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ORIGINAL PAPER

Quality choice in a health care market: a mixed duopoly approach

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Abstract We investigate a health care market with uncertainty in a mixed duopoly, where a partially privatized public hospital competes against a private hospital in terms of quality choice. We use a simple Hotelling-type spatial competition model by incorporating mean–variance analysis and the framework of partial privatization. We show how the variance in the quality perceived by patients affects the true quality of medical care provided by hospitals. In addition, we show that a case exists in which the quality of the partially privatized hospital becomes higher than that of the private hospital when the patient's preference for quality is relatively high.

Keywords Quality choice · Health care market · Mixed duopoly

JEL Classification L32 · L33 · I11

Introduction

Since the seminal work of Arrow [1], a vast amount of research has been conducted on medical and health care services, and various analytical approaches have been developed in order to investigate and explain the health care market and the provision of health care. One such approach is to employ the Hotelling-type spatial competition model.[1] Several recent studies have made contributions to the analysis of the health care market by using this model.[2] For example, Ma and Burgess [19] examined the strategic interaction between quality and price competition with fixed locations in imperfectly competitive markets. Nuscheler [25] studied physicians' incentives to provide quality in the physician–patient relationship under price regulation by using a circular-city model (location-then-quality with price regulation) in a pure market. Brekke et al. [5] analyzed location and quality choices with price regulation by using pure strategies. These studies investigated the Hotelling-type spatial competition model with quality choice in a private market.

On the other hand, examples of studies based on a mixed market are Barros and Martinez-Giralt [2] and Ma [18]. Barros and Martinez-Giralt [2] use the Hotelling's duopoly model to investigate the effects of competition in providers of different reimbursement schemes on their quality and cost efficiency. They focus on the effect of interaction between public and private health care, and also analyze two types of games concerning public leadership, namely, the Stackelberg leadership and the semisequential game. On the other hand, Ma [18] examines a public provider's strategic use of rationing in a mixed duopoly. Ma's study provides an analysis based on the assumption that providers' locations and qualities are given exogenously. These two studies analyze the health care services provided without taking into account the uncertainty that characterizes the health care market. In general, owing to the asymmetry of information, patients are unable to observe the true quality of the services provided by hospitals.

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[1] For an excellent survey of the Hotelling-type spatial competition model, see Gabszewicz and Thisse [10].

[2] The advantage of using the Hotelling-type spatial competition model is that we can analyze location (or preference) as horizontal product differentiation. Further, by incorporating the quality of medical care into the model, we can also examine quality as vertical product differentiation.

Consequently, while choosing a hospital, patients rely not on the true quality but on the perceived quality of hospitals. The perceived quality is affected by bias, and is associated with uncertainty. Therefore, from the viewpoint of theoretical analysis, it might be necessary to investigate the health care market by taking uncertainty into consideration.

In a new approach to the study of health economics, Montefiori [22] recently investigated a health care market under uncertainty, where two profit-maximizing private hospitals provide medical services, by using mean–variance analysis and the Hotelling-type spatial competition model. His study suggests that both the purchaser and the hospitals have incentives to reduce asymmetry of information in order to attain each objective, and his model deals with a private duopoly. However, in many countries, including Japan, public and private hospitals both compete in the health care market. Thus, it is possible to regard the health care market as a mixed market. Therefore, it is necessary to investigate the health care market by taking into consideration the possibility of a mixed oligopoly, where one of the hospitals is publicly owned and seeks to maximize social welfare rather than profit.

The purpose of this paper is to investigate a health care market with uncertainty in a mixed duopoly, where a partially privatized public hospital competes against a private hospital in terms of quality choice.[3] In order to analyze a health care market with uncertainty, we extend Montefiori's model [22], which investigates a private duopoly, to a mixed duopoly model by incorporating the framework of partial privatization[4] developed by Bös [4]. On the basis of Bös's model, along with the analysis of a fully public hospital that maximizes social welfare, we can analyze the case of a partially privatized hospital that maximizes the weighted average of social welfare and its profits. In other words, we can generalize the analysis of a mixed duopoly. Therefore, in our simple model, we assume a mixed duopoly market comprising a partially privatized hospital and a private hospital. Moreover, in order to analyze the impact of patients' preferences for the quality provided by hospitals, we explicitly incorporate patients' preferences for quality into the model.

Since we are interested in the uncertainty of health care services, we first analyze how the variance in the patients' perceived quality affects the true quality provided by hospitals. Second, we examine the difference between the quality of a partially privatized hospital and that of a private hospital. The results indicate that the quality provided by hospitals is affected by the difference between variances in perceived quality. Furthermore, we show that when patient preference for quality is relatively high, the quality of the partially privatized hospital can become even higher than that of the private hospital. This result implies that the partially privatized hospital chooses to overinvest in the quality of its services while the private hospital chooses underinvestment. This is in sharp contrast to the existing literature on mixed oligopoly.

The model

In order to analyze the health care market that involves uncertainty, we follow the basic model presented by Montefiori [22], who investigates a private duopoly.

Hospitals and patients

We consider a very simple Hotelling-type economy involving a linear city with a length of 1 unit in a mixed duopoly. Our model comprises two hospitals, indexed by i (=0, 1), that are health care providers in the market. Hospital 0 is a partially privatized public hospital that maximizes the weighted average between social welfare and its own profits. Hospital 1 is a private hospital that maximizes profits. We assume that the locations of the two hospitals are fixed and that patients have a preference with regard to the hospitals. In order to describe this situation, suppose that hospital 0 is located at endpoint 0 of the market, and that hospital 1 is located at endpoint 1 of the market. Each hospital provides medical services to patients and receives a fixed price M per patient treated. That is, the purchaser sets the amount of reimbursement, M, so as to satisfy the participation constraint of the hospital. Each hospital i chooses a level of quality for the treatment q_i.[5] The quality of treatment affects the utility of patients. The level of quality q_i is perfect information for the hospitals but imperfect information for patients (as described later). Without loss of generality, we assume that the lowest

[3] In addition to health care markets, competition between public and private firms also exists in other industries, such as education, telecommunications, electricity, railways, airlines, TV and radio broadcasting, banking, medical insurance, and life insurance. Therefore, our study may also be applicable to the analysis of other areas.

[4] This (partial) privatization is one of the measures introduced to improve the efficiency of the public sector in developed countries since the 1980s. See Bös [4].

[5] Chalkley and Malcomson [7], Levaggi [12], and Levaggi and Montefiori [13, 14] define the quality of service provided by hospitals as a *multidimensional* vector that includes (various) aspects of medical and non-medical quality. Levaggi and Montefiori [13, 14] describe medical and non-medical quality as follows. Medical quality (health-related services) includes aspects such as prevention, treatment, aftercare, and nursing. Non-medical quality (hotel services) includes the number of beds per room, nurses per ward, accommodation, comfort, kindness toward patients, provision of information, catering services, and so forth. However, in this paper, we use the conventional notion of quality in accordance with the existing literature.

possible level of quality is normalized to zero; this is represented as $q_i \geq 0$.

Patients are distributed uniformly along the unit interval. All patients have a preference for quality of treatment. A patient is located at $y \in [0, 1]$ and has v amount of money. Each patient inelastically demands one unit of medical service in order to recover from ill health and derives a surplus from the medical treatment. We assume that all patients are insured and are subject to a copayment rate of $s \in (0, 1)$.[6] As M is the amount of reimbursement, patients pay sM directly for the treatment they receive. Note that if $s = 1$, the patients must bear the entire cost of the treatment provided by the hospital. This case refers to the situation where the patients are not insured. If $s = 0$, the patients are able to avail themselves of the hospital care service with no copayment, that is, without bearing any costs. This case corresponds to the assumption of Montefiori [22], except for the market structure. In addition to copayment for treatment, a patient located at y must pay transportation costs ty to avail themselves of the medical care from hospital 0 or $t(1 - y)$ for hospital 1, where $t > 0$ is the unit cost of transportation. Thus, we assume linear transportation costs.[7]

The game structure is very simple. Each hospital, i, simultaneously chooses a level of quality for the treatment, q_i. Therefore, in accordance with standard practice, we can solve the optimization problem by using the concept of Nash equilibrium.

Uncertainty

In health care markets, an asymmetry of information between patients and health care providers (or hospitals) exists. In such a case, patients generally cannot ascertain the true quality of the medical care provided by hospitals. In many cases, in order to reduce the asymmetry of information, patients may rely on reputation, advertisements (see [23]) and so on to obtain information regarding the quality of service provided by hospitals. However, such information is imperfect and does not inform patients about the true quality of treatment. In such situations, patients usually choose a hospital on the basis of the quality of medical treatment that they can expect to receive.

In our model, we assume that the hospital is aware of the true quality of the services it provides. Hence, we can interpret the quality provided by a hospital as the *true* quality of treatment. In contrast, patients are unable to correctly ascertain the true quality. In other words, because of the asymmetry of information, patients have imperfect information regarding quality of services provided by a hospital, which is thus referred to as perceived quality.

Here, we deal with uncertainty, which characterizes the health care market. In order to deal theoretically with perceived quality, we use the mean–variance method in keeping with the model proposed by Montefiori [22]. Let $\tilde{q}_i$ denote the (hospital i's) perceived quality, which we assume to be equally and normally distributed with $\bar{q}_i$ as a mean (hereafter referred to as average) of perceived quality and $\sigma^2_{q_i}$ as a variance in the perceived quality, i.e., $\tilde{q}_i \sim N(\bar{q}_i, \sigma^2_{q_i})$. Moreover, we assume that the correlation between the perceived quality and the average quality is given as $\bar{q}_i = E(\tilde{q}_i)$..

Taking uncertainty into account, the utility of a patient located at point y, who avails of the medical service provided by either hospital 0 or hospital 1, is given by

$$u_y = \begin{cases} v + \alpha\bar{q}_0 - \beta\sigma^2_{q_0} - sM - ty & \text{if receiving from hospital 0,} \\ v + \alpha\bar{q}_1 - \beta\sigma^2_{q_1} - sM - t(1-y) & \text{if receiving from hospital 1,} \end{cases}$$

where α indicates the preference for the quality of the hospital's medical care, $\beta > 0$ is the parameter associated to the variance, and sM is the amount of copayment since M is the amount of reimbursement. We assume $\alpha \in (0, 2)$, which implies the existance of a unique interior solution for the quality choice. This assumption ensures the concavity of a hospitals' objective functions. α also implies that the patient's preference for quality is relatively high if $1 < \alpha < 2$, and relatively low if $0 < \alpha < 1$.

The location x of a patient who is indifferent to the choice between the medical services of hospital 0 and hospital 1 is given by

[6] Montefiori [22] assumed the Diagnosis-Related Groups/Prospective Payment System (DRG/PPS) to be implemented as a tax-financed health care system, and that patients were able to avail themselves of the hospital care service at zero cost. In our model, however, we assume that all patients are insured and are subject to a copayment system. This assumption does not affect our analysis and implies no loss of generality.

[7] Since location choice is not a factor in our model, we use the Hotelling-type spatial competition model with linear transportation costs. For the equilibrium of location choice under Hotelling's location model with linear transportation costs, see Economides [8] for a private duopoly and Sanjo [26] for a mixed duopoly. These studies investigated a three-stage game, i.e., a location-then-quality choice and a subsequent price choice.

$$x = \frac{1}{2} + \frac{\alpha(\bar{q}_0 - \bar{q}_1) - \beta(\sigma_{q_0}^2 - \sigma_{q_1}^2)}{2t}. \tag{1}$$

The demands of hospital 0 and that of hospital 1 are given by $D_0 = x$ and $D_1 = 1 - x$, respectively. In other words, D_i expresses the number of patients treated by hospital i. The patient surplus CS is given by

$$\mathrm{CS} = \int_0^x \left(v + \alpha\bar{q}_0 - \beta\sigma_{q_0}^2 - sM - ty\right)\mathrm{d}y + \int_x^1 \left(v + \alpha\bar{q}_1 - \beta\sigma_{q_1}^2 - sM - t(1-y)\right)\mathrm{d}y.$$

The revenue of hospital i is $R_i = MD_i$. Since the amount of reimbursement M is set by the purchaser, the private hospital has an incentive to increase its market share in order to increase its revenue. The costs of hospital i are $C_i = cq_iD_i + F_i$, where $c > 0$ is a cost parameter associated with the number of patients and $F_i > 0$ is the fixed cost of the hospital i.[8] The hospital's costs increase with the increase in the demand for and quality of its services. In what follows, we normalize c to 1 in order to simplify the analysis without loss of generality. That is,

$$C_i = q_iD_i + F_i. \tag{2}$$

The profit of hospital i is given by $\pi_i = R_i - C_i$. Therefore, the two hospitals' profits are given by

$$\pi_0 = (M - q_0)\left(\frac{1}{2} + \frac{\alpha(\bar{q}_0 - \bar{q}_1) - \beta(\sigma_{q_0}^2 - \sigma_{q_1}^2)}{2t}\right) - F_0, \tag{3}$$

$$\pi_1 = (M - q_1)\left(\frac{1}{2} + \frac{\alpha(\bar{q}_1 - \bar{q}_0) - \beta(\sigma_{q_1}^2 - \sigma_{q_0}^2)}{2t}\right) - F_1, \tag{4}$$

respectively. Social welfare, denoted by W, is the sum of patient surplus and two hospitals' profits. Thus,

$$W = v + (1-s)M + (\alpha\bar{q}_0 - \beta\sigma_{q_0}^2 - q_0)x + (\alpha\bar{q}_1 - \beta\sigma_{q_1}^2 - q_1)(1-x) - t\left(x^2 - x + \frac{1}{2}\right) - F_0 - F_1. \tag{5}$$

Since we are dealing with the partial privatization of a public hospital in this paper, in keeping with Bös [4],[9] we formulate the objective function of a partially privatized hospital as

$$V = (1-\theta)W + \theta\pi_0, \tag{6}$$

where $\theta \in [0, 1]$ is the degree of privatization. In Eq. 6, we assume that the weight on welfare and profits has a continuous and linear relationship with the degree of privatization. Note that if $\theta = 0$, then hospital 0 is a fully public hospital that maximizes social welfare; in other words, $\theta = 0$ characterizes a fully public hospital. In contrast, if $\theta = 1$, then hospital 0 is a fully privatized hospital that maximizes its own profits. In this case, our study completely corresponds with that of Montefiori [22]. If $\theta \in (0, 1)$, then hospital 0 is a partially privatized hospital.

Finally, it should be noted that Eqs. 3, 4, 5, and 6 contain both the average quality related to the patients' perceived quality, $\bar{q}_i$, and the true quality provided by hospital, q_i. That is, it is necessary to distinguish between the true quality and the average quality when we solve the optimization problem in the next section.

Equilibrium

In this section, we consider the equilibrium outcome in quality choice.

In our simple model, each hospital is aware of its own quality level, whereas patients are unable to ascertain the true quality provided by hospitals. In other words, an asymmetry of information between patients and hospitals exists. In such a situation, the two hospitals maximize their objectives with respect to the true quality. If the average quality is assumed to be equal to the true quality, we can assume $\bar{q}_i = q_i$.[10] After taking $\bar{q}_i = q_i$ into account, the first-order condition for hospital 0 is given by maximizing V with respect to q_0 as follows:

$$\left.\frac{\partial V}{\partial q_0}\right|_{\bar{q}_i = q_i} = (1-\theta)\left.\frac{\partial W}{\partial q_0}\right|_{\bar{q}_i = q_i} + \theta\left.\frac{\partial \pi_0}{\partial q_0}\right|_{\bar{q}_i = q_i} = 0, \quad i = 0, 1$$

which yields

$$q_0 = \frac{((2-\theta) - (1-\theta)\alpha)q_1 + \theta M}{2 - (1-\theta)\alpha} - \frac{(1 - (1-\theta)\alpha)(t - \beta(\sigma_{q_0}^2 - \sigma_{q_1}^2))}{\alpha(2 - (1-\theta)\alpha)}. \tag{7}$$

Similarly, the first-order condition for hospital 1 is given by maximizing π_1 with respect to q_1,

[8] For other settings of the cost function in the Hotelling model of quality choice, see Economides [8, 9], Calem and Rizzo [6], Bester [3], Lyon [17], Gravelle and Masiero [11], Barros and Martinez-Giralt [2], Brekke et al. [5] and Sanjo [26].

[9] See also Matsumura [20] for the partial privatization of a public firm. His study investigates a mixed market by formulating the model in detail.

[10] Since the average quality, $\bar{q}_i$, is a value rather than a variable, we cannot directly obtain the first-order conditions for both hospitals by maximizing the objective functions with respect to q_i. Therefore, based on theoretical reasoning, we assume $\bar{q}_i = q_i$ in order to obtain reasonable solutions.

$$\left.\frac{\partial \pi_1}{\partial q_1}\right|_{\bar{q}_i=q_i} = -(1-x) - (M-q_1)\left.\frac{\partial x}{\partial q_1}\right|_{\bar{q}_i=q_i} = 0, \quad i=0,1$$

which yields

$$q_1 = \frac{1}{2}\left(q_0 + M - \frac{t+\beta(\sigma_{q_0}^2 - \sigma_{q_1}^2)}{\alpha}\right). \tag{8}$$

Since $\partial^2 V/\partial q_0^2 = -\alpha(2-(1-\theta)\alpha)(2t)^{-1} < 0$ and $\partial^2 \pi_1/\partial q_1^2 = -\alpha/t < 0$ under the assumptions of $\alpha \in (0, 2)$ and $\theta \in [0, 1]$, the second-order conditions are satisfied. By solving Eqs. 7 and 8, we obtain the quality levels of the two hospitals as

$$q_0 = M - \frac{((4-\theta)-3(1-\theta)\alpha)t - (\theta-(1-\theta)\alpha)\beta(\sigma_{q_0}^2-\sigma_{q_1}^2)}{\alpha((2+\theta)-(1-\theta)\alpha)}, \tag{9}$$

$$q_1 = M - \frac{(3-2(1-\theta)\alpha)t + \beta(\sigma_{q_0}^2 - \sigma_{q_1}^2)}{\alpha((2+\theta)-(1-\theta)\alpha)}. \tag{10}$$

Further, using Eqs. 1, 9, and 10, the quantity supplied by hospital 0 is given by

$$x = \frac{1}{2} - \frac{(1-\theta)(1-\alpha)t + \beta(\sigma_{q_0}^2 - \sigma_{q_1}^2)}{2((2+\theta)-(1-\theta)\alpha)t}. \tag{11}$$

From Eqs. 9 and 10, we have

$$q_0 - q_1 = -\frac{(1-\theta)(1-\alpha)t - ((1+\theta)-(1-\theta)\alpha)\beta(\sigma_{q_0}^2-\sigma_{q_1}^2)}{\alpha((2+\theta)-(1-\theta)\alpha)}. \tag{12}$$

Here, we consider the comparative statics in terms of $\phi \equiv \sigma_{q_0}^2 - \sigma_{q_1}^2$. Using Eqs. 9–12, we obtain the following results:

$$\frac{\partial q_0}{\partial \phi} = \frac{(\theta-(1-\theta)\alpha)\beta}{\alpha((2+\theta)-(1-\theta)\alpha)} \gtreqless 0 \quad \text{if} \quad \frac{1}{\alpha} \gtreqless \frac{1-\theta}{\theta}, \tag{13}$$

$$\frac{\partial q_1}{\partial \phi} = -\frac{\beta}{\alpha((2+\theta)-(1-\theta)\alpha)} < 0, \tag{14}$$

$$\frac{\partial x}{\partial \phi} = -\frac{\beta}{2((2+\theta)-(1-\theta)\alpha)t} < 0, \tag{15}$$

$$\frac{\partial}{\partial \phi}(q_0 - q_1) = \frac{((1+\theta)-(1-\theta)\alpha)\beta}{\alpha((2+\theta)-(1-\theta)\alpha)} \gtreqless 0 \quad \text{if} \quad \frac{1}{\alpha} \gtreqless \frac{1-\theta}{1+\theta}. \tag{16}$$

The denominators of Eqs. 13–16 are strictly positive under the assumptions of $\alpha \in (0, 2)$ and $\theta \in [0, 1]$. Therefore, it is obvious that the results of the comparative statics of Eqs. 14 and 15 are strictly negative for $\theta \in [0, 1]$, because $\beta > 0$. As with the results of Eqs. 13 and 16, it depends on the values of α and θ.

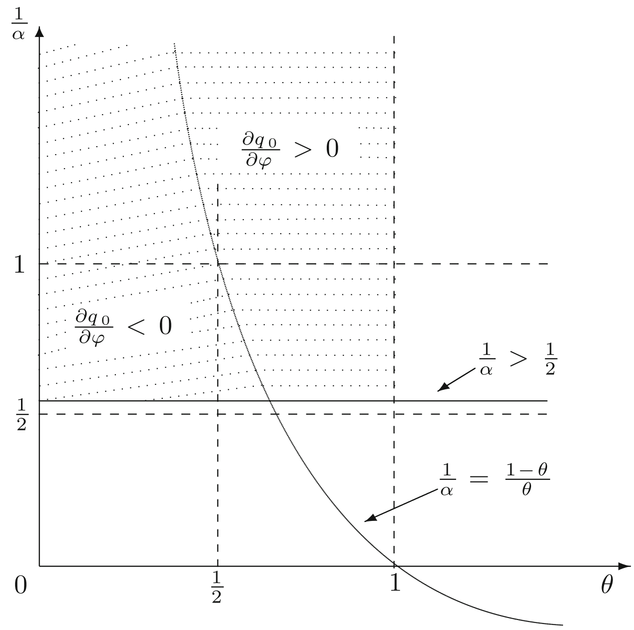

Fig. 1 The comparative statics result of the quality of hospital 0

The result of Eq. 13 is illustrated in Fig. 1. In this result, we obtain three cases; i.e., $\partial q_0/\partial \phi \gtreqless 0$ if $1/\alpha \gtreqless (1-\theta)/\theta$. (1) If $1/\alpha > (1-\theta)/\theta$, then we have $\partial q_0/\partial \phi > 0$. Under the condition of $1/\alpha > (1-\theta)/\theta$ and $\alpha \in (0, 2)$, a partially privatized hospital chooses a higher (lower) quality when the variance in the perceived quality becomes larger (smaller) than that of a rival. This result implies that because θ, which expresses the degree of privatization, approaches 1, the partially privatized hospital strengthens a characteristic as a profit maximizer[11] and has an incentive to reduce the variance in its perceived quality. The reason behind this is as follows. For a given market share, if a hospital has a variance lower than that of a rival, it can maintain a lower quality.[12] A lower quality induces lower costs, as it is obvious from Eq. 2. In other words, the hospital's cost reduces if the variance reduces. Consequently, there is a mechanism whereby higher (lower) quality induces larger (smaller) costs when the variance in the perceived quality is large (small). This result is the same as that obtained by Montefiori [22], where a private duopoly was investigated, while we examine a mixed duopoly market. (2) If $1/\alpha = (1-\theta)/\theta$, then we get $\partial q_0/\partial \phi = 0$. In such a case, the degree of variance is irrelevant to the quality provided by a partially privatized hospital. (3) If $1/\alpha < (1-\theta)/\theta$, then we obtain $\partial q_0/\partial \phi < 0$. In this case, a partially privatized hospital chooses a higher (lower) level of quality when the variance in the perceived quality, $\sigma_{q_0}^2$, becomes smaller (larger) for a given $\sigma_{q_1}^2$. This

[11] See Eq. 6.

[12] See Eq. 1.

implies that, when θ approaches zero, the partially privatized hospital strengthens a characteristic as a welfare maximizer and has an incentive to enhance its quality despite large costs in order to improve social welfare. This result can be easily inferred because the mechanism in this case is the opposite of that in the first case. This is in sharp contrast to the results obtained by Montefiori [22].

On the other hand, the result of Eq. 14 is clearly negative. By using Eq. 10, we obtain $\partial q_1/\partial \rho > 0$, where $\rho \equiv \sigma^2_{q_1} - \sigma^2_{q_0}$. Therefore, for a given $\sigma^2_{q_0}$, the quality of service provided by the private hospital q_1 is low (high) if the variance in the perceived quality $\sigma^2_{q_1}$ is small (large). When q_1 is low (high), the cost of the private hospital is small (large), as shown by Montefiori [22]. Hence, we can conjecture that the private hospital has an incentive to reduce $\sigma^2_{q_1}$, if $\sigma^2_{q_1}$ is determined endogenously in the model. As a result, the action of the private hospital in a mixed duopoly is the same as it would be in a private duopoly.

From Eq. 15, we find that the market share of the partially privatized hospital decreases when the difference between the variance in the perceived quality of the two hospitals becomes large. For a given $\sigma^2_{q_1}$, $\sigma^2_{q_0}$ has a negative effect on the market share of the partially privatized hospital.

Figure 2 illustrates the result obtained from Eq. 16.

From the above discussion, we can summarize the analysis in the following proposition 1.

Proposition 1 Suppose that the variance in the perceived quality of the partially privatized hospital becomes larger than that of the private hospital. (1) The quality of the partially privatized hospital can change in three ways, namely, increase, stay constant, or decrease. (2) The quality of the services provided by the private hospital always becomes lower.

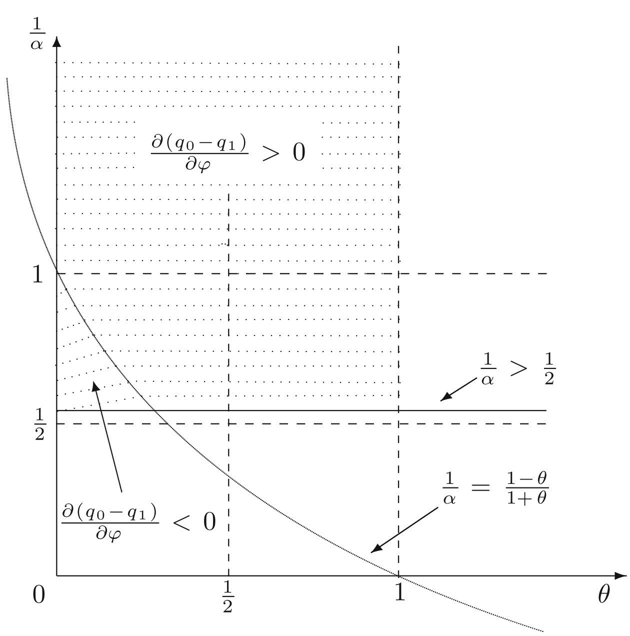

Fig. 2 The comparative statics result of the difference between qualities

Next, we consider the special case in which the variance in the perceived quality for both hospitals is the same; that is, we assume $\sigma^2_{q_0} - \sigma^2_{q_1} = 0$. Under this assumption, we can also consider the situation in which there is no asymmetry of information (see "Appendix").

If $\theta \in [0, 1)$, then the following three results are possible

$$\begin{cases} q_0 > q_1 & \text{if} \quad 1 < \alpha < 2, \\ q_0 = q_1 & \text{if} \quad \alpha = 1, \\ q_0 < q_1 & \text{if} \quad 0 < \alpha < 1. \end{cases} \tag{17}$$

First, from the upper part of Eq. 17, we find that the partially privatized hospital chooses a higher level of quality than the private hospital if the patient's preference for quality is relatively high. When the patient's preference for quality is relatively high, the partially privatized hospital increases the investment in its quality in order to achieve its objective, that is, to maximize the weighted average between social welfare and profits. At this time, a higher quality improves social welfare, resulting in an increase in the utility of patients. An increase in the cost of the partially privatized hospital is then inevitable, because, from Eq. 2, it is obvious that the hospital's cost increases with the quality of its services. Nevertheless, the partially privatized hospital decides to invest in the improvement of its quality despite the large costs involved. On the other hand, the private hospital has no incentive to increase investment in quality because when the partially privatized hospital invests in its quality, the private hospital must incur large costs in order to attract patients and increase its market share. Consequently, the partially privatized hospital chooses to overinvest in quality while the private hospital chooses to underinvest in quality, and we induce the upper part of Eq. 17.

Second, from the middle part of Eq. 17, we obtain the result that the quality levels of the two hospitals are the same when the patient's preference for quality remains unchanged (i.e., $\alpha = 1$). In this case, we obtain the same result as that obtained by Montefiori [22], who investigated the private duopoly market as opposed to our analysis of the mixed duopoly market.

Third, from the lower part of Eq. 17, we find that the partially privatized hospital chooses a lower level of quality than the private hospital when the patient's preference for quality is relatively low. If the patient's preference for quality is low, then the partially privatized hospital has no incentive to invest in quality, because the improvement of quality at a large cost provides a relatively small effect on social welfare. In contrast, the private hospital has an incentive to invest in quality to attract patients. Consequently, we obtain the result that the partially privatized hospital chooses a lower level of quality than that of the private hospital when the patient's preference for quality is relatively low.

In general, from the results of the existing literature regarding mixed oligopoly, it is known that a public firm chooses underinvestment while a private firm chooses overinvestment. For example, Matsumura and Matsushima [21] endogenize production costs in a Hotelling model and show that, as the private firm chooses overinvestment in cost-reducing activities, the costs of the public firm becomes higher than that of the private firm. Nishimori and Ogawa [24] analyze the capacity choice of firms in a mixed duopoly market by using the quantity-setting Cournot model. They show that, whereas a profit-maximizing private firm chooses overcapacity, a welfare-maximizing public firm chooses undercapacity. Lu and Poddar [15] investigate the capacity choice of firms in mixed duopoly market under the environments of sequential or simultaneous capacity choice. They conclude that the public firm never chooses overinvestment in capacity and the private firm never chooses underinvestment in capacity. In short, these studies imply that while the public firm chooses underinvestment, the private firm chooses overinvestment. The reason behind this result is that a private firm engages in excessive strategic behavior. However, the result of the upper part of Eq. 17 reveals that the public firm (the partially privatized hospital in our model) chooses overinvestment in quality under uncertainty.[13] This result is in sharp contrast to the existing literature investigating mixed oligopoly. On the other hand, the lower part of Eq. 17 shows that we obtain the same result as in existing works on mixed oligopoly.

In contrast to the existing mixed oligopoly literature, Levaggi and Montefiori [13] provide a result akin to our analysis in this paper, in the context of cream skimming.[14] They define quality as a multidimensional vector that includes aspects of medical and non-medical quality and investigate both horizontal cream skimming as a legal practice and vertical cream skimming as an illegal behavior in the health care market. The main result of their study is that the medical quality of the public hospital is greater than that of the private hospital, while the non-medical quality of the private hospital is greater than that of the public hospital. This implies that the public hospital chooses overinvestment in the medical quality while the private hospital chooses underinvestment, under the assumption that patients suffering conditions with a higher degree of severity desire higher medical quality. In general, improvements in medical quality are assumed to entail large investments compared to those involving non-medical quality. That is, in order to maximize social welfare, public hospitals invest in medical quality in spite of large costs. On the other hand, as the private hospital has an incentive to increase its profits without a large cost burden, it tends to overinvest on non-medical quality rather than on medical quality. It is likely that Levaggi and Montefiori's assumption is natural in the real health care market. Therefore, we can consider that the upper part of Eq. 17 in our results corresponds to the case of medical quality in the study conducted by Levaggi and Montefiori [13], and the lower part of Eq. 17 corresponds to non-medical quality. Consequently, the result that the (medical) quality of the public hospital is greater than that of the private hospital is obtained both by Levaggi and Montefiori [13] and by our model in this paper.

Proposition 2 is derived from the above discussion.

Proposition 2 (1) When the patient's preference for quality is relatively high (low), the quality of the partially privatized hospital is higher (lower) than that of the private hospital. (2) When the preference for quality remains unchanged, the quality of the partially privatized hospital is identical to that of the private hospital.

In turn, if $\theta = 1$, then we have the following result:

$$q_0 = q_1. \tag{18}$$

When $\theta = 1$, we examine the case in which the partially privatized hospital becomes fully privatized and engages in profit maximization. This case corresponds to that in the study conducted by Montefiori [22], who investigated the private duopoly market. Since both hospitals behave symmetrically in this situation, the quality levels of the two hospitals are identical under the symmetric equilibrium.

Conclusion

In this paper, we investigated a health care market with uncertainty, where a partially privatized public hospital competes against a private hospital in terms of quality choice.

In the health care market, the existance of an asymmetry of information between health care providers and patients is well known. Under the asymmetry of information, patients generally cannot obtain information regarding the true quality provided by hospitals. Thus, when choosing a hospital, they usually rely on the perceived quality, which is affected by bias. Hospitals face patient demand, which is influenced by uncertainty associated with perceived

[13] For a related work, see Lu and Poddar [16]. This study examines the capacity choice of firms under demand uncertainty in a mixed duopoly market.

[14] See also Levaggi and Montefiori [14].

quality. In order to model this situation, we used the simple Hotelling-type spatial competition model and the mean–variance method, in keeping with Montefiori [22]. In addition, since we are interested in not only the fully public hospital but also the partially privatized hospital, we incorporated the framework of partial privatization proposed by Bös [4] into the model, and analyzed the mixed duopoly market.

First, we analyzed how uncertainty affects the quality provided by hospitals. We showed that when the variance in the perceived quality of the partially privatized hospital becomes larger (smaller) than a given variance of the private hospital, a case in which the partially privatized hospital chooses a lower (higher) quality level exists. This result is in sharp contrast to that obtained by Montefiori [22], who investigated a private duopoly market and showed that when the variance in the perceived quality becomes larger (smaller) than a given rival's variance, a profit-maximizing private hospital chooses a higher (lower) quality level.

Next, we investigated the case in which variances in the perceived quality of both hospitals are identical. We showed that the quality of the partially privatized hospital is higher (lower) than that of the private hospital when the patient's preference for quality is relatively high (low). The situation in which the partially privatized hospital chooses a higher level of quality than the private hospital is in sharp contrast to the existing literature investigating the mixed oligopoly market. In general, the existing works on mixed oligopoly obtain the result that private enterprise invests excessively while public enterprise chooses underinvestment. Our results indicate that when patients have a high preference for quality of services, the partially privatized hospital chooses overinvestment in quality in order to maximize its objective, which consists of the weighted average between social welfare and profit. In this situation, even though the hospital's costs increase, the higher quality improves social welfare by increasing the utility of patients. The private hospital then has no incentive to enhance its quality level, since large investments are required to attract patients to the private hospital. As a result, the private hospital chooses a level of quality that is lower than that of the partially privatized hospital. Levaggi and Montefiori [13] provide a result akin to our analysis in this paper in the context of cream skimming, and show that the medical quality of the public hospital is greater than that of the private hospital.

Finally, this study can be extended further to the analysis of location choice of hospitals and the sequential decision of the game. Some studies on health care policy suggest the possibility of public leadership (see Barros and Martinez-Giralt [2]), and hospitals might use location choice as a strategic behavior in the long run.

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Appendix

Substituting $\sigma_{q_0}^2 - \sigma_{q_1}^2 = 0$ into Eqs. 9–12, we can reformulate q_0, q_1, x and the difference between qualities as:

$$q_0 = M - \frac{((4-\theta) - 3(1-\theta)\alpha)t}{\alpha((2+\theta) - (1-\theta)\alpha)},$$

$$q_1 = M - \frac{(3 - 2(1-\theta)\alpha)t}{\alpha((2+\theta) - (1-\theta)\alpha)},$$

$$x = \frac{1}{2} - \frac{(1-\theta)(1-\alpha)}{2((2+\theta) - (1-\theta)\alpha)},$$

$$q_0 - q_1 = -\frac{(1-\theta)(1-\alpha)t}{\alpha((2+\theta) - (1-\theta)\alpha)}. \tag{19}$$

Using Eq. 19, we obtain Eq. 17 under $\theta \in [0, 1)$ and Eq. 18 under $\theta = 1$.

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