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On the Effects of Emission Standards in an Importing Country: A Foreign Duopoly Case*

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Abstract

Employing an environmentally differentiated duopoly model, we analyze how emission standards affect imports, the environment, and social welfare. We show that a strict emission standard is not necessarily import-restrictive, whereas it may possibly degrade the environment. Furthermore, we present evidence that the effect of emission standards on net social surplus depends on the mode of market competition and the degree of marginal social valuation of environmental damage.

JEL classification: D43; F12; F13; L52; Q28

Key words: emission standards; environmentally differentiated duopoly; green market

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1. Introduction

A government often restricts imports from foreign countries for reasons of environmental protection, public health, social security, and others. For example, regulations on emissions and noise of imported vehicles are classified as types of non-tariff barriers, i.e., technical barriers to trade (hereafter, TBT), under the GATT/WTO system. Accordingly, the government, if it is a member of the GATT/WTO, should set technical regulations and standards in accordance with the GATT/WTO agreement on TBT without unnecessarily increasing barriers to foreign trade.

Hence, the following questions are important. Is an emission standard policy trade-restrictive? Can an emission standard policy improve the environment? Furthermore, how does an emission standard policy affect social welfare? We develop answers to these questions, using a model of environmentally differentiated products. That is, the purpose of this paper is to analyze how an emission standard such as a TBT affects imports, the environment, and the social surplus of an importing country.

Many studies analyze the effect of environmental policy in the context of the global economy. That is, there are effects from environmental policies such as emission taxes, emission standards, and eco-labeling on the structure of international trade, production and consumption, and social welfare. For example, some important studies are those of Conrad (1993), Barrett (1994), Kennedy (1994), Mani (1996), Ulph (1996, 1999), Rauscher (1997), Copeland and Taylor (2003), and Neary (2006). They argue that polluting waste and environmental effluent are by-products of production processes in manufacturing industries, and assume that consumers are homogenous.

As mentioned in Valentini (2005), however, we have been observing a growing demand for environmental care. That is, consumers will purchase products that are more environment-friendly or that are produced with more environment-friendly techniques. This implies that consumers strictly care about products imported from foreign countries as well as produced in the domestic country. Also, there is enough evidence that firms are aware of the consumers' behavior.

We deal with products associated with environmental characteristics in a green market where effluents and noises are by-products of consumption by heterogeneous consumers, who differ in terms of their willingness to pay for the products according to the product's environmental quality. In fact, the environmental damage caused by the polluting wastes and effluents associated with the consumption of these products may be external for individual consumers. However, consumers who are very conscious of destruction of the environment would purchase an environment-friendly product even if its price was higher than that of an environmentally unfriendly product. Furthermore, consumers who are not concerned about the environment purchase a lower-priced product. That is, consumers differ in their degree of consciousness about the environment (Scherhorn, 1993). For example, in the context of car exhaust fumes, the emission level of a car with a hybrid engine is much lower than that of a car with a diesel engine. Hence, consumers who care about global warming and air pollution prefer the hybrid car, whereas other consumers do not. Furthermore, more extreme environmentalists may not purchase any type of car, but instead ride a bicycle.

Valentini (2005), which is related to our paper, surveys environmental quality provision and eco-labeling based on product differentiation models. He considers eco-labeling, but does not examine the effect of an emission standard policy. Furthermore, Jayadevappa and Chhatre (2000) discuss issues such as establishing the effects of international trade on environmental quality in a comprehensive literature review.

Because a unit emission level of products in a green market is similar to environmental quality, our paper is closely related to the literature on minimum quality standards (Ronnen, 1991; Valletti, 2000) and on minimum environmental standards (Motta and Thisse, 1999). In particular, Motta and Thisse (1999) analyze the impact of environmental quality standards on market structure and welfare. As will be described below, there are negative externalities involved in the consumption decisions, but what matters from an individual consumer's perspective is the environmental quality of the product personally purchased. Accordingly, they do not consider the impact of an environmental quality standard on totally accumulated pollutants. This implies that the welfare function does not include a term accounting for the social cost of pollution. However, in this paper, we show that aggregate emissions, which are by-products of the consumption of imported products, increase environmental damage of the importing country, and thereby decrease social welfare. Thus, the importing government would develop an emission standard policy, taking the negative environmental externalities into account. Furthermore, Motta and Thisse (1999) deal with the Bertrand duopoly case; however, we address the Cournot duopoly case as well as the Bertrand duopoly case.

In this paper, incorporating the preference behavior of heterogeneous consumers presented by Moraga-González and Padrón-Fumero (2002), we examine the effect of an emission standard on imports, the environment, and social surplus. Here, we recall that the effect of a policy may depend on the mode of market competition. For example, as shown in Eaton and Grossman (1986), in the Cournot (Bertrand) duopoly case, the optimal strategic export policy is a subsidy (tax, respectively). As shown below, we present evidence that the effects of an emission standard depend on the mode of market competition and the degree of marginal social valuation of environmental damage. Specifically, we present evidence for the following conclusions: When a foreign Bertrand duopoly prevails in the green market of an importing country, a strict emission standard on a dirtier product worsens the environment, whereas it increases the total consumer surplus. Thus, if the importing government is significantly concerned about the environment, the emission standard reduces the net social surplus included in the social valuation of environmental damage. On the other hand, when a foreign Cournot duopoly prevails in the green market, a strict emission standard improves the environment and thus increases the net social surplus.

Furthermore, an emission standard policy is usually oriented towards levy charges on polluting products or lower environmental quality products, such as a minimum quality requirement. However, from a theoretical viewpoint, to compare the results derived in the case of an emission standard policy for the dirtier product, we assume that the importing government can regulate the unit emission level of the cleaner product. That is, the importing government can force the exporting foreign firms to adopt a green strategy policy. In this case, we present the following conclusions: When a foreign Bertrand duopoly prevails in the green market of an importing country, a strict emission control on the cleaner product improves the environment and thus increases the net social surplus included in the social valuation of environmental damage. On the other hand, when a foreign Cournot duopoly prevails in the market, because a strict emission control worsens the environment, it reduces the net social surplus if the importing government is significantly concerned about the environment.

The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 first shows the free trade equilibrium, and then examines the effects of emission standard on imports, the environment, and social welfare in the case of a foreign Bertrand duopoly. Similarly, Section 4 analyzes the case of a foreign Cournot duopoly. Finally, Section 5 summarizes our results and raises other issues.

2. The Model

We suppose that consumers in a green market of an importing country purchase products imported from foreign countries. That is, there are no domestic firms producing relevant products. First, let us describe the structure of the green market, applying a vertical product differentiation model. There exists a continuum of heterogeneous consumers who differ in their marginal valuations, θ, of the green features of a product. To simplify, we assume that the consumer-matching value is uniformly distributed in the market, $\theta \in [0,1]$. A consumer for whom θ is close to unity (zero) is conscious (not conscious) of the environment. Let e denote the observable unit level of polluting emissions associated with the product. Each consumer purchases either one or no units of the product. The net surplus of consumer θ who acquires the variant e at a price of p is $u = \max\{v - e\theta - p, 0\}$, $e \in (0, \infty)$, where v is the utility obtained from consuming a single unit of the product irrespective of the variant's unit emission level. A consumer who does not buy any product is assumed to have a net surplus of zero.

There are two kinds of products in the market, which are respectively associated with a higher and a lower level of the unit of emission (hereafter, a dirtier and a cleaner product). Without loss of generality, we assume that foreign firm *D* (*C*) supplies a product with a unit emission level e_D (e_C, respectively) at price p_D (p_C, respectively), and $e_D \geq e_C$.

We derive demand functions for environmentally differentiated products. Let us first consider the marginal consumer who is indifferent between the net surplus given by purchasing the dirtier and the cleaner product. This is characterized by $\tilde{\theta} = \dfrac{p_C - p_D}{e_D - e_C}$. Furthermore, the index of the marginal consumer who is indifferent between the net surplus given by purchasing the cleaner product and nothing is characterized by $\hat{\theta} = \dfrac{v - p_C}{e_D}$. Thus, consumer θ falling into $0 \leq \theta < \tilde{\theta}$ $(\tilde{\theta} < \theta < \hat{\theta})$ purchases the dirtier (cleaner, respectively) product. In addition, consumer θ falling into $\hat{\theta} < \theta \leq 1$ purchases nothing in the market. This implies that the green market is not completely covered by all consumers. See Figure 1.

Let q_D (q_C) represent the quantity demanded for the dirtier (cleaner, respectively) product. Given the assumption of a uniform distribution, the demand functions are expressed by:

$$q_D = \tilde{\theta} = \frac{p_C - p_D}{e_D - e_C}, \tag{1.1}$$

$$q_C = \hat{\theta} - \tilde{\theta} = \frac{e_D(v - p_C) - e_C(v - p_D)}{e_C(e_D - e_C)}. \tag{1.2}$$

From (1.1) and (1.2), we derive the corresponding inverse demand functions:

$$p_D = v - e_D q_D - e_C q_C, \tag{2.1}$$

$$p_C = v - e_C(q_C + q_D). \tag{2.2}$$

Second, let us present the characteristics of foreign firms exporting the products associated with environmental qualities. The cost function of a unit emission level of the product can be generally represented by: $F_i = F_i(e_i), F_i' < 0, F_i'' > 0, i = C, D.$ Following Moraga-González and Padrón-Fumero (2002, Assumption 2), we assume that the cost function is a homogeneous function of degree $\varepsilon \geq 2.$

$$F_D = \alpha e_D^{-\varepsilon}, \tag{3.1}$$

$$F_C = e_C^{-\varepsilon}. \tag{3.2}$$

To avoid multiple equilibria in the decision game of the unit emission levels, we assume that the cost functions are sufficiently asymmetric among the firms: $\alpha > 1.$ Furthermore, to simplify, we assume that marginal costs of production are independent of the unit emission level and are zero. Thus, the profit function of foreign firm *i* is given by $\pi_i = p_i q_i - F_i, i = C, D.$

Third, we assume that the importing country's government maximizes social welfare including the social valuation of environmental damage. Hence, aggregate emissions, which erode the environment of the importing country, are expressed by:

$$E = e_D q_D + e_C q_C. \tag{4}$$

Furthermore, as mentioned above, because there are three types of consumers purchasing the dirtier product, those purchasing the cleaner product, and those never purchasing any products in the market, total consumer surplus can be represented by:

$$CS = \int_0^{\tilde{\theta}} (v - e_D\theta)d\theta - p_D q_D + \int_{\tilde{\theta}}^{\hat{\theta}} (v - e_C\theta)d\theta - p_C q_C + 0. \tag{5}$$

Thus, because there is not producer surplus, net social surplus included in the social valuation of the environmental damage is defined by:

$$W \equiv CS - \gamma E \tag{6}$$

where $\gamma(\geq 0)$ is the marginal social valuation of environmental damage.

In what follows, we consider a three-stage game: in the first stage, the government determines an emission standard; in the second stage, foreign firms determine the unit emission levels, given the emission standard; and in the final stage, they compete on price or quantity in the market of the importing country. We derive a subgame perfect Nash equilibrium by backward induction.

3. Emission Standards in the Foreign Bertrand Duopoly Case

3.1 Free trade equilibrium

As the derivation of the Bertrand-Nash equilibrium in the final stage is straightforward, the procedure of the derivation is omitted. The equilibrium quantities in the final stage are given by:

$$q_D^B = \frac{1}{4e_D - e_C} v, \tag{7.1}$$

$$q_C^B = \frac{2e_D}{e_C(4e_D - e_C)} v. \tag{7.2}$$

Hence, the revenue functions in the second stage are expressed by:

$$R_D^B = \frac{e_D - e_C}{(4e_D - e_C)^2} v^2, \tag{8.1}$$

$$R_C^B = \frac{4e_D(e_D - e_C)}{e_C(4e_D - e_C)^2} v^2. \tag{8.2}$$

In view of (3.1), (3.2), (8.1), and (8.2), the first-order conditions for profit maximization with respect to the unit emission level of each firm are given by:

$$-\frac{(4e_D - 7e_C)}{(4e_D - e_C)^3} v^2 - F_D' = 0, \tag{9.1}$$

$$-\frac{4e_D(4e_D{}^2 - 3e_D e_C + 2e_C{}^2)}{e_C{}^2 (4e_D - e_C)^3} v^2 - F_C' = 0. \tag{9.2}$$

Based on the properties of the revenue functions, (8.1) and (8.2), as in Appendix 1, we derive the reaction function of the unit emission level of foreign firm *i* as:

$$e_i = \beta_i(e_j), \beta_i' > 0, i, j = C, D, i \neq j.$$

That is, the unit emission levels of the products are strategic complements for both firms in the Bertrand duopoly case. Furthermore, we can show that there is a unique and stable Nash equilibrium, $\{e_D^{BF}, e_C^{BF}\}$, under the free trade case (see Appendix 2, and Moraga-González and Padrón-Fumero, 2002, Proposition 3). See Figure 2.

3.2 Emission standard, imports, environment, and welfare

We deal with an emission standard on the dirtier product. Suppose that the government chooses an emission standard lower than or equal to the level in the free trade case: $e_D{}^{BF} \geq \bar{e}_D$. Hence, foreign firm *D* would choose the unit emission level of the dirtier product equal to the emission standard for profit maximization.

For the analysis below, we begin by considering the effect on the ratio of emission levels of the products, which is given by $\lambda^B = \frac{e_D}{e_C} (> \frac{7}{4})$. The effect is expressed as:

$$\frac{d\lambda^B}{d\bar{e}_D} \geq (<) 0 \Leftrightarrow 1 \geq (<) \lambda^B \beta_C' \Leftrightarrow 2 \leq (>) \eta_C \tag{10}$$

where $\lambda^B \beta_C' = \frac{\partial e_C}{\partial \bar{e}_D} \frac{\bar{e}_D}{e_C}$. Because it holds that $\eta_i \equiv -\frac{e_i F_i''}{F_i'} = \varepsilon + 1 > 2, i = C, D,$ given (3.1) and (3.2), a strict emission standard reduces the ratio of emission levels of the products (see Appendix 3). Because this result means a reduction of the difference in environmental qualities between both products, it, in turn, substantially enhances price competition.

Let us show the effect of an emission standard on the dirtier and the cleaner products, respectively. Taking (7.1) and (7.2) into account, we derive:

$$\frac{dq_D{}^B}{d\bar{e}_D} = \frac{\partial q_D{}^B}{\partial \bar{e}_D} + \frac{\partial q_D{}^B}{\partial e_C}\frac{\partial e_C}{\partial \bar{e}_D} \geq (<) 0 \Leftrightarrow \frac{\partial e_C}{\partial \bar{e}_D}\frac{\bar{e}_D}{e_C} \geq (<) 4\lambda^B, \tag{11.1}$$

$$\frac{dq_C{}^B}{d\bar{e}_D} = \frac{\partial q_C{}^B}{\partial \bar{e}_D} + \frac{\partial q_C{}^B}{\partial e_C}\frac{\partial e_C}{\partial \bar{e}_D} < 0. \tag{11.2}$$

Given the expression of the right-hand side of (11.1), because $\frac{\partial e_C}{\partial \bar{e}_D}\frac{\bar{e}_D}{e_C} < 1$ and $4\lambda^B > 1$, we have $\frac{dq_D{}^B}{d\bar{e}_D} < 0$. Thus, a strict emission standard increases imports of both products, compared with the free trade case. That is, a strict emission standard improves the environmental qualities of both products. This, in turn, increases the proportion of consumers in the market because the environmental quality improvement not only raises the valuation of the products by consumers, but also lowers prices. Thus, emission standards on the dirtier product are not necessarily import-restrictive. However, does this imply that the emission standards policy increases aggregate emissions, and thereby deteriorates the environment?

Substituting (7.1) and (7.2) into (4), we have $E^B = \frac{3e_D}{4e_D - e_C}v$ where it holds that $\frac{\partial E^B}{\partial e_D} = -\frac{3e_C}{(4e_D - e_C)^2}v < 0$ and $\frac{\partial E^B}{\partial e_C} = \frac{3e_D}{(4e_D - e_C)^2}v > 0$. Given (4) and (7.1), we have $E^B = 3e_D q_D{}^B$. Hence, the magnitude of the reduction of the quantity demanded is larger than that of the increase in the unit emission level. Thus, an increase in the unit emission level of the dirtier product reduces aggregate emissions. On the other hand, in the case of an increase in the unit emission level of the cleaner product, the opposite events occur.

The effect of an emission standard on aggregate emissions is represented by:

$$\frac{dE^B}{d\bar{e}_D} = \frac{\partial E^B}{\partial \bar{e}_D} + \frac{\partial E^B}{\partial e_C}\frac{\partial e_C}{\partial \bar{e}_D}. \tag{12}$$

Given (12), we derive the following relationships:

$$\frac{dE^B}{d\bar{e}_D} \geq (<) 0 \Leftrightarrow \lambda^B \beta_C' \geq (<) 1 \Leftrightarrow 2 \geq (<) \eta_C .$$

Because $\eta_C > 2,$ a strict emission standard increases aggregate emissions, and thereby worsens the environment, compared with the free trade case.

Furthermore, substituting (7.1) and (7.2) into (5), consumer surplus is generally given by:

$$CS^B = \frac{4e_D{}^2 + e_D e_C - e_C{}^2}{2e_C(4e_D - e_C)^2} v^2$$

where it holds that $\frac{\partial CS^B}{\partial \bar{e}_D} < 0$ and $\frac{\partial CS^B}{\partial e_C} < 0.$ Hence, the effect on consumer surplus is:

$$\frac{dCS^B}{d\bar{e}_D} = \frac{\partial CS^B}{\partial \bar{e}_D} + \frac{\partial CS^B}{\partial e_C}\frac{\partial e_C}{\partial \bar{e}_D} < 0. \tag{13}$$

Thus, a strict emission standard increases consumer surplus.

Finally, the effect on net social surplus is expressed by $\frac{dW^B}{d\bar{e}_D} = \frac{dCS^B}{d\bar{e}_D} - \gamma \frac{dE^B}{d\bar{e}_D}.$ Based on (12) and (13), we summarize the result as follows.

Proposition 1 (Moraga-González and Padrón-Fumero, 2002, Proposition 6)

When a foreign Bertrand duopoly prevails in the market, a strict emission standard on the dirtier product reduces (increases) net social surplus if the marginal social valuation of environmental damage is larger (smaller) than a certain value: $\gamma > (<) \hat{\gamma}^B \equiv \frac{dCS^B / d\bar{e}_D}{dE^B / d\bar{e}_D}.$

If the government substantially gives weight to concerns about the environment, $\gamma > \hat{\gamma}^B$, a strict emission standard further increases aggregate emissions rather than consumer surplus. Thus, paradoxically, the government should mitigate the emission standard on the dirtier product. Otherwise, i.e., $\gamma < \hat{\gamma}^B$, the government should impose a strict emission standard policy on imports of the dirtier product.

3.3 Emission regulation of a cleaner product

Secondly, following the same procedure as in 3.2, we examine the effects of emission regulation of the cleaner product: ${e_C}^F \geq \bar{e}_C > 0$. We begin by showing the effect on the ratio of unit emission levels as follows.

$$\frac{d\lambda^B}{d\bar{e}_C} \geq (<) 0 \Leftrightarrow \frac{\beta_D'}{\lambda^B} \geq (<) 1 \Leftrightarrow 2 \geq (<) \eta_D \tag{14}$$

where $\dfrac{\beta_D'}{\lambda^B} = \dfrac{\partial e_D}{\partial \bar{e}_C} \dfrac{\bar{e}_C}{e_D}$. Because $\eta_D > 2$, a strict emission regulation increases the ratio of emission levels of the products. This implies an increase in the difference in environmental qualities between both products. This, in turn, mitigates price competition.

Let us analyze the effect of the emission regulation policy on imports of the dirtier and the cleaner product, respectively. We easily derive the following expressions:

$$\frac{d{q_D}^B}{d\bar{e}_C} = \frac{\partial {q_D}^B}{\partial \bar{e}_C} + \frac{\partial {q_D}^B}{\partial e_D} \frac{\partial e_D}{\partial \bar{e}_C} \geq (<) 0 \Leftrightarrow \frac{\partial e_D}{\partial \bar{e}_C} \frac{\bar{e}_C}{e_D} \leq (>) \frac{1}{4\lambda^B}, \tag{15.1}$$

$$\frac{d{q_C}^B}{d\bar{e}_C} = \frac{\partial {q_C}^B}{\partial \bar{e}_C} + \frac{\partial {q_C}^B}{\partial e_D} \frac{\partial e_D}{\partial \bar{e}_C} < 0. \tag{15.2}$$

Thus, the effect of a strict emission regulation on imports of the dirtier product is not unidirectional as $\frac{\partial e_D}{\partial \bar{e}_C}\frac{\bar{e}_C}{e_D} < 1$ and $\frac{1}{4\lambda^B} < 1$. That is, a decrease in the unit emission level of the cleaner product directly transfers the demand for the dirtier product to the cleaner product. On the other hand, a decrease in the unit emission level of the cleaner product increases the demand for that product because it induces a decrease in the unit emission level of the dirtier product because of a strategic complements effect. As the former negatively affects imports, but the latter positively affects imports, the total effect on imports is consequently ambiguous. On the other hand, a strict emission regulation increases imports of the cleaner product, compared with the free trade case.

The effect of emission regulation of the cleaner product on aggregate emissions is expressed by $\frac{dE^B}{d\bar{e}_C} = \frac{\partial E^B}{\partial \bar{e}_C} + \frac{\partial E^B}{\partial e_D}\frac{\partial e_D}{\partial \bar{e}_C}$. Hence, we obtain the following relationships:

$$\frac{dE^B}{d\bar{e}_C} \geq (<) 0 \Leftrightarrow \frac{\beta_D'}{\lambda^B} \leq (>) 1 \Leftrightarrow 2 \leq (>) \eta_D.$$

Because $\eta_D > 2$, a strict emission regulation reduces aggregate emissions, $\frac{dE^B}{d\bar{e}_C} > 0$, and thereby improves the environment, compared with the free trade case. This result is opposite to that of the case of an emission standard on the dirtier product. In other words, the government should convey a strict emission regulation not for the dirtier product, but for the cleaner product, to protect the environment.

Furthermore, with respect to the effect on consumer surplus, we easily obtain $\frac{dCS^B}{d\bar{e}_C} < 0$. Therefore, it holds that $\frac{dW^B}{d\bar{e}_C} = \frac{dCS^B}{d\bar{e}_C} - \gamma\frac{dE^B}{d\bar{e}_C} < 0$. We summarize the result as follows.

Proposition 2

When a foreign Bertrand duopoly prevails in the market, a strict emission regulation on the *cleaner product increases net social surplus.*

Proposition 2 suggests that the importing country's government should choose a unit emission level of the cleaner product such as to allow the profit of the foreign firm supplying the product to be approximately equal to the reservation profit, e.g., zero profit.

4. Cournot Duopoly Case

In this section, following the same procedure as in Section 3, we examine the Cournot duopoly case. Then, comparing the results of the Bertrand and Cournot duopoly cases, we present evidence such that the effects of an emission standard depends on the mode of market competition and the degree of marginal social valuation of environmental damage.

4.1 Free trade equilibrium

The quantities in the Cournot–Nash equilibrium of the final stage are given by:

$$q_D^C = \frac{1}{4e_D - e_C} v, \tag{16.1}$$

$$q_C^C = \frac{2e_D - e_C}{e_C(4e_D - e_C)} v. \tag{16.2}$$

where $e_D \geq e_C$ and superscript C denotes Cournot competition. Hence, the equilibrium revenue functions in the second stage are expressed by:

$$R_D^C = \frac{e_D}{(4e_D - e_C)^2} v^2, \tag{17.1}$$

$$R_C^C = \frac{(2e_D - e_C)^2}{e_C(4e_D - e_C)^2} v^2. \tag{17.2}$$

Note that if $e_C = e_D = e$, then $q_C^C = q_D^C = \frac{v}{3e}$, and $R_C^C = R_D^C = \frac{v^2}{9e}$. Given the assumption of asymmetric cost functions as in (3.1) and (3.2), it holds that $\pi_C^C > \pi_D^C$. This means that the profit of a firm with an efficient technology, i.e., foreign firm C, is higher than that of one with an inefficient technology, i.e., foreign firm D, in the *homogeneous product market*.

Taking (17.1) and (17.2) into account, the first-order conditions for profit maximization of the firms in the second stage are given by:

$$-\frac{4e_D + e_C}{(4e_D - e_C)^3}v^2 - F_D{}' = 0, \tag{18.1}$$

$$-\frac{(2e_D - e_C)(8e_D{}^2 - 2e_De_C + e_C{}^2)}{e_C{}^2(4e_D - e_C)^3}v^2 - F_C{}' = 0. \tag{18.2}$$

As shown in Appendix 4, based on (18.1) and (18.2), we derive the reaction functions of the unit emission levels in the Cournot duopoly case as follows:

$$e_C = \phi_C(e_D), \phi_C{}' > 0. \tag{19.1}$$

$$e_D = \phi_D(e_C), \phi_D{}' < 0, \tag{19.2}$$

In view of (19.1) and (19.2), the unit emission levels of the products are strategic complements (substitutes) with respect to foreign firm C (D) in the Cournot duopoly case. A decrease in the unit emission level of the dirtier product reduces the market share and revenue of foreign firm C. So, foreign firm C has an incentive to improve the environmental quality to increase market share. On the other hand, a decrease in the unit emission level of the cleaner product similarly reduces the market share and revenue of foreign firm D. Hence, to increase the market share and thus the revenue, foreign firm D has to reduce the unit emission level of the dirtier product, even though the cost increases.

Here, we note that there is a strategically complementary relationship with respect to the unit emission level of the cleaner product provided by foreign firm C, regardless of the mode of market competition. Accordingly, as shown below, a strict emission standard on the dirtier product always improves the environmental quality of the cleaner product. However, foreign firm C has an incentive to reduce the unit emission level of the cleaner product to mitigate competitiveness in the Bertrand duopoly case. On the other hand, foreign firm C has an incentive to reduce that level to extend its market share in the Cournot duopoly case.

Based on (19.1) and (19.2), there is a unique and stable Nash equilibrium in the stage in which the unit emission levels are determined under free trade, i.e., $\{e_C^{CF}, e_D^{CF}\}$. See Appendix 2. Hereafter, for simplicity of expression, we do not use superscript C of the unit emission level in the Cournot duopoly case. See Figure 3.

4.2 Effect of an emission standard on imports, environment, and welfare

We examine how an emission standard on the dirtier product, i.e., $e_D^{CF} \geq \bar{e}_D$, affects imports, the environment, and net social surplus in the case of a foreign Cournot duopoly. Because we have shown the equilibrium in the final stage in section 4.1, we present the effect of an emission standard on the ratio of the unit emission levels of the products, i.e., $\lambda^C = \dfrac{e_D}{e_C} \geq 1$:

$$\frac{d\lambda^C}{d\bar{e}_D} \geq (<) 0 \Leftrightarrow 1 \geq (<) \lambda^C \phi_C{}' \Leftrightarrow 2 \leq (>) \eta_C \tag{20}$$

where $\lambda^C \phi_C{}' = \dfrac{\partial e_C}{\partial \bar{e}_D} \dfrac{\bar{e}_D}{e_C}$. See also Appendix 2. Given $\eta_C > 2$, a strict emission standard reduces the ratio of the emission levels of the products.

Following a similar derivation in 3.2, we derive the effect on imports as follows.

$$\frac{dq_D{}^C}{d\bar{e}_D} = \frac{\partial q_D{}^C}{\partial \bar{e}_D} + \frac{\partial q_D{}^C}{\partial e_C} \frac{\partial e_C}{\partial \bar{e}_D} \geq (<) 0 \Leftrightarrow \frac{\partial e_C}{\partial \bar{e}_D} \frac{\bar{e}_D}{e_C} \geq (<) 4\lambda^C, \tag{21.1}$$

$$\frac{dq_C{}^C}{d\bar{e}_D} = \frac{\partial q_C{}^C}{\partial \bar{e}_D} + \frac{\partial q_C{}^C}{\partial e_C} \frac{\partial e_C}{\partial \bar{e}_D} \geq (<) \Leftrightarrow \frac{2\bar{e}_D e_C}{8\bar{e}_D{}^2 - 4\bar{e}_D e_C + e_C{}^2} \geq (<) \frac{\partial e_C}{\partial \bar{e}_D} \frac{\bar{e}_D}{e_C}. \tag{21.2}$$

Given the expression on the right-hand side of (21.1), because $\frac{\partial e_C}{\partial \bar{e}_D}\frac{\bar{e}_D}{e_C}<1$ and $4\lambda^C>1$, we have $\frac{dq_D{}^C}{d\bar{e}_D}<0$. Thus, a strict emission standard increases imports of the dirtier products, in contrast to the free trade case, as the valuation by consumers increases because of the emission standard policy. On the other hand, the effect on imports of the cleaner product is not unidirectional because $\frac{2\bar{e}_D e_C}{8\bar{e}_D{}^2-4\bar{e}_D e_C+e_C{}^2}<1$ and $\frac{\partial e_C}{\partial \bar{e}_D}\frac{\bar{e}_D}{e_C}<1$. That is, a strict emission standard on the dirtier product directly reduces the market share of the cleaner product, whereas it indirectly increases the market share as the unit emission level of the cleaner product is reduced through the effect of strategic complements. Thus, as a result, the effect on imports of the cleaner product is ambiguous.

Substituting (17.1) and (17.2) into (4), we have $E^C=\frac{3e_D-e_C}{4e_D-e_C}v$ where it holds that $\frac{\partial E^C}{\partial e_D}=\frac{e_C}{(4e_D-e_C)^2}v>0$ and $\frac{\partial E^C}{\partial e_C}=-\frac{e_D}{(4e_D-e_C)^2}v<0$. Although an increase in the unit emission level of the dirtier product reduces the quantity, it sufficiently increases the unit emission level and the quantity of the cleaner product. Accordingly, an increase in the unit emission level of the dirtier product increases aggregate emissions. On the other hand, an increase in the unit emission level of the cleaner product reduces its quantity, but increases the quantity of the dirtier product. However, it also reduces the unit emission level of the dirtier product. In this case, the strategic substitute effect ensures that an increase in the unit emission level of the cleaner product reduces aggregate emissions.

We derive the effect of an emission standard on aggregate emissions as follows.

$$\frac{dE^C}{d\bar{e}_D}\geq(<)0\Leftrightarrow 1\geq(<)\lambda^C\phi_C{}'\Leftrightarrow 2\leq(>)\eta_C.$$

Because $\eta_C > 2$, a strict emission standard reduces aggregate emissions, i.e., $\frac{dE^C}{d\bar{e}_D} > 0$, and thereby improves the environment.

Furthermore, given (19.2), and taking $\frac{\partial CS^C}{\partial \bar{e}_D} < 0$ and $\frac{\partial CS^C}{\partial e_C} < 0$ into account, the effect on consumer surplus under the Cournot duopoly case is given by $\frac{dCS^C}{d\bar{e}_D} < 0$. Thus, the effect of an emission standard on net social surplus is given by: $\frac{dW^C}{d\bar{e}_D} = \frac{dCS^C}{d\bar{e}_D} - \gamma \frac{dE^C}{d\bar{e}_D} < 0$. We summarize the result as follows.

Proposition 3

When a foreign Cournot duopoly prevails in the market, a strict emission standard on imports of the dirtier product always increases net social surplus.

Proposition 3 implies that a difference in the unit emission levels of the imported products is not allowed, i.e., $\bar{e}_D = e_C$. In other words, we may interpret that the government only admits quantity competition by foreign firms in *a homogenous product market*. Furthermore, Proposition 1 states that a strict emission standard on the dirtier product is not the preferable policy in the Bertrand duopoly case, if the government substantially gives weight to concerns about the environment. The difference in these results is because of the difference in the effect on the environment. That is, in the Bertrand (Cournot) duopoly case, a decrease in the unit emission level of the dirtier product degrades (improves, respectively) the environment.

4.3 Emission regulation of a cleaner product

Finally, we examine how an emission regulation on the cleaner product, i.e., $e_C^{CF} \geq \bar{e}_C > 0$, affects imports, the environment, and net social surplus. Because equation (19.2) shows strategic substitutes relationships between the unit emission levels of the products, we easily derive the following expressions:

$$\frac{dq_D{}^C}{d\bar{e}_C} = \frac{\partial q_D{}^C}{\partial \bar{e}_C} + \frac{\partial q_D{}^C}{\partial e_D}\frac{\partial e_D}{\partial \bar{e}_C} > 0, \tag{22.1}$$

$$\frac{dq_C{}^C}{d\bar{e}_C} = \frac{\partial q_C{}^C}{\partial \bar{e}_C} + \frac{\partial q_C{}^C}{\partial e_D}\frac{\partial e_D}{\partial \bar{e}_C} < 0. \tag{22.2}$$

Thus, a strict emission regulation reduces imports of the dirtier product, whereas it increases imports of the cleaner product. Hence, the emission regulation on the cleaner product is an import barrier for the dirtier product, whereas it promotes imports of the cleaner product. Do these results mean that the emission control policy improves the environment and net social surplus?

Using (19.2), we directly obtain the following:

$$\frac{dE^C}{d\bar{e}_C} = \frac{\partial E^C}{\partial \bar{e}_C} + \frac{\partial E^C}{\partial e_D}\frac{\partial e_D}{\partial \bar{e}_C} < 0, \tag{23}$$

$$\frac{dCS^C}{d\bar{e}_C} = \frac{\partial CS^C}{\partial \bar{e}_C} + \frac{\partial CS^C}{\partial e_D}\frac{\partial e_D}{\partial \bar{e}_C} < 0. \tag{24}$$

Paradoxically, a strict emission regulation increases aggregate emissions and thereby degrades the environment, although it increases consumer surplus.

Therefore, taking (23) and (24) into account, with respect to the effect on net social surplus, we summarize our findings in the following proposition.

Proposition 4

When a foreign Cournot duopoly prevails in the market, a strict emission regulation on the cleaner product reduces (increases) net social surplus if the marginal social valuation of *environmental damage is larger (smaller) than a certain level:* $\gamma > (<) \hat{\gamma}^C \equiv \dfrac{dCS^C / d\bar{e}_C}{dE^C / d\bar{e}_C}$.

A decrease in the unit emission level of the cleaner product increases environmental damage, although it increases consumer surplus. If the government values the domestic environment significantly, i.e., $\gamma > \hat{\gamma}^C$, the emission regulation policy in the foreign Cournot duopoly case is not desirable. Furthermore, as shown in Proposition 2, a strict emission regulation on the cleaner product is preferable in the Bertrand duopoly case. The difference in these results corresponds to the difference in the effect on the environment. That is, in a foreign Bertrand (Cournot) duopoly, the effect of an increase in the emission level of the cleaner product on the environment is positive (negative, respectively).

5. Concluding Remarks

We have examined the impact of emission standards as TBT on imports, the environment, and social welfare, based on the green market model presented by Moraga-González and Padrón-Fumero (2002). The main conclusions of this paper state that an emission standard policy for polluting products does not necessarily restrict imports of the product, whereas it may worsen the environment and social welfare. That is, we have shown that the effects of an emission standard policy on the environment and net social surplus depend on the mode of competition and the degree of social marginal valuation of environmental damage.

There are some remaining issues as follows. First, because we have dealt with an emission standard policy as a TBT or NTB in the paper, it might not be natural to assume that domestic firms do not exist in the green market of the importing country. But, in the case that a domestic firm produces the product, we can derive the same results as those in the paper.

Second, we have assumed that the importing government can commit to the emission standard policy before the firms decide the investment or product line associated with environmental qualities of the products. However, we should consider the timing of an emission standard policy because the government may have an incentive to change the emission standard after firms have invested. Related to the first issue, for example, we can consider that after a domestic firm decides to investment to produce a cleaner product, the government may choose a prohibitive level of an emission standard to restrict imports of a dirtier product. In this case, the domestic firm can be a monopolistic producer to provide the cleaner product to domestic consumers in the green market of the importing country. So, we should analyze the effect of the prohibitive emission standard policy on social welfare.

Third, we have supposed that the firms do not bear the burden of production costs. However, in the context of endogenous quality choice and strategic R&D policy (Jinji and Toshimitsu, 2007), we examined that the nature of reaction functions with respect to qualities and the first-order properties of revenue functions depend on the degree of marginal production costs. Thus, with nonzero production costs, our conclusions may be revised.

Fourth, we have analyzed the effect of environmental policy on imports, the environment, and social welfare. However, we need to address the effect of traditional trade policies, i.e., tariff and import quota, on them. On the effect of tariffs, see Toshimitsu (2006a). Furthermore, by the classification of Besanko (1987), our model is in line to the analysis of design or technological standards of pollution. In this paper, we have discussed the effect of an emission standard that responds to a design standard policy for environmental quality of the products. He also analyzes performance standards of pollution. If we can interpret import quotas as performance standards, we should analyze the effect of import quotas as performance standards on the environment and social welfare (Toshimitsu, 2006b).

Finally, we have discussed an emission standard policy from a viewpoint where the pollution is a by-product of consumption of the products. However, recently, it is clear that the environment and nature in a worldwide context is actually damaged by the production of environmental-friendly goods such as bio-gasoline. This implies that a cleaner product in the consumption process is a dirtier product in the production process, based on the terms of our paper. Thus, we should analyze the effects of environmental policy, considering environmental performance of products from a viewpoint of the production and consumption processes.

Appendix 1

We obtain the nature of the revenue functions in (8.1) and (8.2) as follows. The first-order properties are:

$$\frac{\partial R_D^B}{\partial e_D} \geq (<) 0 \Leftrightarrow \frac{7}{4} e_C \geq (<) e_D, \ \frac{\partial R_C^B}{\partial e_C} < 0, \ \frac{\partial R_D^B}{\partial e_C} < 0, \text{ and } \frac{\partial R_C^B}{\partial e_D} > 0. \qquad \text{(A.1)}$$

Given the first expression, the effect on the revenue of foreign firm *D* is not unidirectional. However, to warrant the existence of an interior solution, we assume such that $\frac{7}{4} e_C < e_D$. The second expression shows that a decrease in the unit emission level of the cleaner product increases its firm's revenue. Furthermore, the third (fourth) expression shows that a decrease in the unit emission level of the cleaner (dirtier, respectively) product increases (reduces, respectively) the revenue of foreign firm *D* (*C*). That is, a decrease in the unit emission level of the cleaner product increases the difference in environmental qualities of the products. This, in turn, mitigates competitiveness. On the other hand, a decrease in the unit emission level of the dirtier product enhances price competition as it reduces the difference in the environmental qualities of the products.

The second-order properties are:

$$\frac{\partial^2 R_D^B}{\partial {e_D}^2} \geq (<) 0 \Leftrightarrow e_D \geq (<) \frac{5}{2} e_C, \ \frac{\partial^2 R_C^B}{\partial {e_C}^2} > 0, \text{ and } \frac{\partial^2 R_i^B}{\partial e_i \partial e_j} > 0, i, j = C, D, i \neq j. \qquad \text{(A.2)}$$

Because 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 partial derivative in the third expression implies that the unit emission levels of the products are strategic complements in the Bertrand duopoly case. That is, the prices of both products fall because of a decrease in the unit emission level of the dirtier product, as the difference in environmental qualities of the products is likely to vanish. Thus, foreign firm *C* improves the environmental quality to reduce the strict price competition. On the other hand, prices and revenues of both foreign firms increase by a decrease in the unit emission level of the cleaner product, as the environmental quality difference between both products widens. Hence, there are two effects of a decrease in the unit emission level by foreign firm *D* on its revenue: a negative effect because of strict price competition, and a positive effect because of an increase in the valuation by consumers. As the latter effect is greater than the former, foreign firm *D* has an incentive to improve the environmental quality by less than the degree of improvement in the cleaner product, even though the cost increases.

Appendix 2

The determinant of the matrix can be generally expressed as:

$$\Delta^k = \frac{\partial^2 \pi_D{}^k}{\partial e_D{}^2}\frac{\partial^2 \pi_C{}^k}{\partial e_D{}^2} - \frac{\partial^2 \pi_D{}^k}{\partial e_D \partial e_C}\frac{\partial^2 \pi_C{}^k}{\partial e_C \partial e_D}, k = B, C. \tag{A.3}$$

Furthermore, the following equations hold:

$$e_i \frac{\partial^2 R_i^k}{\partial e_i^2} + e_j \frac{\partial^2 R_i^k}{\partial e_i \partial e_j} = -2F_i', i, j = C, D, i \neq j, k = B, C. \tag{A.4}$$

Given (A.4), the determinant in (A.3) can be rewritten as:

$$\begin{aligned}\Delta^k = {} & \frac{e_D}{e_C}\frac{\partial^2 R_D{}^k}{\partial e_D \partial e_C}\left(-\frac{F_D'}{e_D}\right)(\eta_D - 2) + \frac{e_C}{e_D}\frac{\partial^2 R_C{}^k}{\partial e_C \partial e_D}\left(-\frac{F_C'}{e_C}\right)(\eta_C - 2) \\ & + \left(-\frac{F_D'}{e_D}\right)(\eta_D - 2)\left(-\frac{F_C'}{e_C}\right)(\eta_C - 2),\end{aligned} \tag{A.5}$$

where $\eta_i \equiv -\frac{e_i F_i''}{F_i'} = \varepsilon + 1 > 2, i = C, D,$ holds, given (3.1) and (3.2).

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

Appendix 3

In what follows, as we have the same results regardless of the model of competition, we omit superscript $k = B, C.$ In general, it holds that:

$$\frac{\partial e_i}{\partial e_j}\frac{e_j}{e_i} = -\frac{\dfrac{\partial^2 \pi_i}{\partial e_i \partial e_j} e_j}{\dfrac{\partial^2 \pi_i}{\partial e_i{}^2} e_i}, i, j = C, D, i \neq j. \tag{A.6}$$

Hence, taking (A.4) into account, we derive:

$$\frac{\partial e_i}{\partial e_j}\frac{e_j}{e_i} \geq (<) 1 \Leftrightarrow 2 \geq (<) \eta_i, i, j = C, D, i \neq j. \tag{A.7}$$

Given $\eta_i > 2,$ it holds that $\dfrac{\partial e_i}{\partial e_j}\dfrac{e_j}{e_i} < 1, i, j = C, D, i \neq j.$

Appendix 4

Given (17.1) and (17.2), the first-order properties are given by:

$$\frac{\partial R_i^C}{\partial e_i} < 0 \text{ and } \frac{\partial R_i^C}{\partial e_j} > 0, i, j = C, D, i \neq j. \tag{A.8}$$

The second expression of these properties implies that an increase in the unit emission level of foreign firm *j* increases the revenue of foreign firm *i*. That is, an increase in the unit emission level implies that environmental quality of the product deteriorates. This in turn reduces the market share of foreign firm *j*, allowing foreign firm *i* to increase its market share and thus its revenue.

Furthermore, the second-order properties are given by:

$$\frac{\partial^2 R_i^C}{\partial e_i^{\,2}} > 0, i = C, D, \quad \frac{\partial^2 R_D^C}{\partial e_D \partial e_C} < 0, \text{ and } \frac{\partial^2 R_C^C}{\partial e_C \partial e_D} > 0. \tag{A.9}$$

As the sign of the first expression is positive, the cost function of a unit emission level is assumed sufficiently convex, so that the second-order condition for profit maximization holds. In addition, the second expression indicates the followings. An increase in the unit emission level of the cleaner product reduces the difference in environmental qualities between the products. As the difference becomes small, a competition among the firms intensifies. Accordingly, the marginal revenue of foreign firm *D* declines. On the other hand, the third expression indicates that an increase in the unit emission level of the dirtier product increases the quality difference, and thus increases the marginal revenue of foreign firm *C*. The signs of the cross partial derivatives of the second and the third equations mean that the unit emission levels of the products are strategic complements (substitutes) for foreign firm *C* (*D*) in the Cournot duopoly case.

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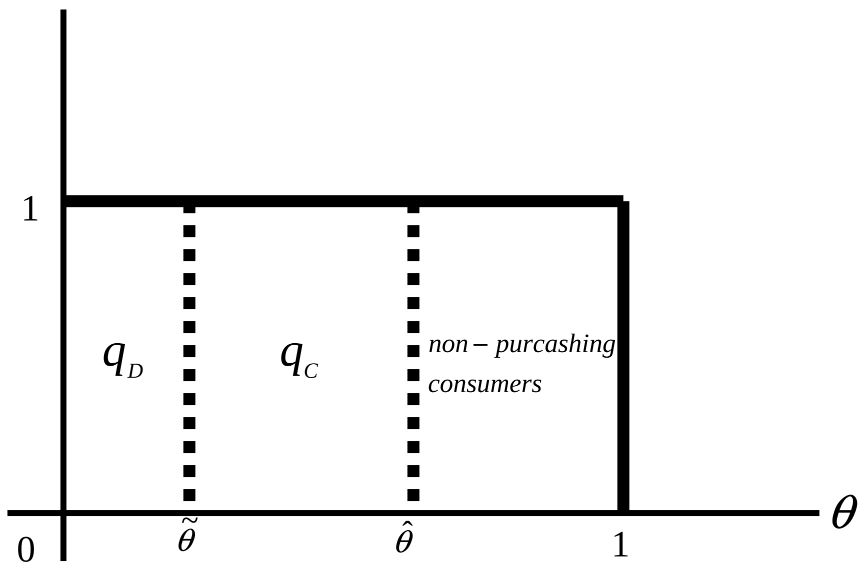
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Figure 1

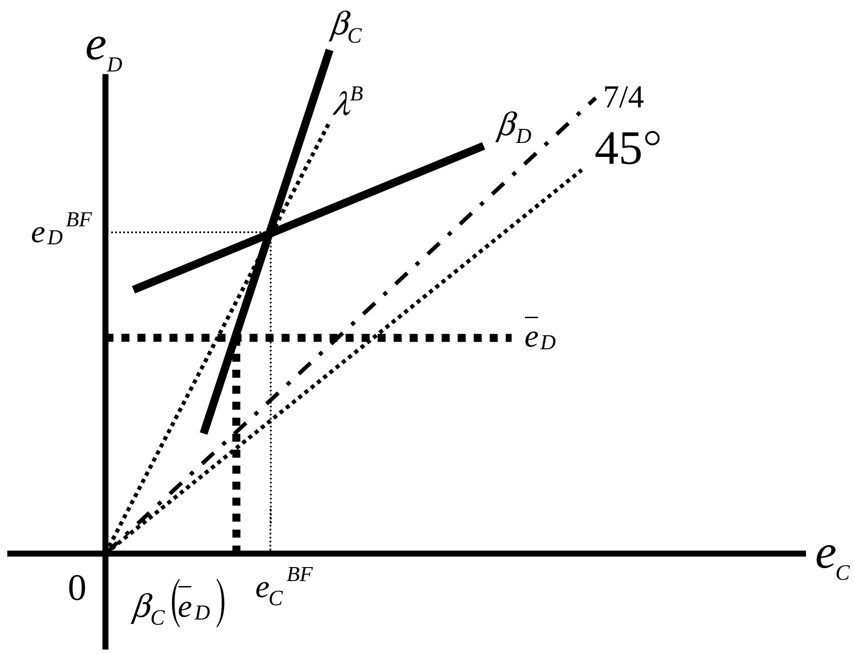

Figure 2

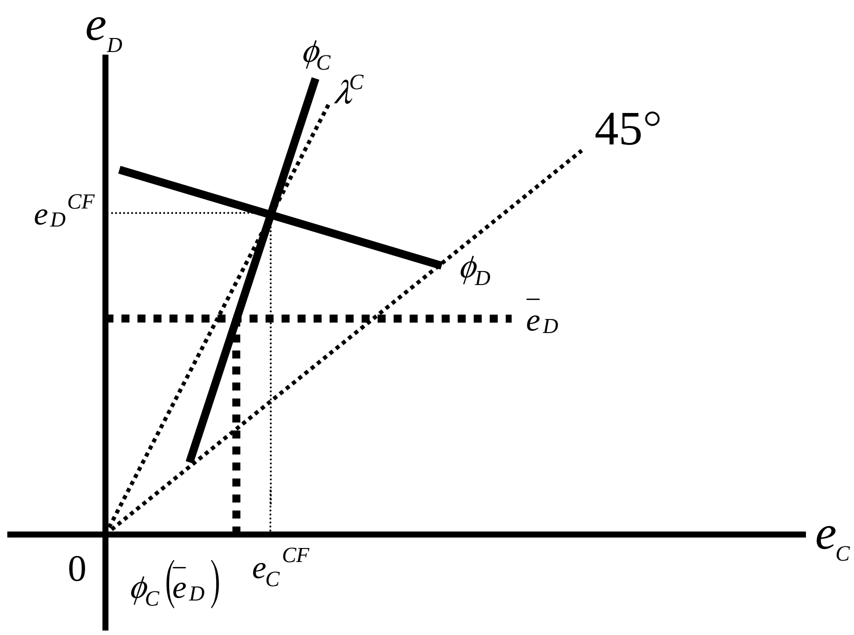

Figure 3