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Comparing Cournot and Bertrand Equilibria in a Reciprocal Dumping Model with Product R&D Investment*

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This paper analyzes and compares Cournot and Bertrand equilibria in a reciprocal dumping model in which two firms compete in domestic and foreign markets with differentiated goods and product R&D investment. It is shown that in a symmetric equilibrium: (i) R&D expenditure and product quality can be higher under Cournot competition than under Bertrand competition; (ii) domestic and export prices are higher and domestic sales and exports can be higher under Cournot competition than under Bertrand competition; (iii) profits can be higher under Bertrand competition than under Cournot competition; (iv) consumer surplus can be higher under Cournot competition than under Bertrand competition; and (v) social welfare can be higher in the Bertrand equilibrium than in the Cournot equilibrium. This result implies that profits can affect social welfare more than consumer surplus does in a reciprocal dumping model with differentiated goods and product R&D investment.

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1. INTRODUCTION

When market structure is imperfectly competitive, international trade can be happening with countries in which there are firms exporting their products and selling them in domestic markets at the same time under the condition that the difference between the price set in domestic market and export price is positive. It is called a reciprocal dumping which explains a reason why intra-industry trade appears.[1] Brander (1981) first introduced a reciprocal dumping model which was extended by Brander and Krugman (1983). Since international trade increasingly occurs between similar countries and intra-industry trade between them has been grown steadily over time, many scholars have studied international trade related issues using a reciprocal dumping model.

Some papers extend the theory of reciprocal dumping in several ways. Pinto (1986) setups a repeated game version of the reciprocal dumping model and shows that discount rate and transportation costs play a crucial role in determining a Nash equilibrium of the supergame. Dei (1990) inserts multinational corporations into a reciprocal dumping model and compares the results derived to those derived without them. Weinstein (1992) extends a reciprocal dumping model and shows that firms in markets with a large number of domestic competitors are more inclined to dump unilaterally than firms in less competitive markets. Dastidar (1998) examines some trade intervention in a reciprocal dumping model and shows that the assumption of increasing returns to scale changes the previous results regarding the effect of trade policies. Murray and Turdaliev (1999) study the extent to which higher dimensionality changes the outcome of reciprocal dumping and show that dumping is universal. Friberg and Ganslandt (2008) investigate whether intra-industry trade in a reciprocal dumping model can decrease social welfare in an international oligopoly with differentiated goods and find some conditions in which social welfare in international trade is lower than that in autarky in Cournot and Bertrand models. Fujiwara (2009) studies the welfare effects of trade liberalization in a differential game model of reciprocal dumping and shows that welfare in autarky is greater than welfare in trade for some level of tariff. Some scholars have studied various issues using a reciprocal dumping model. Bernhofen (1995) examines price dumping of intermediate goods in a variant of the reciprocal dumping model. Baldwin and Ottaviano (2001) show that multiproduct multinationals simultaneously can involve in intra-industry FDI and intra-industry trade. Long et al. (2011) study how trade liberalization influences the innovation incentives of firms in a reciprocal dumping model with heterogenous firms and endogenous R&D. Oshiro (2013) develops a framework, which is based on a reciprocal dumping model, and shows how tariff competition for mobile firms affects the location patterns of the industry and welfare. Some papers

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[1] Several studies have investigated the impact of intra-industry trade on the economy. For instance, Arndt (2010) examined the effects of cross-border production networks and vertical intra-industry trade on macroeconomic adjustment and the effectiveness of monetary and fiscal stabilization policies.

examine the reciprocal dumping empirically. Examples include Norman (1990), Coldwell and Reid (1994), Feenstra et al. (2001), and Friberg and Ganslandt (2006).

In interesting work by Symeonidis (2003), he derives and compares Cournot and Bertrand equilibria in a differentiated duopoly with product R&D investment. He shows that R&D expenditure, prices, and firms' profits are always higher under Cournot competition than under Bertrand competition and the rankings of output, consumer surplus, total welfare depend on the degree of horizontal differentiation and R&D spillovers. However, he analyzes this issue with no trade so that results derived are understandable in the limited range. Since product R&D is more prevalent than process R&D in international markets, extending this issue to international markets seems to be more valuable.[2)]

The purpose of this paper is to analyze and compare Cournot and Bertrand equilibria in a reciprocal dumping model in which two firms compete in domestic and foreign markets with differentiated goods and product R&D investment. For the analysis, we build on the work by Symeonidis (2003) and construct an international R&D game which comprises two stages. During stage one, firms in home and foreign countries compete in R&D expenditures. During stage two, they compete on quantity or price. In the model, product R&D investment of a firm raises the quality of its product, which increases the demand for its product. Because of this reason, the firm can charge higher prices for its product. This mechanism has an influence on the profitability of both firms.

The principal results in a symmetric equilibrium are as follows. First, R&D expenditure and product quality can be higher under Cournot competition than under Bertrand competition. Second, domestic and export prices are higher and domestic sales and exports can be higher under Cournot competition than under Bertrand competition. Third, profits can be higher under Bertrand competition than under Cournot competition. Fourth, consumer surplus can be higher under Cournot competition than under Bertrand competition. Fifth, social welfare can be higher in the Bertrand equilibrium than in the Cournot equilibrium. This result implies that profits can affect social welfare more than consumer surplus does in a reciprocal dumping model with differentiated goods and product R&D investment.

The remainder of the paper is organized as follows. In section 2, we present the basic model and show how product qualities are associated with R&D expenditures. In sections 3 and 4, the Cournot and Bertrand equilibrium values are derived. In section 5, we compare the Cournot and Bertrand equilibrium values and give explanations of the results. Section 6 contains our concluding remarks.

[2)] See Scherer and Ross (1990).

2. THE BASIC MODEL

We assume that there are two countries, which we call Home country and Foreign country. Each country has one firm: firm *H* is in Home country and firm *F* in Foreign country. Both firms produce one type of differentiated product which is consumed by a large group of consumers in both countries. Both firms invest in R&D to improve the quality of product. We consider a two-stage game. At the first stage, both firms choose a quality, indicated by *u*, which is represented by either a brand image or some physical characteristic. A firm's investment in R&D improves the quality of product which in turn increases the consumer's willingness to pay for the product. However, this entails a cost. At the second stage, quantity or price competition take place.

We assume that S_H (S_F) identical consumers reside in Home (Foreign) country. The representative consumer in both countries has the following utility function:

$$U_i(x_i, x_j^*, z_i) = x_i + x_j^* - \frac{x_i^2}{u_i^2} - \frac{\left(x_j^*\right)^2}{\left(u_j^*\right)^2} - \gamma \frac{x_i}{u_i}\frac{x_j^*}{u_j^*} + z_i, \quad i,j = H,F \text{ and } i \neq j. \tag{1}$$

It is a quality-augmented version of the standard quadratic utility function, suggested by Sutton (1997/1998) and has been used in the analysis of product R&D.[3] $x_i\,(x_j)$ and $p_i\,(p_j)$ denote firm $i(j)$'s demand and price for domestic sales, respectively, while $x_i^*\,(x_j^*)$ and $p_i^*\,(p_j^*)$ indicate firm $i(j)$'s demand and price for export, respectively. The qualities of $x_i\,(x_j)$ and $x_i^*\,(x_j^*)$ are $u_i\,(u_j)$ and $u_i^*\,(u_j^*)$, respectively, and money spent on the composite of all other goods is indicated by $z_i = M_i - p_i x_i - p_j^* x_j^*$, $i,j = H,F$ and $i \neq j$. We presume that consumers expend a fraction of their total income on the goods such that income effects on the product market are ignored.[4] γ, $0 < \gamma < 2$, is a measure of the degree of horizontal differentiation between the products. In the limit as γ goes to 0 the products become independent, whereas in the limit as γ goes to 2 they become perfect substitutes when $u_i = u_j^*$ and $u_j = u_i^*$.

Maximizing the utility subject to $z_i = M_i - p_i x_i - p_j^* x_j^*$, $i,j = H,F$ and $i \neq j$, yields the inverse demand functions of the representative consumer for x_i and x_j^* in Home country and x_j and x_i^* in Foreign country:

$$p_i = 1 - \frac{2x_i}{u_i^2} - \frac{\gamma}{u_i}\frac{x_j^*}{u_j^*}, \quad i,j = H,F \text{ and } i \neq j \tag{2}$$

$$p_j^* = 1 - \frac{2x_j^*}{(u_j^*)^2} - \frac{\gamma}{u_j^*}\frac{x_i}{u_i}, \quad i,j = H,F \text{ and } i \neq j, \tag{3}$$

in the area of quantities where prices are positive. We can also easily derive direct demand functions as

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[3] For example, Symeonidis (1999;2000;2003)

[4] It guarantees an interior solution in utility maximization problem.

$$x_i = \frac{u_i[2(1-p_i)u_i - \gamma(1-p_j^*)u_j^*]}{(4-\gamma^2)}, \quad i,j = H,F \quad \text{and} \quad i \neq j \tag{4}$$

$$x_j^* = \frac{u_j^*[2(1-p_j^*)u_j^* - \gamma(1-p_i)u_i]}{(4-\gamma^2)}, \quad i,j = H,F \quad \text{and} \quad i \neq j, \tag{5}$$

in the area of prices where quantities are positive. Notice that $x_i\ (x_j^*)$ is decreasing in $p_i\ (p_j^*)$ and increasing in $u_i\ (u_j^*)$. Also, $x_i\ (x_j^*)$ is increasing in $p_j^*\ (p_i)$ and decreasing in $u_j^*\ (u_i)$. Further, $x_j\ (x_i^*)$ is decreasing in $p_j\ (p_i^*)$ and increasing in $u_j\ (u_i^*)$. Also, $x_j\ (x_i^*)$ is increasing in $p_i^*\ (p_j)$ and decreasing in $u_i^*\ (u_j)$. Since there are S_H identical consumers in Home country and S_F identical consumers in Foreign country, firm H sells $S_H x_H$ in Home country and $S_F x_H^*$ in Foreign country, and firm *F* sells $S_F x_F$ in Foreign country and $S_H x_F^*$ in Home country. Both firms have the constant marginal production cost $c<1$.

The functions associating qualities u_i and u_j^*, $i,j=H,F$ and $i \neq j$, with the R&D expenditures R_i and R_j^*, $i,j=H,F$ and $i \neq j$, are a modified version of the one proposed by Motta (1992):

$$u_i = \varepsilon R_i^{1/4}, \quad i,j = H,F \quad \text{and} \quad i \neq j \tag{6}$$

$$u_j^* = \varepsilon (R_j^*)^{1/4}, \quad i,j = H,F \quad \text{and} \quad i \neq j, \tag{7}$$

where $\varepsilon > 0$ is a measure of the efficiency of R&D.[5] This parameter is industry-specific and exogenously set by technology. Equations (6) and (7) show decreasing returns to R&D. This assumption is needed because the second-order condition for an interior maximum in the R&D stage must be satisfied.

3. COURNOT EQUILIBRIUM

We now consider a two-stage game wherein each firm simultaneously chooses a quality of product in the first stage and each firm simultaneously decides the quantity in order to maximize its profit in the second stage. We compute a symmetric subgame-perfect equilibrium in pure strategies in the two-stage game. In the second stage, each firm suffers not only a constant marginal production cost but also transport costs when it exports its good. We take the form of transport costs as $t+\tau c$, where t and τ denote the specific and the ad valorem component of transport costs, respectively.[6] It is assumed that t and τ are common to both firms.

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[5] Symeonidis (2003) interprets ε as an inverse measure of the cost of R&D or an index of technological opportunity in the industry.

[6] This form of transport costs follows Gao and Miyagiwa (2005). They also show that this specification of transport costs includes that of an iceberg type suggested by Samuelson (1954).

Holding R&D expenditures fixed, firm i's second-stage profit is written as follows:

$$\pi_i(x_i, x_i^*, x_j, x_j^*) = \{S_i[p_i(x_i, x_j^*) - c]x_i - R_i\} + \{S_j[p_i^*(x_i^*, x_j) - c - t - \tau c]x_i^* - R_i^*\},$$

$$i, j = H, F \text{ and } i \neq j, \tag{8}$$

where the quantity and the price are all positive. Each firm takes the other firm's quantities as given and chooses its quantities of home and foreign market to maximize (8). Solving firm i's and j's profit maximization problem yields the best response functions for firm i and j as follows:

$$x_i = \frac{u_i[(1-c)u_i u_j^* - \gamma x_j^*]}{4u_j^*}, \quad i, j = H, F \text{ and } i \neq j \tag{9}$$

$$x_i^* = \frac{u_i^*[(1-c-t-\tau c)u_i^* u_j - \gamma x_j]}{4u_j}, \quad i, j = H, F \text{ and } i \neq j.[7] \tag{10}$$

These functions slope downward because the quantities in the same market are strategic substitutes.

In this model, we can examine each national market separately, due to the constant marginal production costs. By solving equation (9) and the equation of firm j's best-response function in its export market from interchanging subscripts i and j in equation (10) simultaneously, we can obtain the equilibrium quantities for firm i's home market. Also, by solving equation (10) and the equation of firm j's best-response function in its national market from interchanging subscripts i and j in equation (9) simultaneously, we can get the equilibrium quantities for firm j's national market. Cournot equilibrium quantities are as follows:

$$\tilde{x}_i = \frac{u_i[4(1-c)u_i - \gamma(1-c-t-\tau c)u_j^*]}{16-\gamma^2}, \quad i, j = H, F \text{ and } i \neq j \tag{11}$$

$$\tilde{x}_j^* = \frac{u_j^*[4(1-c-t-\tau c)u_j^* - \gamma(1-c)u_i]}{16-\gamma^2}, \quad i, j = H, F \text{ and } i \neq j, \tag{12}$$

where "~" denotes Cournot equilibrium and x_i and x_j^*, $i, j = H, F$ and $i \neq j$, are positive for $\frac{\gamma(1-c-t-\tau c)}{4(1-c)} < \frac{u_i}{u_j^*} < \frac{4(1-c-t-\tau c)}{\gamma(1-c)}$, $i, j = H, F$ and $i \neq j$.

Substituting the equilibrium quantities into (2), (3), and (8) yields firm i's and j's equilibrium prices and profits as a function of R&D expenditures via (6) and (7):

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[7] The following second-order conditions for firm i and j are satisfied: $-\frac{4S_i}{u_i^2} < 0$ and $-\frac{4S_j}{(u_i^*)^2} < 0$, $i, j = H, F$ and $i \neq j$.

$$\tilde{p}_i = \frac{[8+c(8-\gamma^2)]u_i - 2\gamma(1-c-t-\tau c)u_j^*}{u_i(16-\gamma^2)}, \quad i,j=H,F \text{ and } i \neq j \tag{13}$$

$$\tilde{p}_j^* = \frac{[8+(8-\gamma^2)(c+t+\tau c)]u_j^* - 2(1-c)\gamma u_i}{u_j^*(16-\gamma^2)}, \quad i,j=H,F \text{ and } i \neq j \tag{14}$$

$$\tilde{\pi}_i = \frac{2\{S_i[4(1-c)u_i - \gamma(1-c-t-\tau c)u_j^*]^2 + S_j[4(1-c-t-\tau c)u_i^* - \gamma(1-c)u_j]^2\}}{(16-\gamma^2)^2} - R_i - R_i^*,$$

$$i,j=H,F \text{ and } i \neq j. \tag{15}$$

The dumping margin is computed in accordance with the difference between the home and the *ex-factory* export price of the good. This implies that the dumping margin computation is on the basis of the difference between the home and the export prices before all trade-related costs are involved in the price of the good.[8] Therefore, the dumping margins for firm i and j are given by

$$\theta_i = p_i - (p_i^* - t - \tau c) \text{ and } \theta_j = p_j - (p_j^* - t - \tau c), \quad i,j=H,F \text{ and } i \neq j. \tag{16}$$

We will check that in equilibrium $\tilde{\theta}_i > 0$ and $\tilde{\theta}_j > 0$, $i,j=H,F$ and $i \neq j$, and thus reciprocal dumping.

In the first stage, both firms simultaneously choose R&D expenditures and thus qualities of product to maximize the profits:

$$\tilde{\pi}_i(R_i, R_i^*, R_j, R_j^*) = \{S_i[\tilde{p}_i(u_i, u_j^*) - c]\tilde{x}_i(u_i, u_j^*) - R_i\} + \{S_j[\tilde{p}_i^*(u_i^*, u_j) - c - t - \tau c]\tilde{x}_i^*(u_i^*, u_j) - R_i^*\}$$

$$, \quad i,j=H,F \text{ and } i \neq j. \tag{17}$$

Recently, European Union (2019) announced the new provision on dual quality in different markets as follows:

"The new provision on dual quality under the New Deal for Consumers clarifies that misleading consumers in respect to product composition may, following a case-by-case assessment by the competent authorities, be considered as an unfair commercial practice that is prohibited by EU law."[9]

Due to the aforementioned regulations existing in reality, a symmetric situation is created. Alternatively, by assuming a symmetric situation, we posit that the same quality standards for a product are required in both national markets. Thus, $u_i = u_i^*$ and thus $R_i = R_i^*$, $i,j=H,F$ and $i \neq j$, are required. Furthermore, we assume $S_i = S_j = S$, $i,j=H,F$ and $i \neq j$, for the symmetric analysis. Then, equation (17) becomes

$$\tilde{\pi}_i(R_i, R_j) = S[\tilde{p}_i(u_i, u_j^*) - c]\tilde{x}_i(u_i, u_j^*) + S[\tilde{p}_i^*(u_i^*, u_j) - c - t - \tau c]\tilde{x}_i^*(u_i^*, u_j) - 2R_i,$$

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[8] See Blonigen and Haynes (2002) and Gao and Miyagiwa (2005) for more details.

[9] https://ec.europa.eu/commission/presscorner/detail/en/QANDA_19_3333

$i, j = H, F$ and $i \neq j$. (18)

For both firm *i* and *j*, the first-order conditions are

$$\frac{d\tilde{\pi}_i}{dR_i} = \frac{\partial \tilde{\pi}_i}{\partial u_i}\frac{du_i}{dR_i} + \frac{\partial \tilde{\pi}_i}{\partial u_i^*}\frac{du_i^*}{dR_i} - 2 = 0, \quad i, j = H, F \text{ and } i \neq j. \quad (19)$$

Putting the expressions for the various partial derivatives into (19), setting $u_i = \varepsilon R_i^{1/4}$ and $u_j^* = \varepsilon R_j^{1/4}$, $i, j = H, F$ and $i \neq j$, to solve for the symmetric equilibrium, we obtain the following equilibrium level of R&D expenditures and product qualities:

$$\tilde{R}_i = \tilde{R}_j \equiv \tilde{R} = \frac{64S^2\varepsilon^4[2(1-c)^2 + 2(1-c-t-\tau c)^2 - \gamma(1-c)(1-c-t-\tau c)]^2}{(16-\gamma^2)^4},$$

$i, j = H, F$ and $i \neq j$ (20)

$$\tilde{u}_i = \tilde{u}_j = \tilde{u} = \varepsilon \tilde{R}^{1/4} = \frac{2^{3/2}S^{1/2}\varepsilon[2(1-c)^2 + 2(1-c-t-\tau c)^2 - \gamma(1-c)(1-c-t-\tau c)]^{1/2}}{(16-\gamma^2)},$$

$i, j = H, F$ and $i \neq j$.[10] (21)

Substituting the equilibrium value of R&D expenditures from (20) into (11) to (15) yields the following expression for the equilibrium values under Cournot competition:

$$\tilde{x}_i = \tilde{x}_j = \frac{8S\varepsilon^4[(4-\gamma)(1-c) + \gamma(t+\tau c)][(4-\gamma)(1-c)(1-c-t-\tau c) + 2(t+\tau c)^2]}{(16-\gamma^2)^3},$$

$i, j = H, F$ and $i \neq j$ (22)

$$\tilde{x}_i^* = \tilde{x}_j^* = \frac{8S\varepsilon^4[4(1-c-t-\tau c) - \gamma(1-c)][(4-\gamma)(1-c)(1-c-t-\tau c) + 2(t+\tau c)^2]}{(16-\gamma^2)^3},$$

$i, j = H, F$ and $i \neq j$ (23)

$$\tilde{p}_i = \tilde{p}_j = c + \frac{2[4(1-c) - \gamma(1-c-t-\tau c)]}{16-\gamma^2}, \quad i, j = H, F \text{ and } i \neq j \quad (24)$$

$$\tilde{p}_i^* = \tilde{p}_j^* = c + \frac{2(4-\gamma)(1-c) + (8-\gamma^2)(t+\tau c)}{16-\gamma^2}, \quad i, j = H, F \text{ and } i \neq j \quad (25)$$

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[10] The second-order conditions for an interior maximum at the symmetric equilibrium require that

$$\frac{2S\varepsilon^2\{3\gamma(1-c)(1-c-t-\tau c) - 4[(1-c)^2 + (1-c-t-\tau c)^2]\}}{\tilde{R}^{3/2}(16-\gamma^2)^2} < 0. \quad \text{That is,}$$

$4[(1-c)^2 + (1-c-t-\tau c)^2] > 3\gamma(1-c)(1-c-t-\tau c)$.

$$\tilde{\pi}_i = \tilde{\pi}_j = \frac{32S^2\varepsilon^4}{(16-\gamma^2)^4}\left[(1-c)\left((4-\gamma)(1-c)+\gamma(t+\tau c)\right)+(1-c-t-\tau c)\left((4-\gamma)(1-c)-4(t+\tau c)\right)\right]^2$$
$$+\frac{16S^2\varepsilon^4}{(16-\gamma^2)^4}\left[2(4-\gamma^2)(1-c)(1-c-t-\tau c)+(16+\gamma^2)(t+\tau c)^2\right]\left[(4-\gamma)(1-c)(1-c-t-\tau c)+2(t+\tau c)^2\right],$$
$$i,j=H,F \text{ and } i\neq j. \tag{26}$$

Notice that there is reciprocal dumping since $\tilde{\theta}_i = \tilde{p}_i - (\tilde{p}_i^* - t - \tau c) = \frac{2(t+\tau c)}{4-\gamma} > 0$, $\tilde{\theta}_j = \tilde{p}_j - (\tilde{p}_j^* - t - \tau c) = \frac{2(t+\tau c)}{4-\gamma} > 0$, $i,j=H,F$ and $i\neq j$, in equilibrium.

Eventually, equilibrium consumer surplus and welfare are given as follows:

$$\tilde{CS}_i = \left[\tilde{x}_i + \tilde{x}_j^* - \frac{\tilde{x}_i^2}{\tilde{u}_i^2} - \frac{\left(\tilde{x}_j^*\right)^2}{\left(\tilde{u}_j^*\right)^2} - \gamma\frac{\tilde{x}_i}{\tilde{u}_i}\frac{\tilde{x}_j^*}{\tilde{u}_j^*}\right] - S\tilde{p}_i\tilde{x}_i - S\tilde{p}_j^*\tilde{x}_j^*, \quad i,j=H,F \text{ and } i\neq j,$$

$$\text{and } \tilde{CS}_i = \tilde{CS}_j \tag{27}$$

$$\tilde{W}_i = \tilde{CS}_i + \tilde{\pi}_i,\ \tilde{W}_j = \tilde{CS}_j + \tilde{\pi}_j, \text{ and } \tilde{W}_i = \tilde{W}_j,\ i,j=H,F \text{ and } i\neq j. \tag{28}$$

4. BERTRAND EQUILIBRIUM

We turn to a two-stage game wherein both firms simultaneously choose a quality of product in the first stage and both firms simultaneously decide the prices in order to maximize their respective profits in the second stage. We again compute a symmetric subgame-perfect equilibrium in pure strategies in the two-stage game.

Holding R&D expenditures fixed, firm *i*'s second-stage profit is written as follows:

$$\pi_i(p_i, p_i^*, p_j, p_j^*) = \{S_i[p_i - c]x_i(p_i, p_j^*) - R_i\} + \{S_j[p_i^* - c - t - \tau c]x_i^*(p_i^*, p_j) - R_i^*\},$$

$$i,j=H,F \text{ and } i\neq j, \tag{29}$$

where the quantity and the price are all positive. Each firm takes the other firm's prices as given and chooses its prices of home and foreign market to maximize (29). Solving firm *i*'s and *j*'s profit maximization problem yields the best response functions for firm *i* and *j* as follows:

$$p_i = \frac{2(1+c)u_i + \gamma(p_j^* - 1)u_j^*}{4u_i}, \quad i, j = H, F \text{ and } i \neq j \tag{30}$$

$$p_i^* = \frac{\gamma(p_j - 1)u_j + 2(1+c+t+\tau c)u_i^*}{4u_i^*}, \quad i, j = H, F \text{ and } i \neq j.^{11)} \tag{31}$$

These functions slope upward because the prices in the same market are strategic complements.

We again examine each national market separately, due to the constant marginal production costs. By solving equation (30) and the equation of firm *j*'s best-response function in its export market from interchanging subscripts *i* and *j* in equation (31) simultaneously, we can get the equilibrium prices for firm *i*'s home market. Also, by solving equation (31) and the equation of firm *j*'s best-response function in its national market from interchanging subscripts *i* and *j* in equation (30) simultaneously, we can obtain the equilibrium prices for firm *j*'s national market. Bertrand equilibrium prices are as follows:

$$\hat{p}_i = \frac{[8(1+c) - \gamma^2]u_i - 2\gamma(1-c-t-\tau c)u_j^*}{(16-\gamma^2)u_i}, \quad i, j = H, F \text{ and } i \neq j \tag{32}$$

$$\hat{p}_j^* = \frac{[8(1+c+t+\tau c) - \gamma^2]u_j^* - 2\gamma(1-c)u_i}{(16-\gamma^2)u_j^*}, \quad i, j = H, F \text{ and } i \neq j, \tag{33}$$

where "^" denotes Bertrand equilibrium and p_i and p_j^*, $i, j = H, F$ and $i \neq j$, are positive for $\frac{2\gamma(1-c-t-\tau c)}{[8(1+c)-\gamma^2]} < \frac{u_i}{u_j^*} < \frac{[8(1+c+t+\tau c)-\gamma^2]}{2\gamma(1-c)}$, $i, j = H, F$ and $i \neq j$. We will also examine reciprocal dumping which implies $\hat{\theta}_i > 0$ and $\hat{\theta}_j > 0$, $i, j = H, F$ and $i \neq j$ in equilibrium.

Substituting the equilibrium prices into (4), (5), and (29) yields firm *i*'s and *j*'s equilibrium quantities and profits as a function of R&D expenditures via (6) and (7):

$$\hat{x}_i = \frac{2u_i\left[(8-\gamma^2)(1-c)u_i - 2\gamma(1-c-t-\tau c)u_j^*\right]}{(4-\gamma^2)(16-\gamma^2)}, \quad i, j = H, F \text{ and } i \neq j \tag{34}$$

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11) The following second-order conditions for firm *i* and *j* are satisfied: $-\frac{4S_i u_i^2}{(4-\gamma^2)} < 0$ and $-\frac{4S_j (u_i^*)^2}{(4-\gamma^2)} < 0$, $i, j = H, F$ and $i \neq j$.

$$\hat{x}_j^* = \frac{2u_j^*\left[(8-\gamma^2)(1-c-t-\tau c)u_j^* - 2\gamma(1-c)u_i\right]}{(4-\gamma^2)(16-\gamma^2)}, \quad i,j=H,F \text{ and } i\neq j \tag{35}$$

$$\hat{\pi}_i = \frac{2S_i\left[(8-\gamma^2)(1-c)u_i - 2\gamma(1-c-t-\tau c)u_j^*\right]^2}{(4-\gamma^2)(16-\gamma^2)^2} + \frac{2S_j\left[(8-\gamma^2)(1-c-t-\tau c)u_i^* - 2\gamma(1-c)u_j\right]^2}{(4-\gamma^2)(16-\gamma^2)^2} - R_i - R_i^*, \quad i,j=H,F \text{ and } i\neq j. \tag{36}$$

In the first stage, each firm simultaneously chooses R&D expenditures and thus qualities of product to maximize the profits:

$$\hat{\pi}_i(R_i,R_i^*,R_j,R_j^*) = \{S_i[\hat{p}_i(u_i,u_j^*)-c]\hat{x}_i(u_i,u_j^*) - R_i\} + \{S_j[\hat{p}_i^*(u_i^*,u_j)-c-t-\tau c]\hat{x}_i^*(u_i^*,u_j) - R_i^*\}$$

$$, \quad i,j=H,F \text{ and } i\neq j. \tag{37}$$

Considering European Union's provision mentioned earlier, we again assume that the same qualities of a product are required in both national markets. Further, we assume $S_i = S_j = S$, $i,j=H,F$ and $i\neq j$, for the symmetric analysis. Then, equation (37) becomes

$$\hat{\pi}_i(R_i,R_j) = S[\hat{p}_i(u_i,u_j^*)-c]\hat{x}_i(u_i,u_j^*) + S[\hat{p}_i^*(u_i^*,u_j)-c-t-\tau c]\hat{x}_i^*(u_i^*,u_j) - 2R_i,$$

$$i,j=H,F \text{ and } i\neq j. \tag{38}$$

For both firm *i* and *j*, the first-order conditions are

$$\frac{d\hat{\pi}_i}{dR_i} = \frac{\partial\hat{\pi}_i}{\partial u_i}\frac{du_i}{dR_i} + \frac{\partial\hat{\pi}_i}{\partial u_i^*}\frac{du_i^*}{dR_i} - 2 = 0, \quad i,j=H,F \text{ and } i\neq j. \tag{39}$$

Putting the expressions for the various partial derivatives into (39), setting $u_i = \varepsilon R_i^{1/4}$ and $u_j^* = \varepsilon R_j^{1/4}$, $i,j=H,F$ and $i\neq j$, to solve for the symmetric equilibrium, we get the following equilibrium level of R&D expenditures and product qualities:

$$\hat{R}_i = \hat{R}_j \equiv \hat{R} = \frac{(8-\gamma^2)^2 S^2\varepsilon^4[(8-\gamma^2)(1-c)^2 + (8-\gamma^2)(1-c-t-\tau c)^2 - 4\gamma(1-c)(1-c-t-\tau c)]^2}{4(16-\gamma^2)^4(4-\gamma^2)^2},$$

$$i,j=H,F \text{ and } i\neq j \tag{40}$$

$$\hat{u}_i = \hat{u}_j = \hat{u} = \varepsilon\hat{R}^{1/4} =$$

$$\frac{S^{1/2}\varepsilon^2(8-\gamma^2)^{1/2}[(8-\gamma^2)(1-c)^2 + (8-\gamma^2)(1-c-t-\tau c)^2 - 4\gamma(1-c)(1-c-t-\tau c)]^{1/2}}{\sqrt{2}(16-\gamma^2)(4-\gamma^2)^{1/2}},$$

$$i,j=H,F \text{ and } i\neq j.^{12)} \tag{41}$$

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12) The second-order conditions for an interior maximum at the symmetric equilibrium require that $\frac{S(8-\gamma^2)\varepsilon^2\{6\gamma(1-c)(1-c-t-\tau c) - (8-\gamma^2)[(1-c)^2 + (1-c-t-\tau c)^2]\}}{2\tilde{R}^{3/2}(16-\gamma^2)^2(4-\gamma^2)} < 0$. That is,

Substituting the equilibrium value of R&D expenditures from (40) into (32) to (36) yields the following expression for the equilibrium values under Bertrand competition:

$$\hat{x}_i = \hat{x}_j = \frac{(8-\gamma^2)S\varepsilon^4[(2-\gamma)(4+\gamma)(1-c)+2\gamma(t+\tau c)]}{(4-\gamma^2)^2(16-\gamma^2)^3}\times$$

$$\{(1-c)[(2-\gamma)(4+\gamma)(1-c)+2\gamma(t+\tau c)]+(1-c-t-\tau c)[(8-\gamma^2)(1-c-t-\tau c)-2\gamma(1-c)]\}$$

$$,\ i,j=H,F \text{ and } i\neq j \tag{42}$$

$$\hat{x}_i^* = \hat{x}_j^* = \frac{(8-\gamma^2)S\varepsilon^4[(2-\gamma)(4+\gamma)(1-c)-(8-\gamma^2)(t+\tau c)]}{(4-\gamma^2)^2(16-\gamma^2)^3}\times$$

$$\{(1-c)[(2-\gamma)(4+\gamma)(1-c)+2\gamma(t+\tau c)]+(1-c-t-\tau c)[(8-\gamma^2)(1-c-t-\tau c)-2\gamma(1-c)]\}$$

$$,\ i,j=H,F \text{ and } i\neq j \tag{43}$$

$$\hat{p}_i = \hat{p}_j = c+\frac{(8-\gamma^2)(1-c)-2\gamma(1-c-t-\tau c)}{16-\gamma^2},\ i,j=H,F \text{ and } i\neq j \tag{44}$$

$$\hat{p}_i^* = \hat{p}_j^* = c+\frac{(4+\gamma)(2-\gamma)(1-c)+8(t+\tau c)}{16-\gamma^2},\ i,j=H,F \text{ and } i\neq j \tag{45}$$

$$\hat{\pi}_i = \hat{\pi}_j = \frac{(8-\gamma^2)S^2\varepsilon^4}{2(16-\gamma^2)^6(4-\gamma^2)^3}$$

$$\times[(1-c)\big((2-\gamma)(4+\gamma)(1-c)+2\gamma(t+\tau c)\big)+(1-c-t-\tau c)\big((8-\gamma^2)(1-c-t-\tau c)-2\gamma(1-c)\big)]$$

$$\times\{2(4-\gamma^2)(16-\gamma^2)^2[2(1-c)(1-c-t-\tau c)(2-\gamma)^2(4+\gamma)^2+(t+\tau c)^2(64-12\gamma^2+\gamma^4)]$$

$$-(8-\gamma^2)[(1-c)\big((2-\gamma)(4+\gamma)(1-c)+2\gamma(t+\tau c)\big)+(1-c-t-\tau c)\big((8-\gamma^2)(1-c-t-\tau c)-2\gamma(1-c)\big)]\}$$

$$,i,j=H,F \text{ and } i\neq j. \tag{46}$$

Notice that there is reciprocal dumping since $\hat{\theta}_i = \hat{p}_i - (\hat{p}_i^* - t - \tau c) = \frac{(2+\gamma)(t+\tau c)}{4+\gamma} > 0$, $\hat{\theta}_j = \hat{p}_j - (\hat{p}_j^* - t - \tau c) = \frac{(2+\gamma)(t+\tau c)}{4+\gamma} > 0$, $i,j=H,F$ and $i\neq j$, in equilibrium.

At last, equilibrium consumer surplus and welfare are given as follows:

$(8-\gamma^2)[(1-c)^2+(1-c-t-\tau c)^2] > 6\gamma(1-c)(1-c-t-\tau c)$.

$$\hat{CS}_i = \left[\hat{x}_i + \hat{x}_j^* - \frac{\hat{x}_i^2}{\hat{u}_i^2} - \frac{\left(\hat{x}_j^*\right)^2}{\left(\hat{u}_j^*\right)^2} - \gamma \frac{\hat{x}_i}{\hat{u}_i}\frac{\hat{x}_j^*}{\hat{u}_j^*} \right] - S\hat{p}_i\hat{x}_i - S\hat{p}_j^*\hat{x}_j^*, \quad i, j = H, F \quad \text{and} \quad i \neq j,$$

$$\text{and} \quad \hat{CS}_i = \hat{CS}_j \tag{47}$$

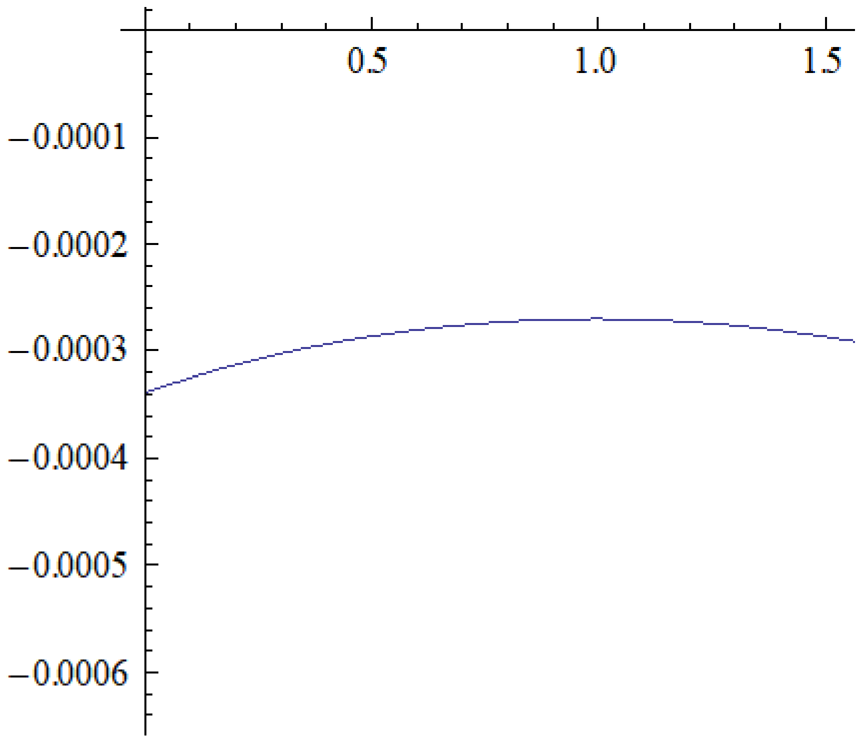
$$\hat{W}_i = \hat{CS}_i + \hat{\pi}_i, \quad \hat{W}_j = \hat{CS}_j + \hat{\pi}_j, \text{ and } \hat{W}_i = \hat{W}_j, \quad i, j = H, F \quad \text{and} \quad i \neq j. \tag{48}$$

5. COMPARISON

In this section, we compare the equilibrium values under Bertrand competition to those under Cournot competition. We first compare R&D expenditures under the two regimes. When we subtract (20) from (40), we have complex solutions. Therefore, we use some plausible numbers which are $c = 0.5$, $t = 0.1$, $\tau = 0.2$, $S = 1$, $\varepsilon = 1$.[13] Figure 1 shows the relationship between γ and $\hat{R} - \tilde{R}$ with plausible numbers.

Figure 1. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{R} - \tilde{R}$, with Plausible Numbers

[13] Those numbers satisfy the conditions: $1 - c > 0$, $1 - c - t - \tau c > 0$, $4[(1-c)^2 + (1-c-t-\tau c)^2] > 3\gamma(1-c)(1-c-t-\tau c)$, $(8-\gamma^2)[(1-c)^2 + (1-c-t-\tau c)^2] > 6\gamma(1-c)(1-c-t-\tau c)$ for $\gamma \in (0, 1.5)$. Further, those guarantee that quantities and prices are all positive for $\gamma \in (0, 1.5)$.



It also implies that there is the same relationship between γ and $\hat{u}-\tilde{u}$ with plausible numbers since $\hat{u}=\varepsilon\hat{R}^{1/4}$ and $\tilde{u}=\varepsilon\tilde{R}^{1/4}$. From Figure 1, we have the following proposition.

Proposition 1. *R&D expenditure, and hence also quality, can be higher under Cournot competition than under Bertrand competition in a reciprocal dumping model.*

This result extends the one found by Symeonidis (2003), who considered the case of no trade. Similar to the model where R&D expenditure and quality are higher under Cournot competition than under Bertrand competition in a no-trade scenario, our model demonstrates that they can also be higher under quantity competition than under price competition in a reciprocal dumping model.

We now check the ranking of price levels under the two competitions. When we compare (24) and (25) to (44) and (45), respectively, there is a clear ranking of the two regimes:

$$\hat{p}_i - \tilde{p}_i = \frac{-\gamma^2(1-c)}{16-\gamma^2} < 0, \quad \hat{p}_j - \tilde{p}_j = \frac{-\gamma^2(1-c)}{16-\gamma^2} < 0, \quad i, j = H, F \text{ and } i \neq j$$

$$\hat{p}_i^* - \tilde{p}_i^* = \frac{-\gamma^2(1-c-t-\tau c)}{16-\gamma^2} < 0, \quad \hat{p}_j^* - \tilde{p}_j^* = \frac{-\gamma^2(1-c-t-\tau c)}{16-\gamma^2} < 0, \quad i, j = H, F \text{ and } i \neq j.$$

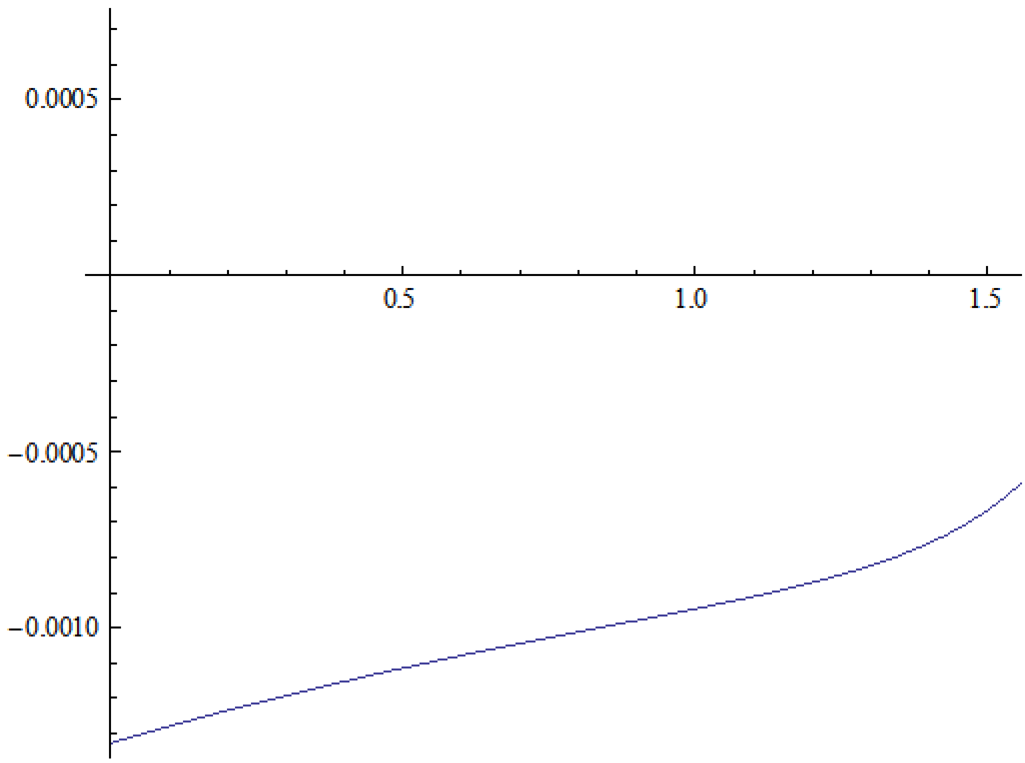
Hence, we have the following proposition.

Proposition 2. *Domestic and export prices are higher under quantity competition than under price competition in a reciprocal dumping model.*

This result extends the one found by Symeonidis (2003), who examined only domestic price. While he proved domestic price is higher under Cournot competition than under Bertrand competition, our model shows that both domestic and export prices are higher under quantity competition than under price competition in spite of transport costs.

We next investigate the ranking of output levels under the two competitions by subtracting (22) and (23) from (42) and (43), respectively. Since complex solutions come out, we use plausible numbers. Figure 2 shows the relationship between γ and $\hat{x}_i - \tilde{x}_i$ or $\hat{x}_j - \tilde{x}_j$, $i, j = H, F$ and $i \neq j$, with plausible numbers.

Figure 2. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{x}_i - \tilde{x}_i$ or $\hat{x}_j - \tilde{x}_j$, $i, j = H, F$ and $i \neq j$, with Plausible Numbers



From figure 2, we have the following proposition.

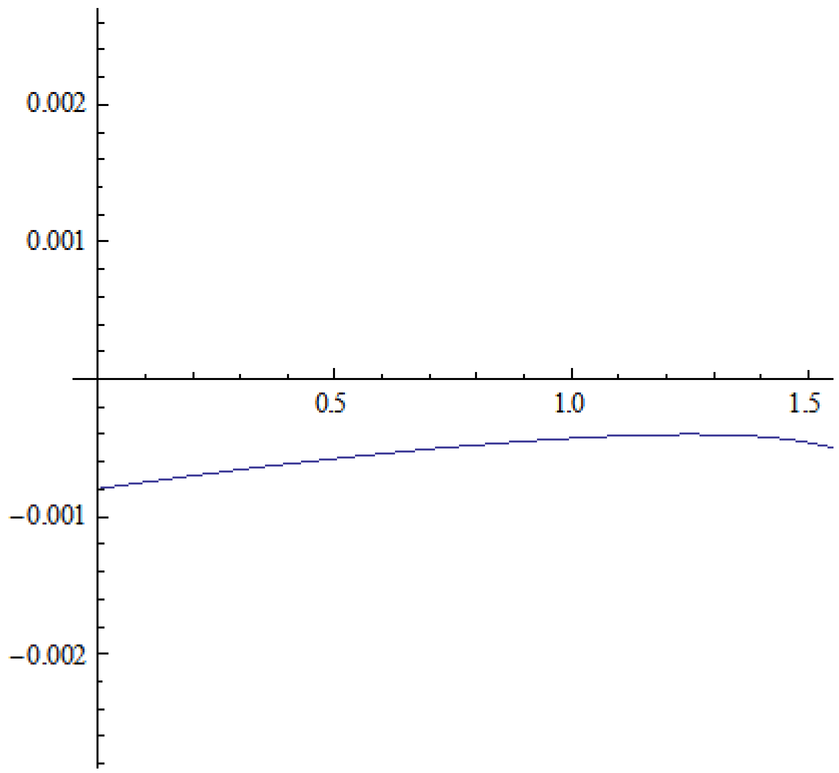
Proposition 3. *Domestic sales can be higher under Cournot competition than under Bertrand competition in a reciprocal dumping model.*

This result is different from the one derived by Symeonidis (2003), who found the ranking of domestic sales depended on the degree of horizontal differentiation and R&D spillovers. In this model, for any given quality, the firms under Bertrand competition produce more output in domestic market than those under Cournot competition.[14] However, since R&D expenditure and quality can be higher under Cournot competition than under Bertrand competition and higher quality raises more demand, the ranking can be reversed.

Figure 3 shows the relationship between γ and $\hat{x}_i^* - \tilde{x}_i^*$ or $\hat{x}_j^* - \tilde{x}_j^*$, $i, j = H, F$ and $i \neq j$, with plausible numbers.

Figure 3. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{x}_i^* - \tilde{x}_i^*$ or $\hat{x}_j^* - \tilde{x}_j^*$, $i, j = H, F$ and $i \neq j$, with Plausible Numbers

14) Subtracting (11) from (34) yields $\frac{\gamma^2 u_i[2u_i(1-c) - \gamma u_j^*(1-c-t-\tau c)]}{(4-\gamma^2)(16-\gamma^2)}$, $i, j = H, F$ and $i \neq j$, which is positive by symmetry.



From figure 3, we have the following proposition.

Proposition 4. *Exports can be higher under Cournot competition than under Bertrand competition in a reciprocal dumping model.*

This following is an explanation of this result. For any given quality, the firms under Bertrand competition exports more than those under Cournot competition when the goods are sufficiently differentiated and vice versa when the goods are not sufficiently differentiated.[15] However, higher R&D expenditure and quality under Cournot competition than under Bertrand competition can lead to higher exports under quantity competition than under price competition in a reciprocal dumping model.

We now compare profits under the two competitions by subtracting (26) from (46).

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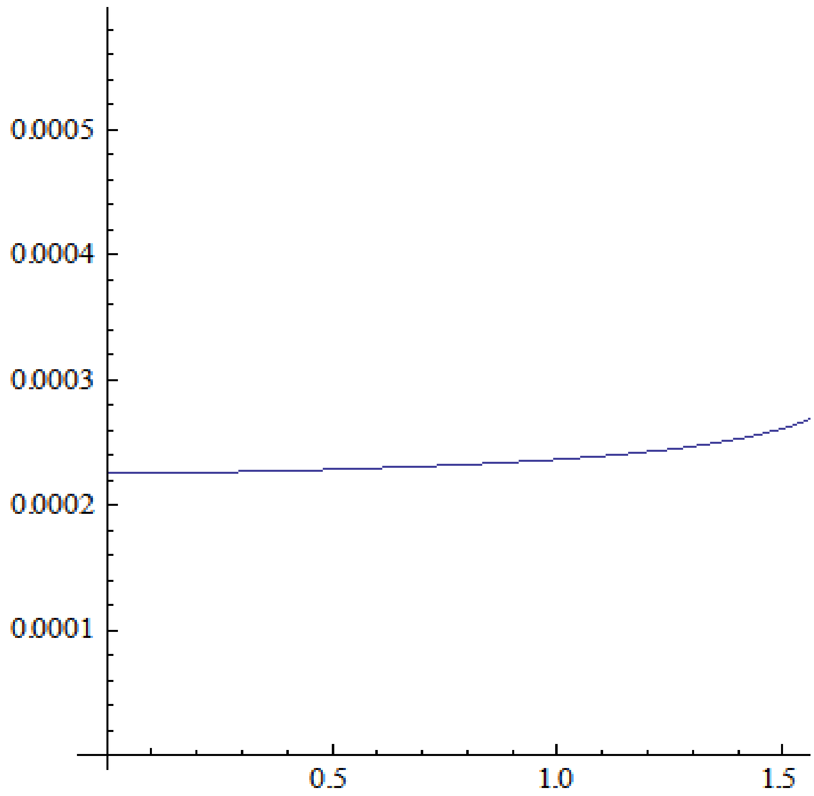
[15] Subtracting (12) from (35) yields $\frac{\gamma^2 u_j^*[2u_j^*(1-c-t-\tau c)-\gamma u_i(1-c)]}{(4-\gamma^2)(16-\gamma^2)}$, $i, j = H, F$ and $i \neq j$, which is positive when γ is sufficiently small, $\gamma < \frac{2(1-c-t-\tau c)}{1-c}$, and negative when γ is sufficiently large, $\gamma > \frac{2(1-c-t-\tau c)}{1-c}$, by symmetry.

Since solutions are complex, plausible numbers are used. Figure 4 shows the relationship between γ and $\hat{\pi}_i - \tilde{\pi}_i$ or $\hat{\pi}_j - \tilde{\pi}_j$, $i, j = H, F$ and $i \neq j$, with plausible numbers.

Figure 4. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{\pi}_i - \tilde{\pi}_i$ or $\hat{\pi}_j - \tilde{\pi}_j$, $i, j = H, F$ and $i \neq j$, with Plausible Numbers



From figure 4, we have the following proposition.

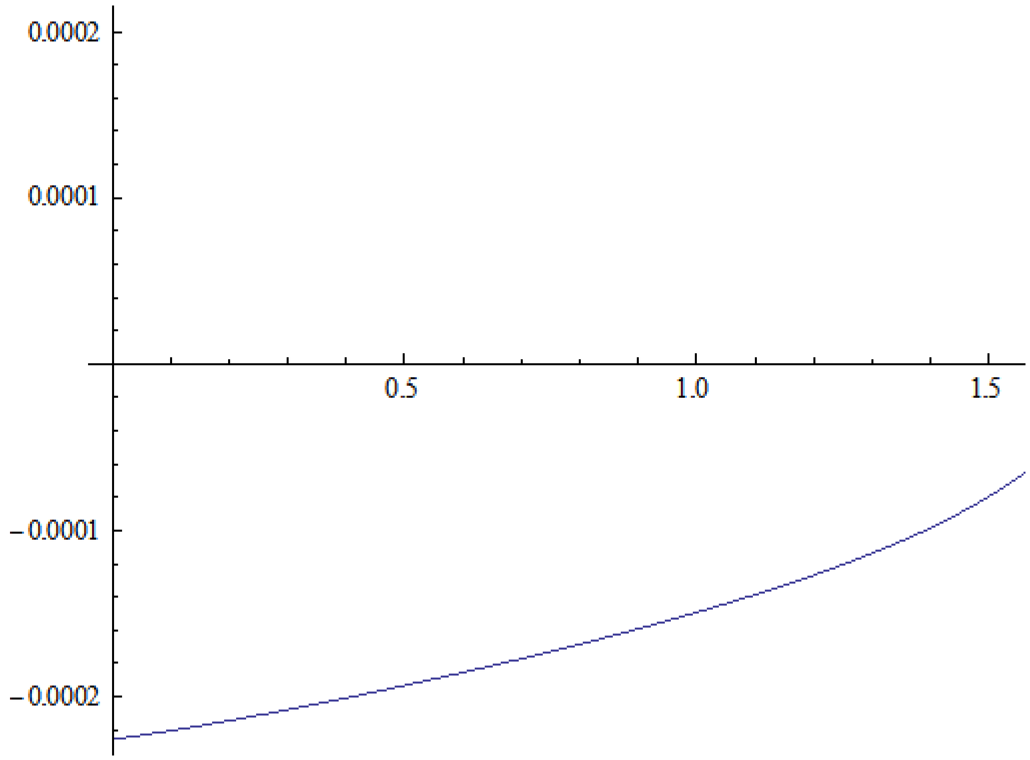
Proposition 5. *Profits can be higher under Bertrand competition than under Cournot competition in a reciprocal dumping model.*

The result can be accounted for in the following way. Although R&D expenditure and quality, domestic and export prices, domestic sales and exports can be higher under Cournot competition than under Bertrand competition, decreasing returns to R&D can lead to higher profits under price competition than under quantity competition in a reciprocal dumping model.

We next compare consumer surplus under the two regimes by subtracting (27) from

(47). Since we get complex solutions, plausible numbers are used. Figure 5 shows the relationship between γ and $\hat{CS}_i - \tilde{CS}_i$ or $\hat{CS}_j - \tilde{CS}_j$, $i, j = H, F$ and $i \neq j$, with plausible numbers.

Figure 5. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{CS}_i - \tilde{CS}_i$ or $\hat{CS}_j - \tilde{CS}_j$, $i, j = H, F$ and $i \neq j$, with Plausible Numbers



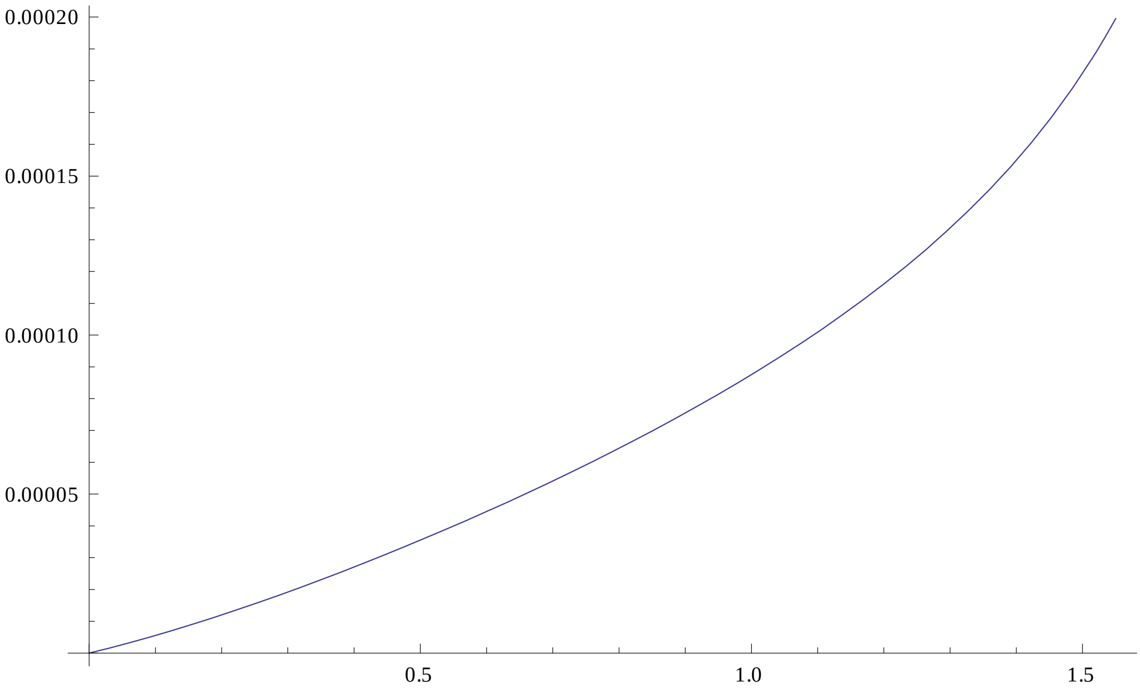
From figure 5, we have the following proposition.

Proposition 6. *Consumer surplus can be higher under Cournot competition than under Bertrand competition in a reciprocal dumping model.*

Here is how this result can be explained. Even though prices in domestic market are higher under Cournot competition than under Bertrand competition, higher output in domestic market through higher R&D expenditure and quality under Cournot competition than under Bertrand competition can lead to higher consumer surplus under quantity competition than under price competition in a reciprocal dumping model.

Finally, we examine the ranking of social welfare under the two regimes by subtracting (28) from (48). Since solutions are complex, we use plausible numbers. Figure 6 shows the relationship between γ and $\hat{W}_i - \tilde{W}_i$ or $\hat{W}_j - \tilde{W}_j$, $i, j = H, F$ and $i \neq j$, with plausible numbers.

Figure 6. The Relationship between the Horizontal Line, γ, and the Vertical Line, $\hat{W}_i - \tilde{W}_i$ or $\hat{W}_j - \tilde{W}_j$, $i, j = H, F$ and $i \neq j$, with Plausible Numbers



From figure 6, we have the following proposition.

Proposition 7. *Social welfare can be higher in the Bertrand equilibrium than in the Cournot equilibrium in a reciprocal dumping model.*

This result admits of the following explanation. Although consumer surplus can be greater under Cournot competition than under Bertrand competition, profits can be greater under Bertrand competition than Cournot competition. Nevertheless, as profits can have a greater impact on social welfare than consumer surplus, social welfare can be higher under price competition rather than quantity competition in a reciprocal dumping model.

6. CONCLUDING REMARKS

We have derived the Cournot and Bertrand equilibrium levels of R&D expenditure, domestic and export prices, domestic sales, exports, firms' profits, consumer surplus, and social welfare in a reciprocal dumping model in which two firms compete in domestic and foreign markets with substitute goods and product R&D investment and analyzed the rankings of those values. Comparing the results derived to those of Symeonidis (2003) who examined R&D expenditure, prices, output, consumer surplus, firms' profit, and total welfare with no trade, we find some similarities and differences between them. It is similar that R&D expenditure can be higher and prices are higher in the Cournot equilibrium than in the Bertrand equilibrium in both models. However, while the rankings of output, consumer surplus, and total welfare depend on the degree of horizontal differentiation and R&D spillovers in the model of Symeonidis (2003), domestic sales, exports, and consumer surplus can be higher under quantity competition than under price competition and total welfare can be higher under price competition than under quantity competition in a reciprocal dumping model. Furthermore, while profits are higher under Cournot competition than under Bertrand competition in the model of Symeonidis (2003), they can be higher under Bertrand competition than under Cournot competition in a reciprocal dumping model.

These findings carry significant implications, as some results from a reciprocal dumping model diverge from conventional wisdom. In conventional wisdom, it is believed that consumer surplus is higher in the Bertrand equilibrium than in the Cournot equilibrium, and profits are higher under Cournot competition than under Bertrand competition. However, in a reciprocal dumping model, we can observe a different pattern. Consumer surplus can be higher in the Cournot equilibrium than in the Bertrand equilibrium, and profits can be higher under Bertrand competition than under Cournot competition. Additionally, social welfare follows a similar trend. In conventional wisdom, social welfare is higher under Bertrand competition than under Cournot competition, given that consumer surplus has a greater impact than profits. Conversely, in a reciprocal dumping model, social welfare can be higher under Bertrand competition than under Cournot competition, as profits can have a greater impact than consumer surplus. These results suggest that there may be no conflict between firms and governments within a country over their preferred choice of competition in a situation where product R&D is taking place and reciprocal dumping is occurring, thus avoiding the costs that could arise from their conflict.

This paper has potential for further extension. One possible extension is to develop a model of antidumping protection and analyze its impact on R&D expenditure and social welfare under both Cournot and Bertrand competition. Another possible extension is to include the effects of R&D spillovers and examine how they influence R&D expenditure and social welfare.

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