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Environmental Technology Transfer via Free Trade

Takeshi Iida
Graduate School of Economics, Kobe University

Kenji Takeuchi
Graduate School of Economics, Kobe University

Abstract

This paper considers a model of international duopoly with global pollution to investigate the impact of tariff policy and licensing contracts on environmental technology transfer. Our main finding is that free trade is not always preferable. When the protection of intellectual property rights (IPR) is within a certain range, there is a possibility that the total world welfare is higher under a positive tariff rate than under a zero tariff rate. This implies that the protection of IPR being beyond the range is a prerequisite for the justification of free trade.

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1 Introduction

Transfer of low-carbon and renewable technology to fast-growing economies is a key aspect in addressing global climate change (IPCC 2007, 218-224). Developing countries often claim that compulsory licensing, by which a government forces the holder of a patent to grant the use of the technologies to the state or others, is effective for the transfer of environmental technologies. Industrialized countries, however, tend to prefer a free trade policy, where technology is indirectly transferred through the trade of commodities that are produced in their countries. From this standpoint, it is necessary to remove tariffs and other trade barriers to decrease the price of environmental technology.

A World Bank (2008) summary of applied tariffs for solar photovoltaic technology in 18 high-GHG-emitting developing countries found that except in one case, import tariffs range from 32 to 6 percent. These are much higher than the average tariffs in high-income OECD countries (4%). Tariff barriers on fluorescent lamps in these 18 countries are also high, varying from 30 to 5 percent, again with one exception. The tariff on fluorescent lamps is the highest across all clean technologies assessed.

This paper considers an international duopoly model to investigate the impact of tariff policy and licensing contracts on environmental technology transfer. Our main finding is that free trade is not always preferable to tariffs. When the protection of intellectual property rights is within a certain range, there is a possibility that the total world welfare is higher under a positive tariff rate than under a zero tariff rate.

Some previous studies have examined the relationship between trade policy and environmental technology transfer (e.g., see Hattori, 2007; Itoh and Tawada, 2003; and Takarada, 2005). The previous studies assume that the technological transfer is free of charge, and focus mainly on transfer through public funding: on the other hand, this study considers two channels for the transfer of technology of a private firm: international trade and licensing contracts. [1] Qiu and Yu (2009) analyze the incentive of a developing country to participate in an international environmental agreement through environmental technology transfer. Although they consider environmental technology transfer between firms using licensing fee, they do not consider the relation between the technology transfer and trade policy. We incorporate royalty fees in our model and emphasize the interaction between the trading of products and the licensing of technology through the setting of tariffs.

Many studies have investigated the interaction between environmental policy and trade policy (e.g., see Lai and Hu, 2008; Ohori, 2006; Riveiro, 2008 for recent contributions). Instead, this paper does not consider environmental policy instruments since it is assumed to be sometimes difficult to implement an environmental tax in the real world. The proposal

[1] Popp (2008) considers public funding and private firm behavior as sources of technological transfer. A representative example of public funding is aid from governments or non-governmental organizations in the form of official developmental assistance. Private transfer of technology can take place in three ways: trade, foreign direct investment, and license to a local firm.

of a carbon tax, which gives firms disadvantage in the global market, typically faces the strong refusal from industry groups even in developed countries. Thus, the tariff in our analysis plays two offsetting roles: protecting the local firms and diffusing environmental advanced technology.

Some studies have examined the role of trade policy as second-best policy instruments. For example, Copeland (1996) considers the role of trade policy to control pollution generated by a foreign firm. He shows that a tariff on the foreign product operates to protect the domestic firm in addition to restrict pollution. Assuming asymmetric information for the cost of clean technology, Ludema and Takeno (2006) investigate the role of tariff on the incentive of a foreign firm to adopt clean technology. They show that a tariff induces the foreign firm to adopt clean technology under the complete information. However, these literatures do not consider the role of tariff to remedy pollution caused by the local firm.

Regibeau and Gallegos (2004) investigate the role of a tariff to remedy a home firm's pollution activity. They consider how the tariff makes an effect on the incentive of the home firm to adopt clean technology and show that the home firm adopts clean technology if tariff rate arise after adopting the technology. Although the mechanism of our model is similar to theirs, our paper takes into account the cost of adopting a clean technology as endogenously determined through licensing contract with the foreign firm. As a result, there is a case that licensing contract does not occur in our model.

Although the basic structure of our model is similar to those of Kabiraj and Marjit (2003) and Mukherjee and Pennings (2006), there are three important differences. First, we consider global pollution while these studies do not. Accordingly, our analysis can address the situation when technological transfer is potentially beneficial for any country from the environmental point of view. Second, our analysis incorporates intellectual property rights (IPR) as a factor having significant implications for technological transfer. One of our findings suggests that the protection of IPR is a prerequisite for justifying free trade. Third, in contrast to Kabiraj and Marjit (2003), our model does not assume that the difference in production cost is a significant incentive for technological transfer. This is done to confine the analysis to the difference in the environmental impacts of production technology.

The remainder of this paper is organized as follows. We present an international duopoly model with pollution in Section 2. In Section 3, we investigate the free trade policy and compare it with a case where the local country determines the tariff rate after the licensing activity. The final section provides our conclusions.

2 The model

We consider a model of duopoly with one foreign firm and one local firm. We represent the foreign by subscript f and the local by l. We suppose that the product is homogeneous except for its environmental properties. The product produced by the local firm generates global external diseconomy. The foreign firm has clean technology; therefore, its product does not adversely affect the environment. The clean technology of the foreign firm is transferable. If the technology is transferred by a licensing agreement to the local firm, its product does not cause environmental damage. We assume that the license fee is paid by royalties, although a qualitatively similar result is obtained under the assumption of a fixed fee.

The profits of the foreign firm and the local firm are $\pi_f^{j,k} = (p - t^k)q_f^{j,k} + r^j q_l^{j,k}$ and $\pi_l^{j,k} = (p - r^j)q_l$, respectively, where $j = \{F, T\}$ represents the trade policy with F denoting free trade and T denoting the tariff policy, and $k = \{L, N\}$ represents the state of licensing contract with L denoting licensing and N denoting no licensing. The parameter t denotes the tariff rate imposed on the product of the foreign firm and $r > 0$ is the royalty rate. Note that when there is no licensing, $r = 0$. Further, in the case of free trade, $t = 0$. Following Qiu and Yu (2009), we assume a linear inverse demand function $p = \alpha - q_f - q_l$, and standardize the marginal private cost of producing the product to zero. [2] The social welfare of the foreign country is the sum of the producer surplus minus environmental damage: $SW_f^{j,k} = \pi_f^{j,k} - (\gamma/2)ED$.[3] The social welfare of the local country is the sum of the consumer surplus, profit of the local firm, and the tariff revenue minus the environmental damage: $SW_l^{j,k} = (q_f^{j,k} + q_l^{j,k})^2/2 + \pi_l^{j,k} + t^k q_f^{j,k} - (\gamma/2)ED$. We assume that one unit of production generates one unit of pollution. Environmental damage is represented as $ED = (\beta q_l^{j,k})^2$ and is common for both countries. [4] The evaluation of environmental damage is denoted by $\gamma/2$. [5] Since licensing eliminates environmental damage, $ED = 0$ when there is licensing. The exogenous parameter $\beta \in (0, 1]$ represents the degree of IPR protection. If $\beta \in (0, 1)$, IPR protection is imperfect, which means that the local firm can freely copy the technology of the foreign firm. We assume that it is impossible to imitate the technology perfectly and remove the case where $\beta = 0$.

3 Comparing free trade and tariff policy

3.1 Free trade

We consider the case of free trade where the tariff rate is fixed at zero. A lower tariff rate can increase the export of products with low carbon emission from the developed country to the developing country, which can help diffuse the environmental technology embodied in it. The timing of this game is as follows. In the first stage, the foreign firm offers royalty r

[2]We assume that the marginal cost is the same for clean technology and dirty technology. This assumption enables us to focus on the technology transfer motivated only by environmental impact. In contrast, Kabiraj and Marjit (2003) analyzed the situation where the difference in marginal cost drives technology transfer.

[3]We omit the consumption in the foreign country for convenience. However, because the markets are segmented between local and foreign, the result holds even if we include the foreign market.

[4]Since we consider global pollution including climate change resulting from the emission of carbon dioxide, environmental damage is assumed to be the same for both the foreign country and the local country.

[5]The γ should be different between the foreign and the local country depending on the situation and characteristic of the environmental issue. For example, assuming higher gamma for the foreign country and including the foreign environmental policy would allow us to address the issue of competitive environmental policy between countries. However, under the present framework of analysis, we obtain qualitatively same results even with different gamma. We assume $\gamma_f = \gamma_l = \gamma/2$ to simplify the analysis.

to the local firm. In the second stage, the local firm decides whether or not to accept the offer. In the final stage, the firms engage in quantity competition. The equilibrium concept is subgame perfect equilibrium (SPE). The game is solved backwards.

The second stage equilibrium quantity and profit with and without licensing become $q_f^{F,L} = (\alpha + r)/3$, $q_l^{F,L} = (\alpha - 2r)/3$, and $\pi_i^{F,L} = \left(q_i^{F,L}\right)^2$: and $q_i^{F,N} = \alpha/3$ and $\pi_i^{F,N} = \left(q_i^{F,N}\right)^2$, respectively, where $i = \{f, l\}$. Because $\pi_l^{F,L} < \pi_l^{F,N}$ when $r > 0$, the local firm has no incentive for accepting a licensing contract. Moreover, since the contract does not change the profit of the foreign firm, there is no licensing. The equilibrium in the free trade regime is denoted as follows: $p^F = \alpha/3, q_f^F = q_l^F = \alpha/3, \pi_f^F = \pi_l^F = \alpha^2/9, SW_f^F = \alpha^2(2 - \beta^2\gamma)/18, SW_l^F = \alpha^2(6 - \beta^2\gamma)/18, SW_w^F = \alpha^2(4 - \beta^2\gamma)/9$.

Because the licensing of the environmental technology does not improve the competitiveness of the local firm, the local firm has no incentive for technological transfer via licensing. As a result, there is no licensing agreement under the free trade regime.

3.2 Tariff policy

In this section, we investigate the case where the tariff rate is determined after the licensing agreement. In the real world, as pointed out by Mukherjee and Pennings (2006) and Neary and Leahy (2000), a government has the incentive to change the pre-announced tariff rate. Therefore, we analyze a no-commitment regime as probable tariff policy. In the first stage of this game, the foreign firm offers a licensing contract with royalty r to the local firm. In the second stage, the local firm decides whether or not to accept the offer. In the third stage, the local government determines the tariff rate t. In the final stage, the firms engage in quantity competition.

We obtain the third stage equilibrium quantity and the profit under no license as $q_f^{T,N} = \alpha(1 + \beta^2\gamma)/(9 + \beta^2\gamma)$ and $q_l^{T,N} = 4\alpha/(9 + \beta^2\gamma)$, and $\pi_f^{T,N} = \left(q_f^{T,N}\right)^2$ and $\pi_l^{T,N} = \left(q_l^{T,N}\right)^2$, respectively. The third stage equilibrium quantity and tariff rate under a licensing contract are $q_f^{T,L} = (\alpha + 3r)/9$ and $q_l^{T,L} = 2(2\alpha - 3r)/9$, and $t^L = \alpha/3$, respectively. Moreover, the profits of the foreign firm and the local firm are $\pi_f^{T,L} = (\alpha^2 + 42\alpha r - 45r^2)/81$ and $\pi_l^{T,L} = \left(q_l^{T,L}\right)^2$, respectively.

The tariff rate under no license is

$$t^N = \frac{\alpha}{3} - \frac{4\alpha\beta^2\gamma}{3(9 + \beta^2\gamma)}. \tag{1}$$

The first term of equation (1) is the tariff rate when there is no environmental damage. The second term is the marginal environmental damage generated by increasing the tariff by one unit. Therefore, $4\alpha\beta^2\gamma/3(9 + \beta^2\gamma) = \partial[(\gamma/2)ED]/\partial q_l \cdot \partial q_l/\partial t$. In the absence of an environmental policy, the local government considers the environmental impact in determining the tariff. Since the product of the local firm is associated with pollution and is not exposed to the tariff, the local government sets a lower tariff to diffuse the environmentally friendly product of the foreign firm. Since there is no environmental damage, on the other hand, the local country can raise the tariff rate to protect its firm when licensing occurs. In summary, we obtain the following proposition.

Proposition 1. The optimal tariff is higher with licensing than without licensing: $t^L > t^N$.

Moreover, with regard to the relation between the tariff with licensing and that without licensing, we obtain the following corollary.

Corollary 1. The difference between the tariff with licensing and that without licensing is larger when β or γ is larger: $\partial[t^L - t^N]/\partial\beta > 0$ and $\partial[t^L - t^N]/\partial\gamma > 0$.

Because environmental damage is larger when β and γ are larger, to suppress environmental damage, the local government tends to diffuse the environmentally friendly product produced by the foreign firm, which lowers t^N.

In the licensing contract, the foreign firm offers r^*, which maximizes its own profit subject to $\pi_l^{T,L} \geq \pi_l^{T,N}$. We obtain the corner solution and derive the license fee $r^* = 2\alpha\beta^2\gamma/(27 + 3\beta^2\gamma)$ such that $q_l^{T,N} = q_l^{T,L}$. Unlike in free trade, because $t^L > t^N$, the local firms has an incentive to adopt the pollution-free technology; therefore, the license fee is positive.

Although the result of Proposition 1 is the same as that obtained in Regibeau and Gallegos (2004), unlike their analysis, we take into account the cost of adopting a clean technology as endogenously determined through licensing contract. In our model, especially, foreign firm is reluctant to license the technology, because it faces a higher tariff by licensing its technology.

When the foreign firm licenses the technology, the quantity and profit of the foreign firm are $q_f^{T,L} = \alpha(3 + \beta^2\gamma)/3(9 + \beta^2\gamma)$ and $\pi_f^{T,L} = \alpha^2 \left(9 + 30\beta^2\gamma + \beta^4\gamma^2\right)/9\left(9 + \beta^2\gamma\right)^2$, respectively. Licensing occurs if $\pi_f^{T,L} \geq \pi_f^{T,N}$. Rearranging this condition and solving for β leads to the next proposition (see Appendices for the proofs of the propositions).

Proposition 2. Licensing occurs if and only if $\beta \leq \sqrt{3/2\gamma}$ when the foreign firm offers r^*.

Since $t^L > t^N$, the foreign firm faces a higher tariff by licensing its technology: this is the cost of licensing the technology for the foreign firm. However, as pointed out by Mukherjee and Pennings (2006), the foreign firm may offset the negative effect of higher tariff by the revenue from the license fee. When $\gamma < 1.5$, because $\sqrt{3/2\gamma} > 1$ and $\beta \in (0, 1]$, the foreign firm always licenses its technology to the local firm. Because, in this case, environmental damage is small, $t^L - t^N$ is small and consequently the cost of licensing is small enough for the foreign firm to license its technology. On the other hand, when $\gamma > 1.5$ and IPR protection is perfect ($\beta = 1$), there is no licensing agreement. In this case, because the local firm cannot imitate the technology and environmental damage is large, the local government lowers the tariff rate to diffuse the environmentally friendly product produced by the foreign firm, which increases the licensing cost for the foreign firm. Moreover, when γ is large, the local government may subsidize the foreign firm. We thus obtain the following corollary.

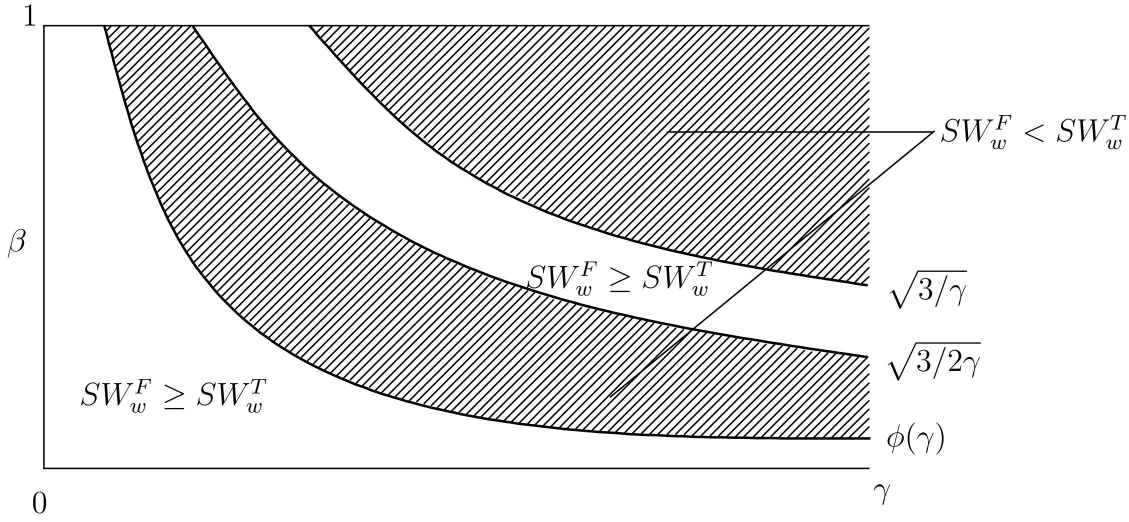

Figure 1: proposition 3

Corollary 2. When $\beta \in \left(\sqrt{3/\gamma}, 1\right]$, that is, when there is no licensing, the local government subsidizes the foreign firm, and therefore, $t^N < 0$.

3.3 Comparison

We compare world welfare under free trade with that under tariff policy.

Proposition 3. World welfare under tariff policy is higher than (resp. lower than or equal to) that under free trade when $\beta \in \left(\phi(\gamma), \sqrt{3/2\gamma}\right]$ and $\beta \in \left(\sqrt{3/\gamma}, 1\right]$ (resp. otherwise).

Figure 1 is the illustration of proposition 3. The vertical axis shows the IPR protection and the horizontal axis shows the environmental damage. The shaded part is the area where world welfare under tariff policy is higher than that under free trade. When $\beta \in (0, \phi(\gamma)]$, environmental damage is small and is avoided through the imitation of the technology; thus, the benefit of a licensing contract is very small. Consequently, it is beneficial for world welfare to adopt a free trade regime where there is no distortion of tariff. When $\beta \in \left(\phi(\gamma), \sqrt{3/2\gamma}\right]$, there is licensing only in the tariff policy. In this case, the benefit of technology transfer is larger than the cost of tariff, which decreases the foreign firm's production activity. When $\beta \in \left(\sqrt{3/2\gamma}, \sqrt{3/\gamma}\ \right]$, there is no licensing agreement under free trade and tariff policy. Because larger β and γ and no licensing imply greater environmental damage, it is beneficial for world welfare to remove the cost of tariff and diffuse the environmentally friendly product. Further, there is no licensing when $\beta > \sqrt{3/\gamma}$. However, in this case, the local government subsidizes the foreign firm, which in turn is beneficial for the environment and the foreign firm. Note that in principal, the foreign country does not prefer tariff policy to free trade, even though the local country always prefers it. When there is licensing, if the benefit from the reduction in environmental damage is larger than the cost of tariff, the foreign country prefers tariff policy to free trade. This tendency, therefore, increases when environmental damage is large. When $\beta \in \left(\sqrt{3/\gamma}, 1\right]$, because the foreign firm receives subsidy, the foreign country prefers tariff policy to free trade even though there is no licensing agreement. Comparison of social welfare in each country leads to the following proposition.

Proposition 4. When $\beta \in \left(\psi(\gamma), \sqrt{3/2\gamma}\right]$ and $\beta \in \left(\sqrt{3/\gamma}, 1\right]$ both countries prefer tariff policy to free trade.

Because $\psi(\gamma) - \phi(\gamma) \approx 0.4102654/\sqrt{\gamma} > 0$, the range where tariff policy is preferable to free trade for both countries is smaller than that for world welfare.

Kabiraji and Marjit (2003) focus on the welfare of the local country and conclude that the tariff policy that induces the licensing contract is always preferable. This technology transfer is induced by the difference in the marginal costs of production between the foreign firm and the local firm. In contrast, our model assumes that the marginal cost is the same and the environmental impact is different across the two countries. Taking world welfare into consideration, the results of our analysis show that there are regions where free trade is preferable to tariff policy. However, free trade is not always preferable. Since we have global pollution and there does not exist an environmental policy instrument in the local country, there exists a case where tariff policy is preferable to free trade. Moreover, Proposition 4 shows that the tariff policy can be Pareto improving to free trade in some cases.

4 Conclusion

This paper examined the welfare implications of the free trade regime and licensing agreement within a framework of international duopoly with global pollution. We have shown that free trade is not preferable if the protection of IPR is within a certain range. This implies that the protection of IPR being beyond the range is a prerequisite for the justification of free trade. We have also revealed that the optimal tariff is higher with licensing than without it. Since there is no environmental damage under the licensing agreement, the local country can raise the tariff rate to protect its firm. In contrast, without licensing, the local government sets a lower tariff level and diffuse the product of the foreign firm. This is because the product of the local firm is associated with pollution when there is no licensing contract.

Appendix

The proof of Proposition 2

We obtain

$$\pi_f^{T,L} - \pi_f^{T,N} = \frac{4\alpha^2\beta^2\gamma\left(3-2\beta^2\gamma\right)}{9\left(9+\beta^2\gamma\right)^2}. \tag{2}$$

Then, $\pi_e^{T,L} \geq \pi_e^{T,N}$ if $\beta \leq \sqrt{3/2\gamma}$.

Q.E.D.

The equilibrium value under the case of no-commitment

We obtain equilibrium price and social welfare for the case of the no-commitment when $\beta \in \left(0, \sqrt{3/2\gamma}\right]$ as follows,

$$p^T = \frac{2\alpha\left(6+\beta^2\gamma\right)}{3\left(9+\beta^2\gamma\right)}, \quad q_f^T = \frac{\alpha\left(3+\beta^2\gamma\right)}{3\left(9+\beta^2\gamma\right)}, \quad q_l^T = \frac{4\alpha}{9+\beta^2\gamma}, \tag{3}$$

$$\pi_f^T = \frac{\alpha^2\left(9+30\beta^2\gamma+\beta^4\gamma^2\right)}{9\left(9+\beta^2\gamma\right)^2}, \quad \pi_l^T = \frac{16\alpha^2}{\left(9+\beta^2\gamma\right)^2}, \tag{4}$$

$$SW_f^T = \frac{\alpha^2\left(9+30\beta^2\gamma+\beta^4\gamma^2\right)}{9\left(9+\beta^2\gamma\right)^2}, \quad SW_l^T = \frac{\alpha^2\left(189+18\beta^2\gamma+\beta^4\gamma^2\right)}{6\left(9+\beta^2\gamma\right)^2}, \tag{5}$$

$$SW_w^T = \frac{\alpha^2\left(15+\beta^2\gamma\right)\left(39+5\beta^2\gamma\right)}{18\left(9+\beta^2\gamma\right)^2}. \tag{6}$$

When $\beta > \sqrt{3/2\gamma}$, licensing does not occur. In this case the result is denoted as follows,

$$p^T = \frac{4\alpha}{9+\beta^2\gamma}, \quad q_f^T = \frac{\alpha\left(1+\beta^2\gamma\right)}{9+\beta^2\gamma}, \quad q_l^T = \frac{4\alpha}{9+\beta^2\gamma}, \tag{7}$$

$$\pi_f^T = \frac{\alpha^2\left(1+\beta^2\gamma\right)^2}{\left(9+\beta^2\gamma\right)^2}, \quad \pi_l^T = \frac{16\alpha^2}{\left(9+\beta^2\gamma\right)^2}, \tag{8}$$

$$SW_f^T = \frac{\alpha^2\left(1-6\beta^2\gamma+\beta^4\gamma^2\right)}{\left(9+\beta^2\gamma\right)^2}, \quad SW_l^T = -\frac{\alpha^2\left(-7+\beta^2\gamma\right)}{2\left(9+\beta^2\gamma\right)}, \tag{9}$$

$$SW_w^T = \frac{\alpha^2\left(65-14\beta^2\gamma+\beta^4\gamma^2\right)}{2\left(9+\beta^2\gamma\right)^2}. \tag{10}$$

The proof of Proposition 3

We compare SW_w^F with SW_w^T when $\beta \in \left(0, \sqrt{3/2\gamma}\,\right]$ and have

$$SW_w^F - SW_w^T = \frac{\alpha^2 \left(63 - 132\beta^2\gamma - 33\beta^4\gamma^2 - 2\beta^6\gamma^3\right)}{18\left(9 + \beta^2\gamma\right)^2}. \tag{11}$$

Solving $(63 - 264\beta^2 - 132\beta^4 - 16\beta^6) = 0$ with respect to β we obtain

$$\beta = \sqrt{\frac{33 - 11\left(247 + 4\sqrt{1567}\right)^{1/3} + \left(247 + 4\sqrt{1567}\right)^{2/3}}{2\left(247 + 4\sqrt{1567}\right)^{1/3}\gamma}} \equiv \phi(\gamma).$$

Therefore, $SW_w^F \geq SW_w^T$ if $\beta \in (0, \phi]$ and $SW_w^F < SW_w^T$ if $\beta \in \left(\phi, \sqrt{3/2\gamma}\,\right]$.

Comparing SW_w^F with SW_w^T when $\beta \in \left(\sqrt{3/2\gamma}, 1\right)$, we have

$$SW_w^F - SW_w^T = \frac{\alpha^2 \left(3 - \beta^2\gamma\right)\left(21 + \beta^2\gamma\right)\left(1 + 2\beta^2\gamma\right)}{18\left(9 + \beta^2\gamma\right)^2}. \tag{12}$$

Solving $(3 - \beta^2\gamma) = 0$ with respect to β we obtain $\beta = \sqrt{3/\gamma}$. Therefore, $SW_w^F \geq SW_w^T$ if $\beta \in \left(\sqrt{3/2\gamma}, \sqrt{3/\gamma}\right]$ and $SW_w^F < SW_w^T$ if $\beta \in \left(\sqrt{3/\gamma}, 1\right]$.

Q.E.D.

The proof of Proposition 4

First, we compare the social welfare of the foreign country under free trade with that under tariff policy. We compare SW_f^F with SW_f^T when $\beta \in \left(0, \sqrt{3/2\gamma}\,\right]$ and obtain

$$SW_f^F - SW_f^T = \frac{\alpha^2 \left(144 - 105\beta^2\gamma - 18\beta^4\gamma^2 - \beta^6\gamma^3\right)}{18\left(9 + \beta^2\gamma\right)^2}. \tag{13}$$

Solving $(144 - 105\beta^2\gamma - 18\beta^4\gamma^2 - \beta^6\gamma^3) = 0$ with respect to β, we obtain

$$\beta = \sqrt{\frac{-6 + \left(171 + 2\sqrt{7310}\right)^{1/3} + \left(171 - 2\sqrt{7310}\right)\left(171 + 2\sqrt{7310}\right)^{2/3}}{\gamma}} \equiv \psi(\gamma).$$

Threfore, $SW_f^F \geq SW_f^T$ if $\beta \in (0, \psi]$ and $SW_f^F < SW_f^T$ if $\beta \in \left(\psi, \sqrt{3/2\gamma}\right]$.

We compare SW_f^F with SW_f^T when $\beta \in (0.866, 1)$ and obtain

$$SW_f^F - SW_f^T = \frac{\alpha^2 \left(3 - \beta^2\gamma\right)\left(48 + 37\beta^2\gamma + \beta^4\gamma^2\right)}{18\left(9 + \beta^2\gamma\right)^2}. \tag{14}$$

Solving $(3-\beta^2\gamma)=0$ with respect to β we obtain $\beta=\sqrt{3/\gamma}$. Therefore, $SW_w^F \geq SW_w^T$ if $\beta \in \left(\sqrt{3/2\gamma}, \sqrt{3/\gamma}\right]$ and $SW_w^F < SW_w^T$ if $\beta \in \left(\sqrt{3/\gamma}, 1\right]$.

Next, we compare the social welfare of the foreign country under free trade with that under tariff policy. We compare SW_l^F with SW_l^T when $\beta \in \left(0, \sqrt{3/2\gamma}\ \right]$ and obtain the result,

$$SW_l^F - SW_l^T \quad = \quad -\frac{\alpha^2\left(81+27\beta^2\gamma+15\beta^4\gamma^2+\beta^6\gamma^3\right)}{18\left(9+\beta^2\gamma\right)^2} < 0. \tag{15}$$

We compare SW_l^F with SW_l^T when $\beta \in \left(\sqrt{3/2\gamma}, 1\right]$ and obtain the result,

$$SW_l^F - SW_l^T \quad = \quad -\frac{\alpha^2\left(3-\beta^2\gamma\right)^2}{18\left(9+\beta^2\gamma\right)} < 0. \tag{16}$$

Q.E.D.

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