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Abstract

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Keywords: Process R&D, Network Externalities, Cournot, Bertrand, Product Differentiation

JEL Code: L13, D43, O31

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1 Introduction

This paper revisits the Cournot-Bertrand comparison of firms' incentives to invest in cost reducing (process) R&D. Developing a model of differentiated network goods duopoly, where firms non-cooperatively choose levels of investments in process R&D before engaging in product market competition, this paper demonstrates the following. First, while network externalities have a positive effect on R&D regardless of the nature of product market competition, the effect is larger in the case of Bertrand competition compared to that in the case of Cournot competition. Second, and more importantly, Bertrand R&D is higher than Cournot R&D, unless network externalities are sufficiently weak. These are new results.

Analyses of the equilibrium investment levels in process R&D in the case of non-network goods oligopoly suggest that under Cournot competition firms invest more in process R&D than that under Bertrand competition (see, for example, Qiu (1997) and Lin and Saggi (2002)).[1] This is because an increase in a firm's investment in process R&D has, not only a direct positive effect, but also a strategic effect on its profit, which works through influencing rival firm's strategic variable – quantity or price. While under Cournot competition the strategic effect is positive, it is negative under Bertrand competition. The reason for this ranking to be reversed in network goods oligopoly under certain conditions is as follows. When firms produce network goods, an increase in output (or a decrease in price) of a firm enhances consumers' expectations regarding network size, which shifts

[1] Bester and Petrakis (1993) argue that Bertrand competition may provide a firm greater incentive to undertake process R&D than Cournot competition depending on the degree of product differentiation, when process R&D involves a fixed amount of investment and the extent of marginal cost reduction due to process R&D is exogenously given. Subsequent studies, including Qiu (1997) and Lin and Saggi (2002), demonstrate that, if the extent of marginal cost reduction depends on the level of investment in R&D, Cournot competition leads to higher R&D investments than Bertrand competition, regardless of the degree of product differentiation. Bonnano and Haworth (1998) reaffirms this Cournot-Bertrand ranking of process R&D in the case of vertically differentiated products.

its demand curve outward and that in turn has a positive effect on its profit. Thus, in the presence of network externalities, an increase in a firm's investment in process R&D has an additional positive effect (henceforth, network effect) on its profit regardless of the nature of competition. Further, Bertrand firms play more aggressively in the product market than Cournot firms even in network goods oligopoly and more aggressive play has an indirect positive effect on profits, via consumers' expectations, which is larger in the case of stronger network externalities (Pal, 2014). As a result, the positive network effect is larger under Bertrand competition than under Cournot competition and it over compensates for the negative strategic effect under Bertrand competition, unless network externalities are sufficiently weak.

Starting with the seminal works of Farrell and Saloner (1985, 1986) and Katz and Shapiro (1985, 1986), a number of studies have examined the implication of network externalities on product development and introduction of new products by oligopolistic firms in different scenarios.[2] However, the literature on process R&D in the context of network goods oligopoly is rather sparse. Boivin and Vencatachellum (2002) and Saaskilahti (2006) are the only two exceptions in this regard. While Boivin and Vencatachellum (2002) argue that firms in Cournot oligopoly tend to invest more in process R&D in the presence of network externalities compared to that in absence of network externalities[3], Saaskilahti (2006) focuses on possible implications of product compatibility and product quality on investment in process R&D in a linear city model of price competition. This paper contributes to this literature by exploring the effects of the nature of product market competition and the strength of network externalities on firms choice of investment in process R&D.

[2]See, for example, Katz and Shapiro (1992), Kristiansen and Thum (1997), Kristiansen (1996, 1998), Cerquera (2006) and Xing (2014).

[3]They also argue that multiple R&D equilibria may exist in the case of non-linear network effects.

2 The Model

Consider an industry with two profit maximizing firms, firm 1 and firm 2, producing differentiated network goods and are engaged either in Cournot competition or in Bertrand competition in the product market. Following existing literature on network goods oligopoly, we consider that the inverse demand function faced by firm i is as follows.[4]

$$p_i = \alpha - q_i - \beta q_j + n(y_i + \beta y_j), \quad i, j = 1, 2, \quad i \neq j; \tag{1}$$

where p_i and q_i denote price and quantity, respectively, of good i. y_i is consumers' expectation regarding firm i's total sales. $\alpha > 0$, $\beta \in (0, 1)$ and $n \in [0, 1)$ are preference parameters. Lower value of β indicates higher degree of product differentiation. The parameter n $(= \frac{\partial p_i}{\partial y_i})$ measures the strength of network externalities – higher value of n indicates stronger network externalities. Corresponding direct demand function of firm i is given by

$$q_i = \frac{\alpha(1-\beta) - p_i + \beta p_j + n y_i (1-\beta^2)}{1-\beta^2}, \quad i, j = 1, 2, \quad i \neq j. \tag{2}$$

Firms invest in cost reducing process R&D. The cost function of firm i $(= 1, 2)$ is given by $C_i(q_i, x_i) = (c - x_i)q_i + \frac{\lambda}{2}x_i^2$, where $c \in (0, \alpha)$ is the marginal (average) cost of production in absence of R&D investment, $x_i \in [0, c]$ is the amount of investment in R&D and $\frac{\lambda}{2}x_i^2$ is the cost of investing x_i amount in R&D by firm i. For simplicity, we assume that $\lambda > \hat{\lambda}$, where $\hat{\lambda} = \frac{2\alpha(2-n-\beta^2)}{c(1-\beta)(2-n+\beta)^2(2-n-\beta)} > 0$.[5]

Stages of the game involved are as follows. In the first stage, each firm simultaneously and independently decide the level of investment in R&D so that its profit is maximized. In the

[4]See, for example, Economides (1996), Hoernig (2012), Chirco and Scrimitore (2013), Pal (2014) and Pal (2015). The underlying utility function of the representative consumer can be written as $U = m + \alpha(q_1 + q_2) - \frac{1}{2}(q_1^2 + q_2^2 + 2\beta q_1 q_2) + n[(y_1 + \beta y_2)q_1 + (y_2 + \beta y_1)q_2 - \frac{1}{2}(y_1^2 + y_2^2 + 2\beta y_1 y_2)]$, where m is the quantity of numeraire good.

[5]These parametric restrictions ensure that, in each of cases analyzed in the paper, the equilibrium outputs are positive, $x_i \in [0, c]$ is satisfied in the equilibrium, and both the second order condition and the stability condition are satisfied.

second stage, firms engage either in Cournot competition or in Bertrand competition in the product market. The mode of product market competition is exogenously determined and it is common knowledge. We solve this game by the standard backward induction method by considering Cournot competition and Bertrand competition respectively in Section 2.1 and Section 2.2.

2.1 Cournot Competition

If firms are engaged in Cournot competition in the product market, the second stage problem of firm i can be written as $\underset{q_i}{Max}\ \pi_i(q_i, q_j; y_i, y_j, x_i) = p_i(q_i, q_j; y_i, y_j)q_i - C_i(q_i, x_i),\ i, j = 1, 2; i \neq j$, where $p_i(.)$ is given by equation (1). From the first order condition of this maximization problem, we obtain firm i's quantity reaction function as follows.

$$RF_i^C: \quad q_i = \frac{\alpha - (c - x_i) - \beta q_j + n(y_i + \beta y_j)}{2},\ i, j = 1, 2; i \neq j \tag{3}$$

Clearly, a firm's quantity reaction curve shifts outward due to higher consumers' expectation regarding (a) its own sales and (b) its rival's sales, though the effect of the latter is smaller than that of the former. Further, such shifts are larger in the presence of stronger network externalities. Following Katz and Shapiro (1985) and subsequent studies, we consider that consumers' expectations satisfy 'rational expectations' conditions. That is, $y_1 = q_1$ and $y_2 = q_2$ are satisfied in the equilibrium. Solving RF_1^C and RF_2^C along with the conditions $y_1 = q_1$ and $y_2 = q_2$, we get the second stage equilibrium outputs of firms as follows.

$$q_i^C(x_i, x_j; n) = \frac{(\alpha - c)\{2 - n - \beta(1 - n)\} + (2 - n)x_i - \beta(1 - n)x_j}{(2 - n)^2 - \beta^2(1 - n)^2},\ i, j = 1, 2; i \neq j. \tag{4}$$

It follows that $\frac{\partial q_i^C(x_i,x_j;n)}{\partial x_i} > 0$, $\frac{\partial q_i^C(x_i,x_j;n)}{\partial x_j} < 0$, $\mid \frac{\partial q_i^C(x_i,x_j;n)}{\partial x_i} \mid > \mid \frac{\partial q_i^C(x_i,x_j;n)}{\partial x_j} \mid$, $\frac{\partial}{\partial n}[\frac{\partial q_i^C(x_i,x_j;n)}{\partial x_i}] > 0$ and $\frac{\partial}{\partial n}[\frac{\partial q_i^C(x_i,x_j;n)}{\partial x_j}] > 0$. Substituting $q_1^C(x_1, x_2; n)$ and $q_2^C(x_1, x_2; n)$ in profit expressions we get the second stage equilibrium profits: $\pi_i^C(x_i, x_j; n),\ i, j = 1, 2; i \neq j$.

Next, from the first order conditions of firm i's problems in the first stage of the game, $\underset{x_i}{Max}\ \pi_i^C(x_i, x_j; n)$, we obtain its R&D reaction function

$$RRF_i^C: \quad x_i = \frac{2(2-n)[(\alpha-c)\{2-n-\beta(1-n)\} - \beta(1-n)x_j]}{\{(2-n)^2-(1-n)^2\beta^2\}^2\lambda - 2(2-n)^2}, \ i,j = 1,2; i \neq j. \quad (5)$$

Solving R&D reaction functions of firm 1 and firm 2 we get the equilibrium R&D investments as follows.

$$x_i^{C*} = \frac{2(2-n)(\alpha-c)}{\{2-n-(1-n)\beta\}\{2-n+(1-n)\beta\}^2\lambda - 2(2-n)}, \quad i = 1,2. \quad (6)$$

Upon inspection we obtain the following.

Lemma 1: $\frac{\partial x_i^{C*}}{\partial n} > 0$ *for all* $n \in [0,1)$, $i = 1,2$.

Lemma 1 states that, in the equilibrium under Cournot competition, each firm would invest more in R&D in the presence of stronger network externalities. The intuition behind this result is as follows. Note that in the first stage of the game firm i chooses x_i in order to maximize $\pi_i^C(.)$, taking x_j, q_i and q_j as given. Therefore, we have[6]

$$\frac{d\pi_i^C(.)}{dx_i} = \frac{\partial \pi_i^C}{\partial x_i} + \frac{\partial \pi_i^C}{\partial q_j}\frac{\partial q_j}{\partial x_i} + nq_i[\frac{\partial q_i}{\partial x_i} + \beta\frac{\partial q_j}{\partial x_i}]. \quad (7)$$

An increase in x_i affects firm i's profit in three reinforcing ways. The direct effect (the first term in the right hand side of equation (7)) is positive because an increase x_i reduces its marginal cost. The first order strategic effect (the second term in the right hand side of (7)) is positive because a reduction in its marginal cost reduces its rival's output and a reduction in rival's output has a positive effect on its profit. The third term in the right hand side of (7) is the second order effect due to the presence of network externalities, i.e., the network effect. A reduction in firm i's marginal cost increases its output, which enhances consumers' expectations regarding its sales and that in turn shifts its demand

[6] $\frac{d\pi_i^C(.)}{dx_i} = \frac{\partial \pi_i^C}{\partial x_i} + \frac{\partial \pi_i^C}{\partial q_i}\frac{\partial q_i}{\partial x_i} + \frac{\partial \pi_i^C}{\partial q_j}\frac{\partial q_j}{\partial x_i} + \frac{\partial \pi_i^C}{\partial y_i}\frac{\partial y_i}{\partial q_i}\frac{\partial q_i}{\partial x_i} + \frac{\partial \pi_i^C}{\partial y_j}\frac{\partial y_j}{\partial q_j}\frac{\partial q_j}{\partial x_i}$. Now, (a) by the first order condition in stage 2 $\frac{\partial \pi_i^C}{\partial q_i} = 0$, (b) $\frac{\partial y_i}{\partial q_i} = 1$ since in the equilibrium $y_i = q_i$, $i = 1,2$, (c) $\frac{\partial \pi_i^C}{\partial y_i} = \frac{\partial p_i}{\partial y_i}q_i = nq_i$ and (d) $\frac{\partial \pi_i^C}{\partial y_j} = \frac{\partial p_i}{\partial y_j}q_i = n\beta q_i$.

curve outward and, thus, leads to higher profit. On the other hand, a reduction in firm i's marginal cost reduces its rival's output and, thus, dampens consumer's expectations regarding its rival's sales, which has a negative effect on firm i's profit (since $\frac{\partial p_i}{\partial y_j} = n\beta > 0$). However, since (i) a reduction in a firm's marginal cost increases its output more than proportionately than the corresponding decrease in its rival's output and (ii) products are differentiated, the effect through consumers' expectations regarding a firm's own sales dominates the effect through consumers' expectations regarding its rival's sales. Therefore, the network effect is also positive. Further, stronger the network externalities, higher is the network effect of R&D on firm's profit.

2.2 Bertrand Competition

In the case of Bertrand competition, taking p_j, y_i and x_i as given, firm i decides p_i to maximize its profit $\pi_i(p_i, p_j, y_i, x_i) = p_i q_i(p_i, p_j, y_i) - C_i(q_i(p_i, p_j, y_i), x_i),\ i, j = 1, 2,\ i \neq j;$ where $q_i(p_i, p_j, y_i)$ is given by equation (2). Solving firm i's problem, we get its price reaction function as follows.

$$RF_i^B: \ p_i = \frac{\alpha(1-\beta) + \beta p_j + (c - x_i) + n(1-\beta^2)y_i}{2} \tag{8}$$

Note that, higher consumers' expectation regarding a firm's sales shifts it price reaction curve outward and such shift is greater in the presence of stronger network externalities. However, consumers' expectation regarding rival's sales does not have any effect on its price reaction function, unlike as in the case of Cournot competition. Solving price reaction functions, RF_1^B and RF_2^B, together with 'rational expectations' conditions, $y_1 = q_1$ and $y_2 = q_2$, we obtain the second stage equilibrium prices as follows.

$$p_i^B(x_i, x_j; n) = \frac{(2-n+\beta)\{(1-\beta)\alpha + (1-n)c\} - (1-n)\{(2-n)x_i + \beta x_j\}}{(2-n)^2 - \beta^2}, \ i, j = 1, 2, \ i \neq j. \tag{9}$$

From (9) it is evident that $\frac{\partial p_i^B(x_i,x_j;n)}{\partial x_i} < 0$, $\frac{\partial p_i^B(x_i,x_j;n)}{\partial x_j} < 0$ and $\left| \frac{\partial p_i^B(x_i,x_j;n)}{\partial x_i} \right| > \left| \frac{\partial p_i^B(x_i,x_j;n)}{\partial x_j} \right|$ for all $n \in [0, 1)$. Substituting $p_1^B(x_1, x_2; n)$ and $p_2^B(x_1, x_2; n)$ from (9) in profit expressions we get firm i's second stage equilibrium profit $\pi_i^B(x_i, x_j; n)$, $i, j = 1, 2$, $i \neq j$. Now, solving firm 1's problem in the first stage of the game, $\underset{x_i}{Max}\ \pi_i^B(x_i, x_j; n)$, we obtain its R&D reaction function

$$RRF_i^B:\ \ x_i = \frac{2\,(2-n-\beta^2)\,\{(\alpha-c)(2-n+\beta)(1-\beta)-\beta(1-n)x_2\}}{\{(2-n)^2-\beta^2\}^2\,(1-\beta^2)\,\lambda-2\,(2-n-\beta^2)^2}. \tag{10}$$

Solving RRF_1^B and RRF_2^B we get the equilibrium R&D investments under Bertrand competition as follows.

$$x_i^{B*} = \frac{2(\alpha-c)\,(2-n-\beta^2)}{(1+\beta)(2-n-\beta)^2(2-n+\beta)\lambda-2\,(2-n-\beta^2)},\ \ i = 1, 2. \tag{11}$$

Form (11) Lemma 2 is immediate.

Lemma 2: $\frac{\partial x_i^{B*}}{\partial n} > 0$ *for all* $n \in [0, 1)$*,* $i = 1, 2$.

Lemma 2 states that, as in the case of Cournot competition, the strength of network externalities has a positive effect on the equilibrium R&D investment under Bertrand competition as well. The mechanism behind this result is as follows. We have

$$\frac{d\pi_i^B(.)}{dx_i} = \frac{\partial \pi_i^B}{\partial x_i} + \frac{\partial \pi_i^B}{\partial p_j}\frac{\partial p_j}{\partial x_i} + \frac{\partial \pi_i^B}{\partial y_i}\frac{\partial y_i}{\partial p_i}\frac{\partial p_i}{\partial x_i} + \frac{\partial \pi_i^B}{\partial y_i}\frac{\partial y_i}{\partial p_j}\frac{\partial p_j}{\partial x_i}$$

$$\Rightarrow \frac{d\pi_i^B(.)}{dx_i} = \frac{\partial \pi_i^B}{\partial x_i} + \frac{\partial \pi_i^B}{\partial p_j}\frac{\partial p_j}{\partial x_i} + \frac{np_i}{(1-n)(1-\beta^2)}[-\frac{\partial p_i}{\partial x_i} + \beta\frac{\partial p_j}{\partial x_i}], \tag{12}$$

since $\frac{\partial \pi_i^B}{\partial y_i} = np_i$, $\frac{\partial y_i}{\partial p_i} = \frac{-1}{(1-n)(1-\beta^2)}$ and $\frac{\partial y_i}{\partial p_j} = \frac{\beta}{(1-n)(1-\beta^2)}$.[7] That is, an increase in x_i affects firm i's profit via three channels. First, there is a positive direct effect (the first term in the right hand side of equation (12)) because an increase in x_i reduces its marginal cost. Second, the strategic effect (the second term in the right hand side of (12)) is negative. This is because (i) a reduction in its marginal cost induces it to set a lower price and that, in turn, forces a reduction in rival's price and (ii) a reduction in rival's price reduces its

[7] From 'rational expectations' conditions we have $y_i = q_i$ and q_i is given by equation (2). That is, $y_i = q_i \Rightarrow y_i = \frac{\alpha(1-\beta)-p_i+\beta p_j+ny_i(1-\beta^2)}{1-\beta^2} \Rightarrow y_i = \frac{\alpha(1-\beta)-p_i+\beta p_j}{(1-n)(1-\beta^2)}$. Also note that $\frac{\partial \pi_i^B}{\partial y_j} = 0$, since from equation (2) we have $\frac{\partial q_i}{\partial y_j} = 0$.

own profit. Third, there is a positive network effect (the third term in the right hand side of (12)), which works through effects of prices on consumers' expectations. In the presence of network externalities, a reduction in firm i's price enhances consumers' expectation regarding its sales and, thus, increases its profit, On the other hand, a reduction in firm j's price dampens consumers' expectations regarding firm i's sales, which in turn hurts firm i's profit. Since (a) the negative effect of a firm's R&D on its price is larger than that on its rival's price and (b) in the case of differentiated products the magnitude of the own price effect on consumers' expectation regarding a firm's sales is larger than the magnitude of the cross price effect, the network effect is positive. Stronger network externalities lead to larger second order effects of prices, through consumers' expectations, on firm's profit. Thus, the positive network effect of R&D on firm's profit is larger in the presence of stronger network externalities.

2.3 Cournot-Bertrand Comparison

Let us now turn to compare equilibrium R&D levels under Cournot and Bertrand competition. In Section 2.1 and Section 2.2 we have observed that, while under Cournot competition both the direct effect and the strategic effect of an increase in firm i's R&D on its profit are positive and, thus, reinforces each other, under Bertrand competition the negative strategic effect counteracts the positive direct effect. As a result, in absence of network externalities, each firm's incentive to invest in process R&D is stronger under Cournot competition than that under Bertrand competition a la Lin and Saggi (2002) and Qiu (1997). Presence of network externalities adds a twist to this comparison.

We have seen that, regardless of the nature of market competition, the network effect of R&D is always positive and it is larger in the presence of stronger network externalities (see Lemma 1 and Lemma 2). This is consistent with the finding of Vives (2008) that an increase in market size raises firms' cost reduction expenditure under both Bertrand and Cournot competition. Now, comparing marginal effects of the strength of network externalities on equilibrium R&D under alternative modes of product market competition we get the following.

Lemma 3: $0 < \frac{\partial x_i^{C*}}{\partial n} < \frac{\partial x_i^{B*}}{\partial n}$ *for all* $n \in [0, 1)$, $i = 1, 2$.

Lemma 3 states that an increase in the strength of network externalities leads to more than proportionate increase in Bertrand R&D than Cournot R&D. This is because network effect is stronger, as firms play more aggressively in the product market, under Bertrand competition than that under Cournot competition. It implies that in the presence of sufficiently strong network externalities the equilibrium R&D under Bertrand competition might be greater than that under Cournot competition. Now, from equations (6) and (11), we obtain the following.

$$x_i^{C*} - x_i^{B*} = \frac{2(\alpha - c)\beta^2\lambda[(2 - 3n + n^2)^2\beta + (2 - n)^2 n\beta^2 - (1 - n)^3\beta^3 - (2 - n)^3 n]}{H},$$

where $H = [(2 - n - \beta)^2(1 + \beta)(2 - n + \beta)\lambda - 2(2 - n - \beta^2)][\{2 - n - (1 - n)\beta\}\{2 - n + (1 - n)\beta\}^2\lambda - 2(2 - n)] > 0$, since $\lambda > \hat{\lambda} > 0$. Clearly, $Sign\,[x_i^{C*} - x_i^{B*}] = Sign\, f(n, \beta)$, where $f(n, \beta) = [(2 - 3n + n^2)^2\beta + (2 - n)^2 n\beta^2 - (1 - n)^3\beta^3 - (2 - n)^3 n]$. It can be shown that $f(n, \beta) \begin{cases} > 0, \text{ if } 0 \leq n < \hat{n}(\beta) \\ = 0, \text{ if } n = \hat{n}(\beta) \\ < 0, \text{ if } \hat{n}(\beta) < n < 1 \end{cases}$; where $\hat{n}(0) = 0$, $\hat{n}(1) = 0.434802$ and $\frac{\partial \hat{n}(\beta)}{\partial \beta} > 0$ for all $\beta \in [0, 1]$. The dasshed curve in Figure 1 depicts $n = \hat{n}(\beta)$ in the βn-plane. At each point below (above) the dassed curve, i.e., in (outside) the shaded region, we have $n < \hat{n}(\beta)$ ($n > \hat{n}(\beta)$) and, thus, $x_i^{C*} > x_i^{B*}$ ($x_i^{B*} > x_i^{C*}$). It follows that, for Cournot R&D to be greater than Bertrand R&D, the strength of network externalities must be less than a critical value ($\hat{n}(\beta)$), which is smaller in the case of higher degree of product differentiation.

Proposition 1: *If network externalities are sufficiently strong ($n > \bar{n}$), the equilibrium R&D under Bertrand competition is greater than that under Cournot competition, regard-*

less of the degree of product differentiation, where $\bar{n} = 0.434802$. *Moreover, even when network externalities are not sufficiently strong* $(n < \bar{n})$, *Bertrand R&D can be higher than Cournot R&D in the equilibrium, unless the strength of network externalities is less than a critical level. In the later case, the higher the degree of product differentiation, the greater is the possibility of Bertrand R&D to be higher than Cournot R&D.*

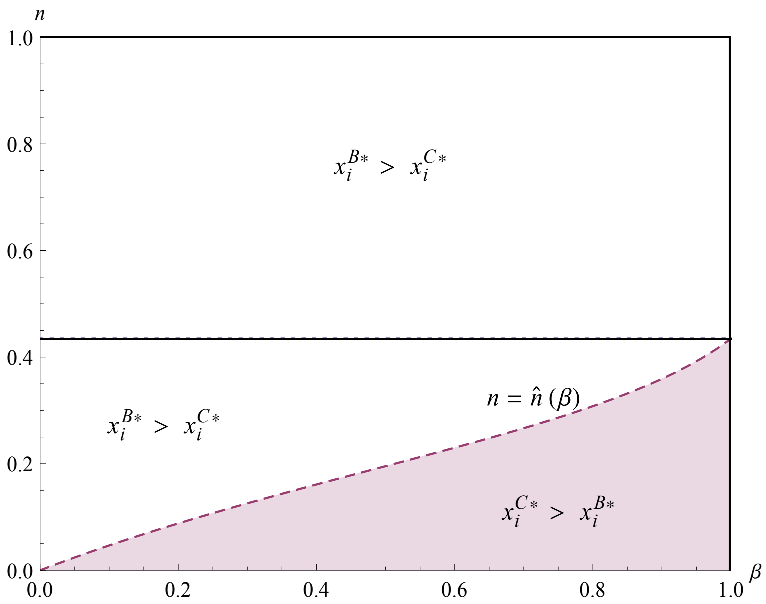

Figure 1: Equilibrium R&D - Cournot vs. Bertrand

3 Conclusion

In this paper we have demonstrated that a firm's incentive to invest in process R&D is higher in the presence of stronger network externalities, regardless of the nature of product market competition - Cournot or Bertrand. However, the effect of network externalities on R&D is greater under Bertrand competition than that under Cournot competition, which drives the result that Bertrand competition induces firms to invest more in process R&D compared to Cournot competition, unless the strength of network externalities is less than a critical level. Clearly, the standard Cournot-Bertrand R&D ranking reverses in network goods industries for a wide range of parametric configurations. We, thus, offer new insights to understand the effects of product market competition on firm's incentive to innovate. Our results are relevant to the literature on optimal technology licensing agreements in oligopoly.

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