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Abstract

This paper investigates the incentives for cost reduction in a differentiated industry. It compares price and quantity competition and the social optimum. Typically the results depend upon the degree of product substitutability. When goods are imperfect substitutes, both Cournot and Bertrand competition result in underinvestment in cost reduction. Overinvestment may occur when the goods are sufficiently close substitutes. Similarly, Cournot competition provides a stronger incentive to innovate than Bertrand competition if the degree of substitutability is low, and a weaker incentive if this degree is high.

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1 Introduction

This paper investigates the incentives for cost-reducing innovation in a differentiated industry. We compare two alternative categories of product market competition, Cournot and Bertrand, and the social optimum. Our framework allows us to address the question of how the degree of substitutability of products affects this comparison. Indeed, our analysis reveals that this degree has an important impact on the incentives to innovate. For example, we establish that both Cournot and Bertrand competition lead to underinvestment in cost reduction relative to the social optimum when the firms enjoy a quasi-monopolistic position because the customers of each firm regard the brand of the other firm as a poor substitute. But, when product competition is increased and goods become rather close substitutes, this result may be reversed and market competition may result in overinvestment. Similarly, Cournot competition provides stronger incentives to innovate than Bertrand competition if the degree of substitutability is low, whereas the incentive may be weaker if the degree of substitutability is sufficiently high. These results demonstrate the importance of product differentiation for the study of technological innovation; they indicate that the abstraction of homogeneous goods is no longer appropriate when goods are imperfect substitutes.

Our analysis focuses on the gains from innovation when there is no consideration of preemptive innovation. As Arrow (1962) we consider a firm undertaking a cost reducing investment that cannot be imitated by competitors. Thus there is no competition in research and development in the form of a patent race, which is well-known to create distortions from the social optimum. Also, we abstract from possible spillovers or externalities as in Spence (1984), where the technological knowledge of one firm depends on the innovation expenditures of the entire industry. Our framework isolates the pure incentive to innovate created by product market competition. In such an environment the conventional conclusion from the analysis of homogeneous goods is that competition reduces the level of innovation below the socially optimal level (see Dasgupta and Stiglitz (1980)). The argument is that the innovator cannot appropriate the full social surplus generated by the introduction of a new technique.

Oligopolistic competition, however, involves additional features that may modify this conclusion. First, innovation has strategic effects that depend on the form of market competition. Brander and Spencer (1983) pointed out that in a Cournot model a cost reduction by one firm lowers the equilibrium output of its competitors. This effect favors innovation because the market price is negatively related with aggregate industry output. In fact, Brander and Spencer concluded that the strategic use of innovation may result in cost reduction beyond the point where total costs are minimized for the output chosen. Okuno-Fujiwara and Suzumura (1988) have shown that the strategic effect is reversed when firms compete by setting prices in a Bertrand model. This is so because a cost reduction lowers the equilibrium price chosen by the competitor and so increases product market competition.

Our model of a differentiated industry displays these different strategic effects; but at the same time it makes clear that there are also other effects that are important. Therefore the implications for social welfare cannot be determined by simply looking at the strategic effects of cost reduction. Similarly, one cannot conclude that expenditures on innovation are necessarily higher with quantity competition than with price competition. A second factor that is important for these issues is the market share or equilibrium output of the innovator. Clearly, the higher the output the larger is the total gain from a given reduction in unit costs of production. As a result, market competition influences the incentives for innovation also through the determination of equilibrium output. A well-known observation in the theory of imperfect competition is the possibility of excessive product differentiation. This means a firm may actually produce a higher output in the market equilibrium than the social planner would choose. This effect may outweigh the problem of appropriating consumer surplus and so there may be excessive investment in innovation from the viewpoint of social welfare. Also, despite the strategic effect mentioned above, Bertrand competition may result in a higher investment level than Cournot competition. When goods are relatively close substitutes, this happens because price competition is more effective and results in a more drastic increase in the innovator's market share than quantity competition.

The following Section describes the demand structure of a simple differentiated duopoly. Section 3 derives the criterion for the social welfare maximizing investment in cost reduction. The market incentives for innovation are discussed in Section 4. Section 5 compares the gains from cost reduction under price and quantity competition and relates them to the social optimum. Section 6 provides concluding remarks. All proofs are relegated to the Appendix.

2 The Model

We consider an economy with an oligopolistic sector, consisting of two firms that produce a differentiated good, and a competitive numeraire sector. The two firms operate under constant returns to scale. Firm 1's unit cost of production is c_1. Before the market opens it can reduce this cost by the amount $0 < \Delta < c_1$. This cost reduction requires an investment I. Firm 2's unit cost equals c_2 and is exogenously fixed. Our analysis can easily be extended to the case where both firms can invest in cost reduction; we discuss some of the implications below. An important assumption is that technological innovation in one firm has no value for the competitor. The interpretation is that the duopolists produce different goods by employing a different technology. They are not engaged in a patent race which would give the winner the exclusive right to adopt the more productive technology.

The demand structure of our model is adopted from Dixit (1979). The representative consumer's utility is a function of consumption $x = (x_1, x_2)$ of the two goods and the numeraire good m. It is given by $U(x) + m$ with

$$U(x) = \alpha(x_1 + x_2) - (\beta x_1^2 + 2\gamma x_1 x_2 + \beta x_2^2)/2, \tag{1}$$

where $\alpha > \max[c_1, c_2]$ and $0 < \gamma < \beta$. The assumption that preferences are linear in the numeraire good eliminates income effects and allows us to perform partial equilibrium welfare analysis. The specification of $U(.)$ generates a linear demand structure so that we can explicitly derive the Bertrand and Cournot equilibrium and study how the incentives for innovation depend upon the substitutability of the two products. The latter is measured by the parameter γ. The higher γ, the higher is the degree of substitutability. When γ tends to zero, the two firms effectively become monopolists; in the limit $\gamma = \beta$ the two goods are perfect substitutes.

3 The Social Optimum

First we investigate the efficiency of cost reduction from the viewpoint of social welfare. Given the costs c_1 and c_2, a social planner would choose the quantities x_1 and x_2 so as to maximize

$$U(x) + m - c_1x_1 - c_2x_2. \tag{2}$$

From the first-order conditions of this programming problem, we get the solution

$$\begin{aligned} x_1^*(c_1, c_2) &= [\beta(\alpha - c_1) - \gamma(\alpha - c_2)]/[\beta^2 - \gamma^2] \\ x_2^*(c_1, c_2) &= [\beta(\alpha - c_2) - \gamma(\alpha - c_1)]/[\beta^2 - \gamma^2]. \end{aligned} \tag{3}$$

In our analysis of the social optimum we will consider only parameter constellations under which the social planner produces positive quantities of both goods. To ensure that this is the case both with and without cost reduction in industry 1 we have to assume

$$\gamma < \bar{\gamma}_S \equiv \beta \min\left[\frac{\alpha - c_1}{\alpha - c_2}, \frac{\alpha - c_2}{\alpha - c_1 + \Delta}\right]. \tag{4}$$

Note that $\bar{\gamma}_S < \beta$. Thus equation (4) rules out that the two goods are rather close substitutes. Indeed, with homogeneous goods the social planner would operate only the firm with the most efficient technology. By requiring a sufficient degree of differentiation, we abstract from such boundary cases and their technical problems which are inessential to the main issues.

Given (3), social welfare depends on the firms' production costs according to

$$V(c_1, c_2) \equiv U(x_1^*(c_1, c_2), x_2^*(c_1, c_2)) - c_1 x_1^*(c_1, c_2) - c_2 x_2^*(c_1, c_2). \tag{5}$$

Using the function $V(\cdot)$ we can specify the conditions under which cost reduction increases social welfare. Define

$$I_S^* \equiv V(c_1 - \Delta, c_2) - V(c_1, c_2). \tag{6}$$

Then, investing in cost reduction is socially desirable if and only if $I \leq I_S^*$. Obviously, $I_S^* > 0$.

4 Market Competition

In the following sections we study the two-stage game where in the first stage firm 1 decides on investing in cost reduction and in the second stage both firms compete in the market. For given prices (p_1, p_2), consumer preferences generate the inverse demand system

$$p_1 = \alpha - \beta x_1 - \gamma x_2; \quad p_2 = \alpha - \gamma x_1 - \beta x_2 \tag{7}$$

Below we will introduce parameter restrictions that guarantee that the quantities x_1 and x_2 are always positive in equilibrium. Given the cost c_i, firm i's profit is

$$[p_i - c_i] x_i. \tag{8}$$

First we study the Cournot equilibrium in which each firm i chooses its quantity x_i so as to maximize (8) subject to (7) taking the quantity x_j of its competitor as given. This results in the equilibrium quantities $(\hat{x}_1, \hat{x}_2)$ where

$$\begin{aligned} \hat{x}_1(c_1, c_2) &= [2\beta(\alpha - c_1) - \gamma(\alpha - c_2)]/[4\beta^2 - \gamma^2] \\ \hat{x}_2(c_1, c_2) &= [2\beta(\alpha - c_2) - \gamma(\alpha - c_1)]/[4\beta^2 - \gamma^2]. \end{aligned} \tag{9}$$

A reduction in firm 1's unit cost increases $\hat{x}_1$ and decreases $\hat{x}_2$; total supply $\hat{x}_1 + \hat{x}_2$ is increased. Firm 1 recognizes that its innovation affects firm 2's quantity decision. Indeed, this effect is strategically advantageous for firm 1 because by (7) its price is negatively related with x_2. As Brander and Spencer (1983) point out, this consideration will induce firm 1 to reduce its cost beyond the point where its costs are minimized for its own output $\hat{x}_1$.

As in the previous Section, we focus on situations where both firms are active in the market. Again this requires restrictions on the range of the substitutability parameter γ. It follows from (9) that Cournot competition will not force one of the firms out of the market if and only if $\gamma < \bar{\gamma}_C$, where $\bar{\gamma}_C \equiv 2\bar{\gamma}_S$. Note that as $\bar{\gamma}_C > \bar{\gamma}_S$, Cournot competition may involve positive profits for both firms even under parameter constellations where producing both goods is socially inefficient. In this sense the market equilibrium may support excessive product differentiation.

By (9) firm 1's second-stage payoff depends upon both firms' costs according to

$$\Pi_1^C(c_1, c_2) = [\alpha - \beta\hat{x}_1(c_1, c_2) - \gamma\hat{x}_2(c_1, c_2) - c_1]\hat{x}_1(c_1, c_2). \tag{10}$$

The function $\Pi_1^C(\cdot)$ determines firm 1's profit from investing in cost reduction in the first stage. Let

$$I_C^* \equiv \Pi_1^C(c_1 - \Delta, c_2) - \Pi_1^C(c_1, c_2), \tag{11}$$

then in the Cournot market firm 1 undertakes the investment I only if $I \leq I_C^*$. Using the envelope theorem, it is easily checked that $\partial \Pi_1^C / \partial c_1 < 0$ which implies $I_C^* > 0$.

We next turn to the Bertrand equilibrium in which the duopolists compete by setting prices. Inverting (7) gives the demand system

$$x_1 = [\beta(\alpha - p_1) - \gamma(\alpha - p_2)]/[\beta^2 - \gamma^2]; x_2 = [\beta(\alpha - p_2) - \gamma(\alpha - p_1)]/[\beta^2 - \gamma^2]. \quad (12)$$

Each firm i chooses its price p_i so as to maximize its profit, given by (8), subject to (12) and taking the competitor's price p_j as fixed. This results in the equilibrium prices $(\hat{p}_1, \hat{p}_2)$ where

$$\begin{aligned} \hat{p}_1(c_1, c_2) &= [(2\beta + \gamma)(\beta - \gamma)\alpha + 2\beta^2 c_1 + \gamma\beta c_2]/[4\beta^2 - \gamma^2] \\ \hat{p}_2(c_1, c_2) &= [(2\beta + \gamma)(\beta - \gamma)\alpha + \gamma\beta c_1 + 2\beta^2 c_2]/[4\beta^2 - \gamma^2]. \end{aligned} \quad (13)$$

Lowering c_1 reduces both $\hat{p}_1$ and $\hat{p}_2$. The second effect is strategically disadvantageous for firm 1 because by (12) its output is positively related with p_2. In contrast with Cournot competition, Bertrand competition creates a negative strategic incentive to innovate. Of course, this does not necessarily mean that innovation becomes less profitable. The gains from cost reduction do not only depend on the strategic effect but also on how much total production costs are decreased. As these costs are proportional to the level of output, this second aspect becomes especially important if x_1 is relatively high. Therefore, if price competition results in a higher output level than quantity competition, it is no longer clear which market structure induces a higher innovation effort.

In the Bertrand market both firms operate if $\hat{p}_1(c_1, c_2) > c_1$ and $\hat{p}_2(c_1 - \Delta, c_2) > c_2$. This is the case if $\gamma < \bar{\gamma}_B$, where $\bar{\gamma}_B$ is implicitly defined by $\bar{\gamma}_B = \bar{\gamma}_S[2 - (\bar{\gamma}_B/\beta)^2]$. As $\bar{\gamma}_S < \bar{\gamma}_B < \bar{\gamma}_C$, Bertrand competition is less likely to imply socially inefficient production of both goods than Cournot competition. This is closely related to the observation of Vives (1985) that Bertrand competition is more efficient than Cournot competition in markets with product differentiation.

In the Bertrand market firm 1's equilibrium profit is

$$\Pi_1^B(c_1, c_2) = [\hat{p}_1(c_1, c_2) - c_1][\beta(\alpha - \hat{p}_1(c_1, c_2)) - \gamma(\alpha - \hat{p}_2(c_1, c_2))]/[\beta^2 - \gamma^2]. \tag{14}$$

Consequently price competition induces firm 1 to invest in cost reduction only if $I \leq I_B^*$, where

$$I_B^* \equiv \Pi_1^B(c_1 - \Delta, c_2) - \Pi_1^B(c_1, c_2). \tag{15}$$

Using the envelope theorem one can show that $\partial \Pi_1^B(c_1, c_2)/\partial c_1 < 0$, which implies $I_B^* > 0$. Clearly, the gains from cost reduction depend both on c_1 and c_2. Our first result examines the impact of the duopolists' unit costs on these gains.

Proposition 1: *I_S^*, I_C^*, and I_B^* are decreasing in c_1 and increasing in c_2.*

The first observation shows that the marginal return on investment in cost reduction is decreasing. When for a given c_1 an investment up to I^* is profitable in order to reduce costs to $c_1 - \Delta$, then a second reduction from $c_1 - \Delta$ to $c_1 - 2\Delta$ is still profitable only if the required investment is less than I^*. In a dynamic, multi-period framework cost reduction at some point in time also affects the gains from innovation in the future. These dynamics and the development of industry structure in a homogeneous Cournot market have been studied by Flaherty (1980). The second observation depends on the fact that the two goods are substitutes. Therefore, the higher the cost c_2, the higher is the output of firm 1 and the benefit from lowering total production costs $c_1 x_1$.

Proposition 1 also allows us to derive some insights for the case where both firms simultaneously compete by reducing costs in the first game stage. Its second part implies that innovation becomes less profitable for firm 1 when also firm 2 reduces its cost. This means technological innovations are strategic substitutes in the terminology of Bulow, Geanakoplos, and Klemperer (1985). In the symmetric case $c_1 = c_2$ both firms invest in a cost reduction of size Δ only if the necessary investment I satisfies $I \leq I^o$ with $I_C^o < I_C^*$ in the Cournot market and $I_B^o < I_B^*$ in the Bertrand market.

5 The Incentives for Innovation

This Section studies how competition affects firm 1's incentives for cost reduction. In addition we compare firm 1's decision with the social optimum. Typically our results will depend on parameter constellations, in particular on the substitutability parameter γ and the size of the innovation Δ. The following Proposition compares the attractiveness of cost reduction under Cournot and Bertrand competition for relatively low values of γ.

Proposition 2: *If $\gamma < \bar{\gamma}_S$, then $I_C^* > I_B^*$.*

The intuition for this result is related to the difference in the strategic effect under Cournot and Bertrand competition. Obviously in the limiting case $\gamma = 0$, where firm 1 is a monopolist, price and quantity decisions result in the same outcome and so $I_B^* = I_C^*$. Also, for low values of γ the type of market competition has only a small impact on firm 1's output x_1. Therefore the gain from reducing total cost $c_1 x_1$ does not differ very much in the two categories of equilibrium. In this situation the strategic effect determines the relative profitability of innovation. Innovation becomes more attractive in the Cournot market because it decreases the competitor's output whereas in the Bertrand market it lowers the competitor's price.

The conclusion of Proposition 2 may be reversed when we consider values of $\gamma > \bar{\gamma}_S$. Notice that in the range $(\bar{\gamma}_S, \bar{\gamma}_B)$ each of the duopolists is active in the market both under price and quantity competition, whereas the social planner would operate only one of the two firms. Within this range, it may turn out that Bertrand competition provides stronger incentives to innovate than Cournot competition. To illustrate this, we focus on the special case where the firms have identical costs.

Proposition 3: *Let $\gamma < \bar{\gamma}_B$ and $c_1 = c_2 = c$. Then for each Δ there is a $\gamma^o(\Delta) \in (\bar{\gamma}_S, \bar{\gamma}_B)$ such that $I_C^* > I_B^*$ if $\gamma < \gamma^o$ and $I_C^* < I_B^*$ if $\gamma > \gamma^o$. Moreover, $\gamma^o(\cdot)$ decreases with Δ.*

The fact that investment in cost reduction may be greater under Bertrand competition than under Cournot competition has been observed by Delbono and Denicolo (1990) for the case of a homogeneous oligopoly. The second part of Proposition 3 goes in the same direction and shows that this also happens in a differentiated goods market when the degree of substitutability is sufficiently large. The result can be explained by the difference in firm 1's equilibrium output under Cournot and Bertrand competition. For values $\gamma \geq \bar{\gamma}_B$ firm 1's cost advantage after the innovation would force firm 2 out of the Bertrand market. This means that for γ close to $\bar{\gamma}_B$ firm 2's output is rather low even when $\gamma < \bar{\gamma}_B$. In the Cournot market this effect is less drastic because $\bar{\gamma}_B < \bar{\gamma}_C$. Accordingly, for $\gamma^0 < \gamma < \bar{\gamma}_B$ firm 1's market share in the Bertrand equilibrium is large in comparison with the Cournot outcome. As a result, price competition creates a relatively strong incentive for firm 1 to innovate and expand its output. In fact, this incentive outweighs the negative strategic effect that occurs because firm 2's price is reduced.

In the remainder we compare the market incentives for innovation with the social optimum and restrict ourselves to the case $\gamma < \bar{\gamma}_S$. For this part of our analysis it is helpful to distinguish between 'small' and 'large' cost reductions. More precisely, we call a cost reduction Δ 'small' if $\Delta \leq 2(c_1 - c_2)$ and 'large' otherwise. Of course, small cost reductions are relevant only when firm 1 initially has a cost disadvantage as $c_1 - c_2 \geq 0.5\Delta > 0$. It turns out that in the case of large cost reductions this comparison is unambiguous for all values of the substitutability parameter within the range $(0, \bar{\gamma}_S)$.

Proposition 4: *Let $\gamma < \bar{\gamma}_S$ and $\Delta \geq 2(c_1 - c_2)$. Then $I_S^* > I_C^* > I_B^*$.*

Even though its competitor cannot imitate the innovation, firm 1 does not appropriate the full social surplus generated by the introduction of a new technique. The reason is that we rule out price differentiation so that it cannot capture total consumer surplus. This leads to underinvestment relative to the social optimum as Dasgupta and Stiglitz (1980) have observed. Yet, this is not the whole story. There may be some counterbalancing effects when we consider small cost reductions. As an important observation, in this case the conclusion of Proposition 4 may no longer hold and market competition may result in overinvestment relative to the social optimum. As the following Proposition shows this happens in the Cournot market when γ is large enough and, at the same time, Δ is relatively small.

Proposition 5: *Let $\gamma < \bar{\gamma}_S$ and $\Delta < 2(c_1 - c_2)$. Then there is a $\gamma' \in (0, \bar{\gamma}_S)$ such that $I_S^* > I_C^*$ for all $\gamma < \gamma'$. For each $\gamma \in (\gamma', \bar{\gamma}_S)$ there exists a $\Delta_C^*(\gamma) < 2(c_1 - c_2)$ such that $I_S^* > I_C^*$ if $\Delta > \Delta_C^*(\gamma)$ and $I_S^* < I_C^*$ if $\Delta < \Delta_C^*(\gamma)$. Moreover, $\Delta_C^*(.)$ increases with γ.*

The statement of Proposition 5 is illustrated in Figure 1, which depicts all parameter constellations such that $0 \leq \gamma \leq \bar{\gamma}_S$ and $0 \leq \Delta \leq 2(c_1 - c_2)$. In the figure the function $\Delta_C^*(\cdot)$ represents the borderline between regions I and II. That is, one has $I_S^* > I_C^*$ for parameter values γ and Δ in region I and $I_S^* < I_C^*$ in regions II and III.

**** insert Figure 1 here ****

As an implication of Proposition 2, overinvestment is less likely to occur with price competition than with quantity competition. Yet, also in the Bertrand market there are parameter constellations where this happens.

Proposition 6: *Let $\gamma < \bar{\gamma}_S$ and $\Delta < 2(c_1 - c_2)$. Then there is a $\gamma'' \in (0, \bar{\gamma}_S)$ such that $I_S^* > I_B^*$ for all $\gamma < \gamma''$. For each $\gamma \in (\gamma'', \bar{\gamma}_S)$ there is a $\Delta_B^*(\gamma) < 2(c_1 - c_2)$ such that $I_S^* > I_B^*$ if $\Delta > \Delta_B^*(\gamma)$ and $I_S^* < I_B^*$ if $\Delta < \Delta_B^*(\gamma)$. Moreover, $\Delta_B^*(.)$ increases with γ.*

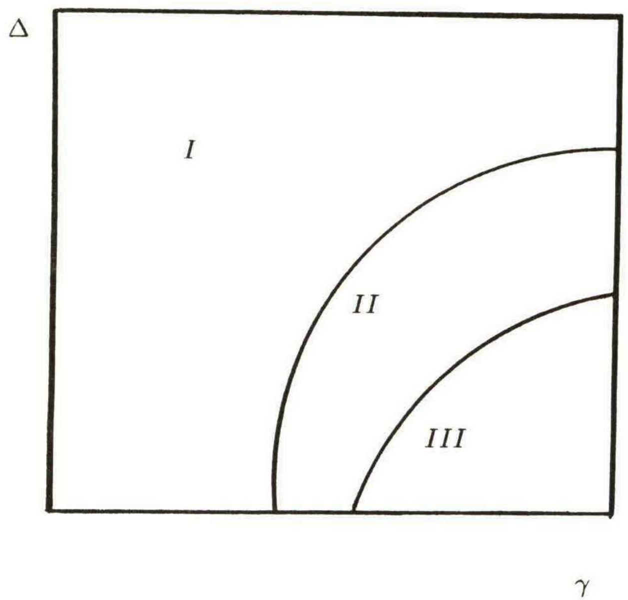

Figure 1

Of course, by Proposition 2 one has $\gamma' < \gamma''$ and $\Delta_C^* > \Delta_B^*$. In Figure 1 the function $\Delta_B^*(\cdot)$ represents the borderline between regions II and III. That is, one has $I_S^* > I_B^*$ for parameter values γ and Δ in regions I and II and $I_S^* < I_C^*$ in region III.

Social welfare in a market with differentiated products is affected by two opposing effects. On the one hand, the nonappropriability of total consumer surplus tends to reduce the duopolists output below the social optimum. This is clearly the case for rather low values of γ, where each firm behaves almost like a monopolist and contracts output to maximize profit. In this situation there is underinvestment in cost reduction relative to the social optimum. On the other hand, there is the well-known tendency towards excessive product differentiation. This may induce firms to produce a higher output than the social planner would choose. In the present context this obviously happens with values of $\gamma > \bar{\gamma}_S$ where both firms produce positive quantities under Bertrand and Cournot competition whereas the social planner would operate only the more efficient firm. Indeed, when $0 < \Delta < 2(c_1 - c_2)$ firm 1 starts out with a cost disadvantage before reducing its cost to $c_1 - \Delta$. Without the possibility of innovation, firm 1's welfare maximizing output x_1^* tends to zero as γ approaches $\bar{\gamma}_S$. In the limit $\gamma = \bar{\gamma}_S$ producing a positive quantity x_1^* is socially optimal only when c_1 is reduced to $c_1 - \Delta$. Yet, for relatively small values of Δ the welfare maximizing output of firm 1 is still rather small. This fact makes cost reduction relatively unattractive from the viewpoint of social welfare. In contrast, even for values of γ close to $\bar{\gamma}_S$ firm 1 faces no risk to become unprofitable under market competition and its output is relatively high compared with the social optimum. This fact explains why high values of γ and low values of Δ may induce overinvestment in cost reduction.

6 Conclusion

In this paper we have used a simple linear demand structure which enabled us to compute the gains from technological innovation in a differentiated industry. In particular, we compared the social optimum and the market outcome under price and quantity competition. In contrast with earlier studies, which focused on homogeneous goods markets or symmetric cost structures, we found that typically an unambiguous comparison is not possible; the relative profitability of innovation may depend on the degree the product substitutability.

One of the most debated issues in the literature on innovation is the relation between the degree of market competition and the incentives to innovate. As is well known, price competition is more competitive than quantity competition in the sense that it results in lower prices and higher outputs. Yet, our analysis shows that one cannot draw a general conclusion on whether cost reduction is more or less likely to occur in a more competitive environment. On the one hand, Cournot and Bertrand competition create different strategic incentives. As we have shown, the positive strategic effect associated with quantity competition makes innovation more attractive in the Cournot market than in the Bertrand market when the degree of product substitutability is sufficiently low. On the other hand, the higher effectiveness of price competition allows a firm to gain a larger market share by reducing its cost than under quantity competition. With a sufficiently high degree of product substitutability this may lead to a stronger incentive to innovate.

Similarly, we demonstrated that two opposing effects determine whether market competition leads to under- or overinvestment in cost reduction relative to the social optimum. The first effect is related to the nonappropriability of total consumer surplus in the absence of perfect price discrimination. This effect leads to underinvestment when the goods are imperfect substitutes. The second effect has to do with the well known tendency towards excessive product differentiation and becomes relevant when the degree of substitutability is sufficiently large. We demonstrated that in this case the market outcome may indeed result in overinvestment in innovation with respect to the socially optimal level.

Our analysis has focused on the case where firms not only produce differentiated goods but also employ different technologies. As an assumption, cost reduction in one firm cannot be imitated by the competitors. One possible extension could consider the case where the firms are engaged in a race for an innovation that would be useful for each of them. Such an analysis could also address the question of optimal patent duration.

7 Appendix

Proof of Proposition 1: Maximizing (2) yields the first-order conditions

$$\alpha - \beta x_i^* - \gamma x_j^* - c_i = 0. \tag{A.1}$$

Multiplying (A.1) by x_i^* and substituting into (2) leads to

$$V(c_1, c_2) = 0.5\beta(x_1^{*2} + x_2^{*2}) + \gamma x_1^* x_2^*. \tag{A.2}$$

Using (3) and rearranging terms then yields

$$V(c_1, c_2) = \frac{(\alpha - c_1)(\alpha - c_2)}{\beta + \gamma} + \frac{\beta(c_2 - c_1)^2}{2(\beta^2 - \gamma^2)}. \tag{A.3}$$

By (6) this implies

$$I_S^* = \Delta\left[\frac{\alpha - c_2}{\beta + \gamma} + \frac{\beta(c_2 - c_1 + 0.5\Delta)}{\beta^2 - \gamma^2}\right]. \tag{A.4}$$

Similarly, using the first-order condition for profit maximization in the Cournot market one gets $\Pi_1^C(c_1, c_2) = \beta \hat{x}_1^2$. Therefore (9) implies

$$\Pi_1^C(c_1, c_2) = \frac{4\beta^3(\alpha - c_1)^2 - 4\beta^2\gamma(\alpha - c_1)(\alpha - c_2) + \beta\gamma^2(\alpha - c_2)^2}{(2\beta - \gamma)^2(2\beta + \gamma)^2}. \tag{A.5}$$

By (11) this yields

$$I_C^* = \Delta\left[\frac{4\beta^2(\alpha - c_2)}{(2\beta + \gamma)^2(2\beta - \gamma)} + \frac{8\beta^3(c_2 - c_1 + 0.5\Delta)}{(2\beta + \gamma)^2(2\beta - \gamma)^2}\right]. \tag{A.6}$$

Finally, by the first-order condition for $\hat{p}_1$ one has $\Pi_1^B(c_1, c_2) = (\hat{p}_1 - c_1)^2\beta/(\beta^2 - \gamma^2)$ so that by (13)

$$\Pi_1^B(c_1, c_2) = \frac{[(2\beta + \gamma)(\beta - \gamma)\alpha - (2\beta^2 - \gamma^2)c_1 + \gamma\beta c_2]^2\beta}{[4\beta^2 - \gamma^2]^2[\beta^2 - \gamma^2]}. \tag{A.7}$$

By (15) one then obtains

$$I_B^* = \Delta\left[\frac{2\beta(2\beta^2 - \gamma^2)(\alpha - c_2)}{(2\beta - \gamma)^2(2\beta + \gamma)(\beta + \gamma)} + \frac{2\beta(2\beta^2 - \gamma^2)^2(c_2 - c_1 + 0.5\Delta)}{(2\beta - \gamma)^2(2\beta + \gamma)^2(\beta^2 - \gamma^2)}\right]. \tag{A.8}$$

Proposition 1 then simply follows by differentiating I_S^*, I_C^* and I_B^* with respect to c_i because $0 < \gamma < \beta$.

Q.E.D.

Proof of Proposition 2: By (A.6) and (A.8) one has $I_C^* > I_B^*$ iff

$$\frac{2\beta\gamma^3(\alpha - c_2)}{(4\beta^2 - \gamma^2)(\beta + \gamma)} > \frac{2\beta\gamma^4(c_2 - c_1 + 0.5\Delta)}{(4\beta^2 - \gamma^2)(\beta^2 - \gamma^2)}. \tag{A.9}$$

(A.9) is equivalent to $\gamma < \beta(\alpha - c_2)/(\alpha - c_1 + 0.5\Delta)$ which holds because, by (4), $\gamma < \bar{\gamma}_S$.

Q.E.D.

Proof of Proposition 3: Define $\gamma^o = \beta(\alpha - c)/(\alpha - c + 0.5\Delta)$. Then by (A.9), $I_C^* > I_B^*$ if $\gamma < \gamma^o$ and $I_C^* < I_B^*$ if $\gamma > \gamma^o$. Clearly $\gamma^o > \bar{\gamma}_S$ because $\gamma^o/\beta = (\alpha - c)/(\alpha - c + 0.5\Delta) > (\alpha - c)/(\alpha - c + \Delta) = \bar{\gamma}_S$.

It remains to show that $\gamma^o < \bar{\gamma}_B$. Let $x^o \equiv \gamma^o/\beta$ and $\bar{x}_B \equiv \bar{\gamma}_B/\beta$. Then by definition of γ^o one has $\Delta = [\alpha - c][2 - 2x^o]/x^o$. By definition of $\bar{\gamma}_B$ one has $\bar{x}_B/[2 - \bar{x}_B^2] = \bar{\gamma}_S/\beta = [\alpha - c]/[\alpha - c + \Delta]$, i.e. $\Delta = [\alpha - c][2 - \bar{x}_B - \bar{x}_B^2]/\bar{x}_B$. Therefore

$$[2 - 2x^o]/x^o = [2 - \bar{x}_B - \bar{x}_B^2]/\bar{x}_B > [2 - 2\bar{x}_B]/\bar{x}_B, \qquad (A.10)$$

where the inequality holds because $\bar{x}_B < 1$. By (A.10) one has $\bar{x}_B > x^o$ which proves $\gamma^o < \bar{\gamma}_B$. Finally, by definition, γ^o decreases with Δ.
Q.E.D.

Proof of Proposition 4: By (A.4) and (A.6) one has $I_S^* > I_C^*$ if and only if

$$\frac{(4\beta^3 - 2\beta\gamma^2 - \gamma^3)(\alpha - c_2)}{(\beta + \gamma)(2\beta + \gamma)^2(2\beta - \gamma)} > \frac{(8\beta^5 + \gamma^4\beta)(c_1 - c_2 - 0.5\Delta)}{(\beta^2 - \gamma^2)(4\beta^2 - \gamma^2)^2}. \qquad (A.11)$$

Clearly, for $\Delta \geq 2(c_1 - c_2)$ this inequality must hold as the l.h.s. of (A.11) is positive because $\gamma < \beta$.
Q.E.D.

Proof of Proposition 5: Using (A.4) and (A.6) or rearranging (A.11) one obtains $I_S^* < I_C^*$ if and only if

$$\left[\frac{\beta}{\beta^2 - \gamma^2} - \frac{8\beta^3}{(4\beta^2 - \gamma^2)^2}\right](\alpha - c_1 + 0.5\Delta) < \left[\frac{\gamma}{\beta^2 - \gamma^2} - \frac{4\beta^2\gamma}{(4\beta^2 - \gamma^2)^2}\right](\alpha - c_2). \quad (A.12)$$

This is equivalent to

$$(8\beta^5 + \beta\gamma^4)(\alpha - c_1 + 0.5\Delta) < (12\beta^4\gamma - 4\beta^2\gamma^3 + \gamma^5)(\alpha - c_2). \tag{A.13}$$

Define

$$\xi \equiv \frac{\gamma}{\beta},\ g(\Delta) \equiv \frac{\alpha - c_1 + 0.5\Delta}{\alpha - c_2},\ f_C(\xi) \equiv \frac{12\xi - 4\xi^3 + \xi^5}{8 + \xi^4}. \tag{A.14}$$

Then $I_S^* < I_C^*$ if and only if $g(\Delta) < f_C(\xi)$. It is easily verified that $f_C'(\xi) > 0, f_C''(\xi) < 0, f_C(0) = 0$, and $f_C(1) = 1$. This implies $f_C(\xi) > \xi$ for all $0 < \xi < 1$. Let γ' be such that $f_C(\gamma'/\beta) = g(0)$. For $\Delta < 2(c_1 - c_2)$ one has $g(0) = \bar{\gamma}_S/\beta = (\alpha - c_1)/(\alpha - c_2) < 1$. Therefore $\gamma' \in (0, \bar{\gamma}_S)$ and $g(\Delta) > f_C(\gamma/\beta)$ for all $\gamma < \gamma'$. This proves the first part of the Proposition.

To prove the second part, note that $g(2c_1 - 2c_2) = 1$. Therefore, for each $\gamma' < \gamma < \bar{\gamma}_S$ there is a $\Delta_C^*(\gamma) \in (0, 2(c_1 - c_2))$ such that $g(\Delta_C^*) = f_C(\gamma/\beta)$. As $g'(.) > 0$, this implies $g(\Delta) < f_C(\gamma/\beta)$, i.e. $I_C^* > I_S^*$, for $\Delta < \Delta_C^*$ and $g(\Delta) > f_C(\gamma/\beta)$, i.e. $I_C^* < I_S^*$, for $\Delta > \Delta_C^*$. Finally, $\Delta_C^*(.)$ must be increasing as $g'(.) > 0$ and $f'(.) > 0$.
Q.E.D.

Proof of Proposition 6: By (A.4) and (A.8) one has $I_S^* < I_B^*$ if and only if

$$\left[\frac{\beta}{\beta^2 - \gamma^2} - \frac{2\beta(2\beta^2 - \gamma^2)^2}{(4\beta^2 - \gamma^2)^2(\beta^2 - \gamma^2)}\right](\alpha - c_1 + 0.5\Delta) <$$
$$\left[\frac{\gamma}{\beta^2 - \gamma^2} - \frac{2\beta^2\gamma(2\beta^2 - \gamma^2)}{(4\beta^2 - \gamma^2)^2(\beta^2 - \gamma^2)}\right](\alpha - c_2). \tag{A.15}$$

(A.15) is equivalent to

$$(8\beta^5 - \beta\gamma^4)(\alpha - c_1 + 0.5\Delta) > (12\beta^4\gamma - 6\beta^2\gamma^3 + \gamma^5)(\alpha - c_2). \tag{A.16}$$

Using the definitions of (A.14) in the proof of Proposition 5 one has $I_S^* < I_B^*$ if and only if $g(\Delta) < f_B(\xi)$, where $f_B(\xi) \equiv (12\xi - 6\xi^3 + \xi^5)/(8 - \xi^4)$. The function $f_B(.)$ has similar properties as the function $f_C(.)$ in the proof of the foregoing Proposition, namely $f'_B(.) > 0, f''_B(.) < 0, f_B(0) = 0$, and $f_B(1) = 1$. Therefore, the same arguments as above can be used to prove Proposition 6.

Q.E.D.

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