Forthcoming in the *International Journal of Industrial Organization*

INTENSITY OF COMPETITION AND THE CHOICE BETWEEN PRODUCT AND PROCESS INNOVATION *

Giacomo Bonanno
Department of Economics,
University of California,
Davis, CA 95616 - 8578, USA
e-mail: gfbonanno@ucdavis.edu

and

Barry Haworth
School of Economics and Public Affairs,
University of Louisville,
Louisville, KY 40292, USA
e-mail: bmhawo01@homer.louisville.edu

Abstract

Two questions are examined within a model of vertical differentiation. The first is whether cost-reducing innovations are more likely to be observed in regimes of more intense or less intense competition. Following Delbono and Denicolo (1990) and Bester and Petrakis (1993) we compare two identical industries that differ only in the regime of competition: Bertrand versus Cournot. Since Cournot competition leads to lower output and higher prices, it can be thought of as a regime of less intense competition. We find that the increase in profits associated with any given cost reduction is higher in the case of Cournot competition than in the case of Bertrand competition. Thus there are cost-reducing innovations that would be pursued under Cournot competition but not under Bertrand competition.

The second question, which so far has not been analyzed in the literature, is what factors might be important in a firm's decision whether to invest in product innovation (improvement in the quality of its product) or process innovation (cost reduction). We show that the regime of competition might be one such factor. For the high quality firm our result is that *if* there is a difference between the choice made by a Bertrand competitor and the choice made by a Cournot competitor, then the former will opt for product innovation, while the latter will prefer process innovation. For the low-quality firm, on the other hand, the result is reversed: whenever there is a difference, the Bertrand competitor will favor process innovation, while the Cournot competitor will favor product innovation.

* We are grateful to two anonymous referees, Raymond De Bondt, Louis Makowski and Klaus Nehring for helpful comments and suggestions.

1. Introduction

There is a vast literature on the economic aspects of innovation. A wide spectrum of issues has been analyzed, from the timing of innovative ventures, to expenditure patterns in R&D races, to spillover effects and their impact (for an excellent survey of the latter see De Bondt, 1995). The issue we address in this paper is the *relationship between intensity of competition and the profitability of innovative activity*. A traditional line of reasoning, associated with Schumpeter (1943), is that market concentration is a stimulus to innovation. An early challenge to this view came from Arrow (1962), who sought to establish the reverse proposition that more competitive environments would give a greater incentive to innovate. Arrow considered the case of a firm undertaking a cost-reducing investment that cannot be imitated by competitors. He compared a monopoly with a perfectly competitive industry, under the same demand and cost conditions, and showed that the gain from a cost-reducing innovation is higher for a firm in the latter than for the monopolist. A more interesting comparison would be between two oligopolistic industries. It is not clear, however, how "intensity of competition" can be measured in such a setting. Delbono and Denicolo (1990) and Bester and Petrakis (1993) suggested comparing two industries (with the same number of firms and the same linear demand and cost functions) under different regimes of competition: Cournot (where firms' decision variables are output levels) and Bertrand (where firms' decision variables are prices). Since Cournot competition normally leads to lower output and higher prices than Bertrand competition, one can think of the former as a situation where competition is less intense. Delbono and Denicolo (1990) showed that, under the assumption of a homogeneous product, the incentive to introduce a cost-reducing innovation is greater for a Bertrand competitor than for a Cournot competitor: an "Arrow-like" result. Bester and Petrakis (1993), on the other hand, considered the case of differentiated products and

obtained a mixed result: if the degree of differentiation is "large", the incentive to introduce a cost-reducing innovation is higher for the Cournot competitor, while if the degree of differentiation is "small", then the incentive is higher for a Bertrand competitor.

Bester and Petrakis's model is one of *horizontal* differentiation (when prices are equal both products enjoy positive demand). In the first part of the paper we re-examine the issue within a model of *vertical* differentiation (if prices are equal, only one product – the higher quality one – enjoys positive demand) and show that the increase in profits associated with any given cost reduction is higher in the case of Cournot competition than in the case of Bertrand competition, and this is true *no matter how small the degree of differentiation* (thus even if the products are virtually homogeneous). It follows that there are cost-reducing innovations that would be pursued under Cournot competition but not under Bertrand competition (a "Schumpeter-like" result).

In the second part of the paper we address a related issue, which – somewhat surprisingly – has received very little attention in the literature. It is customary to distinguish between two types of innovation: product and process innovation. The former consists in the creation of new goods and services, while the latter leads to a reduction in the cost of producing existing products. The literature has dealt primarily with overall innovative activity (that is, the sum of product and process innovation) or one specific type of innovative activity (either process or product innovation).[1] There have been no attempts to explain *what factors might be important in a firm's decision whether to direct R&D expenditure towards product innovation or towards process innovation*[2]. In this

[1] See surveys by Kamien and Schwartz (1975), Baldwin and Scott (1987), Cohen and Levin (1989), Scherer and Ross (1990) and Tirole (1988).

[2] An exception is Rosenkrantz (1995) which is discussed in Section 5. We are grateful to Raymond De Bondt for bringing this paper to our attention.

paper we take a first step in the direction of filling this gap, by providing an explanation based on the type of competitive regime in which the firms find themselves (Cournot vs. Bertrand). We shall think of *product innovation as an improvement in the quality of a firm's product* (e.g. the introduction of a faster computer chip). Process innovation will be interpreted as a reduction in the firm's costs. We show that, if the choice is between a given cost reduction or a given quality improvement *and the innovator is the high quality firm,* one of three things can happen: (1) both the Cournot competitor and the Bertrand competitor choose the cost reduction, or (2) both choose the quality improvement, or (3) they make different choices, in which case the Cournot competitor chooses the cost reduction, while the Bertrand competitor chooses the quality improvement. That is, *if* Bertrand competition and Cournot competition lead to different choices, *then* the Bertrand competitor will favor product innovation, while the Cournot competitor will opt for process innovation. On the other hand, *if the innovator is the low quality firm,* then the opposite is true: whenever the two regimes of competition yield different choices, the Bertrand competitor will choose process innovation, while the Cournot competitor will choose product innovation.

The paper is organized as follows. Section 2 develops the model, Section 3 deals with cost-reducing innovations, while Section 4 is concerned with the choice between process and product innovation. Section 5 contains some final remarks and a conclusion.

The proofs of all the results are omitted and can be obtained from the authors.

2. A model of vertical differentiation

We use a model of vertical differentiation introduced by Mussa and Rosen (1978). There are N consumers with the same income, denoted by E, but different values of the

taste parameter θ. Each consumer buys at most one unit. If a consumer does not buy the product, her utility is equal to her income E. If a consumer with parameter θ buys one unit of a good of quality k, at price p, her utility is equal to $E - p + \theta k$. The parameter θ is uniformly distributed in the interval (0,1]. It follows that, for every $x \in (0,1]$, the number of consumers with parameter θ less than or equal to x is xN. We consider the case where there are two firms. Firm H sells a product of quality k_H while firm L sells a product of quality k_L, with $k_H > k_L > 0$ (thus 'H' stands for 'high quality' and 'L' for 'low quality'). Let p_i be the price charged by firm i (i=H,L). The demand functions are obtained as follows. Let θ_0 be the value of θ for which the corresponding consumer is indifferent between consuming nothing and consuming the low-quality product. Then θ_0 is the solution to the equation

$$E = E - p_L + \theta k_L.$$

Thus $\theta_0 = \frac{p_L}{k_L}$. Let θ_1 be the value of θ for which the corresponding consumer is indifferent between buying the low-quality product and the high-quality one. Then θ_1 is the solution to the equation

$$E - p_L + \theta k_L = E - p_H + \theta k_H .$$

Thus $\theta_1 = \frac{p_H - p_L}{k_H - k_L}$. Hence the (direct) demand functions are given by

$$D_H(p_H, p_L) = (1 - \theta_1)N = \left(1 - \frac{p_H - p_L}{k_H - k_L}\right)N$$

$$D_L(p_H, p_L) = (\theta_1 - \theta_0)N = \left(\frac{p_H - p_L}{k_H - k_L} - \frac{p_L}{k_L}\right)N$$

Like Bester and Petrakis (1993) and Rosenkrantz (1995) we assume that the two firms operate under constant returns to scale. Thus firm i (i=H,L) has a cost function of the

form $C_i(q_i) = c_i q_i$ with $c_i > 0$. We also assume that higher quality is associated with higher costs: $c_H > c_L$. Finally, we assume that c_H and c_L are such that both demands are positive when the two products are sold at unit cost (i.e. when $p_H = c_H$ and $p_L = c_L$).[3] It is easy to see that this is the case if and only if the following two conditions are satisfied [4]

$$k_H - k_L > c_H - c_L \tag{1a}$$

and

$$k_L c_H > k_H c_L \tag{1b}.$$

The inverse demand functions are given by (where q_H denotes the output of firm H and q_L the output of firm L)

$$f_H(q_H, q_L) = \frac{Nk_H - k_H q_H - k_L q_L}{N}$$

$$f_L(q_H, q_L) = \frac{k_L(N - q_H - q_L)}{N}$$

We consider two cases: the Bertrand case (decision variables are prices) and the Cournot case (decision variables are output levels). We shall use superscript 'B' for the Bertrand case and superscript 'C' for the Cournot case.

In the Bertrand case the profit functions are given by

[3] This assumption guarantees that at all the equilibria we consider, prices and output levels are positive: cf. Remark 1 below.

[4] Note that (1a) and (1b) imply that $c_H < k_H$ and $c_L < k_L$.

$$\Pi_H^B(p_H,p_L) = N(p_H - c_H)\left(1 - \frac{p_H - p_L}{k_H - k_L}\right)$$

$$\Pi_L^B(p_H,p_L) = N(p_L - c_L)\left(\frac{p_H - p_L}{k_H - k_L} - \frac{p_L}{k_L}\right) \tag{2}$$

Prices and output levels at the Bertrand-Nash equilibrium are given by

$$p_H^B = \frac{k_H(2k_H - 2k_L + 2c_H + c_L)}{4k_H - k_L}$$

$$p_L^B = \frac{(k_H k_L - k_L^2 + c_H k_L + 2k_H c_L)}{4k_H - k_L}$$

$$q_H^B = N\frac{(2k_H^2 - 2k_H k_L - 2k_H c_H + k_H c_L + k_L c_H)}{(4k_H - k_L)(k_H - k_L)} \tag{3}$$

$$q_L^B = N\frac{k_H(k_H k_L - k_L^2 + k_L c_H - 2k_H c_L + k_L c_L)}{(4k_H - k_L)(k_H - k_L)k_L}$$

giving the following expressions for the *equilibrium* profits of firms H and L:

$$\pi_H^B(k_H,k_L,c_H,c_L) = N\frac{[2k_H^2 - 2k_H k_L - 2k_H c_H + k_H c_L + k_L c_H]^2}{(4k_H - k_L)^2(k_H - k_L)} = \frac{k_H - k_L}{N}\left(q_H^B\right)^2$$

$$\pi_L^B(k_H,k_L,c_H,c_L) = Nk_H\frac{[k_H k_L - k_L^2 - 2k_H c_L + k_L c_L + k_L c_H]^2}{(4k_H - k_L)^2(k_H - k_L)k_L} = \frac{k_L(k_H - k_L)}{k_H N}\left(q_L^B\right)^2 \tag{4}$$

We now move to the Cournot case, where the profit functions are given by

$$\Pi_H^C(q_H,q_L) = q_H\left(\frac{Nk_H - q_H k_H - q_L k_L}{N} - c_H\right)$$

$$\Pi_L^C(q_H,q_L) = q_L\left(\frac{k_L(N - q_H - q_L)}{N} - c_L\right)$$

Prices and output levels at the Cournot-Nash equilibrium are given by

$$p_H^C = \frac{2k_H^2 - k_H k_L + 2k_H c_H + k_H c_L - c_H k_L}{4k_H - k_L} \qquad q_H^C = N\,\frac{2k_H - k_L - 2c_H + c_L}{4k_H - k_L}$$

$$p_L^C = \frac{k_H k_L + 2k_H c_L + k_L c_H - k_L c_L}{4k_H - k_L} \qquad q_L^C = N\,\frac{k_H k_L + k_L c_H - 2k_H c_L}{(4k_H - k_L)\,k_L} \tag{5}$$

yielding the following expressions for the *equilibrium* profits of firms H and L:

$$\pi_H^C(k_H, k_L, c_H, c_L) = N\,\frac{k_H (2k_H - k_L - 2c_H + c_L)^2}{(4k_H - k_L)^2} = \frac{k_H}{N}\left(q_H^C\right)^2$$

$$\pi_L^C(k_H, k_L, c_H, c_L) = N\,\frac{(k_H k_L - 2k_H c_L + k_L c_H)^2}{(4k_H - k_L)^2\,k_L} = \frac{k_L}{N}\left(q_L^C\right)^2 \tag{6}$$

REMARK 1. The following facts can be checked easily. If the parameter restrictions (1a) and (1b) are satisfied, then, for each firm i (i=H,L), Cournot output is smaller than Bertrand output ($q_i^C < q_i^B$), Cournot price is higher than Bertrand price ($p_i^C > p_i^B$), and Cournot profit is higher than Bertrand profit ($\pi_i^C > \pi_i^B$). Furthermore, all these quantities are positive and equilibrium prices are greater than unit cost ($p_i^C > p_i^B > c_i$).

3. Intensity of competition and the profitability of cost-reducing innovations

In this section we compare the incentives for a given cost reduction between a Bertrand competitor and a Cournot competitor and show that the latter is larger. Let $\Delta_H > 0$ be a non-drastic cost reduction for firm H and $\Delta_L > 0$ a non-drastic cost reduction for firm L, where "non-drastic" means that after the cost reduction the innovator cannot drive the other firm out of the market by charging a price close to unit cost. That is, we assume

that Δ_H and Δ_L are sufficiently small for inequalities corresponding to (1a) and (1b) to be satisfied:

$$k_H - k_L > (c_H - \Delta_H) - c_L \tag{7a}$$

$$k_L (c_H - \Delta_H) > k_H c_L \tag{7b}$$

$$k_H - k_L > c_H - (c_L - \Delta_L) \tag{7c}$$

$$k_L c_H > k_H (c_L - \Delta_L) \tag{7d}$$

For each firm i (i = H,L), let $\Delta\pi_i^C$ be the increase in profits expected from the given cost reduction in the case of Cournot competition and $\Delta\pi_i^B$ the increase in profits expected from the given cost reduction in the case of Bertrand competition:

$$\Delta\pi_H^C = \pi_H^C (k_H, k_L, c_H - \Delta_H, c_L) - \pi_H^C (k_H, k_L, c_H, c_L) \tag{8a}$$

$$\Delta\pi_H^B = \pi_H^B (k_H, k_L, c_H - \Delta_H, c_L) - \pi_H^B (k_H, k_L, c_H, c_L) \tag{8b}$$

$$\Delta\pi_L^C = \pi_L^C (k_H, k_L, c_H, c_L - \Delta_L) - \pi_L^C (k_H, k_L, c_H, c_L) \tag{8c}$$

$$\Delta\pi_L^B = \pi_L^B (k_H, k_L, c_H, c_L - \Delta_L) - \pi_L^B (k_H, k_L, c_H, c_L) \tag{8d}$$

where π_H^C and π_L^C are given by (6) and π_H^B and π_L^B are given by (4).

The following remark confirms Bester and Petrakis's result (1993, p. 525, Proposition 1) that the marginal return on investment in a cost reduction is increasing.

REMARK 2. $\Delta\pi_H^C$ and $\Delta\pi_H^B$ are decreasing in c_H and $\Delta\pi_L^C$ and $\Delta\pi_L^B$ are decreasing in c_L.

Proposition 1 below gives a "Schumpeter-like" result: less intense competition is associated with a greater propensity to introduce cost-reducing innovations. Define a *cost-*

reducing investment opportunity for firm i (i = H, L) as a pair (Δ_i, α) where α is the cost of implementing the innovation and Δ_i is the reduction in unit cost expected from the innovation. It is clear that firm i will carry out the investment if and only if the expected increase in profits is greater than the implementation cost, that is, if and only if $\Delta\pi_i > \alpha$.

PROPOSITION 1. For each i (i = H, L) there are cost-reducing investment opportunities that are carried out by firm i if it operates in a regime of Cournot competition but not if it operates in a regime of Bertrand competition. On the other hand, every cost-reducing investment carried out under Bertrand competition is also carried out under Cournot competition.

Proposition 1 follows directly from the following fact: for all k_H, k_L, c_H, c_L, Δ_H and Δ_L that satisfy (7), and for every i = H,L, $\Delta\pi_i^C > \Delta\pi_i^B$. The intuition behind Proposition 1 is as follows. A cost reduction by firm i has a direct (positive) effect on the profits of firm i as well as a *strategic* or indirect effect through the change it induces in the choice variable of the competitor. In a Bertrand regime the strategic effect is *negative*: the competitor will respond to a reduction in c_i by reducing its own price, thereby increasing the intensity of competition[5]. In a Cournot regime on the other hand, a cost

[5] The strategic effect is given by $\frac{\partial \Pi_i^B}{\partial p_j}\frac{\partial p_j^B}{\partial c_i}$ where $i \neq j$, Π_i^B is given by (2) and p_i^B is given by (3). It is straightforward to verify that $\frac{\partial \Pi_i^B}{\partial p_j} > 0$ and $\frac{\partial p_j^B}{\partial c_i} > 0$ so that $\frac{\partial \Pi_i^B}{\partial p_j}\frac{\partial p_j^B}{\partial c_i} > 0$. In the terminology of Bulow et al (1985), in the Bertrand case (with linear demand) prices are strategic complements: a reduction in c_i leads to a reduction in p_i which in turn leads to a reduction in p_j, that is, an "aggressive" response by the competitor.

reduction has *positive* strategic effects, that is, it leads to a softening of competition[6]. Note that Proposition 1 holds no matter how small the degree of product differentiation, that is, no matter how close k_L is to k_H. Thus in a model of vertical differentiation the mixed result obtained by Bester and Petrakis (1993) does not hold.

4. On the choice between process and product innovation

We now turn to the choice between process and product innovation. Assume that one of the two firms, say firm H, has invested in R&D (e.g. it has hired a team of engineers) and the corresponding cost is sunk. Suppose that the firm has two options:

(1) it can instruct its researchers to pursue *product* innovation, expected to lead to an increase in the quality of the firm's product from $\hat{k}_H$ to $\hat{k}_H + \Delta k$ (with $\Delta k > 0$); or

(2) it can instruct them to pursue *process* innovation, expected to lead to a reduction in the firm's unit cost from $\hat{c}_H$ to $\hat{c}_H - \Delta c$ (with $0 < \Delta c \leq \hat{c}_H$).

Assume that there are no other costs involved in the implementation of the innovation. The choice facing the firm is illustrated in Figure 1. For example, the firm's product could be a computer chip with quality represented by the operating speed (measured in MHz) and the choice could be between increasing the speed from 166 MHz to 200 MHz or reducing the unit cost of its present product (the 166 MHz chip) from $800 to $720. Define a *product/process investment opportunity* as a triple (Δc, Δk, α) where α is the

---

[6] The strategic effect is given by $\frac{\partial \Pi_i^C}{\partial q_j}\frac{\partial q_j^C}{\partial c_i}$ which is negative, as one can easily verify (cf., in particular, (5)). In the terminology of Bulow et al (1985), in the Cournot case (with linear demand) output levels are strategic substitutes: a reduction in c_i leads to an increase in q_i which in turn leads to a reduction in q_j, that is, a "submissive" response by the competitor.

cost of implementing the innovation (e.g. the cost of hiring a team of researchers), which is *the same for both types of innovation*, Δc is the expected reduction in unit cost if process innovation is pursued (e.g. if the researchers are instructed to seek a cheaper production process for the existing product) and Δk is the expected quality increase if product innovation is pursued (e.g. if the researchers are instructed to improve the quality of the product). A process/product investment opportunity (Δc, Δk, α) is *profitable* if the expected increase in profits from at least one of the two types of innovation (cost reduction or quality improvement) is greater than α, the (common) cost of implementing the innovation. We shall first consider the case where *the innovator is the high quality firm*. The following proposition states that a Bertrand competitor is more prone to choose product innovation, while a Cournot competitor is more prone to choose process innovation.

PROPOSITION 2. The following is true for the high-quality firm. Given a profitable product/process investment opportunity (Δc, Δk, α), either both the Bertrand and the Cournot competitor choose the same type of innovation or, if they make different choices then the Bertrand competitor chooses product innovation, while the Cournot competitor chooses process innovation.

As illustrated in Figure 1, Proposition 2 follows from the following fact which applies to the high-quality firm. Fix arbitrary $\bar{k}_H$, $\bar{k}_L$, $\bar{c}_H$ and $\bar{c}_L$ that satisfy restrictions (1a) and (1b); then in the (k_H,c_H)-plane both the Bertrand isoprofit curve [obtained from (4)] and the Cournot isoprofit curve [obtained from (6)] that go through the point $(\bar{k}_H, \bar{c}_H)$ are increasing; furthermore, the Bertrand isoprofit curve is steeper (at that point) than the Cournot isoprofit curve. It follows that the two isoprofit curves cannot cross

more than once. Figure 1 shows the three possible cases[7]. **Case 1** (Figure 1a): both the Bertrand competitor and the Cournot competitor choose product innovation. **Case 2** (Figure 1b): both the Bertrand competitor and the Cournot competitor choose process innovation. **Case 3** (Figure 1c): the Bertrand competitor and the Cournot competitor make different choices. In this case the Bertrand competitor opts for product innovation, while the Cournot competitor chooses process innovation.

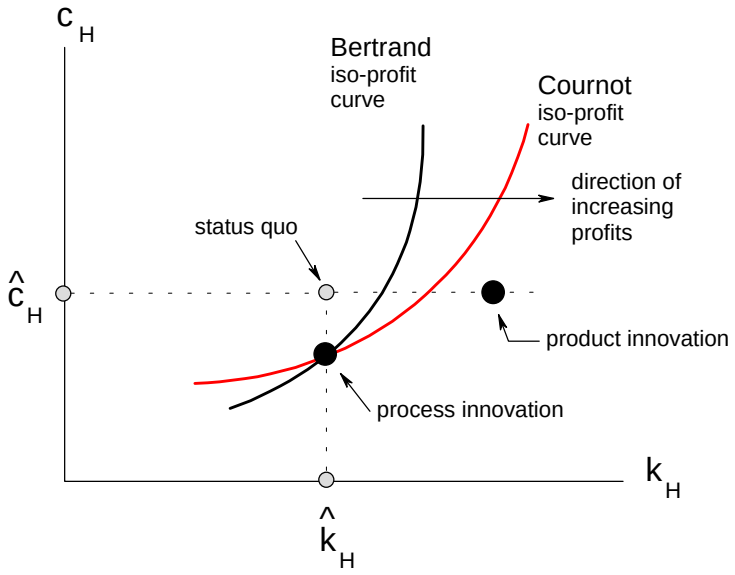

Figure 1a

[7] It is useful to consider not the isoprofit curve that goes through the status quo (or pre-innovation) point, but rather the isoprofit curve that goes through the point that represents process innovation.

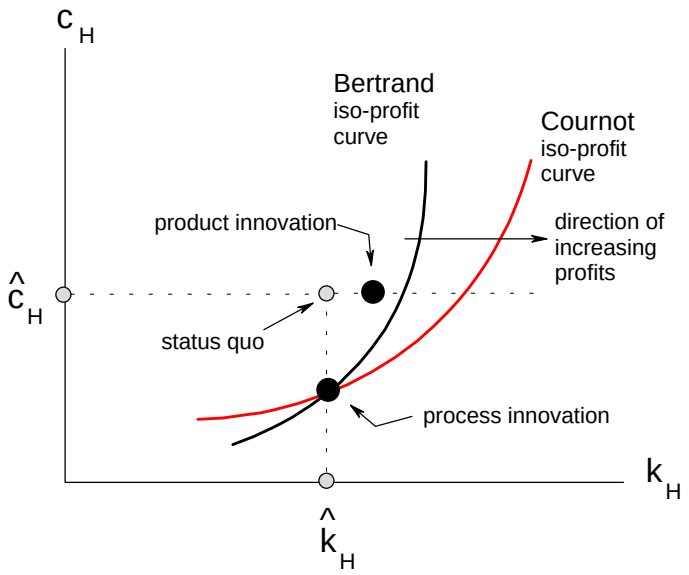

Figure 1b

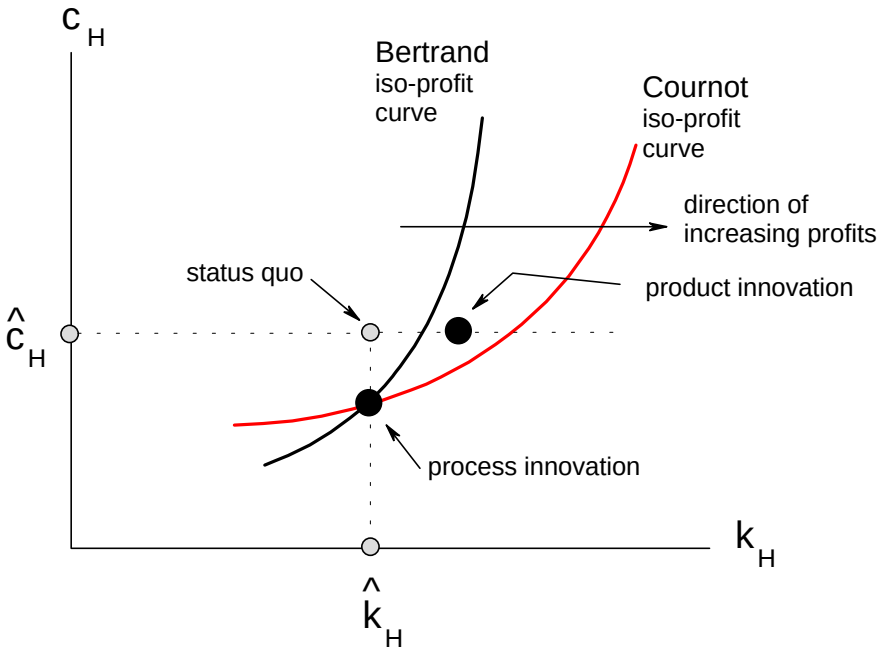

Figure 1c

The proof of Proposition 2 involves a number of rather complex algebraic manipulations which are hard to interpret. To obtain some intuition as to why a Bertrand competitor has a propensity to favor product over process innovation, recall that in a Bertrand regime a cost reduction has a negative strategic effect, in that it leads to an intensification of competition (see Section 2), with the consequence that at the equilibrium following process innovation *both* firms charge lower prices than at the pre-innovation equilibrium. Product innovation, on the other hand, will always lead to an increase in the price of firm H (the innovator), even though the equilibrium price of firm L (the competitor) may increase or decrease, as shown in Figure 2. Of course, this intuitive explanation is only partially correct for three reasons: (1) as shown in Figure 1b, even a Bertrand competitor will choose process innovation over product innovation if the former "dominates" the latter (thus one can only speak of a *tendency* of Bertrand competitors to favor product innovation), (2) the analogous intuition for the Cournot competitor cannot be established, since both product and process innovation have a positive strategic effect, as shown in Figure 3 and (3) it is easier to understand a comparison between regimes of competition *holding the type of innovation fixed* (as we did in Section 2) than a comparison of different types of innovation *holding the regime of competition fixed* (as we are doing here), because there is no obvious way of making a change in quality (e.g. an increase of 34 MHz) directly comparable with a cost reduction (e.g. $80).

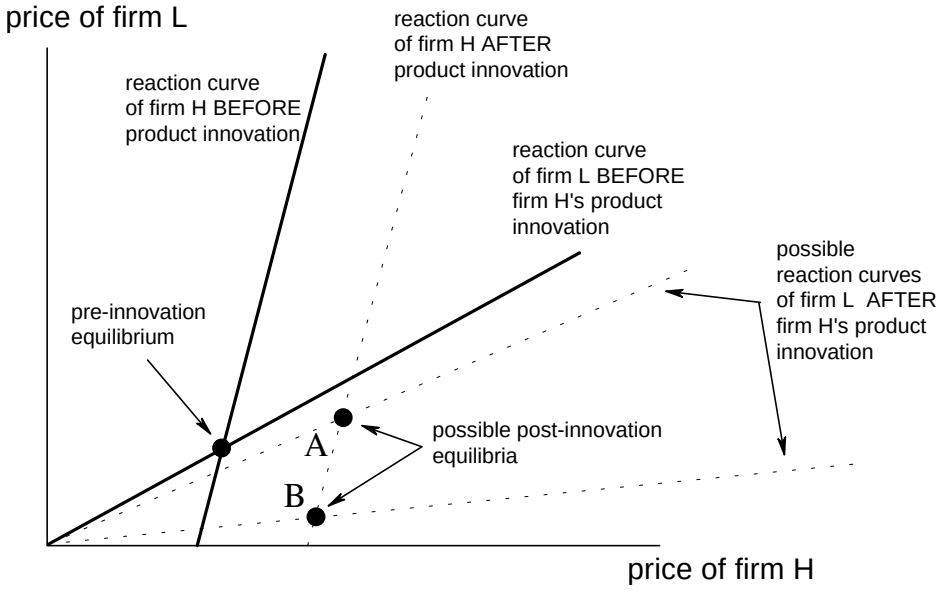

Figure 2

The effect of **product** innovation in the Bertrand case when the innovator is firm H

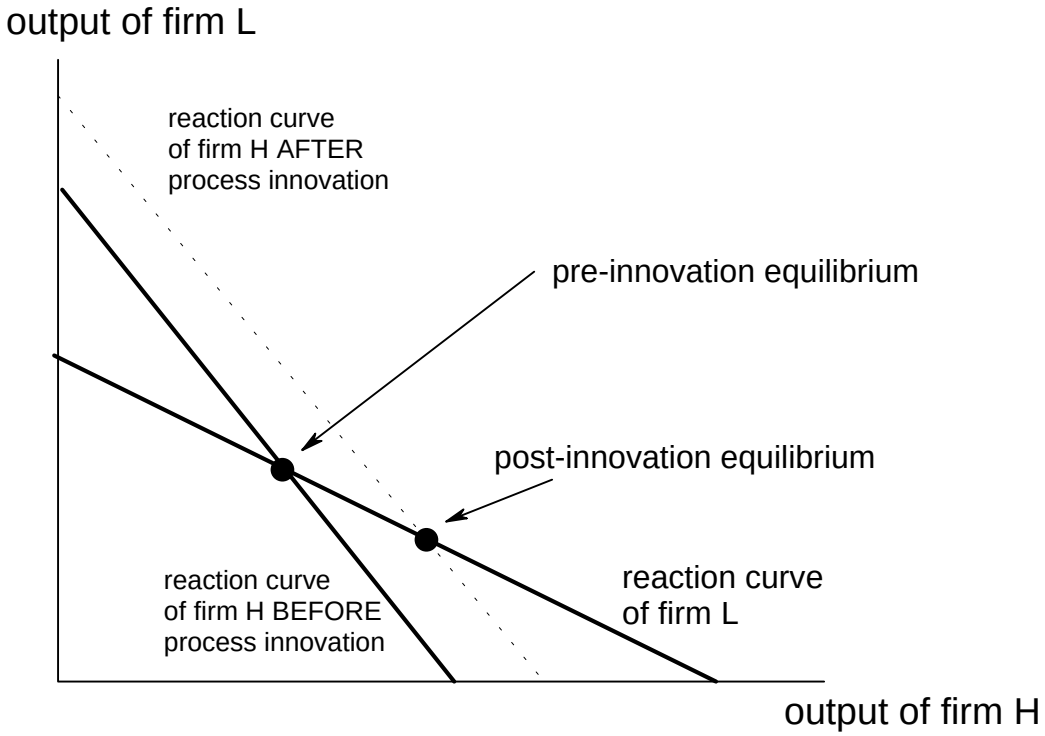

Figure 3a

The effect of **process** innovation in the Cournot case when the innovator is firm H

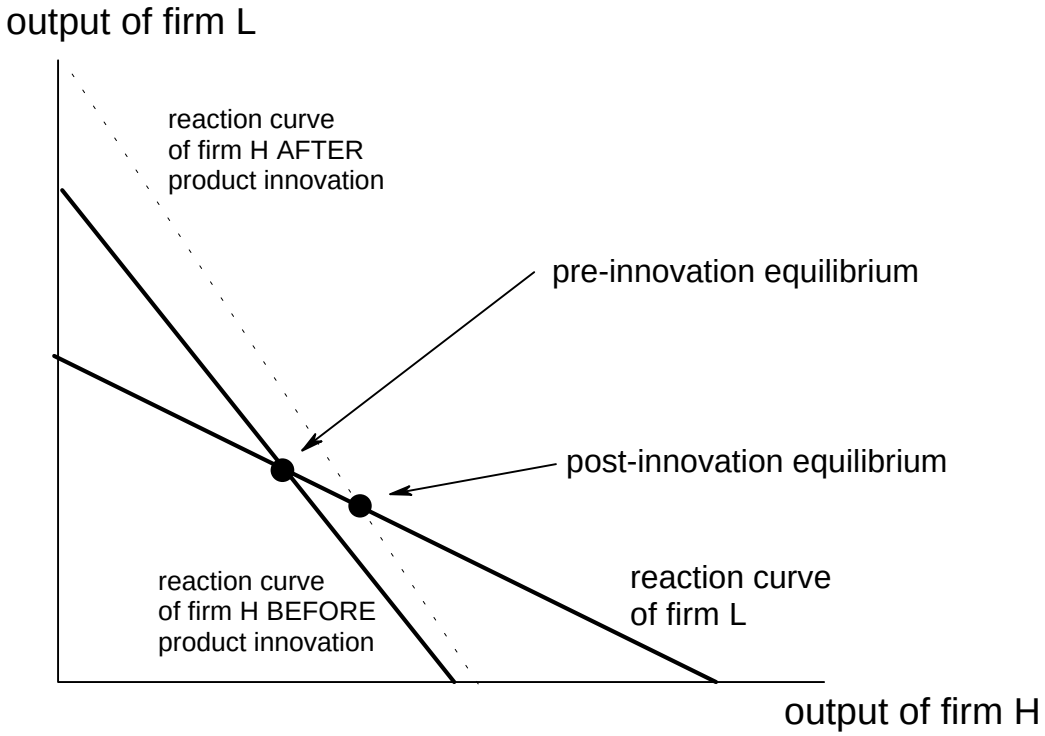

Figure 3b

The effect of **product** innovation in the Cournot case when the innovator is firm H

We now turn to the case where *the innovator is the low quality firm.*

PROPOSITION 3. The following is true for the low-quality firm. Given a profitable product/process investment opportunity (Δc, Δk, α), either both the Bertrand and the Cournot competitor choose the same type of innovation or, if they make different choices then the Bertrand competitor chooses process innovation, while the Cournot competitor chooses product innovation.

Proposition 3 follows from the following fact which applies to the low-quality firm. Fix arbitrary $\bar{k}_H$, $\bar{k}_L$, $\bar{c}_H$ and $\bar{c}_L$ that satisfy restrictions (1a) and (1b). Then in the (k_L,c_L)-plane the Cournot isoprofit curve [obtained from (6)] that goes through the point $(\bar{k}_L, \bar{c}_L)$ is increasing and steeper (at that point) than the Bertrand isoprofit curve [obtained from (4)] that goes through the same point. Note that, while the Cournot isoprofit curve is always increasing, the Bertrand isoprofit curve might not be (it *will* be increasing if the degree of differentiation is not too small). Indeed, it has been shown in the literature (Gabszewicz and Thisse, 1979, 1980; Shaked and Sutton, 1982) that when there is Bertrand competition a low-quality firm might refrain from increasing the quality of its product *even if it could do so at zero cost.* This will happen when the degree of differentiation is very small. On the other hand, when competition is Cournot style, the low-quality firm does have an incentive to increase the quality of its product (Bonanno, 1986). The comparison between process and product innovation is therefore interesting mainly in the case where the low quality firm would profit from a costless quality improvement (that is, when the Bertrand iso-profit curve is increasing). In this case we have a reversal of the result of Proposition 2: when the innovator is the *low-quality* firm and the Bertrand competitor makes a different choice from the Cournot competitor, then

the latter will opt for *product* innovation, while the former will choose *process* innovation.

As for the case of Proposition 2, the proof of Proposition 3 involves a number of complex algebraic manipulations which are hard to interpret. Some intuition for the result can be obtained by examining the strategic effects. Consider, for example, the case of Bertrand competition. Process innovation by the low-quality firm has negative strategic effects, since it induces the innovator to reduce its price (firm L's reaction curve shifts down) and the competitor (firm H) will respond by also lowering its price. Product innovation by firm L, on the other hand, would potentially have positive strategic effects, since it shifts the innovator's reaction curve up. However, unlike the case of Proposition 2 – where a quality improvement by the high quality firm increased the degree of differentiation – here a quality improvement by firm L reduces the degree of differentiation and induces an aggressive response by the competitor: the reaction curve of firm H shifts to the left. To put it differently, a cost reduction for firm L has only an *indirect* effect on firm H's profits, through a reduction in the price of the innovator. A quality improvement by firm L, on the other hand, has a *direct* effect on the competitor's profits (it reduces firm H's revenue) and therefore induces a more aggressive response by firm H.

5. Conclusion

Within a model of vertical differentiation (due to Mussa and Rosen, 1978) we examined two issues. The first, which has received considerable attention in the literature, is whether more intense competition is associated with a stronger or weaker incentive to introduce a cost-reducing innovation. Following Delbono and Denicolo (1990) and Bester

and Petrakis (1993) we compared two identical industries (same demand and cost functions, same number of firms) that differed only in the regime of competition: Bertrand style versus Cournot style. Since Cournot competition leads to lower output and higher prices than Bertrand competition, it can be thought of as a regime of less intense competition. Our finding was that the incentive to introduce a cost-reducing innovation is stronger for a Cournot competitor.

We then turned to an issue that so far has received little attention in the literature, namely what factors might be important in a firm's decision whether to invest in product innovation (improvement in the quality of its product) or process innovation (cost reduction). We found that the regime of competition might be one such factor. For the high quality firm our result is that *if* there is a difference between the choice made by a Bertrand competitor and the choice made by a Cournot competitor, then the former will opt for product innovation, while the latter will prefer process innovation. For the low-quality firm, on the other hand, the result is reversed: whenever there is a difference, the Bertrand competitor will favor process innovation, while the Cournot competitor will favor product innovation.

As far as we know, the only other paper in the literature that deals with the choice between process and product innovation is Rosenkrantz (1995). She considers a model of horizontal differentiation, similar to the model used by Bester and Petrakis (1993). A two-stage Cournot duopoly model is considered where in stage 1 the firms simultaneously choose their unit cost c_i and their product characteristic d_i (the choice of c_i is called process innovation and the choice of d_i is called product innovation); in the second stage the firms choose outputs. Note, therefore, the following substantial differences: (1) for us product innovation means an improvement in the quality of the product (ours is a model of vertical differentiation), while for Rosenkrantz product innovation means a change in the horizontal characteristic of the product; (2) while we

compare the investment choice of *one firm in different regimes of competition* (Bertrand versus Cournot), Rosenkrantz analyzes the simultaneous choices of *both firms within the same regime of competition* (Cournot); (3) while we assume that the firm is faced with the choice between product and process innovation, Rosenkrantz allows each firm to mix both types of innovation and is interested in studying how the optimal mix varies with the parameters of the model (in particular the consumers' reservation price).

A natural question to ask is: how robust are these results? The answer to this question is two-fold. First of all, one cannot hope to obtain any results whatsoever in a very general model where properties of demand and costs are specified only qualitatively. The reason is that one needs to compare equilibria and in order to do so one needs to be able to compute them. Indeed the model used in this paper is as "general" as the models used in the literature on this topic (e.g. Delbono and Denicolo, 1990, Bester and Petrakis, 1993 and Rosenkrantz, 1995). The type of issues considered can only be analyzed in models that have a lot of structure and the richer the structure the less general the model. Secondly, although the model is rather specific, the results can be understood (fully, as in the case of Proposition 1 or only partially, as in the case of Propositions 2 and 3) in terms of *qualitative* properties, such as the strategic effects of different types of innovation.

References

Arrow, K. (1962), Economic welfare and the allocation of resources for inventions. in: R. Nelson (Ed.), *The rate and direction or inventive activity*, Princeton University Press, Princeton, NJ.

Baldwin, W.L. and J.T. Scott (1987), *Market structure and technological change*, Harwood Academic Publishers, Chur (Switzerland).

Bester, H. and E. Petrakis (1993), The incentives for cost reduction in a differentiated industry, *International Journal of Industrial Organization*, 11, 519-534.

Bonanno, G. (1986), Vertical differentiation with Cournot competition, *Economic Notes*, 15, 68-91.

Bulow, J., J. Geanakoplos and P. Klemperer (1985), Multimarket oligopoly: Strategic substitutes and complements, *Journal of Political Economy,* 93, 488-511.

Cohen, W. and R.C. Levin (1989), Empirical studies in innovation and market structure, in: R. Schmalensee and R.D. Willig (Eds.), *Handbook of industrial organization*, Vol. 2, Elsevier Science Publishers, Amsterdam.

De Bondt, R. (1995), Spillovers and innovative activities, mimeo, Katholieke Universiteit Leuven.

Delbono, F. and V. Denicolo (1990). R&D investment in a symmetric and homogeneous oligopoly, *International Journal of Industrial Organization*, 8, 297-313.

Gabszewicz, J and J-F. Thisse (1979), Price competition, quality and income disparities, *Journal of Economic Theory*, 20, 340-359.

Gabszewicz, J and J-F. Thisse (1980), Entry (and exit) in a differentiated industry, *Journal of Economic Theory* , 22, 327-338.

Kamien, M.I. and N.L. Schwartz (1975), Market structure and innovation: a survey, *Journal of Economic Literature*, 13, 1-37.

Mussa, M. and S. Rosen (1978), Monopoly and product quality, *Journal of Economic Theory*, 18, 301-317.

Rosenkrantz, S. (1995), Simultaneous choice of process and product innovation, mimeo, Wissenschaftszentrum, Berlin.

Shaked, A. and J. Sutton (1982), Relaxing price competition through product differentiation, *Review of Economic Studies*, 49, 3-13.

Scherer, F.M. and D. Ross (1990), *Industrial market structure and economic performance*, Houghton Mifflin Company, Boston.

Schumpeter, J. (1943), *Capitalism. socialism and democracy*, Allan and Unwin, London.

Tirole, J. (1988), *The theory of industrial organization*, M.I.T. Press, Cambridge.

Proofs of results in Bonanno-Haworth "Intensity of competition and the choice between product and process innovation"

(for Referees' use: not meant for publication)

Proof of Proposition 1. We need to show that $\Delta\pi_H^C - \Delta\pi_H^B > 0$ (where $\Delta\pi_H^C$ and $\Delta\pi_H^B$ are given by (8a) and (8b), respectively) and $\Delta\pi_L^C - \Delta\pi_L^B > 0$ (where $\Delta\pi_L^C$ and $\Delta\pi_L^B$ are given by (8c) and (8d), respectively). Straightforward manipulations lead to:

$$\Delta\pi_H^C - \Delta\pi_H^B = -\frac{Nk_L\Delta_H}{(4k_H - k_L)^2(k_H - k_L)}[(k_H c_L - k_L c_H) + (k_H c_L - k_L c_H + k_L\Delta_H)] \qquad \text{(A1a)}$$

$$\Delta\pi_L^C - \Delta\pi_L^B = \frac{Nk_H k_L\Delta_L}{(4k_H - k_L)^2(k_H - k_L)}\,[2(k_H - k_L) - 2(c_H - c_L) - \Delta_L] \qquad \text{(A1b)}$$

The fractions in both expressions are positive (since $k_H > k_L > 0$). The term in square brackets in (A1a) is negative, since its first term is negative by (1b) and its second term is negative by (7b). The term in square brackets in (A1b) is positive since it is greater than $2[(k_H - k_L) - (c_H - c_L + \Delta_L)]$, which is positive by (7c). ■

Proof of Proposition 2. Fix arbitrary k_H, k_L, c_H, c_L subject to the restrictions (1). Using the implicit function theorem the slope of the Bertrand isoprofit curve at this point is given by:

$$-\frac{\dfrac{\partial\pi_H^B}{\partial k_H}}{\dfrac{\partial\pi_H^B}{\partial c_H}} \qquad \text{(A2)}$$

where π_H^B is given by (4). Similarly, the slope of the Cournot isoprofit curve is equal to (where π_H^C is given by (6))

$$-\frac{\dfrac{\partial\pi_H^C}{\partial k_H}}{\dfrac{\partial\pi_H^C}{\partial c_H}} \qquad \text{(A3)}$$

We want to show that (A2) and (A3) are positive and that (A2) is greater than (A3). From (4) we get that

$$\frac{\partial\pi_H^B}{\partial c_H} = -\Phi\,\frac{2N(2k_H - k_L)}{(4k_H - k_L)^2(k_H - k_L)} \qquad \text{(A4)}$$

where

$$\Phi = 2k_H^2 - 2k_H c_H - 2k_H k_L + k_H c_L + k_L c_H \qquad \text{(A5).}$$

Since the fraction in (A4) is positive (because $k_H > k_L$), we have that (A4) is negative if and only if (A5) is positive. By inspection, (A5) is indeed positive. In fact, since, by (1b), $k_L c_H > k_H c_L$, (A5) is greater than $2k_H[(k_H - k_L) - (c_H - c_L)]$ which is positive by (1a). Thus in order to prove that (A2) is positive (that is, that the Bertrand isoprofit curve of firm H is increasing) it only remains to prove that $\frac{\partial \pi_H^B}{\partial k_H} > 0$. Now, from (4) we get

$$\frac{\partial \pi_H^B}{\partial k_H} = \frac{N\Phi}{(4k_H - k_L)^3 (k_H - k_L)^2}\,\Psi \qquad \text{(A6)}$$

where $\Phi > 0$ is given by (A5) and

$$\Psi = (k_H - k_L)(8k_H^2 - 6k_H k_L + 4k_L^2) + \Theta \qquad \text{(A7).}$$

with

$$\Theta = 8k_H^2 c_H + 2k_L^2 c_L - 4k_H^2 c_L - k_H k_L c_L + 5k_L^2 c_H - 10k_H k_L c_H \qquad \text{(A8)}$$

Since $k_H > k_L$, the fraction in (A6) and the first term in (A7) are positive. Thus (A6) is positive if Θ is positive. Note that $\frac{\partial \Theta}{\partial c_H} = 5(k_H - k_L)^2 + 3k_H^2 > 0$. Hence Θ is increasing in c_H and to show that $\Theta > 0$ it is enough to show that Θ is positive at the minimum value of c_H, which, by (1b), is equal to $\frac{k_H c_L}{k_L}$. Now substituting $\frac{k_H c_L}{k_L}$ for c_H in (A8) and simplifying we obtain

$$\frac{2(k_H - k_L)c_L(4k_H^2 - 3k_H k_L - k_L^2)}{k_L} > 0.$$

Thus we have proved that the Bertrand isoprofit curve of firm H is increasing.

Next we prove that (A3) is positive. From (6) we get

$$\frac{\partial \pi_H^C}{\partial c_H} = -\frac{4Nk_H(2k_H - k_L - 2c_H + c_L)}{(4k_H - k_L)^2} \qquad \text{(A9)}$$

which is negative since the expression in brackets in the numerator is equal to the sum of $(k_H - c_H)$, which is positive (cf. footnote 3), and $[(k_H - k_L) - (c_H - c_L)]$, which is positive by (1a).

Thus to prove that (A3) is positive it only remains to prove that $\frac{\partial \pi_H^C}{\partial k_H} > 0$. From (6) we obtain

$$\frac{\partial \pi_H^C}{\partial k_H} = \frac{N(2k_H - k_L - 2c_H + c_L)}{(4k_H - k_L)^3}\,\Gamma \qquad \text{(A10)}$$

where

$$\Gamma = (k_H - k_L)^2 + (c_H - c_L)(4k_H + k_L) + 7k_H^2 + 4k_H c_H + k_L c_H \qquad \text{(A11).}$$

Since the numerator of (A10) is positive (cf. the remark after (A9)) and $\Gamma > 0$ (since $k_H > k_L$ and $c_H > c_L$) it follows that (A3) is positive, that is, the Cournot isoprofit curve of firm H is increasing.

To complete the proof of Proposition 2 we need to show that (A2) is greater than (A3). Simple manipulations lead to the following expression for (A2) minus (A3):

$$\frac{k_L}{4k_H(4k_H - k_L)(2k_H - k_L)(k_H - k_L)}\ F(k_H, k_L, c_H, c_L) \qquad \text{(A12)}$$

where

$$F(k_H,k_L,c_H,c_L) = 5k_H k_L c_L - 12k_H^2 c_L + 4k_H^2 k_L + 8k_H k_L c_H - 3k_H k_L^2 - 2k_L^2 c_H - k_L^3 + k_L^2 c_L \qquad \text{(A13)}$$

Our objective is to show that (A12) is positive. Since the fraction in (A12) is positive (because $k_H > k_L > 0$), this is equivalent to (A13) being positive. Note that F is increasing in c_H, since $\frac{\partial F}{\partial c_H} = 8k_H k_L - 2k_L^2 > 0$. Thus it is enough to show that F is positive at the minimum value of c_H, which, by (1b), is given by $\frac{k_H c_L}{k_L}$. Substituting $\frac{k_H c_L}{k_L}$ for c_H in (A13) and simplifying we obtain

$$F\left(k_H, k_L, \frac{k_H c_L}{k_L}, c_L\right) = (k_L - c_L)(4k_H^2 - 3k_H k_L - k_L^2)$$

which is positive since $k_H > k_L > 0$ and (cf. footnote 3) $k_L > c_L$. ■

Proof of Proposition 3. Fix arbitrary k_H, k_L, c_H, c_L subject to the restrictions (1). Using the implicit function theorem the slope of the Bertrand isoprofit curve at this point is given by:

$$-\frac{\frac{\partial \pi_L^B}{\partial k_L}}{\frac{\partial \pi_L^B}{\partial c_L}} \qquad \text{(A14)}$$

where π_L^B is given by (4). Similarly, the slope of the Cournot isoprofit curve is equal to (where π_L^C is given by (6))

$$-\frac{\frac{\partial \pi_L^C}{\partial k_L}}{\frac{\partial \pi_L^C}{\partial c_L}} \qquad \text{(A15)}$$

First we show that (A15) is positive. From (6) we get

$$\frac{\partial \pi_L^C}{\partial c_L} = -\frac{4Nk_H(k_Hk_L + k_Lc_H - 2k_Hc_L)}{k_L(4k_H - k_L)^2} \tag{A16}$$

which is negative, since the expression in brackets in the numerator is positive. In fact, since, by (1b), $k_Lc_H > k_Hc_L$, that expression is greater than $k_Hk_L - k_Hc_L = k_H(k_L - c_L) > 0$ (since $k_L > c_L$: cf. footnote 3).

Again from (6) we get

$$\frac{\partial \pi_L^C}{\partial k_L} = \frac{N(k_Hk_L + k_Lc_H - 2k_Hc_L)}{k_L^2(4k_H - k_L)^3}[4k_H^2k_L + k_Hk_L^2 + 4k_Hk_Lc_H + k_L^2c_H + 2k_H^2c_L + 6k_Hc_L(k_H - k_L)]$$

which is positive since $k_H > k_L$ (for positivity of the numerator see the remark after (A16)).

Thus we have proved that (A15) is positive, that is, the Cournot isoprofit curve of firm L is increasing.

Now we turn to (A14). From (4) we get

$$\frac{\partial \pi_L^B}{\partial c_L} = -\frac{2Nk_H(2k_H - k_L)}{(4k_H - k_L)^2(k_H - k_L)k_L}\,\Xi \tag{A17}$$

where

$$\Xi = k_Hk_L - k_L^2 - 2k_Hc_L + k_Lc_H + k_Lc_L \tag{A18}.$$

The fraction in (A17) is positive, since $k_H > k_L$. Thus (A17) is negative since (A18) is positive. In fact, (A18) is (since, by (1b), $k_Lc_H > k_Hc_L$) greater than
$k_Hk_L - k_L^2 - k_Hc_L + k_Lc_L = (k_H - k_L)(k_L - c_L) > 0$, since $k_L > c_L$ (see footnote 3).

It follows that the sign of (A14) is equal to the sign of $\frac{\partial \pi_L^B}{\partial k_L}$. From (4) we get

$$\frac{\partial \pi_L^B}{\partial k_L} = \frac{N k_H\,\Xi}{(4k_H - k_L)^3(k_H - k_L)^2k_L^2}(\Omega_1 + \Omega_2) \tag{A19}$$

where $\Xi > 0$ is given by (A18) and

$$\Omega_1 = k_Hk_L(k_H - k_L)(4k_H - 7k_L) \tag{A20}$$

$$\Omega_2 = k_Hc_L(k_H - k_L)(8k_H - 9k_L) - k_H^2k_Lc_L + k_Hk_L^2c_H - 2k_L^3c_H - 2k_L^3c_L + 4k_H^2k_Lc_H \tag{A21}$$

Since, by (1b), $k_L c_H > k_H c_L$, (A21) is greater than (A22), which is obtained by replacing $4k_H^2 k_L c_H$ in (A21) with $2k_H^2 k_L c_H + 2k_H^3 c_L$:

$$k_H c_L (k_H - k_L)(8k_H - 9k_L) + 2c_L (k_H^3 - k_L^3) + 2k_L c_H (k_H^2 - k_L^2) + k_H k_L (k_L c_H - k_H c_L) \quad \text{(A22)}.$$

Since $k_H > k_L$ and, by (1b), $k_L c_H > k_H c_L$, a sufficient condition for (A22), and therefore (A21), to be positive is $8k_H - 9k_L > 0$. On the other hand, a sufficient condition for Ω_1 to be positive is $4k_H - 7k_L > 0$, which implies the previous one. Hence we can conclude that a sufficient (although not necessary) condition for (A14) to be positive, that is, for the Bertrand isoprofit curve of firm L to be increasing is:

$$k_H > \frac{7}{4} k_L .$$

That is, the degree of differentiation should be not too small.

In order to complete the proof of Proposition 3 we only need to show that (A14) is less than (A15). Simple manipulations lead to the following expression for (A14) minus (A15):

$$\frac{k_L}{4k_H(4k_H - k_L)(2k_H - k_L)(k_H - k_L)} \; G(k_H, k_L, c_H, c_L) \qquad \text{(A23)}$$

where

$$G(k_H,k_L,c_H,c_L) = -5k_H k_L c_H - 12k_H^3 + 13k_H^2 k_L + 2k_H k_L c_L + 12k_H^2 c_H - 8k_H^2 c_L - k_H k_L^2 - k_L^2 c_H \quad \text{(A24)}$$

Our objective is to show that (A23) is negative. Since the fraction in (A23) is positive (since $k_H > k_L > 0$), this is equivalent to (A24) being negative. Note that G is increasing in c_H, since $\frac{\partial G}{\partial c_H} = 12k_H^2 - 5k_H k_L - k_L^2 > 0$ (since $k_H > k_L$). Thus it is enough to show that G is negative at the maximum value of c_H, which by (1a), is given by $k_H - k_L + c_L$. Substituting $k_H - k_L + c_L$ for c_H in (A24) and simplifying we obtain

$$G(k_H, k_L, k_H - k_L + c_L, c_L) = -(k_L - c_L)(4k_H^2 - 3k_H k_L - k_L^2)$$

which is negative since $k_H > k_L > 0$ and (cf. footnote 4) $k_L > c_L$. ■