Effect of a Tariff on the Environment and Welfare: The Case of an Environmentally Differentiated Duopoly in a Green Market

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Abstract

Based on an environmentally differentiated duopoly model, we analyze the effect of an *ad valorem* tariff on the unit emission level of the products acquired with environmental quality, the environment and social welfare. The Bertrand and Cournot duopoly cases are examined. We show that the effect of a tariff depends on the mode of market competition and the degree of the marginal social damage from aggregate emissions.

JEL classification: D43; F12; F13; Q28

Keywords: green market; environmentally differentiated duopoly; *ad valorem* tariff

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1. Introduction

Since the acceleration of globalization in the early 1990s, there has been considerable debate about the extent to which environmental problems affect international trade, and vice versa. Namely, international trade affects both the extent and the pattern of the production and consumption of products in various countries; therefore, if these activities have significant effects on the environment of the countries where production and consumption take place, international trade will affect the environment. Equally, policies designed to improve the environment in which production and consumption take place will affect the volume and the pattern of international trade.

Some fundamental environmentalists insist that trade liberalization is harmful to the environment, which should be protected with trade restrictions. As a result, the study of international economics has expanded to incorporate various environmental issues. The representative studies analyzing the subject include Barrett (1994), Rauscher (1997), Ulph (1999, 2001), Copeland and Taylor (2003), Chao and Yu (2004) and others. In response to the statements of the environmentalists, these economists have attempted to explain the interaction between international trade and the environment. For example, their works have examined the linkages between the regulation of international trade and policies to protect the environment. One issue they have addressed is how trade policies such as tariffs and import quotas influence the environment and social welfare. Another issue is the investigation of how environmental policies such as green taxes, emission standards, and eco-labels, among other environmental policies, affect international trade, factor mobility and international allocation of firms.

Previous studies mentioned above have mainly discussed polluting wastes or environmental effluents that are produced through the production process in manufacturing industries. In this paper, by contrast, we will focus on products with environmental characteristics in a green market where environmental effluents are produced through the consumption of heterogeneous consumers, who differ in terms of their willingness to pay for the products associated with the effluent. In fact, the environmental damage caused by the polluting wastes and effluents produced in the consumption of these products may be external for individual consumers. However, some consumers who are very afraid of the destruction of the environment would purchase an environmentally friendly good even if its price were higher than that of an ordinary good. On the other hand, other consumers who are not concerned about the environment would purchase a lower-priced ordinary good. That is, consumers differ in their degree of consciousness about the environment. For example, consumers who are not conscious of the environment may choose to purchase cars with ordinary gas engines, whereas those who are conscious of the environment may prefer to purchase a car with a hybrid engine that has a much lower emission level. Moreover, fundamental environmentalists do not purchase any type of car.

This paper is an analysis of environmental quality regulation through trade policy in the context of duopolistic competition between domestic and foreign firms. That is, employing the preference behavior of heterogeneous consumers and the products associated with the environmental characteristic assumed in Morga-Gonzalez and Pandron-Fumero (2002), we will analyze the effect of an *ad valorem* tariff on the unit emission level of the product, as well as its effect on the environment and social welfare. In other words, our purpose is to investigate an optimal tariff policy in the presence of negative environmental externality.

We will show the main results as follows. Suppose that a developed (less developed) country imports a dirtier (cleaner) product produced in a (developed) less developed country. If environmental valuation is socially significant, (i) the developed country should restrict imports of the dirtier product produced in the less developed country in the Bertrand duopoly case, while in the Cournot duopoly case, the government should choose a free trade policy or reduce the tariff rate; and (ii) the less developed country should choose a free trade policy for the cleaner product produced in the developed country in the Bertrand duopoly case, while in the Cournot duopoly case, the government should restrict imports of the cleaner product produced in the developed country.

Although few studies have directly analyzed the subject in this paper, some related previous works analyzed how a tariff policy affects quality choice of firms and social welfare, based on a model of a vertically differentiated product market with international oligopoly (Polavarapu and Vaidya (1996a, b), Herguera et al. (2002), Morga-Gonzalez and Viaene (2005), and others). Our research is formally close to Herguera et al. (2002) and Morga-Gonzalez and Viaene (2005), who analyze the effect of a tariff on quality choice and welfare, and show an (*ex-ante* and *ex-post*) optimal tariff rate, in the cases of Bertrand and Cournot duopoly. For example, Herguera et al. compare the effects of the optimal ex-ante and ex-post tariffs on domestic welfare. They also show that an optimal ex-ante tariff is prohibitive tariff in the Cournot duopoly. Moreover, Morga-Gonzalez et al. examine a policy mix of a tariff-cum-subsidy.

The remainder of the paper is structured as follows. Section 2 presents a model, in which we establish the preferences of heterogeneous consumers in a green market and assume that a firm incurs a cost associated with the unit emission level of an environmentally differentiated product. Section 3 shows the equilibrium unit emission levels and then analyzes the effect of an *ad valorem* tariff on them in the cases of Bertrand and Cournot duopoly. Section 4 examines the effect of the tariff on the environment and social welfare of the developed country. Section 5 addresses the case of the less developed country. In these two sections both Bertrand and Cournot duopoly cases are analyzed. Finally, section 6 summarizes the results and show a few remaining issues.

2. The Model

Based on a model of environmentally differentiated duopoly, we first present the preferences of consumers. There exists a continuum of heterogeneous consumers who differ in their marginal valuation θ of the green features of the product: $\theta \in [0,1]$. To simplify, the consumer matching value θ is assumed to be uniformly distributed in the market. The consumer whose value is close to unity (zero) is conscious (unconscious) of the environment. Let e denote the observable per unit level of polluting emissions, environmental wastes and effluents of the product. Each consumer purchases either zero units or, at most, one unit of the product. The net surplus of consumer θ who acquires the variant e at price p is given by $u(\theta,e) = v - e\theta - p,\ e \in (0,\infty)$, where v is the utility obtained from consuming a single unit of the product regardless of the unit emission level. If a consumer does not purchase any product in the market, the net surplus is assumed to be zero.

Suppose that a firm that produces a product associated with a higher (lower) unit emission level is a dirtier (cleaner) firm. Without any loss of generality, firm 1 (firm 2) is assumed to be a dirtier (cleaner) firm supplying a product acquired with unit emission level e_1 (e_2) at price p_1 (p_2), and $e_1 > e_2$.

Let us derive the demand function of environmentally differentiated products. The index of the marginal consumer whose net surplus is indifferent between purchasing the dirtier or cleaner product is given by $\tilde{\theta} = \frac{p_2 - p_1}{e_1 - e_2}$. Furthermore, the index of the marginal consumer who either wants to purchase the cleaner product or chooses not to purchase any product is $\hat{\theta} = \frac{v - p_2}{e_2}$. Accordingly, consumer θ falling into the range $\tilde{\theta} < \theta < \hat{\theta}$ purchases the cleaner product, whereas consumer θ falling into the range $1 \geq \theta > \hat{\theta}$ does not purchase any product. The latter type of consumers may be fundamental environmentalists who choose to ride a bicycle, i.e., an outside good, rather than driving a car. This implies that the green market is not completely covered by all of the consumers. In other words, if there is such a small value of v that $e_2 + p_2 > v$, a partially covered market holds. Throughout the partially covered market case is assumed.

Let q_1 (q_2) represent the demand for the dirtier (cleaner) product. Given the assumption of uniform distribution, the demand functions are

$$q_1 = \tilde{\theta} = \frac{p_2 - p_1}{e_1 - e_2}, \tag{1.1}$$

$$q_2 = \hat{\theta} - \tilde{\theta} = \frac{e_1(v - p_2) - e_2(v - p_1)}{e_2(e_1 - e_2)}. \tag{1.2}$$

Moreover, the corresponding inverse demand functions are

$$p_1 = v - e_1 q_1 - e_2 q_2, \tag{2.1}$$

$$p_2 = v - e_2 q_1 - e_2 q_2. \tag{2.2}$$

Before the price or quantity competition, the firms must determine the environmental quality of the product. This implies that the firm builds a product line or invests in R&D to improve the environmental quality in advance of production. We assume that the firms must incur costs associated with the unit emission level: $C_i = C_i(e_i), C_i' < 0, C_i'' > 0, i = 1,2$. Following Moraga-Gonzalez and Pandron-Fumero (2002, Assumption 2 and Proposition 3) and others, the cost function is assumed to be a homogeneous function of degree ε:

$$C_1 = \alpha e_1^{-\varepsilon}, \tag{3.1}$$

$$C_2 = e_2^{-\varepsilon}, \tag{3.2}$$

where $\varepsilon \geq 2$. In order to avoid multiple equilibria in the decision game of the unit emission levels, we assume that cost functions are significantly asymmetry among the firms: $\alpha > 1$. It may be justified to assume that the cleaner firm locates in the developed country (DC), whereas the dirtier firm locates in the less developed country (LDC). Given this assumption, the LDC firm cannot choose to produce a cleaner product because of the inefficient cost performance. Although the DC firm can select a dirtier product, it is not profitable for it to do so. Thus, the DC firm produces a cleaner product. Moreover, to simplify, we assume that the marginal cost of production is independent of the unit emission level and is zero. We thus focus on how the tariff policy directly affects the environmental qualities endogenously chosen by the firms.

The government of an importing country imposes an *ad valorem* tariff, $\tau_i, 0 \leq \tau_i < 1, i = 1,2,$ on an environmentally differentiated product. Thus the profit function of firm *i* is expressed as

$$t_i \tilde{\pi}_i = p_i q_i - t_i C_i(e_i) \equiv \pi_i, i = 1,2,$$

where $t_i = \dfrac{1}{1-\tau_i}, t_i \geq 1, i = 1,2.$ The equation above implies that the tariff is formally the same as a tax that is levied on the cost of an environmental R&D investment determined by the unit emission level. Accordingly, an increase in the tariff rate raises the cost. We assume that the government can ex ante commit to the credible tariff policy which is not so prohibitive that it would enable a domestic firm to monopolize the market in an importing country.

The aggregate emissions, which cause environmental damages, are given by

$$E = e_1 q_1 + e_2 q_2. \tag{4}$$

Therefore, the net social welfare of country *i* included the valuation of environmental damages is expressed as

$$\begin{aligned} W_i^E &\equiv W_i - \gamma E_i, i = 1,2, \\ W_i &\equiv CS_i + \pi_i + T_{ij}, i, j = 1,2, i \neq j, \end{aligned} \tag{5}$$

where CS_i and π_i represent the consumer and producer surplus of country *i*, respectively. As we do not treat an environmental tax on the domestic firm, i.e., $t_i = 1$, it holds that $\pi_i = p_i q_i - C_i(e_i)$. $T_{ij} = \tau_j p_j q_j, i, j = 1,2, i \neq j,$ is the tariff revenue of country *i*. Moreover,

$\gamma(\geq 0)$ is the marginal social damage from aggregate emission. Hereafter we call $W_i, i=1,2$ as the gross social welfare of country *i*.

We present a three-stage game: in the first stage, the government chooses an *ad valorem* tariff rate; in the second stage, the firms simultaneously determine the unit emission level of the environmentally differentiated products, given the tariff rate; and in the final stage, the firms compete in terms of price or quantity, given the unit emission levels and the tariff rate. We derive a subgame perfect Nash equilibrium by backward induction.

3. Equilibrium Unit Emission Level and the Effect of a Tariff

3.1. The Bertrand Duopoly Case

As the derivation of the Bertrand–Nash equilibrium in the final stage is straightforward, the procedure is omitted. The equilibrium quantities in the final stage are: $q_1^B(e_1,e_2)=\dfrac{1}{4e_1-e_2}v,$ $q_2^B(e_1,e_2)=\dfrac{2e_1}{e_2(4e_1-e_2)}v.$ Hence the revenue functions in the second stage are given by

$$R_1^B(e_1,e_2)=\frac{e_1-e_2}{(4e_1-e_2)^2}v^2, \tag{6.1}$$

$$R_2^B(e_1,e_2)=\frac{4e_1(e_1-e_2)}{e_2(4e_1-e_2)^2}v^2. \tag{6.2}$$

We have the nature of the revenue functions in (6.1) and (6.2) as follows (Aoki and Prusa, 1997, Lemma 2; Aoki, 2003, Lemma 1). The first-order properties are

$$\partial R_1^B \Big/ \partial e_1 \geq (<) 0 \Leftrightarrow \frac{7}{4}e_2 \geq (<) e_1,\ \ \partial R_2^B \big/ \partial e_2 < 0,\ \ \partial R_1^B \big/ \partial e_2 < 0, \text{ and } \partial R_2^B \big/ \partial e_1 > 0.$$

The effect on the revenue of the dirtier firm is not unidirectional. So it is assumed for the existence of an interior solution that $\dfrac{7}{4}e_2 < e_1$. A decrease in the unit emission level of the cleaner product increases the firm's revenue. Moreover, a decrease in the unit emission level of the cleaner (dirtier) product increases (reduces) the dirtier (cleaner) firm's revenue. Namely, a decrease in the unit emission level of the cleaner product enlarges the relative environmental quality difference between the products. This in turn relaxes competitiveness. On the other hand, a decrease in the unit emission level of the dirtier product promotes price competition because it reduces the gap in the environmental quality between the products.

The second-order properties are

$\partial^2 R_1^B \big/ \partial e_1{}^2 \geq (<) 0 \Leftrightarrow e_1 \geq (<) \frac{5}{2} e_2$, $\partial^2 R_2^B \big/ \partial e_2{}^2 > 0$, and $\partial^2 R_i^B \big/ \partial e_i \partial e_j > 0, i, j = 1,2, i \neq j$.

As the revenue functions are not necessarily concave, the cost functions should be sufficiently convex to ensure that the second-order conditions hold. Furthermore, the positive cross effect in the third equation above implies that the unit emission levels of the environmentally differentiated products are strategic complements for both firms in the Bertrand duopoly case.

The payoff function relevant for our analysis is $\pi_i^B(e_1, e_2) = R_i^B(e_1, e_2) - t_i C_i(e_i), i = 1,2.$ In view of (6.1) and (6.2), the first-order conditions of both firms' decision problems are

$$-\frac{(4e_1 - 7e_2)}{(4e_1 - e_2)^3} v^2 - t_1 C_1'(e_1) = 0, \tag{7.1}$$

$$-\frac{4e_1(4e_1{}^2 - 3e_1 e_2 + 2e_2{}^2)}{e_2{}^2(4e_1 - e_2)^3} v^2 - t_2 C_2'(e_2) = 0. \tag{7.2}$$

Taking into account (7.1) and (7.2), and based on the cost functions in (3.1) and (3.2), we can derive a unique Nash equilibrium in the stage.

For the following analysis, let us show the effect of a tariff on the unit emission levels. Totally differentiating (7.1) and (7.2), we obtain

$$\frac{de_i}{dt_i} = \frac{C_i'(e_i)}{\Delta^B} \frac{\partial^2 \pi_j{}^B}{\partial e_j{}^2} > 0, i, j = 1,2, i \neq j, \tag{8.1}$$

$$\frac{de_i}{dt_j} = -\frac{C_j'(e_j)}{\Delta^B} \frac{\partial^2 \pi_i{}^B}{\partial e_i \partial e_j} > 0, i, j = 1,2, i \neq j, \tag{8.2}$$

where $dt_i = d\tau_i \big/ t_i{}^2, i = 1,2.$ Δ^B denotes the determinant of the matrix, the sign of which is positive (see Appendix 1). We thus summarize as follows.

Lemma 1. *In the Bertrand duopoly case, the tariff raises the unit emission levels of both products.*

As the firm's marginal revenue decreases because of an increasing tariff, the firm has a greater incentive to raise the unit emission level in order to save more of the costs. Moreover, it holds in the Bertrand duopoly case that the environmentally differentiated products are strategic complements for both firms. Accordingly, the tariff raises the unit emission levels of both products, compared to the free trade case.

3.2. The Cournot Duopoly Case

Let us turn to the Cournot duopoly case. The quantities in the Cournot–Nash equilibrium of the final stage are: $q_1^C(e_1,e_2)=\dfrac{1}{4e_1-e_2}v,\ q_2^C(e_1,e_2)=\dfrac{2e_1-e_2}{e_2(4e_1-e_2)}v$. Hence the equilibrium revenue functions in the second stage are given by

$$R_1^C(e_1,e_2)=\frac{e_1}{(4e_1-e_2)^2}v^2, \tag{9.1}$$

$$R_2^C(e_1,e_2)=\frac{(2e_1-e_2)^2}{e_2(4e_1-e_2)^2}v^2. \tag{9.2}$$

We have the nature of the revenue functions as follows (Aoki, 2003, Lemma 3). From (9.1) and (9.2), the first-order properties are $\partial R_i^C/\partial e_i<0,\ \partial R_i^C/\partial e_j>0, i,j=1,2, i\neq j$. As to the second, an increase in the unit emission level of the rival firm increases the revenue of the other firm. That is, the increase implies that the environmental quality of the product is getting worse. This in turn reduces the market share of the rival firm so that the firm can increase its market share and thus its revenue. Moreover, the second-order properties are $\partial^2 R_i^C/\partial e_i{}^2>0$, $\partial^2 R_1^C/\partial e_1\partial e_2<0$, and $\partial^2 R_2^C/\partial e_2\partial e_1>0$. As the sign of the first is positive, we assume that the cost function of unit emission level is sufficiently convex so that the second-order condition holds. In addition, the second means that an increase in the unit emission level of the cleaner product reduces the difference in the environmental quality between the products. As the difference becomes small, a competition among the firms is intensive. Accordingly, the marginal revenue of the dirtier firm declines. On the other hand, the third indicates that an increase in the unit emission level of the dirtier product increases the quality difference, and thus increases the marginal revenue of the cleaner firm. From the cross partially differential coefficients in the second and the third equations above, we understand that the unit emission levels of the environmentally differentiated products are strategic complements (substitutes) for the cleaner (dirtier) firm in the Cournot duopoly case.

In view of (9.1) and (9.2), the first order conditions of both firms are

$$-\frac{4e_1 + e_2}{(4e_1 - e_2)^3} v^2 - t_1 C_1'(e_1) = 0, \tag{10.1}$$

$$-\frac{(2e_1 - e_2)(8e_1^{\ 2} - 2e_1 e_2 + e_2^{\ 2})}{e_2^{\ 2}(4e_1 - e_2)^3} v^2 - t_2 C_2'(e_2) = 0. \tag{10.2}$$

Taking into account (10.1) and (10.2), and based on the cost functions in (3.1) and (3.2), we can derive a unique Nash equilibrium in the second stage.

Totally differentiating (10.1) and (10.2), we obtain

$$\frac{de_i}{dt_i} = \frac{C_i'(e_i)}{\Delta^C} \frac{\partial^2 \pi_j^{\ C}}{\partial e_j^{\ 2}} > 0, i, j = 1,2, i \neq j, \tag{11}$$

$$\frac{de_1}{dt_2} = -\frac{C_2'(e_2)}{\Delta^C} \frac{\partial^2 \pi_1^{\ C}}{\partial e_1 \partial e_2} < 0, \tag{12.1}$$

$$\frac{de_2}{dt_1} = -\frac{C_1'(e_1)}{\Delta^C} \frac{\partial^2 \pi_2^{\ C}}{\partial e_2 \partial e_1} > 0, \tag{12.2}$$

where $\Delta^C = \frac{\partial^2 \pi_1^{\ C}}{\partial e_1^{\ 2}} \frac{\partial^2 \pi_2^{\ C}}{\partial e_1^{\ 2}} - \frac{\partial^2 \pi_1^{\ C}}{\partial e_1 \partial e_2} \frac{\partial^2 \pi_2^{\ C}}{\partial e_2 \partial e_1}$ is the determinant of the matrix, the sign of which is assumed to be positive (see Appendix 1). We thus summarize as follows.

Lemma 2. *In the Cournot duopoly case, (i) the tariff levied on the dirtier product raises the unit emission levels of both products; (ii) the tariff levied on the cleaner product raises the unit emission level of the cleaner product, whereas it reduces that of the dirtier product.*

The relevant firm has an incentive to raise the unit emission level to save more of the costs because the marginal revenue is reduced by an increasing tariff. Moreover, taking into account the fact that the environmentally differentiated products are strategic complements (substitutes) for the cleaner (dirtier) firm, we can easily interpret the implications of Lemma 2.

4. The Effect of a Tariff on the Environment and Social Welfare: The Case of the Development Country

4.1. The Bertrand Duopoly Case

We now show how the tariff policy by the DC (country 2) on imports of the dirtier product produced in the LDC (country 1) affects the net social welfare of the DC. From (5), that effect is composed of $\frac{dW_2^{EB}}{dt_1}=\frac{dW_2^{B}}{dt_1}-\gamma\frac{dE_2^{B}}{dt_1}$. Let us first analyze the effect of on the aggregate emissions in country *i*. The aggregate emissions in the Bertrand duopoly case is given by

$$E_i^{B}(e_1,e_2)=e_1q_1^{B}+e_2q_2^{B}=\frac{3e_1}{4e_1-e_2}v, \tag{13}$$

where it holds that $\partial E_i^{B}\big/\partial e_1<0$ and $\partial E_i^{B}\big/\partial e_2>0, i=1,2$. As an increase in the unit emission level of the dirtier product reduces its quantity demanded, $e_1q_1^{B}$ decreases. Taking into account (4) and the equilibrium quantities, the cleaner product accounts for a larger relative share of the emissions than does the dirtier product: $e_2q_2^{B}=2e_1q_1^{B}$. Accordingly, an increase in the unit emission level of the dirtier product reduces the aggregate emissions. In the case of an increase in the unit emission level of the cleaner product, the opposite occurs.

Differentiating the aggregate emissions in the DC, E_2^{B}, with respect to the tariff, t_1, we obtain

$$\frac{dE_2^{B}}{dt_1}=\frac{\partial E_2^{B}}{\partial e_1}\frac{\partial e_1}{\partial t_1}+\frac{\partial E_2^{B}}{\partial e_2}\frac{\partial e_2}{\partial t_1}=\frac{3v}{(4e_1-e_2)^2}\left\{e_1\frac{\partial e_2}{\partial t_1}-e_2\frac{\partial e_1}{\partial t_1}\right\}. \tag{14}$$

Taking into account (8.1) and (8.2), (14) can be rewritten as the following relationship:

$$\frac{dE_2^{B}}{dt_1}\geq(<)0\Leftrightarrow 2\geq(<)\eta_2,\ \ \eta_i\equiv\frac{e_iC_i''}{(-C_i')}, i=1,2.$$

As it holds that $\eta_i = \varepsilon + 1 > 2, i = 1,2$ from the nature of the cost functions in (3.1) and (3.2), we have $\frac{dE_2{}^B}{dt_1} < 0$.

Although the tariff raises the unit emission levels of both products, an increase in the level of the cleaner (dirtier) product increases (reduces) the aggregate emissions. In that case, the magnitude of an increase in the level of the cleaner product is sufficiently smaller than that of the dirtier product. Consequently, the tariff reduces the environmental damages in the DC, compared to the free trade case.

Second, we examine the effect of the tariff on the gross social welfare. Differentiating W_2^B with respect to t_1, we obtain

$$\frac{dW_2{}^B}{dt_1} = \left\{ \frac{\partial CS_2{}^B}{\partial e_1} + \frac{\partial R_2{}^B}{\partial e_1} \right\} \frac{\partial e_1}{\partial t_1} + \frac{\partial CS_2{}^B}{\partial e_2} \frac{\partial e_2}{\partial t_1} + \tau_1 \left\{ \frac{\partial R_1{}^B}{\partial e_1} \frac{\partial e_1}{\partial t_1} + \frac{\partial R_1{}^B}{\partial e_2} \frac{\partial e_2}{\partial t_1} \right\} + \frac{\partial \tau_1}{\partial t_1} R_1{}^B, \qquad (15)$$

where it holds that $\partial CS_2{}^B / \partial e_1 < 0$ and $\partial CS_2{}^B / \partial e_2 < 0$. As to the bracket of the first term, we have $\{\bullet\} = -\frac{3}{2(4e_1 - e_2)^2} v^2 < 0$. Taking into account the first-order properties of the revenue functions and Lemma 1, the signs of the first and second terms are negative. Unless the tariff revenue is large, the tariff reduces the gross social welfare: $\frac{dW_2{}^B}{dt_1} < 0$.

Therefore, from the analysis above, we conclude as follows.

Proposition 1. *Suppose, in the Bertrand duopoly case, the developed country imposes an ad valorem tariff on the dirtier product produced in the less developed country.*

(1) The tariff reduces the aggregate emissions in the developed country, compared to the free trade case.

(2) If the marginal social damage from aggregate emissions is larger (less) than some value, i.e., $\gamma > (<) \hat{\gamma}^B \left(\equiv \frac{dW_2{}^B / dt_1}{dE_2{}^B / dt_1} \right)$, *the tariff increases (reduces) the net social welfare, compared to the free trade case.*

The tariff policy by the DC government improves the environment while it reduces the gross welfare. If the DC government regards the domestic environment as important, i.e., $\gamma > \hat{\gamma}^B$, even if the consumer and producer surplus reduce, it should restrict imports of the dirtier product. Otherwise, it should choose a free trade policy. Moreover, if it holds that $\gamma = \hat{\gamma}^B$, there is an optimal tariff rate to maximize the net social welfare.

4.2. The Cournot Duopoly Case

In the Cournot duopoly case, the aggregate emissions of country *i* can be represented as

$$E_i^{\ C}(e_1, e_2) = e_1 q_1^{\ C} + e_2 q_2^{\ C} = \frac{3e_1 - e_2}{4e_1 - e_2} v. \tag{16}$$

Note that the cleaner product accounts for a larger share of the emissions relative to the dirtier product: $e_2 q_2^{\ C} > e_1 q_1^{\ C}$. Moreover, it holds that $\partial E_i^{\ C} / \partial e_1 > 0, \partial E_i^{\ C} / \partial e_2 < 0, i = 1,2.$ An increase in the unit emission level of the dirtier product reduces the quantity demanded of the product, while it sufficiently increases the demanded quantities and unit emission level of the cleaner product. Accordingly, an increase in the unit emission level of the dirtier product increases the aggregate emissions. On the other hand, an increase in the unit emission level of the cleaner product reduces its demanded quantities, but increases the demanded quantities of the dirtier product. However, it reduces the unit emission level of the dirtier product. In that case, the strategic substitute effect ensures that an increase in the unit emission level of the cleaner product reduces the aggregate emissions.

Differentiating the aggregate emissions in the DC, $E_2^{\ C}$, with respect to the tariff, t_1, we obtain

$$\frac{dE_2^{\ C}}{dt_1} = \frac{\partial E_2^{\ C}}{\partial e_1}\frac{\partial e_1}{\partial t_1} + \frac{\partial E_2^{\ C}}{\partial e_2}\frac{\partial e_2}{\partial t_1} = \frac{v}{(4e_1 - e_2)^2}\left\{ e_2 \frac{\partial e_1}{\partial t_1} - e_1 \frac{\partial e_2}{\partial t_1} \right\}. \tag{17}$$

Taking into account the nature of the cost function, we obtain $\frac{dE_2^{\ C}}{dt_1} > 0.$

In the case of the tariff levied on the dirtier product, as shown in Lemma 2, the unit emission levels of both products increase. Moreover, an increase in the unit emission level of the dirtier product increases the aggregate emissions, while that of the cleaner product reduces the aggregate emissions. The magnitude of the latter reduction is too small to offset the environmental damages caused by the increase in emissions of the dirtier product. As a result, the tariff increases the DC's environmental damages, compared to the free trade case.

Second, we show the effect of the tariff on the gross social welfare of the DC. Differentiating W_2^C with respect to t_1, we obtain

$$\frac{dW_2{}^C}{dt_1} = \left\{ \frac{\partial CS_2{}^C}{\partial e_1} + \frac{\partial R_2{}^C}{\partial e_1} \right\} \frac{\partial e_1}{\partial t_1} + \frac{\partial CS_2{}^C}{\partial e_2} \frac{\partial e_2}{\partial t_1} + \tau_1 \left\{ \frac{\partial R_1{}^C}{\partial e_1} \frac{\partial e_1}{\partial t_1} + \frac{\partial R_1{}^C}{\partial e_2} \frac{\partial e_2}{\partial t_1} \right\} + \frac{\partial \tau_1}{\partial t_1} R_1{}^C, \qquad (18)$$

where it holds that $\partial CS_2{}^C / \partial e_1 < 0, \partial CS_2{}^C / \partial e_2 < 0$. With respect to the bracket of the first term, we have $\{\bullet\} = \frac{1}{2(4e_1 - e_2)^2} v^2 > 0$. Taking into account the first-order properties of the revenue functions and Lemma 2, the sign of the first term is positive, while the second is negative. In that case, in general, the effects of levying a tariff on the sum of the consumer and producer surplus and on the tariff revenue are not unidirectional. If the magnitude of the relative effect on a unit emission level of the dirtier product, $\frac{\partial e_1 / \partial t_1}{\partial e_2 / \partial t_1}$, is sufficiently large, the sign of the effect on the sum of the consumer and producer surplus is positive, while that of the tariff revenue as in the third term is negative (see Appendix 2). Namely, the tariff protection significantly increases the profit of the domestic cleaner firm, while it reduces that of the foreign dirtier firm. In that case, it holds that $\frac{dW_2{}^C}{dt_1} > 0$. Otherwise, the tariff reduces the gross social welfare.

Therefore, we summarize as follows.

Proposition 2. *Suppose, in the Cournot duopoly case, the developed country imposes an ad valorem tariff on the dirtier product produced in the less developed country.*

(1) The tariff increases the aggregate emissions in the developed country, compared to the free trade case.

(2) The effect of the tariff on the net social welfare is as follows:

(i) when the magnitude of the effect of a tariff on the unit emission level of a dirtier product is not large, the tariff reduces the net social welfare, compared to the free trade case;

(ii) when the magnitude of the effect of a tariff on the unit emission level of a dirtier product is sufficiently large, if the marginal social damage of aggregate emissions is less (larger) than some value, i.e., $\gamma < (>) \hat{\gamma}^C \left(\equiv \frac{dW_2{}^C / dt_1}{dE_2{}^C / dt_1} \right)$, *the tariff increases (reduces) the net social welfare, compared to the free trade case.*

We have the implications of Proposition 2 (2) as follows. When the magnitude of the effect of the tariff on the unit emission level of a dirtier product is so large, the DC government imposes a tariff on imports of the dirtier product. This means that the DC government does not weight on the domestic environment, i.e., $\gamma \approx 0.$ But, if the DC government should consider the environmental damages significantly, the tariff rate might be higher than that with considering the valuation of environmental damages. On the other hand, when the magnitude of the effect of the tariff on the unit emission level of a dirtier product is small, the DC government should not impose a tariff. Moreover, if $\gamma = \hat{\gamma}^C$, there is an optimal tariff rate to maximize the net social welfare.

In the Cournot duopoly case, the DC government should choose a free trade policy or reduce the tariff rate, if it regards the domestic environment as important, namely γ is large. The result is opposite to that of Proposition 1 (2), in which the DC government should restrict imports of the dirtier product in the Bertrand duopoly case. The difference in the results is largely according to the difference in the effects on the environment in each mode of market competition and in the degree of the marginal social damage from aggregate emissions.

5. The Less Developed Country Case

5.1. The Bertrand Duopoly Case

Following the same procedure as the previous section, let us analyze the case that the LDC government imposes an *ad valorem* tariff on the cleaner product produced in the DC.

Differentiating the aggregate emissions in the LDC, ${E_1}^B$, with respect to the tariff, t_2, we first derive as follows: $\frac{d{E_1}^B}{dt_2} \geq (<) 0 \Leftrightarrow \eta_1 \geq (<) 2.$ From $\eta_1 > 2,$ we obtain $\frac{d{E_1}^B}{dt_2} > 0.$

Let us now show the effect of the tariff policy on the gross social welfare, ${W_1}^B$. Taking into account Lemma 1, the first-order properties of the revenue function of the dirtier domestic firm, and the negative effect of an increase in the unit emission levels on the consumer surplus, we understand that the effect of the tariff on the sum of the consumer and the producer surplus is negative. Unless the tariff revenue is large, the tariff reduces the gross social welfare: $\frac{d{W_1}^B}{dt_2} < 0.$

Therefore, we present the result as follows.

Proposition 3. *Suppose, in the Bertrand duopoly case, the less developed country imposes an ad valorem tariff on the cleaner product produced in the developed country.*

(1) The tariff increases the aggregate emissions in the less developed country, compared to the free trade case.

(2) The tariff reduces the net social welfare, compared to the free trade case.

The statements of Propositions 1 (1) and 3 (1) are intuitively natural. Namely, as the DC (LDC) government restricts imports of the dirtier (cleaner) product, the environment in the DC (LDC) is getting better (worse) than the free trade case. As to Proposition 3 (2), provided that the Bertrand duopoly prevails in the green market, the LDC should choose a free trade policy for imports of the cleaner product produced in the DC to improve the environment and social welfare.

5.2. The Cournot Duopoly Case

First, differentiating the aggregate emissions in the LDC with respect to the tariff, and taking into account Lemma 2, we obtain $d{E_1}^C / dt_2 < 0.$ Although the tariff policy raises the unit emission level of the cleaner product, it significantly reduces the demanded quantities of the cleaner product as well as the unit emission level of the dirtier product. As a result, paradoxically, the LDC government can improve the environment by restricting imports of the cleaner product.

Second, differentiating the gross social welfare of the LDC, W_1^C, with respect to the tariff, t_2, we obtain

$$\frac{dW_1^C}{dt_2} = \left\{ \frac{\partial CS_1^{\ C}}{\partial e_2} + \frac{\partial R_1^{\ C}}{\partial e_2} \right\} \frac{\partial e_2}{\partial t_2} + \frac{\partial CS_1^{\ C}}{\partial e_1} \frac{\partial e_1}{\partial t_2} + \tau_2 \left\{ \frac{\partial R_2^{\ C}}{\partial e_1} \frac{\partial e_1}{\partial t_2} + \frac{\partial R_2^{\ C}}{\partial e_2} \frac{\partial e_2}{\partial t_2} \right\} + \frac{\partial \tau_2}{\partial t_2} R_2^{\ C}. \qquad (19)$$

As to the bracket of the first term, we have $\{\bullet\} = -\dfrac{4e_1^{\ 2} - 2e_1 e_2 - e_2^{\ 2}}{2e_2^{\ 2}(4e_1 - e_2)^2} v^2 < 0$. Taking into account the first-order properties of the revenue functions and Lemma 2, the sign of the first term is negative, while that of the second is positive. Generally, the effect of levying a tariff on the sum of the consumer and producer surplus is not unidirectional. But, if the magnitude of the relative effect on the unit emission level of the cleaner product is sufficiently small, i.e., $-\dfrac{\partial e_2 / \partial t_2}{\partial e_1 / \partial t_2} \le \dfrac{\partial CS_1^{\ C} / \partial e_1}{\partial CS_1^{\ C} / \partial e_2 + \partial R_1^{\ C} / \partial e_2}$, then the sign of that effect is positive (see Appendix 3). Moreover, the sign of the third term which represents the effect on tariff revenues is always negative. Namely, the tariff protection has the following two effects: first, it increases the unit emission level of the cleaner product, and in turn decreases the sum of the corresponding consumer and producer surplus; second, as it reduces the unit emission level of the dirtier product, and in turn increases the corresponding consumer surplus. Hence unless the first negative effect is large, the tariff policy increases the gross welfare, compared to the free trade case. Otherwise, since the tariff policy reduces the gross social welfare, the LDC government should choose a free trade policy.

Based on the analysis above, we have the following results.

Proposition 4. *Suppose, in the Cournot duopoly case, the less developed country imposes an ad valorem tariff on the cleaner products produced in the developed country.*

(1) The tariff reduces the aggregate emissions, compared to the free trade case.

(2) The effect of a tariff on the net social welfare is as follows:

(i) when the magnitude of the effect of a tariff on the unit emission level of a cleaner product is not small, if the marginal social damage of aggregate emissions is larger (less) than

some value, i.e., $\gamma > (<) \tilde{\gamma}^C \left(\equiv \dfrac{dW_1^C / dt_2}{dE_1^C / dt_2} \right)$*, the tariff increases (reduces) the net social welfare, compared to the free trade case;*

(ii) when the magnitude of the effect of a tariff on the unit emission level of a cleaner product is sufficiently small, the tariff increases the net social welfare, compared to the free trade case.

The implication of Proposition 4 (2i) is plausible. If the LDC government significantly weights on the environmental damage, i.e., $\gamma > \tilde{\gamma}^C$, it should restrict imports of the cleaner product, even if the consumer and producer surplus reduce. On the other hand, Proposition 4 (2ii) is more interesting. If the LDC government would impose such a tariff rate that maximizes the gross social welfare, then the rate might be lower than that in the case that the LDC government cares the environment. In other words, paradoxically, the LDC government should charge the higher tariff on imports of the cleaner product whenever it considers the social environmental valuation importantly. The result is opposite to that of Proposition 3 (2), in which the LDC government should not restrict imports of the cleaner product in the Bertrand duopoly case.

6. Concluding Remarks

The characteristics of the model are: consumers produce the environmental wastes and effluents which cause environmental damages; there are heterogeneous consumers who have various preferences of environmental quality of the products in a green market; a firm chooses the environmental quality level of the product; a firm producing a cleaner (dirtier) product locates in a developed (less developed) country because the firm in the developed country has a superior environmental technology to the less developed country’s firm.

Our conclusions are that the effect of the tariff depends on the mode of market competition, in other words, the strategic relationships among the firms, and the degree of the marginal social damage from aggregate emissions. That is, it is natural for people in the developed country to restrict imports of the dirtier product produced in the less developed country to improve the environment and social welfare, while the less developed country should freely import the cleaner product produced in the developed country. However, we have shown that these statements may not necessarily hold in the case of Cournot duopoly.

Furthermore, our model does not necessarily imply that trade policies can be used to achieve environmental goals. In reality, the problems of practical implementations of trade policy are substantial. But, we have theoretically shown that a current tariff rate may not be socially optimal with considering environmental valuation. Suppose the developed country chooses a free trade policy for imports of the dirtier product produced in the less developed. If the government considers negative environmental externalities sufficiently, it should restrict the imports. This is the case of Proposition 1. Also, as shown in Proposition 4, provided that the Cournot duopoly prevails in the green market, the less developed country might impose the higher tariff rate charged on imports of the cleaner product produced in the developed country if it would weight on environment valuation sufficiently.

The conclusions may depend on the specificity of our model. For example, first, in order to focus on the direct effect of tariffs on the effluent of the product, we have assumed that the marginal cost of production is zero. We should examine the case of a nonzero marginal cost, which may also be a function of the effluent. Second, we have treated the case of trade barriers in the form of an *ad valorem* tariff. We intend to analyze the cases of specific tariffs and import quotas. Third, we will analyze the mixed policy case of a tariff (or an import subsidy) and of a production tax (or subsidy). Finally, we have not discussed tariff policy games played by both countries since we have just focused on the impact of a tariff on the environment and social welfare of an importing country. Based on a reciprocal market model, we will examine trade policy games with endogenous choice of environmental qualities and analyze the effect on the environment and social welfare of the world economy as a whole.

Appendix 1

The determinant of the matrix can be generally expressed as

$$\Delta^k = \frac{\partial^2 \pi_1{}^k}{\partial e_1{}^2}\frac{\partial^2 \pi_2{}^k}{\partial e_1{}^2} - \frac{\partial^2 \pi_1{}^k}{\partial e_1 \partial e_2}\frac{\partial^2 \pi_2{}^k}{\partial e_2 \partial e_1}, k = B, C.$$

In the model, the following equations hold:

$$e_i \frac{\partial^2 R_i{}^k}{\partial e_i{}^2} + e_j \frac{\partial^2 R_i{}^k}{\partial e_i \partial e_j} = -2\frac{\partial R_i{}^k}{\partial e_i}, i, j = 1,2, i \neq j, k = B, C,$$

$$-\frac{\partial R_i{}^k}{\partial e_i} = -t_i C_i{}', i = 1,2, k = B, C.$$

Using the two equations above, we can rewrite the determinant as follows:

$$\Delta^k = \frac{e_1}{e_2}\frac{\partial^2 R_1{}^k}{\partial e_1 \partial e_2}\left(t_1 \frac{C_1{}'}{e_1}\right)(2-\eta_1) + \frac{e_2}{e_1}\frac{\partial^2 R_2{}^k}{\partial e_2 \partial e_1}\left(t_2 \frac{C_2{}'}{e_2}\right)(2-\eta_2)$$
$$+\left(t_1 \frac{C_1{}'}{e_1}\right)(2-\eta_1)\left(t_2 \frac{C_2{}'}{e_2}\right)(2-\eta_2), k = B, C,$$

where $\eta_i \equiv \frac{e_i C_i''}{(-C_i')} > 0, i = 1,2.$ Based on the nature of the cost functions in (3.1) and (3.2), it holds that $\eta_i = \varepsilon + 1 > 2, i = 1,2.$

In the Bertrand duopoly case, $k = B$, taking into account the positive cross partial coefficients, the sign of the determinant is positive. Thus the stability condition is satisfied. On the other hand, in the Cournot duopoly case, $k = C$, as the signs of the two cross partial coefficients are different, the sign of the determinant is not always positive. Thus it is assumed that $\Delta^C > 0$.

Appendix 2

With respect to the first and the third terms in (18), we derive the following relationships:

$$\left\{\frac{\partial CS_2{}^C}{\partial e_1} + \frac{\partial R_2{}^C}{\partial e_1}\right\}\frac{\partial e_1}{\partial t_1} + \frac{\partial CS_2{}^C}{\partial e_2}\frac{\partial e_2}{\partial t_1} > (\leq) 0 \Leftrightarrow \frac{\partial e_1 / \partial t_1}{\partial e_2 / \partial t_1} > (\leq) \frac{-\partial CS_2{}^C / \partial e_2}{\partial CS_2{}^C / \partial e_1 + \partial R_2{}^C / \partial e_1},$$

$$\tau_1\left\{\frac{\partial R_1{}^C}{\partial e_1}\frac{\partial e_1}{\partial t_1} + \frac{\partial R_1{}^C}{\partial e_2}\frac{\partial e_2}{\partial t_1}\right\} > (\leq) 0 \Leftrightarrow \frac{\partial e_1 / \partial t_1}{\partial e_2 / \partial t_1} < (\geq) \frac{\partial R_1{}^C / \partial e_2}{-\partial R_1{}^C / \partial e_1},$$

where

$$\frac{-\partial CS_2{}^C/\partial e_2}{\partial CS_2{}^C/\partial e_1+\partial R_2{}^C/\partial e_1}=\frac{16e_1{}^3-12e_1{}^2e_2+2e_1e_2{}^2+e_2{}^3}{e_2{}^2(4e_1-e_2)}>1>\frac{\partial R_1{}^C/\partial e_2}{-\partial R_1{}^C/\partial e_1}=\frac{2e_1}{4e_1+e_2}>0.$$

Therefore, if it holds that $\dfrac{\partial e_1/\partial t_1}{\partial e_2/\partial t_1}>\dfrac{-\partial CS_2{}^C/\partial e_2}{\partial CS_2{}^C/\partial e_1+\partial R_2{}^C/\partial e_1}$, then we obtain

$$\left\{\frac{\partial CS_2{}^C}{\partial e_1}+\frac{\partial R_2{}^C}{\partial e_1}\right\}\frac{\partial e_1}{\partial t_1}+\frac{\partial CS_2{}^C}{\partial e_2}\frac{\partial e_2}{\partial t_1}>0 \text{ and } \left\{\frac{\partial R_1{}^C}{\partial e_1}\frac{\partial e_1}{\partial t_1}+\frac{\partial R_1{}^C}{\partial e_2}\frac{\partial e_2}{\partial t_1}\right\}<0.$$

Appendix 3

With respect to the first and the third terms in (19), we derive the following relationships:

$$\left\{\frac{\partial CS_1{}^C}{\partial e_2}+\frac{\partial R_1{}^C}{\partial e_2}\right\}\frac{\partial e_2}{\partial t_2}+\frac{\partial CS_1{}^C}{\partial e_1}\frac{\partial e_1}{\partial t_2}>(\le)0\Leftrightarrow-\frac{\partial e_2/\partial t_2}{\partial e_1/\partial t_2}<(\ge)\frac{\partial CS_1{}^C/\partial e_1}{\partial CS_1{}^C/\partial e_2+\partial R_1{}^C/\partial e_2},$$

where $\dfrac{\partial CS_1{}^C/\partial e_1}{\partial CS_1{}^C/\partial e_2+\partial R_1{}^C/\partial e_2}=\dfrac{e_2{}^2(12e_1-7e_2)}{(4e_1-e_2)(4e_1{}^2-2e_1e_2-e_2{}^2)}>0.$

References

Aoki, R., 2003, The effect of credible quality investment with Bertrand and Cournot competition, Economic Theory 21, 653–672.

Aoki, R., Prusa, T. J., 1997, Sequential versus simultaneous choice with endogenous quality, International Journal of Industrial Organization 15, 103–121.

Barrett, S., 1994, Strategic environmental policy and international trade, Journal of Public Economy, 54, 325-338.

Chao, Chi-Chur, and Eden S. H. Yu, 2004, Environmental Policy, International Trade, and Factor Market, Elsevier.

Copeland, B. R. and Taylor, M. S., 2003, Trade and the Environment: Theory and Evidence, Princeton University Press, Princeton.

Herguera, I., Kujal, P., and Petrakis, E., 2002, Tariffs, quality reversals, and exit in vertically differentiated industries, Journal of International Economics 58, 467–492.

Moraga-Gonzalez, J. L., Pandron-Fumero, N., 2002, Environmental policy in a green market, Environmental and Resource Economics 22, 419–447.

Moraga-Gonzalez, J. L., Viaene, J-M., 2005, Trade policy and quality leadership in transition economies, European Economic Review 49, 359–385.

Polavarapu, R., Vaidya, A., 1996a, Commercial policy with vertical product differentiation, Journal of Economic Integration 11 (2), 230–247.

Polavarapu, R., Vaidya, A., 1996b, Optimal trade policy with a quality-differentiated product, The International Trade Journal 10 (3), 379–406.

Rauscher, M., 1997, International Trade, Factor Movements, and the Environment, Clarendon Press, Oxford.

Ulph, A. M., 1999, Trade and the Environment, Edward Elgar, Massachusetts.

Ulph, A. M. (ed.), 2001, Environmental Policy, International Agreements, and International Trade, Oxford University Press, New York.