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Congestion-Reducing Investments and Economic Welfare in a Hotelling Model

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Abstract

We investigate optimal quality provision, where quality is determined by congestion. Duopolists make congestion-reducing investments and then compete in prices. We find that unregulated market leads to insufficient investment, and that price cap below the equilibrium price eliminates this inefficiency.

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Key words: congestion-reducing investment, price regulation, spatial competition

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1 Introduction

Congestion is widely observed in many markets. A typical example is the medical market. In Japan, patients often wait for three hours to get medical treatment that takes three minutes. Congestion-reducing investments increase a firm's competitive advantage over its rivals. Arguably, competition between hospitals stimulates congestion-reducing investments and thereby benefits consumers. Although congestion remains widespread, hospitals do not seem to implement efficient congestion-reducing investments.

We investigate optimal provision of quality in a duopoly set up, where quality is determined by congestion.[1] Firms invest in congestion-reducing measures and then compete in prices. We formulate a duopoly model in which the firms compete in a differentiated product market represented by a Hotelling line.[2] Firms compete in congestion-reducing investments and then compete in prices.[3] We find that each firm undertakes insufficient investment from a normative viewpoint. We also consider a model that incorporates price regulation. In many countries, the prices of medical services are highly regulated and most hospitals cannot choose their own prices. We find that a higher regulated price stimulates investments and that the government can use the regulated price to control the investment level.

In a competitive market, there is insufficient investment. In the regulated market, an increase in the price stimulates investment by firms. This suggests that the government should set a price above the competitive price to induce efficient investment. We find that this suggestion is not correct: the government must set a regulated price below the competitive price to induce the first-best level of investment.

2 The Model

We formulate a duopoly model. We use a Hotelling-type linear city model. A linear city of unit length lies on the abscissa of a line and consumers are uniformly distributed with a density of unity along this interval. Suppose that firm 1 locates at point $l_1 = 0$ and that firm 2 locates at point $l_2 = 1$.[4] A consumer living at $y \in [0, 1]$ incurs a transportation cost of $t(l_i - y)^2$ when purchasing the product of firm i. The consumers

[1] Grilo *et al.* (2001), Laussel *et al.* (2004), and Lambertini and Orsini (2005) consider consumption externalities in the context of spatial models. However, these authors treat the degree of congestion as exogenous.

[2] For a discussion of the types of investment competition represented by the Hotelling line, see Ma and Burgess (1993), Ishibashi (2001), and Matsumura and Matsushima (2004).

[3] Several researchers consider models in which firms influence consumer disutility costs (see von Ungern-Sternberg (1988), Dos Santos Ferreira and Thisse (1996), Hendel and Neiva de Figueiredo (1997), and Degryse and Irmen (2001)). In these papers, disutility is related to the transport costs incurred by consumers; the disutility (congestion) discussed in our model is completely different.

[4] We assume maximal differentiation and do not consider location choices. For a discussion of maximal differentiation with endogenous location, see d'Aspremont *et al.* (1979) and Matsumura and Matsushima (2004).

have unit demands; i.e., each consumes either one or no units of the product. Each consumer derives a surplus from consumption (gross of price and transportation costs) of s. We assume that s is sufficiently large that each consumer consumes one unit of the product. Two firms produce the same physical product, the unit production costs which are normalized to zero.

We introduce a negative externality with respect to the consumption of goods. When n consumers buy firm i's product, each consumer incurs a cost of congestion, $c_i n$. The degree of congestion cost, c_i, depends on firm i's congestion-reducing activities, which cost $I(c_i)$. For simplicity, we assume that $I(c_i) = \gamma(c-c_i)^2$, where c is the initial cost (incurred before congestion-reducing activity was undertaken).

The game runs as follows. In the first stage, firm i $(i = 1, 2)$ independently chooses c_i. In the second stage, firm i independently chooses the price, $p_i \in [0, \infty)$.

For a consumer living at

$$x = \frac{1}{2} + \frac{2p_2 - 2p_1 + c_2 - c_1}{2(2t + c_1 + c_2)}, \tag{1}$$

the total cost of buying from either of the two firms is the same. Thus, the demand of firm 1, D_1, and that of firm 2, D_2, are given by

$$D_1(p_1, p_2) = \min\{\max(x, 0), 1\}, \quad D_2(p_1, p_2) = 1 - D_1(p_1, p_2). \tag{2}$$

The social surplus, W, which is the consumer surplus plus the firms' profits, is given by

$$W = s - c_1 D_1^2 - c_2(1 - D_1)^2 - t\left(\int_0^{D_1} y^2 dy + \int_{D_1}^1 (1 - y)^2 dy\right) - I(c_1) - I(c_2) \tag{3}$$

When $0 \leq x \leq 1$, firm i's profit is

$$\pi_i = p_i D_i - I(c_i) = \frac{p_i(p_j - p_i + t + c_j)}{2t + c_j + c_i} - I(c_i). \tag{4}$$

3 Social Optimum

Before discussing the equilibrium outcome, we discuss the social optimum as a benchmark. The welfare-maximizing social planner maximizes (3) with respect to D_1, c_1, and c_2. The first-order conditions are

$$\frac{\partial W(D_1, c_1, c_2)}{\partial c_1} = 0 \quad \Leftrightarrow \quad -D_1^2 + 2\gamma(c - c_1) = 0,$$
$$\frac{\partial W(D_1, c_1, c_2)}{\partial c_2} = 0 \quad \Leftrightarrow \quad -(1 - D_1)^2 + 2\gamma(c - c_2) = 0,$$
$$\frac{\partial W(D_1, c_1, c_2)}{\partial D_1} = 0 \quad \Leftrightarrow \quad 2((t + c_2) - (2t + c_1 + c_2)D_1) = 0.$$

Let the superscript '*' denote the optimal level. From these simultaneous equations, the optimal levels of D_1, c_1, and c_2 are

$$D_1^* = 1/2, \quad c^* = c_1 = c_2 = c - \frac{1}{8\gamma}. \tag{5}$$

4 Equilibrium Outcomes

First, we discuss competition in the second stage, given c_1 and c_2. From (4), the first-order conditions are

$$\frac{\partial \pi_i}{\partial p_i} = 0 \quad \Leftrightarrow \quad \frac{c_j + p_j - 2p_i + t}{2t + c_1 + c_2} = 0 \quad (i = 1, 2, i \neq j).$$

We derive:

$$p_i = \frac{c_i + 2c_j + 3t}{3}.$$

The quantity supplied by firm i is

$$D_i = \frac{3t + c_i + 2c_j}{3(2t + c_1 + c_2)}.$$

Next, we discuss behavior in the first stage. Firm i's profit is

$$\pi_i(c_i, c_j) = \frac{(3t + c_i + 2c_j)^2}{9(2t + c_i + c_j)} - \gamma(c - c_i)^2.$$

Proposition 1 *No firm undertakes congestion-reducing investment.*

Proof: Since

$$\frac{\partial \pi_i}{\partial c_i} = \frac{(t + c_i)(3t + c_i + 2c_j)}{9(2t + c_i + c_j)^2} + 2\gamma(c - c_i) > 0,$$

neither firm has an incentive to reduce congestion. Q.E.D.

Let the superscript 'E' denote the equilibrium outcome. From Proposition 1, we have

$$c^E = c_1 = c_2 = c. \tag{6}$$

$$p^E = p_1 = p_2 = t + c, \quad W^E = s - \frac{t + 6c}{12}. \tag{7}$$

The intuition behind Proposition 1 is as follows. Reducing c_1 (firm 1's congestion cost) improves the competitive advantage of firm 1 and attracts consumers. Observing this, firm 2 reduces its price. The reduction in p_2 accelerates competition and causes firm 1's profit to fall. Thus, firm 1 does not invest, to which its rival responds by raising its price. Although the result that there is no investment might be model specific, we suggest that the property of insufficient investment ($c^E \geq c^*$) is robust in a broad class of price competition models in which there are differentiated goods.[5]

[5] See the last paragraph in the next section. Introducing the congestion reduces elasticity of demand and congestion-reducing investments increase elasticity of demand; thus it has a strong strategic effect

In this section, we considered the situation in which two firms compete on both price and congestion-reducing investment. However, in many markets characterized by congestion, firms cannot freely choose their prices. In many countries, prices in medical markets are regulated. Hospitals compete on price for few services and are subject to price regulation in their major markets. In the next section, we investigate how price regulation affects congestion-reducing investment.

5 Price Regulation

In this section, we consider the case in which a regulated price, $\bar{p}$, is set by the government. Let the superscript 'R' denote the equilibrium outcome under price regulation.

Substituting $p_1 = p_2 = \bar{p}$ into (1) yields

$$x = \frac{1}{2} + \frac{c_2 - c_1}{2(2t + c_1 + c_2)}, \tag{1'}$$

Firm i's profit is

$$\pi_i = \bar{p}x - \gamma(c - c_i)^2 = \frac{\bar{p}(t + c_j)}{2t + c_i + c_j} - \gamma(c - c_i)^2.$$

The first-order condition is

$$\frac{\partial \pi_i}{\partial c_i} = 0 \quad \Leftrightarrow \quad -\frac{\bar{p}(t + c_j)}{(2t + c_i + c_j)^2} + 2\gamma(c - c_i) = 0.$$

This yields

$$c^R = c_1 = c_2 = \frac{2(c - t)\gamma + \sqrt{2\gamma(2\gamma(c + t)^2 - \bar{p})}}{4\gamma}. \tag{9}$$

Given (9), we can state the following proposition.

Proposition 2 *Congestion-reducing investment is increasing in the regulated price $\bar{p}$.*

Because the price is regulated, firms compete only in terms of congestion. Reduced congestion does not lower prices because prices are regulated. An increase in the regulated price increases firm profits per customer. Hence, because each firm has a greater incentive to attract consumers, it accelerates competition in congestion-reducing investments. Thus, the equilibrium level of investment increases in the level of the regulated price.

We now determine the optimal regulated price. The optimal investment level is given by (5). Let $\bar{p^*}$ denote the optimal regulated price, which induces the optimal investment level. From (5) and (9), we have

$$\bar{p^*} = t + c - \frac{1}{8\gamma}. \tag{10}$$

Given (7) and (10), we obtain the following proposition.

Proposition 3 *The optimal regulated price is below the equilibrium price in the nonregulated market; i.e.,* $\bar{p^*} < p^E$.

Proposition 1 states that when there is no price regulation, the equilibrium level of investment is below the optimal level. Proposition 2 states that when there is price regulation, the equilibrium level of investment increases with the regulated price. This suggests that the government should set a regulated price above the equilibrium price to stimulate investment. However, Proposition 3 indicates that the government should set a regulated price below the equilibrium price. When there is price regulation, firms have a strong incentive to invest. This incentive is sufficiently strong to enable the government to induce sufficient investment by setting a low regulated price.

We now compare our model with other models of quality provision. In the literature on quality provision, the following model formulation is often adopted. The utility of a consumer who chooses firm i's product is represented by $U = q_i - p_i - tx^2$, where x is the distance from the consumer to firm i. Firm i controls q_i via quality-improving investments. In the duopoly model, we can show that the investment level is positive but still too small from the normative viewpoint. The optimal level of the ceiling price is equal to the equilibrium price. Thus, a price strictly smaller than the equilibrium one does not induce efficient investments. The model of the quality-improving investment which increases q_i attracts consumers irrespective of firm i's output level. On the other hand, in our model, the effectiveness of firm i's congestion-reducing investment increases in its output-quantity level and investment increases firm i's incentive to expand its output more effectively. In other words, strategic effect of the investment is stronger in our model; thus under price competition context firms have stronger incentives for reducing investment more effectively in our model. Under the price regulation, this strategic effect disappears. As we discussed above, each firm can more effectively expand its output via investment in our model; thus each firm has a stronger incentive for investments under the price regulation. This is why the price strictly smaller than the equilibrium one does induce efficient investment in our model, while it does not in the quality-provision model mentioned above.

Finally, we discuss the effect of an increase in the number of firms. As pointed out by Hendel and Neiva de Figueiredo (1997), the strategic effect of investment in duopoly is stronger than that in oligopoly ($n \geq 3$). In oligopoly, firm $i+1$ balances the incentives provided by both neighbors, i and $i+2$. When firm i diminishes its investment level, firm $i+1$ not only takes into account the decrease but also the (unchanged) investment level of firm $i+2$. The decrease in the investment level of firm i is less effective than in the duopoly. In other words, the strategic effect is smaller in the triopoly than the duopoly, and each firm has smaller incentive for avoiding competition by smaller investments. Following their setting, we investigate duopoly and triopoly models in a circular city model. We find that the investment level is positive in the triopoly. However, the investment level is too small from the normative viewpoint and the regulated price which induces the efficient investments is smaller than the equilibrium one. Thus, our result of no-investment depends on the assumption of duopoly but other results hold even if firms have two-sided competitors.

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