\widehat{\pi}_A^N = \left(p - \overline{c}\widehat{q}_A^N\right) \left(\widehat{k}_B - \frac{1}{2}\right). \tag{58}$$

Finally, Hospital B's profits from all patients are

$$\widehat{\pi}_B = \alpha \left(p - \gamma \widehat{q}_B^u\right) \left(\frac{1}{2} - \widehat{k}_A^L\right) + (1-\alpha) \left(p - \widehat{q}_B^u\right) \left(\frac{1}{2} - \widehat{k}_A^H\right) + \left(1 - \widehat{k}_B\right) \left(p - \overline{c}\widehat{q}_B^u\right). \tag{59}$$

After maximising each profit function with respect to the targeted quality level, and simultaneously solving the resulting system of first-order conditions, we obtain the following set of candidate equilibrium quality levels:

$$\widehat{q}_A^L = \frac{p}{2} \left(\frac{\overline{c} + \gamma}{\overline{c}\gamma}\right) - \frac{3}{4}t, \tag{60}$$

$$\widehat{q}_A^H = \frac{p}{2}\left(\frac{\overline{c}+1}{\overline{c}}\right) - \frac{3}{4}t, \tag{61}$$

$$\widehat{q}_A^N = \frac{p}{\overline{c}} - \frac{1}{4}t, \tag{62}$$

$$\widehat{q}_B^u = \frac{p}{\overline{c}} - \frac{t}{2}. \tag{63}$$

The next proposition provides a characterisation of this Nash equilibrium and a parameter condition for its existence.[19]

Proposition 10 *Suppose that Hospital A can perfectly track the cost type of returning patients and therefore practice two-dimensional quality discrimination, while Hospital B has no information about individual patient characteristics and sets a uniform quality level to all its patients. In this case, there exists a parameter set defined by*

$$\underline{p} < p < \min\left\{\frac{\gamma t\overline{c}}{2(1-\alpha)(1-\gamma)}, \frac{3t\overline{c}}{2\alpha(1-\gamma)}\right\}, \tag{64}$$

for which the Nash equilibrium is characterised by

$$\widehat{q}_A^N > \widehat{q}_B^u > \widehat{q}_A^L > \widehat{q}_A^H. \tag{65}$$

Contrary to the game analysed in the previous subsection, in this asymmetric game Hospital A chooses a different set of qualities than in the symmetric game with perfect patient tracking, and Hospital B also chooses a different uniform quality level than in the symmetric game without discrimination. In other words, the equilibrium choice of each hospital depends on the competing hospital's available information technology. This is caused by the fact that the two demand

[19] A formal proof is given in the Appendix.

segments in which the hospitals compete for patients are no longer strategically independent. In the absence of any patient-specific information, Hospital B has only one strategic variable to compete for patients in different segments, which creates a competition externality between the two segments.

The equilibrium profits of each hospital are given by

$$\widehat{\pi}_A = \frac{5}{16} t\overline{c} + \frac{\alpha (1-\alpha)(1-\gamma)^2 p^2}{8t\gamma\overline{c}} \tag{66}$$

and

$$\widehat{\pi}_B = \frac{1}{4} t\overline{c} - \frac{\alpha (1-\alpha)(1-\gamma)^2 p^2}{4t\gamma\overline{c}}. \tag{67}$$

A comparison of (66)-(67) and (8) allows us to reach the following conclusion regarding the profitability of unilateral quality discrimination:[20]

Proposition 11 *If one hospital is able to track returning patients' cost types, while the competing hospital has no information about individual patient characteristics that allows it to quality discriminate, the former hospital earns higher profits than the latter, but both hospitals make less profits than they would in a symmetric game without quality discrimination.*

Thus, in contrast to the asymmetric game analysed in the previous subsection, quality discrimination by one hospital leads to lower profits for both. This is caused by the aforementioned competition externality between the two demand segments that arises when Hospital B has only one strategic variable to compete for patients. For any given uniform quality level chosen by Hospital B, Hospital A has obviously an incentive to quality discriminate based on observable patient characteristics if such information is available. However, if Hospital B expects Hospital

[20] A formal proof is given in the Appendix.

A to use two-dimensional quality discrimination, it will set a higher uniform quality level than if Hospital A were not able to quality discriminate.[21] This intensifies quality competition and ultimately leads to lower profits for both hospitals, with a higher profit loss for the hospital that is not able to quality discriminate. Thus, even if Hospital A has access to an information tracking technology that is not available to the competing hospital, it would benefit from being able to make a credible commitment not to use this information.

6.2 Imperfect tracking

In the main analysis we have assumed that hospitals are able to track returning patients' cost types either perfectly ($\beta = 1$) or not at all ($\beta = 0$). We therefore extend the model to consider the more general case where each hospital has access to an imperfect tracking technology that allows the hospital to determine the cost type of each returning patient with probability $\beta \in (0, 1)$. For simplicity, we restrict attention to the symmetric case in which this probability is equal for both hospitals.

With imperfect recognition of patient types, some patients will be offered the 'wrong' quality of treatment (i.e., the quality intended for a different cost type). How frequently this occurs depends on the precision of the tracking technology. More specifically, the probabilities that a hospital is able to correctly recognise low- and high-cost patients, respectively, are given by

$$\Pr(S_L \mid L) = \beta + (1 - \beta)\alpha \tag{68}$$

and

$$\Pr(S_H \mid H) = \beta + (1 - \beta)(1 - \alpha), \tag{69}$$

[21] Comparing (7) and (63), it is easily verified that $\widehat{q}_B^u > q^u$.

while the probabilities that the hospital mistakes a high-cost patient for a low-cost one, and *vice versa*, are given by, respectively,

$$\Pr(S_L \mid H) = (1-\beta)\alpha \tag{70}$$

and

$$\Pr(S_H \mid L) = (1-\beta)(1-\alpha). \tag{71}$$

Due to the symmetry of the model, we can restrict attention to competition for patients in Hospital A's turf. Consider a patient that is, rightly or wrongly, classified by Hospital A as having treatment costs $s = L, H$. This patient can choose between being treated with quality q_A^s by Hospital A or being treated with quality q_B^N by Hospital B, and the patient is indifferent between these two choices if she is located at k_A^s, given by (19). Hospital A's expected profits from patients identified as high- and low-cost types, respectively, are thus given by

$$E\left(\pi_A^H\right) = \left[\Pr(S_H \mid H)(1-\alpha)\left(p - q_A^H\right) + \Pr(S_H \mid L)\alpha\left(p - \gamma q_A^H\right)\right] k_A^H \tag{72}$$

and

$$E\left(\pi_A^L\right) = \left[\Pr(S_L \mid L)\alpha\left(p - \gamma q_A^L\right) + \Pr(S_L \mid H)\left(1-\alpha\right)\left(p - q_A^L\right)\right] k_A^L. \tag{73}$$

On the other hand, Hospital B's profits from attracting some of Hospital A's previous patients are still given by (23).

Maximisation of (72) and (73) with respect to q_A^H and q_A^L, respectively, yields the following best-response functions:

$$q_A^H(q_B^N) = \frac{p}{2\left(\overline{c} + \alpha(1-\gamma)\,\beta\right)} + \frac{\left(q_B^N - t\right)}{2}, \tag{74}$$

$$q_A^L(q_B^N) = \frac{p}{2\left(\overline{c} - (1-\alpha)\,(1-\gamma)\beta\right)} + \frac{\left(q_B^N - t\right)}{2}. \tag{75}$$

The best-response function for Hospital B's treatment quality offered to new patients, $q_B^N\left(q_A^H, q_A^L\right)$, is given by (25) as in the game with perfect cost type recognition. Compared to the set of best-response functions of that game, we see from (74)-(75) that the only effect of imperfect tracking (i.e., $\beta < 1$) is to reduce the difference in qualities offered to high- and low-cost patients. Otherwise, the strategic nature of quality competition is unaffected by the size of β.

If the Nash equilibrium is an interior solution, it is given by the solution to (74)-(75) and (25), which is the following set of qualities:

$$q^H(\beta) = \frac{p\left[6\overline{c}^2 + 2\beta\overline{c}(1-\gamma)(4\alpha-3) + \alpha\beta(1-\gamma)(\gamma - 2(1-\gamma)(1-\alpha)\beta)\right]}{6\overline{c}\left(\overline{c} + (1-\gamma)\alpha\beta\right)\left(\overline{c} - (1-\gamma)\,(1-\alpha)\,\beta\right)} - \frac{2t}{3}, \tag{76}$$

$$q^L(\beta) = \frac{p\left[6\overline{c}^2 - \beta(1-\gamma)(2\overline{c}\,(1-4\alpha) + (1+2(1-\gamma)\alpha\beta)\,(1-\alpha)\right]}{6\overline{c}\left(\overline{c} + (1-\gamma)\alpha\beta\right)\left(\overline{c} - (1-\gamma)\,(1-\alpha)\,\beta\right)} - \frac{2t}{3}, \tag{77}$$

$$q^N(\beta) = \frac{p\left[3\overline{c}^2 + \beta(1-\gamma)(2\overline{c}\,(2\alpha-1) - (1-\alpha)(1-\alpha+2(1-\gamma)\alpha\beta) + \alpha^2\gamma)\right]}{3\overline{c}\left(\overline{c} + (1-\gamma)\alpha\beta\right)\left(\overline{c} - (1-\gamma)\,(1-\alpha)\,\beta\right)} - \frac{t}{3}. \tag{78}$$

It is relatively easy to verify that the parameter condition (31) in Proposition 3 is sufficient to ensure the existence of this Nash equilibrium. The effects of imperfect tracking on equilibrium quality provision is characterised as follows:[22]

Proposition 12 *Suppose that each hospital uses an imperfect tracking technology that allows it to determine the cost type of each returning patient with probability $\beta \in (0,1)$, and suppose*

[22] A formal proof is given in the Appendix.

that condition (31) in Proposition 3 is satisfied. In this case, the equilibrium qualities are characterised by

$$q^N(\beta) > q^L(\beta) > q^H(\beta), \tag{79}$$

and the full ranking of qualities across all symmetric regimes considered is given by

$$q^N|_{\beta=1} = q^N|_{\beta=0} > q^N(\beta) > q^L|_{\beta=1} > q^L(\beta) > q^R|_{\beta=0} > q^H(\beta) > q^H|_{\beta=1} > q^u. \tag{80}$$

As in the case of perfect tracking, each hospital offers a higher quality to new patients than to returning patients, and a higher quality to suspected low-cost patients than to suspected high-cost patients. This is not surprising, and the intuition behind this result is obviously the same as in the perfect tracking case. However, the difference in qualities offered to suspected low- and high-cost patients is lower under imperfect tracking than if returning patients' cost types can be determined with certainty. This is also very intuitive. With imperfect tracking, some patients will be mis-classified, which implies that the expected treatment cost for each patient in the group of suspected low-cost patients is higher than $\gamma q^L(\beta)$, while the expected treatment cost for each patient in the group of suspected high-cost patients is lower than $q^H(\beta)$. Since the hospitals are rationally aware of this, the optimal response is to reduce the difference between $q^L(\beta)$ and $q^H(\beta)$, compared to the case of perfect cost type recognition. In the limit, when $\beta \to 0$, the tracking technology offers no additional information about a returning patient beyond the *ex ante* probability α of having low treatment costs, so the optimal strategy for each hospital is to offer the same quality, $q^R|_{\beta=0}$, to all returning patients.

It is perhaps more surprising that new patients are offered lower quality under imperfect tracking than under either perfect or no tracking, which implies that the intensity of competition for new patients is non-monotonic in the precision of the tracking technology. Indeed, from (78) we can derive

$$\frac{\partial q^N(\beta)}{\partial \beta} = -\frac{\alpha(1-\alpha)(1-\gamma)^2 p \left[(1-\beta)^2 \bar{c}^2 - \beta^2 \gamma\right]}{3\bar{c}\left(\bar{c}+\alpha\beta(1-\gamma)\right)^2 \left(\bar{c}-\beta(1-\gamma)(1-\alpha)\right)^2}, \tag{81}$$

which shows that the equilibrium quality to new patients decreases (increases) in β when the tracking precision is initially low (high), and reaches a minimum at

$$\beta = \frac{\bar{c}}{\bar{c}+\sqrt{\gamma}} \in (0,1). \tag{82}$$

Thus, the hospitals' incentives to attract new patients by offering higher treatment quality are weakest for an intermediate degree of tracking precision.

7 Concluding remarks

Recent advances in healthcare information technologies allow healthcare providers to more accurately predict the future treatment costs of previously treated patients. While the potential benefits in the form of better and more cost-efficient treatments are undeniable, the other side of the coin is that it arguably increases the scope for quality discrimination across different patient types. This is a potential concern for policymakers, since quality discrimination might lead to inefficiencies in the allocation of healthcare resources, in addition to the obvious issues regarding equity.

In this paper we have investigated the potential implications of quality-discriminating practices among competing hospitals in a spatial market where patients are characterised by *ex ante* unobservable treatment cost heterogeneity and the hospitals face fixed (regulated) prices. In a setting where each patient has a treatment history at one of the hospitals in the market, we assume that hospitals are able to distinguish (i) between new and returning patients and (ii) between different patient cost types (with some degree of precision) among the returning patients. This creates incentives for hospitals to engage in (one- or two-dimensional) quality discrimination across different patient categories, and the main aim of our analysis is to explore the implications of such practices with respect to quality provision, patient utility, provider profits and social welfare.

The main message from our analysis is that quality discrimination tends to be *pro-competitive*. Even if some patient groups are offered lower quality than others, the intensified competition induced by the ability to quality discriminate implies that all patients receive higher quality of care than if such discrimination is not possible. Thus, in healthcare markets with competing providers, our results suggest that patients have generally little to fear from quality-discriminating practices. For profit-oriented healthcare providers, on the other hand, the ability to quality discriminate is a double-edged sword. While each provider has a unilateral incentive to discriminate in order to increase its profits, strategic interaction between competing providers ultimately leads to lower profits in equilibrium, as long as all providers have the same ability to quality discriminate. Whereas quality discrimination generally leads to higher quality provision, it also leads to an inefficient allocation of patients, with excessive patient switching across hospitals. Because of this inefficiency, quality discrimination might in some cases lead to lower social welfare despite its pro-competitive effects.

In order to facilitate our analysis, we have made some modelling choices that are not trivial. Thus, by way of conclusion, we would like to mention some limitations of our analysis. One important limitation is that we analyse quality discrimination in a static model, where each patient already has a treatment history with one of the hospitals. A more complete analysis would require a dynamic framework where new patients today are potentially returning patients tomorrow, which would produce a richer set of incentives for quality provision. Another limitation is that we have assumed a cost structure where quality is always underprovided from a viewpoint of social welfare. In an alternative setting where the marginal cost of quality provision might be higher than the marginal treatment benefit from higher quality, overprovision of quality would be a potential welfare concern. This would potentially reduce the scope for welfare-enhancing effects of quality discrimination. Finally, we have assumed that healthcare providers are pure profit maximisers. Although this is a fairly common assumption in the literature, a more complete analysis would allow for the possibility of semi-altruistic provider preferences, where providers also care, at least to some extent, about the utility of the patients they treat. These and other extensions of our analysis are left for further research.

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Appendix: Proofs

Proof of Proposition 3

From (26)-(28), it is straightforward to verify that $q_i^L|_{\beta=1} > q_i^H|_{\beta=1} > 0$ and $q_i^N|_{\beta=1} > q_i^H|_{\beta=1}$ for $p > \underline{p}$. Furthermore, an interior solution requires that some low-cost patients switch hospital, which is true if

$$q_i^N|_{\beta=1} - q_i^L|_{\beta=1} = \frac{t}{3} - \frac{(1-\alpha)(1-\gamma)p}{2\gamma\bar{c}} > 0, \tag{A1}$$

but also that not all high-cost patients switch hospital, which is true if

$$\frac{q_i^H|_{\beta=1} - q_i^N|_{\beta=1} + t}{2t} = \frac{1}{3} - \frac{\alpha\left(1-\gamma\right)p}{4t\overline{c}} > 0. \tag{A2}$$

It is easily verified that the inequalities in (A1) and (A2) both hold if

$$p < \min\left\{\frac{2t\gamma\overline{c}}{3\left(1-\alpha\right)\left(1-\gamma\right)}, \frac{4t\overline{c}}{3\alpha\left(1-\gamma\right)}\right\}. \tag{A3}$$

It remains to show that the parameter set given by (31) in Proposition 3 is non-empty, which requires

$$\frac{2t\gamma\overline{c}}{3\left(1-\alpha\right)\left(1-\gamma\right)} - t = \frac{\left(\left(1-\alpha\right)\left(5\gamma-3\right)+2\alpha\gamma^2\right)t}{3\left(1-\alpha\right)\left(1-\gamma\right)} > 0 \tag{A4}$$

and

$$\frac{4t\overline{c}}{3\alpha\left(1-\gamma\right)} - t = \frac{\left(4-7\left(1-\gamma\right)\alpha\right)t}{3\alpha\left(1-\gamma\right)} > 0. \tag{A5}$$

It is easily confirmed that both conditions hold for $\gamma > 2/3$.

Proof of Proposition 7

(i) A comparison of (44) and (45) yields

$$W|_{\beta=0} - W^u = \frac{1}{18}t\left(8\left(1-\gamma\right)\alpha - 1\right) < (>)\, 0 \text{ if } \alpha < (>)\, \frac{1}{8\left(1-\gamma\right)}, \tag{A6}$$

which implies $W|_{\beta=0} < W^u$ for all $\alpha \in (0,1)$ if $\gamma > 7/8$. Thus, $W|_{\beta=0} < W^u$ if γ is sufficiently high or α is sufficiently low. Furthermore, a comparison of (44) and (46) yields

$$W|_{\beta=1} - W^u = \frac{\Phi}{72t\gamma^2\overline{c}^2}, \tag{A7}$$

where

$$\Phi := 4t^2\gamma^2 \left(8\left(1-\gamma\right)\alpha - 1\right)\bar{c}^2 - 3\alpha\left(1-\alpha\right)\left(1-\gamma\right)^2 p \begin{pmatrix} 3p\left(1-\alpha+\alpha\gamma^2\right)\left(1-2\left(1-\gamma\right)\alpha\right) \\ -4t\gamma\left(1+\left(1-\gamma\right)\alpha\right)\bar{c} \end{pmatrix}. \tag{A8}$$

Thus, the sign of $W|_{\beta=1} - W^u$ is given by the sign of Φ. From (A8) we derive

$$\frac{\partial\Phi}{\partial p} = 6\alpha\left(1-\alpha\right)\left(1-\gamma\right)^2 \left(2t\gamma\left(1+\left(1-\gamma\right)\alpha\right)\bar{c} - 3p\left(1-\alpha+\alpha\gamma^2\right)\left(1-2\left(1-\gamma\right)\alpha\right)\right) \tag{A9}$$

and

$$\frac{\partial^2\Phi}{\partial p^2} = -18\alpha\left(1-\alpha\right)\left(1-\gamma\right)^2\left(1-2\left(1-\gamma\right)\alpha\right)\left(1-\alpha+\alpha\gamma^2\right) < 0 \text{ for } \gamma > \frac{2}{3}. \tag{A10}$$

Thus, Φ is concave in p and reaches a maximum at

$$\widetilde{p} = \frac{2t\gamma\left(1+\left(1-\gamma\right)\alpha\right)\bar{c}}{3\left(1-\alpha+\alpha\gamma^2\right)\left(1-2\left(1-\gamma\right)\alpha\right)}. \tag{A11}$$

Furthermore, we derive

$$\widetilde{p} - \underline{p} = -t\frac{\left(1-2\alpha\right)\left(1-\alpha\right)\left(3-2\gamma\right)+\alpha\left(3-10\alpha+8\alpha\gamma\right)\gamma^2}{3\left(1-\alpha+\alpha\gamma^2\right)\left(1-2\left(1-\gamma\right)\alpha\right)}. \tag{A12}$$

It is easy to verify that $\widetilde{p} < \underline{p}$ if α is sufficiently low or if γ is sufficiently high. In this case, $\partial\Phi/\partial p < 0$ for the entire parameter set given by (31) in Proposition 3, implying that Φ is maximised at $p = \underline{p}$ on this set. Furthermore,

$$\lim_{\gamma\to 1}\Phi\left(\underline{p}\right) = -4t^2 < 0 \tag{A13}$$

and

$$\lim_{\alpha \to 0} \Phi \left(\underline{p} \right) = -4t^2\gamma^2 < 0. \tag{A14}$$

By continuity, it must also be the case that $\Phi \left(\underline{p} \right) < 0$ if γ is sufficiently close to 1, or if α is sufficiently close to 0, and, since $\partial\Phi/\partial p < 0$ on the entire relevant parameter set, it must be the case that $\Phi < 0$, and thus $W|_{\beta=1} < W^u$, if γ is sufficiently high or if α is sufficiently low.

(ii) Evaluating Φ at the upper limit of α yields

$$\lim_{\alpha \to 1} \Phi = -4t^2\gamma^4 \left(8\gamma - 7 \right) > 0 \text{ if } \gamma < \frac{7}{8}. \tag{A15}$$

By continuity, $\Phi > 0$, implying $W|_{\beta=1} > W^u$, if α is sufficiently high *and* γ is sufficiently low. In qualitative terms, the same conditions ensure that $W|_{\beta=0} > W^u$, as can be seen from (A6). Thus, if these conditions hold, social welfare is higher under some form of quality discrimination.

A comparison of (45) and (46) yields

$$W|_{\beta=1} - W|_{\beta=0} = \frac{\alpha \left(1-\alpha \right) \left(1-\gamma \right)^2 p\Theta}{24t\gamma^2\overline{c}^2}, \tag{A16}$$

where

$$\Theta := 4t\gamma \left(1 + \left(1-\gamma \right) \alpha \right) \overline{c} - 3p \left(1 - \alpha + \alpha\gamma^2 \right) \left(1 - 2 \left(1-\gamma \right) \alpha \right). \tag{A17}$$

Thus, the sign of $W|_{\beta=1} - W|_{\beta=0}$ is given by the sign of Θ, which is monotonically decreasing in p. Evaluating Θ at the lower bound of p yields

$$\Theta \left(\underline{p} \right) = t \left(\left(1-\alpha \right) \left(3 \left(2\alpha - 1 \right) + 2 \left(2-\alpha \right) \gamma \right) + \alpha\gamma^2 \left(2\alpha \left(7 - 5\gamma \right) - 3 \right) \right). \tag{A18}$$

It is relatively straightforward to verify that $\Theta\left(\underline{p}\right) > 0$ if α is sufficiently high. By continuity, this must also hold for sufficiently low values of p.

Consider now the welfare ranking for higher values of p. Evaluating Θ at each of the two possible upper bounds of p yields

$$\Theta|_{p=\frac{2t\gamma\bar{c}}{3(1-\alpha)(1-\gamma)}} = -2t\gamma\bar{c}\frac{(1-\alpha)\left(2\gamma+2\alpha\left(3\gamma-2\right)-1\right)+\gamma^2\alpha\left(2\alpha\gamma-1\right)}{(1-\gamma)\left(1-\alpha\right)} \tag{A19}$$

and

$$\Theta|_{p=\frac{4t\bar{c}}{3\alpha(1-\gamma)}} = -4t\bar{c}\frac{(1-2\alpha)\left(1-\alpha\right)+\alpha\gamma\left(1-3\alpha+2\gamma+\alpha\gamma^2\right)}{\alpha\left(1-\gamma\right)}. \tag{A20}$$

It is relatively straightforward to verify that (A19) is negative for all $\alpha \in (0,1)$ and $\gamma > 2/3$, whereas the sign of (A20) is generally ambiguous within the relevant parameter space (notice that $4t\bar{c}/3\alpha\left(1-\gamma\right)$ is the relevant upper bound on p if $\gamma > 2\left(1-\alpha\right)/\alpha)$. Thus, if α is sufficiently high and γ is sufficiently low, social welfare is higher under quality discrimination, with $W|_{\beta=1} > W|_{\beta=0}$ if p is sufficiently low and $W|_{\beta=1} \lesseqgtr W|_{\beta=0}$ if p is sufficiently high.

Proof of Proposition 10

The existence of an interior solution Nash equilibrium requires that some low-cost patients switch hospital, which is true if

$$\widehat{q}_B^u - \widehat{q}^L = \frac{t}{4} - \frac{p\left(1-\gamma\right)\left(1-\alpha\right)}{2\gamma\bar{c}} > 0, \tag{A21}$$

but also that not all high-cost patients switch hospital, which is true if

$$\frac{\widehat{q}_A^H - \widehat{q}_B^u + t}{2t} = \frac{3}{8} - \frac{\alpha\left(1-\gamma\right)p}{4t\bar{c}} > 0. \tag{A22}$$

It is easily verified that the inequalities in (A21) and (A22) both hold if

$$p < \min\left\{\frac{\gamma t\bar{c}}{2(1-\alpha)(1-\gamma)}, \frac{3t\bar{c}}{2\alpha(1-\gamma)}\right\}. \tag{A23}$$

It remains to show that the parameter set given by (64) in Proposition 10 is non-empty, which requires

$$\frac{\gamma t\bar{c}}{2(1-\alpha)(1-\gamma)} - t = \frac{\left((1-\alpha)(3\gamma-2)+\alpha\gamma^2\right)t}{2(1-\gamma)(1-\alpha)} > 0 \tag{A24}$$

and

$$\frac{3t\bar{c}}{2\alpha(1-\gamma)} - t = \frac{(3-5(1-\gamma)\alpha)t}{2\alpha(1-\gamma)} > 0. \tag{A25}$$

It is easily confirmed that both conditions hold for $\gamma > 2/3$. Finally, using (60)-(63) it is straightforward to verify that $\widehat{q}_A^L > \widehat{q}_A^H > 0$ and that $\widehat{q}_A^N > \widehat{q}_B^u$, while we have already shown that $\widehat{q}_B^u > \widehat{q}_A^L$ when the parameter condition in (64) holds.

Proof of Proposition 11

From (66)-(67) it is easily seen that $\widehat{\pi}_A > \widehat{\pi}_B$. Comparing (66) with (8), we derive

$$\widehat{\pi}_A - \pi^u = -\frac{3}{16}t\bar{c} + \frac{\alpha(1-\alpha)(1-\gamma)^2 p^2}{8t\gamma\bar{c}}. \tag{A26}$$

This profit difference is monotonically increasing in p. Suppose first that $\alpha < 3/(3+\gamma)$, which implies that the parameter condition in (64) simplifies to

$$\underline{p} < p < \frac{\gamma t\bar{c}}{2(1-\alpha)(1-\gamma)}. \tag{A27}$$

Evaluating the profit difference in (A26) at the upper bound of p yields

$$\left(-\frac{3}{16}t\bar{c}+\frac{\alpha\left(1-\alpha\right)\left(1-\gamma\right)^{2}p^{2}}{8t\gamma\bar{c}}\right)\Bigg|_{p=\frac{\gamma t\bar{c}}{2(1-\alpha)(1-\gamma)}}=-\frac{t\left(6\left(1-\alpha\right)-\alpha\gamma\right)\bar{c}}{32\left(1-\alpha\right)}, \tag{A28}$$

which is negative for $\alpha < 3/\left(3+\gamma\right)$. By monotonicity, $\widehat{\pi}_A - \pi^u < 0$ for the entire parameter set given by (64) when $\alpha < 3/\left(3+\gamma\right)$. Suppose instead that $\alpha > 3/\left(3+\gamma\right)$, which implies that the parameter condition in (64) simplifies to

$$\underline{p} < p < \frac{3t\bar{c}}{2\alpha\left(1-\gamma\right)}. \tag{A29}$$

Evaluating the profit difference in (A26) at the upper bound of p yields

$$\left(-\frac{3}{16}t\bar{c}+\frac{\alpha\left(1-\alpha\right)\left(1-\gamma\right)^{2}p^{2}}{8t\gamma\bar{c}}\right)\Bigg|_{p=\frac{3t\bar{c}}{2\alpha(1-\gamma)}}=-\frac{3t\left(2\alpha\gamma-3\left(1-\alpha\right)\right)\bar{c}}{32\alpha\gamma}, \tag{A30}$$

which is negative for $\alpha > 3/\left(3+\gamma\right)$. By monotonicity, $\widehat{\pi}_A - \pi^u < 0$ for the entire parameter set given by (64) also when $\alpha > 3/\left(3+\gamma\right)$.

Proof of Proposition 12

The existence of an interior solution Nash equilibrium requires that some low-cost patients switch hospital, which is true if

$$q^{N}\left(\beta\right)-q^{L}\left(\beta\right)=\frac{t}{3}-\frac{\beta\left(1-\gamma\right)\left(1-\alpha\right)\left(3-2\alpha\left(1-\gamma\right)\left(1-\beta\right)\right)p}{6\bar{c}\left(1-\alpha\left(1-\gamma\right)\left(1-\beta\right)\right)\left(1-\left(1-\gamma\right)\left(\beta+\left(1-\beta\right)\alpha\right)\right)}>0, \tag{A31}$$

but also that not all high-cost patients switch hospital, which is true if

$$\frac{q^H(\beta) - q^N(\beta) + t}{2t} = \frac{1}{3} - \frac{\alpha\beta(1-\gamma)(2(1-\beta)(1-\alpha) + \gamma(1+2\alpha+2(1-\alpha)\beta))p}{12t\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0. \tag{A32}$$

It is relatively straightforward to verify that the parameter restriction (31) in Proposition 3 is a sufficient condition for both (A31) and (A32) to hold.

A pairwise comparison of equilibrium quality levels across the three different symmetric games, with no tracking, (15)-(16), perfect tracking, (26)-(28), and imperfect tracking, (76)-(78), yields

$$q^N\big|_{\beta=1} - q^N(\beta) = \frac{\alpha(1-\alpha)\beta(1-\beta)(1-\gamma)^2 p}{3\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0, \tag{A33}$$

$$q^L\big|_{\beta=1} - q^L(\beta) = \frac{(1-\gamma)(1-\alpha)(1-\beta)p\begin{pmatrix} 3(1-\alpha)(1-\alpha+\alpha\beta+2\alpha\gamma) \\ +\alpha\gamma(\beta(6\alpha-\gamma-2)+3\alpha(1-\beta)\gamma)\end{pmatrix}}{6\gamma\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0, \tag{A34}$$

$$q^H(\beta) - q^H\big|_{\beta=1} = \frac{\alpha(1-\gamma)(1-\beta)p\begin{pmatrix} (1-\alpha)(3(1-\alpha+\alpha\beta)+6\alpha(1-\beta)\gamma-4(1-\gamma)\beta) \\ +3\alpha\gamma^2(\beta+(1-\beta)\alpha)\end{pmatrix}}{6\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0, \tag{A35}$$

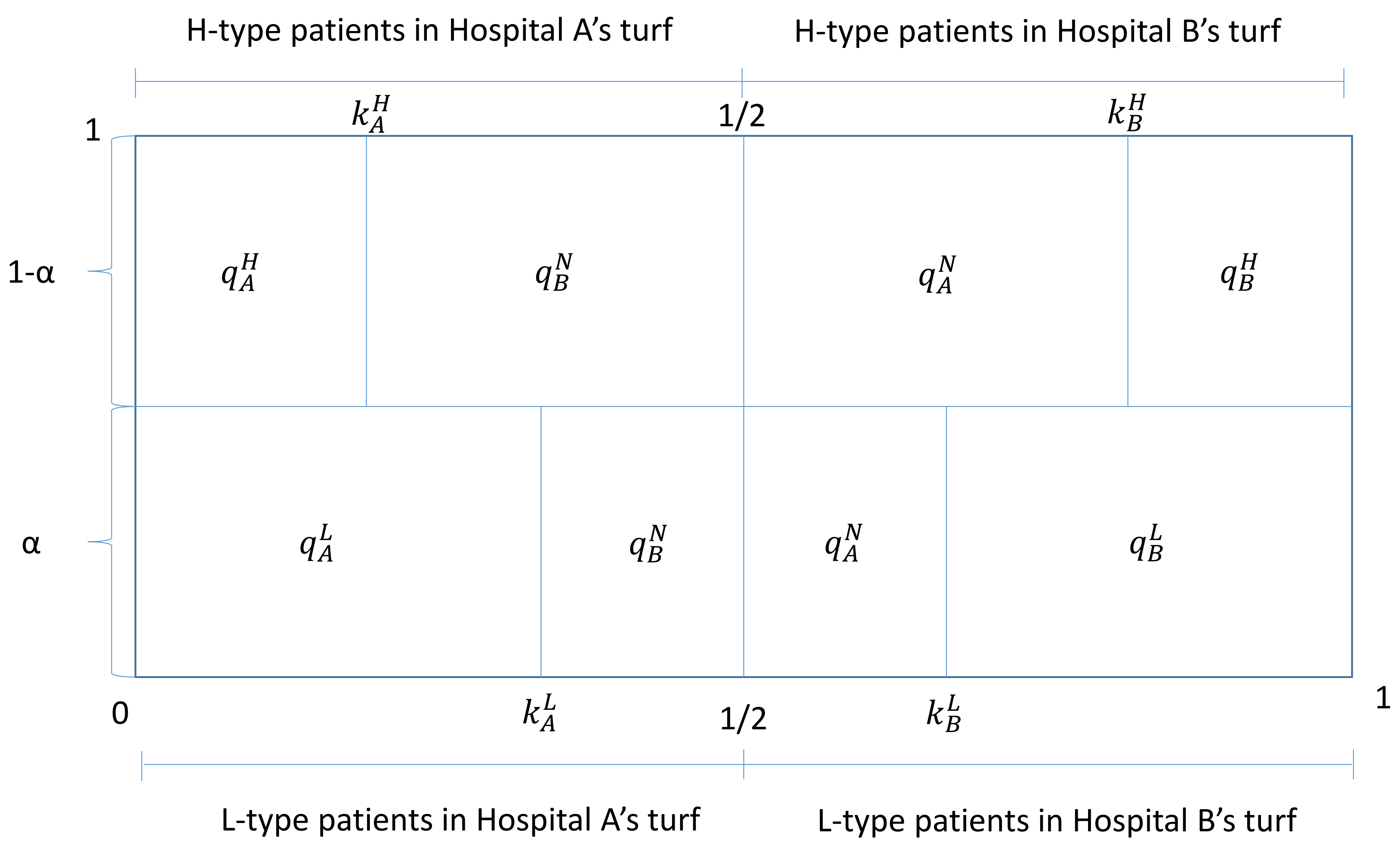
$$q^L(\beta) - q^R\big|_{\beta=0} = \frac{\beta(1-\gamma)(1-\alpha)p(3-4\alpha(1-\gamma)(1-\beta))}{6\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0, \tag{A36}$$

and

$$q^R\big|_{\beta=0} - q^H(\beta) = \frac{\alpha\beta(1-\gamma)p(4(1-\alpha)(1-\beta+\beta\gamma)+(4\alpha-1)\gamma)}{6\bar{c}(1-\alpha(1-\gamma)(1-\beta))(1-(1-\gamma)(\beta+(1-\beta)\alpha))} > 0. \tag{A37}$$

It is straightforward to verify that the expressions in (A33)-(A37) are all positive for $\gamma > 2/3$.

Figure 1. Two-dimensional quality discrimination



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