Comparing Cournot and Bertrand Equilibria in the Presence of Spatial Barrier and R&D

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Abstract

We compare the equilibria under Bertrand and Cournot competition in a barbell model where spatial barrier and process and quality R&D are involved. Conventional wisdom indicates that price competition is stronger, yielding lower prices and profits but a higher welfare level than Cournot competition when products are substitutes. Schumpeter (1943) argues that a weaker competition in the product market will induce firms to invest more in R&D, while Arrow (1962) derives the opposite. We show that this conventional wisdom may not be correct. Moreover, we reconcile the conflict of Schumpeter and Arrow in the presence of spatial barrier.

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1. Introduction

It has been a longstanding dispute in industrial economics that under which competition mode firms will conduct more research and development (R&D) and the economy can yield higher level of welfare in terms of Bertrand and Cournot competition? Conventional wisdom indicates that price competition is stronger, yielding lower prices and profits but a higher welfare level than Cournot competition when products are substitutes (see Singh and Vives (1984), Hackner (2000) and Hsu and Wang (2005)). In seminal papers on R&D, Schumpeter (1943) argues that a weaker competition in the product market will induce firms to invest more in R&D, while Arrow (1962) derives the opposite.[1] It is worth indicating that the traditional results are obtained under the assumption that spatial barrier is absent. However, this assumption may not be innocuous for the sake of prevailing spatial barrier in the real world. This provides us with an incentive to challenge the traditional results by taking into account spatial barrier and R&D.

As process and product R&D as well as spatial barrier are involved in this paper for comparing Bertrand and Cournot equilibria, this paper is closely related to the following literature. Qiu (1997) introduces process R&D and R&D spillovers. He derives that Cournot process R&D is always greater than Bertrand process R&D.

[1] Refer to Kukherjee (2011, p.1045). By comparing R&D investment in a perfectly competitive market with that in a monopoly market, Schumpeter (1943) claims that a monopoly firm will invest more while Arrow (1962) obtains the opposite.

Moreover, Cournot competition is superior to Bertrand competition in terms of welfare, when R&D productivity is high, spillovers are strong, and goods are close substitutes. Häckner (2000) considers quality R&D, and obtains the same results as traditional results if goods are substitutes, while Bertrand price and profit may be higher than those under Cournot competition if goods are complements. Lin and Saggi (2002) take into consideration process and horizontal product R&D. They find that Cournot process R&D is definitely higher than Bertrand process R&D. Symeonidis (2003) takes into account product R&D and R&D spillovers. He shows that Cournot quality R&D is always higher than Bertrand quality R&D. Moreover, output and welfare level are lower in Bertrand than in Cournot competition, if quality R&D spillovers are strong and products are not too horizontally differentiated. By introducing spatial barrier, Liang *et al*. (2006) develop a barbell model in a homogeneous duopoly with asymmetric markets in the absence of R&D. They obtain that Cournot competition is more efficient than Bertrand competition if the big market is sufficiently large and the transport rate is high enough, while traditional results prevail if the markets are symmetric.

We highlight the influences of R&D (including process and quality R&D) and spatial barrier in comparing Bertrand and Cournot equilibria by constructing a theoretical model building upon previous work by Qiu (1997), Häckner (2000), Symeonidis (2003), and Liang *et al*. (2006). However, our model deviates from their models in the following respects: first, the markets in this paper are symmetric, while those in Liang *et al*. (2006) are asymmetric; second, R&D considered in this paper is in the absence of spillovers, while the opposite appears in Qiu (1997) and Symeonidis (2003); and third, spatial barrier is not involved in Qiu (1997), Häckner (2000), and Symeonidis (2003), while R&D is not shown in Liang *et al*. (2006).

The main results derived in this paper are as follows. No matter whether firms conduct process or quality R&D, we show that Bertrand R&D, total output, and welfare are higher but profit is lower than Cournot competition when the transport rate is low, while the reverse occurs otherwise. Thus, we show that the conventional wisdom may not be correct. Moreover, we reconcile the conflict of Schumpeter and Arrow in the presence of spatial barrier.

Our mail results are sharply different from those in related literature. The reasons why these differences arise can be stated as follows. In the absence of spatial barrier, there exists a positively strategic effect in determining process and quality R&D through decreasing the rival's output under Cournot competition, while the strategic effect turns into a negative effect through lowering the rival's price under Bertrand competition in related literature. Therefore, they can obtain that Cournot R&D always higher than Bertrand R&D when goods are substitutes. By contrast, in a barbell (two-market) model, the existence of spatial barrier creates a location advantage for the local firm, who incurs a lower transportation cost, to become a local monopolist in the local market through price undercutting. Thus, the strategic effect in Bertrand competition vanishes because the rival's price can no longer affect the local monopolist's R&D decision, while the positively strategic effect remains unchanged in Cournot competition. As a result, when the spatial barrier is small, the direct effect of R&D, which is positively correlated to firm's total output, prevails so that Bertrand R&D is higher than Cournot R&D in the presence of spatial barrier in this paper. Moreover, as firms charge limit prices through price undercutting in Bertrand competition and the limit prices are positively correlated to the spatial barrier, a higher spatial barrier will cause Bertrand total output to reduce more than Cournot total output. This will lead Cournot R&D to become greater than Bertrand R&D when spatial barrier is sufficiently high, because the former enjoys a positively strategic effect.[2] As the marginal production cost (consumers' willingness to pay) is decreasing (increasing) in the magnitude of process (quality) R&D, it follows that Cournot total output and welfare will be larger than those in Bertrand competition when the spatial barrier is sufficiently high. Thus, we show in this paper that the conventional argument in comparing welfare may not be correct. Moreover, we

[2] Although Bertrand total output is still larger than Cournot total output under a high level of spatial barrier, the positively strategic effect is capable of making Cournot R&D become higher than Bertrand R&D.

reconcile the conflict of Schumpeter (1943) and Arrow (1962) in the presence of spatial barrier. Next, in the absence of R&D, Liang *et al*. (2006) obtain that total output and welfare level are larger in Bertrand than in Cournot competition. By introducing R&D in Liang *et al*. (2006) model, we show that total output and welfare level can be lower in Bertrand than in Cournot fashion. This result occurs because Cournot R&D is higher than Bertrand R&D when the transport rate is high.

Other related literature in comparing Cournot and Bertrand equilibria and R&D includes: Denicolo (1990), Reynolds and Isaac (1992), Bonanno and Haworth (1998), Arya *et al*. (2008), Mukherjee (2011), Chang and Ho (2014), and Haraguchi and Matsumura (2016). As they are not closely related to our paper, we do not describe them in detail.

The remainder of this paper is organized as follows. Section 2 sets up a basic model. Section 3 compares Cournot and Bertrand equlibria in a barbell model where both firms undertake process R&D. Section 4 extends the analysis to the case where firms undertake quality R&D. The final section concludes the paper.

2. The Basic Model

Building upon previous work by Qiu (1997), Häckner (2000), Symeonidis (2003), and Liang *et al*. (2006), we consider a spatial framework, in which there are two separately symmetric markets, denoted as markets 1 and 2, located at the opposite endpoints of the line segment with unit length, respectively.[3] Two firms, firm A and firm B, are located at markets 1 and 2, whose locations are denoted as $x_A = 0$ and $x_B = 1$, respectively. Assume that the marginal production cost for both firms is a constant c in the absence of R&D. Process R&D investment by firm i (i = A, B), denoted by ε_i, lowers its marginal production cost from c to $(c_i = c - \varepsilon_i)$. The cost function for process R&D is $\gamma(\varepsilon_i)^2/2$, where $\gamma > 0$ is the cost parameter of process R&D. By following Häckner (2000) and Symeonidis (2003), quality R&D investment by firm i, denoted by α_i, enhances consumers' willingness to pay for good i from 1 to $(1+\alpha_i)$. The cost function for quality R&D is $\delta(\alpha_i)^2/2$, where $\delta > 0$ is the cost parameter of quality R&D.[4] We further assume that the transport cost function is linear in distance described as $T = t|x_i - x_k^l|$, where T is the transportation cost for firm i selling its product to consumer l at market k (k = 1, 2), t is the per unit distance per unit output transport rate, and x_k^l denotes the location of consumer l resided at market k ($x_1^l = 0, x_2^l = 1$).

Assume that there are n consumers resided at each market, and that no consumers are resided inside the line segment. For simplicity, we normalize n = 1. The utility function of consumer l resided at market k can be expressed as

[3] The barbell model was first proposed by Hwang and Mai (1990) and subsequently employed by Gross and Holahan (2003), Liang *et al.* (2006), Wang *et al.* (2016), *etc.*

[4] Please also refer to Economides (1989, p. 23).

$U_k^l = \sum_{i\in\{A,B\}} (1+\alpha_i)q_{ki}^l - \left(\frac{1}{2}\right)\left(\sum_{i\in\{A,B\}} q_{ki}^l\right)^2 - \sum_{i\in\{A,B\}} t\left|x_i - x_k^l\right| q_{ki}^l + z,$ where q_{ki}^l is consumer l's demand for the product of firm *i* at market *k*; and *z* is the numeraire good. Consumer *l*'s budget constraint can be expressed as $I = \sum_{i\in\{A,B\}} p_{ki}^m q_{ki}^l + z,$ where *I* denotes consumer *l*'s income, and p_{ki}^m is the mill price charged by firm *i* at market *k*. Maximizing utility yields the first-order condition for q_{ki}^l as $1+\alpha_i - \sum_{i\in\{A,B\}} q_{ki}^l - t\left|x_i - x_k^l\right| - p_{ki}^m = 0.$ The delivered price, defined as the mill price plus the transportation cost, is expressed as $p_{ki} = p_{ki}^m + t\left|x_i - x_k^l\right|$. Then, the demand function for good *i* in market *k* can be described as:

$$p_{ki} = 1+\alpha_i - \sum_{i\in\{A,B\}} q_{ki}. \tag{1}$$

We assume in this paper that firms engage in Bertrand competition in each market. It is well recognized in literature, such as Böckem (1994), that products are horizontally differentiated while located at different sites along the location line. Thus, the two firms' products exhibit no horizontal differentiation if they are sold at the same market, while they are horizontally differentiated otherwise. Accordingly, as products exhibit no horizontal differentiation at the same market and firms compete in Bertrand fashion at each market, firm *i* will capture the entire demand, equal share of the demand, zero demand in market *k*, if the difference in the delivered prices between firm i and firm j is smaller than, equals, larger than the difference in quality levels between firm i and firm j, i.e., $p_{ki} - p_{kj} <,=,> \alpha_i - \alpha_j, i \neq j, i, j = A, B, k = 1,2.$ Thus, the demand for firm i's product at each market under Bertrand competition can be expressed as follows:

$$q_{1i}^T = \begin{cases} 0 & if\ \left(1+\alpha_i^T\right) - p_{1i}^T < \left(1+\alpha_j^T\right) - p_{1j}^T, \\ \left[\left(1+\alpha_i^T\right) - p_{1i}^T\right]/2 & if\ \left(1+\alpha_i^T\right) - p_{1i}^T = \left(1+\alpha_j^T\right) - p_{1j}^T, i, j = A, B, i \neq j, \\ \left(1+\alpha_i^T\right) - p_{1i}^T & if\ \left(1+\alpha_i^T\right) - p_{1i}^T > \left(1+\alpha_j^T\right) - p_{1j}^T, \end{cases} \quad (2.1)$$

$$q_{2i}^T = \begin{cases} 0 & if\ \left(1+\alpha_i^T\right) - p_{2i}^T < \left(1+\alpha_j^T\right) - p_{2j}^T, \\ \left[\left(1+\alpha_i^T\right) - p_{2i}^T\right]/2 & if\ \left(1+\alpha_i^T\right) - p_{2i}^T = \left(1+\alpha_j^T\right) - p_{2j}^T, i, j = A, B, i \neq j, \\ \left(1+\alpha_i^T\right) - p_{2i}^T & if\ \left(1+\alpha_i^T\right) - p_{2i}^T > \left(1+\alpha_j^T\right) - p_{2j}^T, \end{cases} \quad (2.2)$$

where superscript "T" denotes variables associated with the case of Bertrand competition.

Assume that the quality R&D is non-drastic so that firms are unable to use its advanced quality to drive the rival out of the rival's advantage market. This means that the difference in quality levels between firm i and firm j cannot be larger than the transport rate. As firm A (B) incurs no transportation cost for selling its product at market 1 (2), each firm can capture the whole market where it owns location advantage under Bertrand competition. Thus, each firm becomes a local monopolist at its advantageous market. Since each local monopolist will be undercut by its rival, the equilibrium price will be equal to the rival's marginal cost at the market where the monopolist locates plus the difference in quality levels as follows:

$$\begin{cases} p_{1A}^T = (\alpha_A^T - \alpha_B^T) + t + c_B, \\ p_{2B}^T = (\alpha_B^T - \alpha_A^T) + t + c_A. \end{cases} \tag{3}$$

Since each firm becomes a local monopolist under Bertrand competition, each firm's profit function can be described as:

$$\pi_i^T = (p_{ki}^T - c_i)q_{ki}^T - \gamma(\varepsilon_i^T)^2/2 - \delta(\alpha_i^T)^2/2, (i,k) = (A,1),(B,2). \tag{4}$$

By the restriction that the equilibrium price cannot be higher than the monopoly price, we obtain a cap of the transport rate as follows:[5]

$$\bar{t} = \frac{1}{2} + \alpha_i^T - \frac{\alpha_j^T}{2} - (c_i - \frac{c_j}{2}). \tag{5}$$

Under Cournot competition, both firms can survive at each market. Firm *i*'s profit function is the sum of the profits from markets 1 and 2 as follows:

$$\pi_i^C = q_{1i}^C(p_1^C - c_i - tx_i^C) + q_{2i}^C[p_2^C - c_i - t(1 - x_i^C)] - \gamma(\varepsilon_i^C)^2/2 - \delta(\alpha_i^C)^2/2, i = A,B, \tag{6}$$

where superscript "*C*" denotes variables associated with the case of Cournot competition.

Each firm maximizes its profit by choosing its outputs at markets 1 and 2, respectively. We can obtain the equilibrium outputs as follows:

$$\begin{aligned} q_{1i}^C &= [1 + \alpha_i^C - 2c_i + c_j - t(2x_i^C - x_j^C)]/3, i,j = A,B, i \neq j, \\ q_{2i}^C &= [1 + \alpha_i^C - 2c_i + c_j - t(1 - 2x_i^C + x_j^C)]/3, i,j = A,B, i \neq j. \end{aligned} \tag{7}$$

3. Process R&D

[5] Provided that the firms' locations are $(x_A, x_B) = (0,1)$, the monopoly price is $(1 + \alpha_i^T + c_i)/2$. By using (3), we can obtain the cap of transport rate by equating the equilibrium prices and the monopoly price.

In this section we compare Cournot and Bertrand equilibria, when both firms only undertake process R&D. Thus, firm *i*'s marginal production cost is reduced to $c_i = c - \varepsilon_i (i = A, B)$, and meanwhile $\alpha_i = 0$. The game in question becomes a two-stage game, in which one extra R&D stage occurs prior to the output (price) stage. By backward induction, we can solve for the subgame perfect Nash equilibrium, beginning with the final stage.

3.1. Bertrand competition

By substituting $c_i = c - \varepsilon_i (i = A, B)$ into (3), we can derive the equilibrium prices under Bertrand competition in stage 2 as $p_{1A}^T = t + c - \varepsilon_B$ and $p_{2B}^T = t + c - \varepsilon_A$.

In stage 1, by substituting $\alpha_i = 0$, $c_i = c - \varepsilon_i$ and (1) - (3) into (4), we can manipulate the profit-maximizing condition for ε_i^T as follows:

$$\frac{d\pi_A^T}{d\varepsilon_A^T} = \frac{\partial \pi_A^T}{\partial p_{1A}^T}\frac{\partial p_{1A}^T}{\partial \varepsilon_A^T} + \frac{\partial \pi_A^T}{\partial p_{2B}^T}\frac{\partial p_{2B}^T}{\partial \varepsilon_A^T} + \frac{\partial \pi_A^T}{\partial \varepsilon_A^T} = q_{1A}^T - \gamma \varepsilon_A^T = 0, \tag{8.1}$$

$$\frac{d\pi_B^T}{d\varepsilon_B^T} = \frac{\partial \pi_B^T}{\partial p_{2B}^T}\frac{\partial p_{2B}^T}{\partial \varepsilon_B^T} + \frac{\partial \pi_B^T}{\partial p_{1A}^T}\frac{\partial p_{1A}^T}{\partial \varepsilon_B^T} + \frac{\partial \pi_B^T}{\partial \varepsilon_B^T} = q_{2B}^T - \gamma \varepsilon_B^T = 0. \tag{8.2}$$

The terms on the right-hand side of (8) can be referred to as the own price effect, the strategic effect, and the direct effect in that order.[6] As firm *i*'s equilibrium price equals the rival's marginal production cost, it follows that $\partial p_{1A}^T / \partial \varepsilon_A^T = \partial p_{2B}^T / \partial \varepsilon_B^T = 0$.

[6] As firms charge limit prices to foreclose the rival in its advantageous market, the first-order conditions in price stage do not hold, i.e., $\partial \pi_A^T / \partial p_{1A}^T \neq 0$ and $\partial \pi_B^T / \partial p_{2B}^T \neq 0$. Thus, envelop theorem, $\partial \pi_A^T / \partial p_{1A}^T = \partial \pi_B^T / \partial p_{2B}^T = 0$, cannot apply in this paper.

Thus, the own price effect equals zero. Second, recall that each firm becomes a local monopolist at its advantageous market. The rival's price cannot affect the monopolist's profit, i.e., $\partial\pi_A^T / \partial p_{2\mathrm{B}}^T = \partial\pi_B^T / \partial p_{1\mathrm{A}}^T = 0$. This will lead the strategic effect to vanish. Finally, the direct effect consists of the marginal benefit and the marginal cost of R&D. The marginal benefit of R&D is positive, which is positively correlated to firm *i*'s output. A rise in firm *i*'s output will increase this marginal benefit, resulting in a higher level of R&D. On the other hand, the marginal cost of R&D is negative, which will decrease the level of R&D by increasing its marginal cost. Based on the above analysis, we find that the equilibrium level of process R&D under Bertrand competition is solely determined by the direct effect. A greater output will raise the marginal benefit of R&D attracting the firm to increase its level of R&D.

By solving the profit-maximizing conditions for ε_i^T in stage 1, we obtain the optimal Bertrand R&D as follows:[7]

$$\varepsilon_i^T = \frac{1-c-t}{\gamma-1}, i = A, B, \tag{9}$$

where the stability condition requires $\gamma^2 - 1 > 0$.

We find from (9) that a rise in the transport rate will decrease firm *i*'s Bertrand

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[7] Provided that $\alpha_i^T = 0$, the monopoly price becomes $\left(1 + c - \varepsilon_i^{T*}\right)/2$. Moreover, the equilibrium price is $t + c - \varepsilon_i^{T*}$. By equating the monopoly price and equilibrium price, we get the cap of transport rate as $\overset{=}{t} = \frac{\gamma(1-c)}{2\gamma-1}$.

R&D. This result occurs, because a higher transport rate will increase the undercutting price, which will decrease firm *i*'s output leading to a decline in the marginal benefit of R&D. As a result, the optimal Bertrand R&D will fall.

3.2. Cournot competition

By substituting $c_i = c - \varepsilon_i (i = A, B)$ and $(x_A^C, x_B^C) = (0,1)$ into (7), we obtain the equilibrium outputs in stage 2.

In stage 1, by substituting $c_i = c - \varepsilon_i$, (1), (7), and $(x_A^C, x_B^C) = (0,1)$ into (6), we have the profit-maximizing condition for ε_i^C as follows:

$$\frac{\partial \pi_i^C}{\partial \varepsilon_i^C} = \frac{\partial \pi_i^C}{\partial q_{1j}^C}\frac{\partial q_{1j}^C}{\partial \varepsilon_i^C} + \frac{\partial \pi_i^C}{\partial q_{2j}^C}\frac{\partial q_{2j}^C}{\partial \varepsilon_i^C} + \frac{\partial \pi_i^C}{\partial \varepsilon_i^C} = \frac{4}{3}\left(q_{1i}^C + q_{2i}^C\right) - \gamma \varepsilon_i^C = 0, i \neq j, i, j = A, B. \quad (10)$$

The first and second terms on the right-hand side of (10) can be referred to as the strategic effect. A higher firm *i*'s Cournot R&D will decrease firm *i*'s marginal production cost, resulting in a reduction in firm *j*'s outputs in markets 1 and 2. This will increase firm *i*'s profit. Thus, the strategic effect is positive. Next, the third term is denoted as the direct effect. Similarly, this effect consists of the marginal benefit and the marginal cost of R&D. The optimal Cournot process R&D is determined by the balance of the strategic and the direct effects.

We find from (10) that the optimal Cournot R&D is positively correlated to the firm's total output. By comparing (8) with (10), we find that the strategic effect under Bertrand competition in the barbell model will vanish. Moreover, given the same total output, Cournot R&D is greater than Bertrand R&D. This result occurs because the strategic effect in Cournot mode is positive while vanishes in Bertrand fashion such that the net marginal benefit of R&D under Cournot competition equaling $[(\frac{4}{3}(q_{1i}^C + q_{2i}^C)]$ is greater than that equaling (q_{ki}^T) under Bertrand competition. Thus, we have:

Lemma 1. *Consider a barbell model. The strategic effect under Bertrand competition will vanish. Given the same output level, the net marginal benefit of process R&D under Cournot competition equaling* $[(\frac{4}{3}(q_{1i}^C + q_{2i}^C)]$ *is greater than that equaling* (q_{ki}^T) *under Bertrand competition.*

Lemma 1 is different from the result in Qiu (1997) and Lin and Saggi (2002), in which the strategic effect under Bertrand competition is negative.

By solving (10), we get the equilibrium level of R&D as follows:

$$\varepsilon_i^C = \frac{4[2(1-c)-t]}{9\gamma - 8}, i = A, B, \qquad (11)$$

where the second-order and stability conditions require $\gamma > 8/3$.

We find from (11) that a rise in the transport rate will decrease Cournot R&D. Intuitively, a higher transport rate will increase the equilibrium price and then decrease the total output caused by a bigger spatial barrier. Thus, the marginal benefit of R&D declines, which reduces Cournot R&D.

3.3. Bertrand vs. Cournot competition

By subtracting (11) from (9), we obtain the difference in Bertrand and Cournot R&D as follows:[8]

$$\varepsilon_i^{T*} - \varepsilon_i^{C*} = \frac{[\gamma(1-c) - t(5\gamma - 4)]}{(\gamma - 1)(9\gamma - 8)} > (<) 0, \text{ if } t < t_0 \left(t_0 < t < \overset{=}{t}\right), \tag{12}$$

where $t_0 = \dfrac{\gamma(1-c)}{5\gamma - 4}$.

In order to help explain the intuition behind the result in (12), we need eq. (13), which is derived by (2), (3), and (7) as:

$$q_{ki}^T = 1 - t - c + \varepsilon_i^{T*}, \text{ and } q_{1i}^C + q_{2i}^C = \frac{2(1 - c + \varepsilon_i^{C*}) - t}{3}. \tag{13}$$

Eq. (12) shows that Bertrand process R&D is greater (smaller) than Cournot process R&D, when the transport rate is low (high), i.e., $t < t_0 \left(t_0 < t < \overset{=}{t}\right)$. The intuition is as follows. The relative magnitude of Bertrand and Courot R&D is determined by the following forces. First, recall that given the same output level, the net marginal benefit of R&D under Cournot competition equaling $[(\frac{4}{3})(q_{1i}^C + q_{2i}^C)]$ is greater than that equaling (q_{ki}^T) under Bertrand competition. This means that firms tends to invest more R&D in Cournot competition than in Bertrand competition at the same total output. Second, given the same transport rate and R&D level,

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[8] Recall that $\gamma > 8/3$. We find from footnote 6 and (12) that $t_0 < \overset{=}{t}$. Accordingly, (12) shows that the optimal level of process R&D under Bertrand competition is larger than that under Cournot competition, when the transport rate is low, i.e., $t < t_0$, while the reverse occurs when the transport rate is high, i.e., $t_0 < t < \overset{=}{t}$.

Bertrand competition is always stronger than Cournot competition such that the total output in the former will incline to be larger than the latter as shown in (13). This will induce firms to invest more R&D in Bertrand competition than in Cournot competition. Third, it should be noted that firms become local monopolists in Bertrand competition and that a higher transport rate represents a bigger spatial barrier strengthening the monopoly power. It follows that a rise in the transport rate will lead the total output and then the net marginal benefit of R&D under Bertrand competition to decline more than those under Cournot competition caused by a higher limit price.[9] By attributing to the above three forces, we can conclude that Bertrand process R&D is greater (smaller) than Cournot process R&D, when the transport rate is low (high).

Based on the above analysis, we can establish:

Proposition 1. *Bertrand process R&D is higher than Cournot process R&D, when the transport rate is low, i.e.,* $t < t_0$, *while the reverse occurs when the transport rate is high, i.e.,* $t_0 < t < \bar{\bar{t}}$.

[9] We can calculate from (13) that $\partial q_{ki}^{T} / \partial t = -1 < (4/3)(\partial(q_{1i}^{C} + q_{2i}^{C}) / \partial t) = -4t/9$, where the cap of the transport rate can be derived from (5) as $\bar{t} = (\frac{1-c_i}{2}) < 1$.

Proposition 1 is in sharp different from the result in Qiu (1997) and Lin and Saggi (2002), in which Cournot process R&D is always greater than Bertrand process R&D. This difference arises because the strategic effect under Bertrand competition in the non-spatial model is negative while that under Cournot competition is positive. Moreover, Schumpeter (1943) argues that a weaker competition in the product market will induce firms to invest more in R&D, while Arrow (1962) derives the opposite. We reconcile the conflict of Schumpeter and Arrow in the presence of spatial barrier.

Next, by substituting (9) and (11) into (13), we derive the difference in Bertrand and Cournot total outputs as follows:[10]

$$Q^{T*} - Q^{C*} = \frac{2\gamma[(1-c)(3\gamma-2) - t(6\gamma-5)]}{(\gamma-1)(9\gamma-8)} > (<) 0, \; if \; t < t_1 \left(t_1 < t < \bar{\bar{t}}\right), \tag{14}$$

where $t_1 = \dfrac{(1-c)(3\gamma-2)}{6\gamma-5}$.

We find from (14) that Bertrand total output is larger (smaller) than Cournot total output, if the transport rate is low (high). This result can be explained as follows. As shown in (13), given the same transport rate and R&D level, the competition in Bertrand mode is always fiercer than Cournot competition such that Bertrand total output in the former tends to be larger than the latter.[11] Next, recall that Cournot

[10] We find from the stability condition under Cournot competition that $\gamma > 8/3$. By subtracting t_1 from the cap of transport rate in footnote 7, we obtain $\bar{\bar{t}} - t_1 = 2(1-c)(\gamma-1)/[(2\gamma-1)(6\gamma-5)] > 0$.

[11] $q_{ki}^{T} - (q_{1i}^{C} + q_{2i}^{C}) = (1 - c + \varepsilon_i^{T*} - 2t)/3 > 0$ where the cap of the transport rate can be

R&D is higher and then results in a lower marginal production cost than Bertrand R&D when the transport rate is higher than t_0, while the reverse occurs otherwise. Moreover, the difference in Cournot and Bertrand R&D is increasing in the transport rate.[12] As a result, when the transport rate is sufficiently high, i.e., $t > t_1$, the influence from process R&D prevails such that Cournot total output is larger than Bertrand total output. On the contrary, Cournot total output is smaller when the transport rate is low.

It is apparently that the difference in Bertrand and Cournot prices will be opposite to the difference in Bertrand and Cournot total outputs. This can be evidenced by substituting (9) and (11) into Bertrand and Cournot price, respectively, as follows:

$$p_{kA}^{T*} - p_k^{C*} = \frac{\gamma[t(6\gamma-5)-(1-c)(3\gamma-2)]}{(\gamma-1)(9\gamma-8)} > (<) 0, \mathit{if}\ t_1 < t < \overset{=}{t} (t < t_1); k = 1,2. \quad (15)$$

Based on the above analysis, we establish the following proposition:

Proposition 2. *Supposing that firms do process R&D*, *Bertrand total output* (*price*) *is smaller* (*larger*) *than Cournot total output* (*price*) *when the transport rate is high*, *i.e.*, $t_1 < t < \overset{=}{t}$, *while the reverse occurs when the transport rate is low*, *i.e.*, $t < t_1$.

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derived from (5) as $t < \bar{t} = (1 - c + \varepsilon_i^{T*}) / 2$.

[12] By differentiating (12) with respect to t, we obtain: $\partial(\varepsilon_i^{C*} - \varepsilon_i^{T*}) / \partial t = (5\gamma - 4)/[(\gamma-1)(9\gamma-8)] > 0$ where $\gamma > 8/3$.

Proposition 2 is sharply different from the result in Liang *et al*. (2006), in which Bertrand total output is always greater than Cournot total output when firms locate at the opposite endpoints of the line segment. Moreover, Proposition 2 is significantly different from the existing literature, such as Singh and Vives (1984), Häckner (2000), and Hsu and Wang (2005), where Bertrand price is always lower than Cournot price in the absence of R&D investment.

By substituting (9) and (11) into the profit function under Bertrand and Cournot competition, respectively, we can derive the difference in Bertrand and Cournot profits as follows:[13]

$$\pi_A^{T*} - \pi_A^{C*} = \frac{-\left[t^2 H_1 - t(1-c)H_2 + (1-c)^2 H_3\right]}{2(\gamma-1)^2(9\gamma-8)^2} < (>) 0, \text{ if } t < t_2 \left(t_2 < t < \overset{=}{t}\right), \quad (16)$$

where $t_2 = \dfrac{\gamma(1-c)\left(99\gamma^3 - 212\gamma^2 + 146\gamma - 32 - \sqrt{H_4}\right)}{H_1}$,

$H_1 = 252\gamma^4 - 709\gamma^3 + 746\gamma^2 - 352\gamma + 64 > 0,$

$H_2 = 198\gamma^4 - 424\gamma^3 + 292\gamma^2 - 64\gamma > 0,$

$H_3 = 36\gamma^4 - 55\gamma^3 + 20\gamma^2 > 0,$

[13] Recall that $\gamma > 8/3$. It follows that

$$\overset{=}{t} - t_2 = \frac{\gamma(1-c)\left[\sqrt{(9\gamma^2 + 2\gamma - 4)(9\gamma-8)^2(\gamma-1)^2}(2\gamma-1) + H_5\right]}{H_1(2\gamma-1)} > 0,$$

where $H_5 = 54\gamma^4 - 186\gamma^3 + 242\gamma^2 - 142\gamma + 32 > 0.$

$$H_4 = 729\gamma^6 - 2592\gamma^5 + 2961\gamma^4 - 358\gamma^3 - 1700\gamma^2 + 1216\gamma - 256 > 0.$$

We find from (16) that Bertrand profit is smaller than Cournot profit when the transport rate is low, i.e., $t < t_2$, while the reverse emerges when the transport rate is high, i.e., $t_2 < t < \overset{=}{t}$. The Bertrand and Cournot profits are depicted in Figure 1. In Figure 1, firm *i*'s Bertrand profit is always increasing in the transport rate (*t*), while Cournot profit is decreasing in *t* first and then increasing in *t*.

Intuitively, a higher transport rate can affect firm *i*'s Bertrand profit through the direct and indirect effects.[14] A higher transport rate will mitigate the competition between firms through a larger spatial barrier. This will raise both firms' Bertrand profits through increasing the price level. Thus, the direct effect is positive. Moreover, we find from (9) that a rise in the transport rate will reduce both firms' R&D under Bertrand competition. It follows that a lower level of the rival's R&D will raise firm *i*'s Bertrand profit. Therefore, the indirect effect is positive. As a result, both the direct and indirect effects are positive to firm *i*'s Bertrand profit so that Bertrand profit is always increasing in *t*.

Similarly, a higher transport rate can affect firm *i*'s Cournot profit through the

[14] Differentiating Bertrand firm *i*'s profit with respect to *t* yields

$$\frac{d\pi_i^T}{dt} = \frac{\partial \pi_i^T}{\partial t} + \frac{\partial \pi_i^T}{\partial \varepsilon_j^T}\frac{\partial \varepsilon_j^T}{\partial t}, i \neq j, i, j = A, B.$$

The first and second terms on the right-hand side of the above equation denote the direct and indirect effects, respectively.

direct and indirect effects.[15] However, the direct effect is different from that under Bertrand competition. A higher transport rate will raise firm *i*'s Cournot profit at market *i* through increasing rival *j*'s effective marginal cost (the marginal production cost plus the transport rate) at market *i*, while lower firm *i*'s Cournot profit at market *j* through increasing its effective marginal cost at market *j*. Thus, the signs of the two terms in the direct effect are opposite, leading to an indeterminate direct effect. Next, eq. (11) shows that a rise in the transport rate will decrease both firms' R&D investment under Cournot competition. Thus, the indirect effect under Cournot competition is positive through lowering the rival's R&D investment. However, the negative direct effect at market *j* will outweigh the positive direct effect at market *i* and the indirect effect such that the net effect is negative when the transport rate is low, while the net effect is positive otherwise. Based on the above analysis, we find that Bertrand profit will be smaller than Cournot profit as the traditional result when the transport rate is low. By contrast, when the transport rate is high, the monopoly rent under Bertrand competition is so big that it becomes higher than Cournot profit caused by a heavy level of the spatial barrier. Thus, we have the following proposition:

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[15] Differentiating Cournot firm *i*'s profit with respect to *t* yields

$$\frac{d\pi_i^C}{dt} = \left[\frac{\partial \pi_{1i}^C}{\partial t} + \frac{\partial \pi_{2i}^C}{\partial t}\right] + \left[\frac{\partial \pi_{1i}^C}{\partial \varepsilon_j^C}\frac{\partial \varepsilon_j^C}{\partial t} + \frac{\partial \pi_{2i}^C}{\partial \varepsilon_j^C}\frac{\partial \varepsilon_j^C}{\partial t}\right], i \neq j, i, j = A, B.$$

The first and second terms on the right-hand side of the above equation denote the direct and indirect effects, respectively.

(Insert Figure 1 here)

Proposition 3. *Provided that firms invest in process R&D, Bertrand profit is smaller than Cournot profit when the transport rate is low, i.e.,* $t < t_2$, *while the reverse occurs when the transport rate is high, i.e.,* $t_2 < t < \overset{=}{t}$.

As Bertrand competition is more competitive, the existing literature, such as Singh and Vives (1984), Häckner (2000), and Hsu and Wang (2005), obtains that Cournot profit is always higher than Bertrand profit when products are substitutes in the absence of R&D. Proposition 3 is different from the result in earlier literature. We show that Bertrand profit can be higher when process R&D and spatial barrier are involved.

Lastly, the social welfare equals the total consumers' surplus plus the total profit. The total consumers' surplus, consisting of the consumers' surplus at markets 1 and 2, is defined as $CS^m = CS_1^m + CS_2^m = (1/2)(Q_1^m)^2 + (1/2)(Q_2^m)^2, m = C, T,$ where m denotes the competition mode. Then, we obtain the difference in Bertrand and Cournot welfare as follows:[16]

[16] By manipulating, we obtain from footnote 7 and (17) that

$$t_3 - \overset{=}{t} = \frac{\gamma(1-c)\left[\sqrt{(4\gamma-3)(9\gamma-8)}(2\gamma-1)-\left(12\gamma^2-15\gamma+4\right)\right]}{\left(20\gamma^2-27\gamma+8\right)(2\gamma-1)}.$$

By the stability condition that $\gamma > 8/3$, the denominator is positive. Moreover, the numerator is

$$SW^{C*} - SW^{T*} = (CS^C - CS^T) + (\pi^C - \pi^T)$$
$$= \frac{t^2(20\gamma^2 - 27\gamma + 8) - 8\gamma t(1-c)(\gamma - 1) - \gamma^2(1-c)^2}{(\gamma-1)(9\gamma-8)} > (<) 0, \text{ if } t_3 < t < \bar{\bar{t}}\,(t < t_3), \tag{17}$$

where $\pi^m = \pi_A^m + \pi_B^m, m = C, T,$ denotes the total profit under competition mode *m*;

and $t_3 = \dfrac{\gamma(1-c)\left[4(\gamma-1) + \sqrt{36\gamma^2 - 59\gamma + 24}\right]}{20\gamma^2 - 27\gamma + 8}$.

Eq. (16) shows that Cournot competition is welfare inferior (superior) to Bertrand competition, when the transport rate is low (high). This result can be explained as follows. Recall Proposition 2 that Bertrand total output is greater (smaller) than Cournot total output, when the transport rate is low (high). Therefore, the total consumers' surplus under Bertrand competition is superior (inferior) to that under Cournot competition, when the transport rate is low (high). Next, we find from Proposition 3 that Bertrand profit is smaller (larger) than Cournot profit, when the transport rate is low (high). Moreover, Figure 1 shows that the positive magnitude of the difference in Bertrand and Cournot total profit reduces caused by a sufficiently higher Cournot R&D than Bertrand R&D, when the transport rate is sufficiently high. As a result, Cournot competition can be welfare superior to Bertrand mode, when the transport rate is sufficiently high. Thus, we obtain:

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negative, because
$\left[\sqrt{(4\gamma-3)(9\gamma-8)}(2\gamma-1)\right]^2 - \left(12\gamma^2 - 15\gamma + 4\right)^2 = -(\gamma-1)\left(20\gamma^2 - 27\gamma + 8\right) < 0.$ Thus,
$t_3 - \bar{\bar{t}} < 0.$

Proposition 4. *The presence of process R&D will cause Cournot competition to be more* (*less*) *efficient than Bertrand fashion*, *when the transport rate is high* (*low*), *i.e.*, $t_3 < t < \overset{=}{t}$ ($t < t_3$).

Proposition 4 is sharply different from the result in Singh and Vives (1984), Qiu (1997), Häckner (2000), Hsu and Wang (2005), where Bertrand welfare is always higher than Cournot welfare in the absence of R&D. Moreover, in the absence of R&D spillover in Qiu (1997) and in the symmetry of the markets in Liang *et al.* (2006), both papers also obtain that Bertrand competition is always welfare superior to Cournot competition.

4. Quality and Process R&D

In this section, we first compare the equilibria in Bertrand and Cournot competition under which only quality R&D is involved, and then conduct the comparisons when both quality and process R&D are incorporated. In what follows we assume that firms invest in quality R&D only. Therefore, we have $c_i = c$ (i = A, B) and firm i's quality R&D investment α_i.

In stage 1, by substituting $c_i = c$ and (1) - (3) into (4), we can obtain firm i's reduced profit function, and then derive the profit-maximizing condition for α_i^T in

Bertrand competition as follows:

$$\frac{d\pi_A^T}{d\alpha_A^T} = \frac{\partial \pi_A^T}{\partial p_{1A}^T}\frac{\partial p_{1A}^T}{\partial \alpha_A^T} + \frac{\partial \pi_A^T}{\partial p_{2B}^T}\frac{\partial p_{2B}^T}{\partial \alpha_A^T} + \frac{\partial \pi_A^T}{\partial \alpha_A^T} = q_{1A}^T - \delta \alpha_A^T = 0, \tag{18.1}$$

$$\frac{d\pi_B^T}{d\alpha_B^T} = \frac{\partial \pi_B^T}{\partial p_{2B}^T}\frac{\partial p_{2B}^T}{\partial \alpha_B^T} + \frac{\partial \pi_B^T}{\partial p_{1A}^T}\frac{\partial p_{1A}^T}{\partial \alpha_B^T} + \frac{\partial \pi_B^T}{\partial \alpha_B^T} = q_{2B}^T - \delta \alpha_B^T = 0\,. \tag{18.2}$$

Similar to the analysis in (8), the terms on the right-hand side of (18) can be referred to as the own price effect, the strategic effect, and the direct effect in that order. Regarding the own price effect, we find that a rise in firm *i*'s quality R&D increases its price, and that the effect of a higher quality R&D on its profit is ambiguous, depending upon the relative strength of the enhancing price and the declining quantity demand.[17] Therefore, the own price effect is indeterminate. Recall that this effect in the analysis of process R&D of (8) is zero. Next, the strategic effect remains to equal zero as that in (8), because the rival's price has no influence on the monopolist's profit. Finally, the direct effect also consists of the marginal benefit and the marginal cost of R&D, in which the former is denoted as $p_{1A}^T - c$ ($p_{2B}^T - c$) for firm A (B) while the latter equals $\delta \alpha_i^T$.[18] By manipulating, we figure out that the sum of the own price effect and the marginal benefit of R&D, which is denoted as

[17] Given $\varepsilon_i = 0,$ by differentiating (3) with respect to α_i, we obtain $\partial p_{1A}^T / \partial \alpha_A^T = \partial p_{2B}^T / \partial \alpha_B^T = 1 > 0$, and by differentiating (4) with respect to p_i, we have $\partial \pi_A^T / \partial p_{1A}^T = 1 + \alpha_A^T - 2p_{1A}^T + c$ and $\partial \pi_B^T / \partial p_{2B}^T = 1 + \alpha_B^T - 2p_{2B}^T + c$.

[18] A unit increase in quality R&D enhances a unit of demand, which will raise the profit by the difference between the price level and marginal production cost.

the net marginal benefit of R&D, equals $q_{1A}^T(q_{2B}^T)$.

By assuming $\delta = \gamma$ and solving (18.1) and (18.2) simultaneously, we obtain that the optimal quality R&D is the same as eq. (9).[19] This result arises because the net marginal benefit of quality R&D is the same as that of process R&D. Therefore, provided that the cost parameter of quality R&D is identical to that of process R&D, i.e., $\delta = \gamma$, the marginal cost of quality R&D will also the same as that of process R&D, leading to this result. Besides, Bertrand total output, profit, and social welfare are also identical to those in the case of process R&D.[20]

We now proceed to the analysis of Cournot competition. By substituting $c_i = c$ into (7), we obtain firm *i*'s Cournot output, and then substituting these Cournot output into (6) gives firm *i*'s reduced profit function. Thus, we can derive the profit-maximizing condition for α_i^C as follows:

$$\frac{\partial \pi_i^C}{\partial \alpha_i^C} = \frac{\partial \pi_i^C}{\partial q_{1j}^C}\frac{\partial q_{1j}^C}{\partial \alpha_i^C} + \frac{\partial \pi_i^C}{\partial q_{2j}^C}\frac{\partial q_{2j}^C}{\partial \alpha_i^C} + \frac{\partial \pi_i^C}{\partial \alpha_i^C} = \frac{4}{3}\left(q_{1i}^C + q_{2i}^C\right) - \delta\alpha_i^C = 0, i \neq j, i, j = A, B. \quad (19)$$

Similar to the analysis in (10), the first and second terms on the right-hand side of (19) can be referred to as the strategic effect, which is positive. The third term can

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19 The second and stability condition are fulfilled as follows: $\partial^2\pi_A^T / \partial\alpha_A^{T2} = \partial^2\pi_B^T / \partial\alpha_B^{T2} = -\gamma < 0$ and $\gamma^2 - 1 > 0$.

20 In addition to the equilibria being identical to those in the case of process R&D, the cap of the transport rate $\overset{=}{t}$ also remains unchanged. Provided that $c_i = c$, the monopoly price becomes $\left(1 + c + \alpha_i^{T*}\right)/2$. Moreover, the equilibrium price is $t + c$. By equating the monopoly price and equilibrium price with $\delta = \gamma$, we derive the cap of transport rate as $\overset{=}{t} = \frac{\gamma(1-c)}{2\gamma - 1}$, which is the same as that in footnote 7.

be denoted as the direct effect, consisting of the marginal benefit and the marginal cost of quality R&D.

Likewise, by assuming $\delta = \gamma$, we figure out that (19) will be identical to (10). Thus, the optimal quality R&D will be the same as that in (11). It follows that Cournot total output, profit, and social welfare are also identical to those in the case of process R&D, because the optimal quality R&D is the same as the optimal process R&D. The intuition behind the above results can be stated as follows. We find from (7) and (8) that the key factor in determining firm's profit in Cournot competition is $\alpha_i - c_i$. It is worth indicating that product R&D raises firm's profit by enhancing its demand (consumers' willingness to pay) while process R&D is from decreasing its production cost. When $\delta = \gamma$, it will create the same effect in raising firm's profit, regardless of whether the change in R&D comes from the demand or cost side. As a result, the optimal levels of quality and process R&D are the same. Therefore, Cournot total output, profit, and social welfare are also identical in both cases of R&D by the same token.

Based on the above analysis, we find that given $\delta = \gamma$, not only Bertrand equilibria in the case of quality R&D are the same as those in the case of process R&D, but Cournot equilibria also have the same result. Accordingly, we can conclude that given $\delta = \gamma$, the comparisons of Bertrand and Cournot equilibria in the case of quality R&D will have the same results as those in the case of process R&D. Thus, we have:

Proposition 5. *Supposing that firms invest in quality R&D and that* $\delta = \gamma$, *we can propose*:

(1) *Firms invest in more* (*less*) *quality R&D in Bertrand than in Cournot competition*, *if the transport rate is low* (*high*), *i.e.*, $t < (>) t_0$.

(2) *Bertrand total output is larger* (*smaller*) *than Cournot total output*, *if the transport rate is low* (*high*), *i.e.*, $t < (>) t_1$.

(3) *Bertrand profit is larger* (*smaller*) *than Cournot profit*, *if the transport rate is low* (*high*), *i.e.*, $t < (>) t_2$.

(4) *Bertrand is welfare superior* (*inferior*) *to Cournot competition*, *if the transport rate is low* (*high*), *i.e.*, $t < (>) t_3$.

Proposition 5 is in sharp different from the result in Symeonidis (2003), in which Cournot quality R&D and firms' net profit are always higher than those in Bertrand competition, and Bertrand total output and welfare are lower than those in Cournot competition if R&D spillovers are strong and products are not too differentiated.

By substituting optimal Cournot quality R&D into (1) and (7), and then subtracting the Cournot price from the Bertrand price shown as (3), we can obtain the difference in Bertrand and Cournot prices as follows:

$$p_{1A}^{T*} - p_{1A}^{C*} = p_{2B}^{T*} - p_{2B}^{C*} = \frac{[t(6\gamma-4)-3\gamma(1-c)]}{(9\gamma-8)} > (<) 0, \text{ if } t_4 < t (t < t_4), \tag{20}$$

where $t_4 = \dfrac{3\gamma(1-c)}{(6\gamma-4)}$.

We find that the sign of (20) is definitely negative, because the cap of the transport rate $\overset{=}{t}$ is lower than the critical rate t_4.[21] Therefore, Bertrand price is always lower than Cournot price. The intuition behind this result is as follows. First, given the same transport rate and R&D level, the competition in Bertrand mode is always stronger than Cournot competition such that Bertrand total output in the former tends to be larger than the latter. Next, a higher quality R&D will raise Cournot price by enhancing the demand.[22] By contrast, a rise in quality R&D enhances the demand, but generates no effect on Bertrand price. This result occurs because the symmetric firms invest the same amount of R&D investment and meanwhile undertake price undercutting, leading Bertrand price to be equal to $p_{1A}^{T*} = p_{2B}^{T*} = c + t$ having nothing to do with the magnitude of quality R&D. Recall proposition 5 that Cournot R&D is higher and then results in a larger demand than Bertrand R&D when the transport rate is higher than t_0, while the reverse occurs

[21] We can calculate that $\overset{=}{t} - t_4 = [-\gamma(1-c)]/[2(2\gamma-1)(3\gamma-2)] < 0$. Thus, we obtain $\overset{=}{t} < t_4$.

[22] By substituting (7) into (1), we obtain Cournot price as $p_k^{c*} = (1 + \alpha_i^{c*} + 2c + t)/3$.

otherwise. Moreover, the difference in Cournot and Bertrand R&D is increasing in the transport rate. As a result, the influence from quality R&D prevails such that Bertrand price is always lower than Cournot price. Thus we can propose.

Proposition 6. *Provided that firms do quality R&D and that* $\delta = \gamma$, *Bertrand price is always lower than Cournot price*.

It is worth indicating that Proposition 6 is very different from the result in Proposition 2, in which Bertrand price is higher than Cournot price if the transport rate is high in the case of process R&D while the reverse occurs otherwise. In addition, Proposition 6 is the same as the result in Symeonidis (2003).

We have found from Propositions 1-5 that given $\delta = \gamma$, the ranking of the critical transport rates is $0 < t_0 < t_1 < t_3 < \overset{=}{t}$. This implies that given $\delta = \gamma$, the ranking of the critical transport rates will remain unchanged, when both quality and process R&D are involved. By manipulating, we obtain that given $\delta \neq \gamma$ and firms investing in both quality and process R&D, the ranking of the critical transport rates remains unchanged, i.e., $0 < t_0^{'} < t_1^{'} < t_3^{'} < \overset{=}{t}^{'}$, where $t_0^{'}$, $t_1^{'}$, $t_2^{'}$ and $t_3^{'}$ are the corresponding critical transport rates in this case. We skip the procedures to save on space.[23] Accordingly, we can summarize the results as following proposition.

Corollary 1. *Given firms investing in both quality and process R&D and* $\delta \neq \gamma$, *we have*

(1) *Bertrand quality and process R&D are higher* (*lower*) *than those in Cournot competition*, *if the transport rate is low* (*high*), *i.e.*, $0 \le t < t_0^{'} (t_0^{'} < t \le \overset{=}{t}^{'})$.

(2) *Bertrand total output is larger* (*smaller*) *than Cournot total output*, *if the transport rate is low* (*high*), *i.e.*, $0 \le t < t_1^{'} (t_1^{'} < t \le \overset{=}{t}^{'})$.

(3) *Bertrand total profit is smaller* (*larger*) *than Cournot total profit*, *if the transport rate is low* (*high*), *i.e.*, $0 \le t < t_2^{'} (t_2^{'} < t \le \overset{=}{t}^{'})$.

(4) *Bertrand competition is more* (*less*) *efficient than Cournot fashion, if the transport rate is low* (*high*), *i.e.*, $0 \le t < t_3^{'} (t_3^{'} < t \le \overset{=}{t}^{'})$.

Propositions 1-5 and Corollary 1 shows that the interesting results derived in this paper remain valid, regardless of whether firms undertake process R&D only or both quality and process R&D. Thus, the interesting results are robust in this sense.

5. Concluding remarks

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[23] The procedures can be available from the authors upon request.

We have introduced process and quality R&D into the barbell model where the markets are symmetric in the absence of R&D spillovers. The focus of this paper has been on the influences of spatial barrier to the strategic effects of R&D in both competition modes. We have shown that the strategic effect of R&D will vanish in Bertrand while remains a positive effect in Cournot competition, leading to an interesting result that Bertrand R&D can be higher than Cournot R&D.

No matter whether firms undertake process, quality or both R&D investments, we have shown that Bertrand R&D is higher than Cournot R&D when the transport rate is low, while the reverse occurs otherwise. Thus, we can reconcile the conflict of Schumpeter (1943) and Arrow (1962) by taking into account spatial barrier. Next, we have also shown that Cournot fashion is more (less) efficient than Bertrand competition, if the transport rate is high (low), bearing a policy implication that a blanket encouragement of enhancing competition may not be socially desirable. Lastly, provided that firms undertake process R&D, Bertrand price is lower (higher) than Cournot price if the transport rate is low (high). However, given firms undertaking quality R&D, Bertrand price is always lower than Cournot price.

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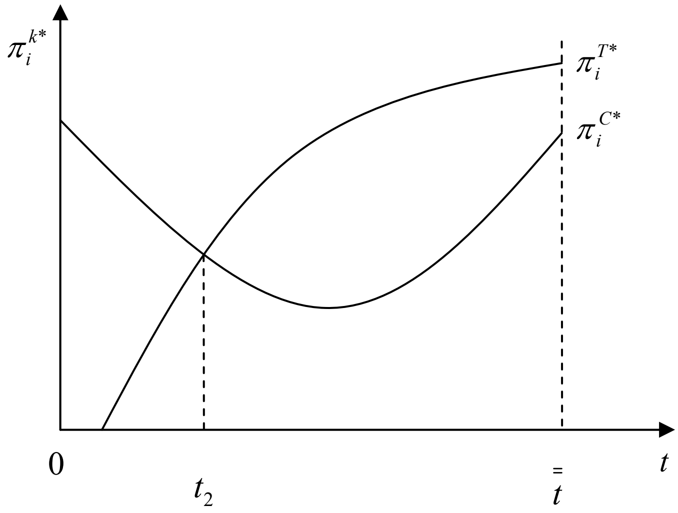

Fig. 1. Firm i's total profit under Cournot and Bertrand competition.