Policy-Induced Environmental Technology Transfer

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Abstract

We investigate how environmental and trade policies affect the transfer of environmental technology in a two-country model with global pollution. By comparing free trade and tariff policy without commitment, the following results are obtained. First, the existence of an environmental policy in a local country induces technology transfer from a foreign country. Second, there is a possibility that free trade is preferable to a tariff policy for both countries even though free trade lowers the environmental tax rate. Third, the quantity of the local firm's product decreases for higher environmental damage. On the other hand, import of environmentally efficient goods from the foreign country increases.

JEL classification numbers: D43; F13; L13; Q56

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1 Introduction

The importance of technology transfer for a global environmental policy has been well recognized.[1] For instance, the United Nations Framework Convention on Climate Change includes provisions calling for the transfer of environmental technologies and

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[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 licensing to a local firm.

know-how related to environmentally sound technologies. However, there seems to be disagreement on how this transfer can be achieved. Developing countries often claim that compulsory licensing, by which a government forces a patent holder to grant the use of the technologies to the state or others, is effective for transferring environmental technologies. On the other hand, industrialized countries tend to prefer a free trade policy, in which technology is indirectly transferred through the trade of commodities produced in their countries. From this standpoint, it is necessary to remove tariffs and other trade barriers to decrease the price of environmental technology.[2]

It is important to note that these transfers of technology, either through licensing contract or through import of environmentally efficient goods, are affected by the design of environmental and trade policies. If a developing country implements an environmental policy, it provides an incentive for the local firm to adopt environmental technology. Stronger environmental regulation would lead to higher value being set on the environmental technology, which in turn would bring higher revenue to the licensor.

In the context of studies on trade and environment, it is often pointed out that a trade liberalization may induce weaker environmental regulation as a means of compensating the domestic firm (see Rauscher, 1994; Ulph and Valentini, 2001). If the weaker environmental regulation discourages the firm from adopting cleaner technology, the value of the technology might decrease. Our main question is whether a developed country still prefers diffusion of environmental technology through free trade, even if trade liberalization leads to weaker environmental regulation in the developing country.

To answer this question, we consider an international duopoly model with global pollution and investigate how environmental and trade policies affect the transfer of environmental technology. We extend the model of Iida and Takeuchi (2010) to include the possibility of an environmental policy in the local country. [3] The main results

[2]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.

[3]Iida and Takeuchi (2010) do not consider environmental policy instruments on the assumption that it is politically difficult to implement an environmental tax. See other studies that consider the trade policy as the second best policy tool, for example, Copeland (1996), Ludema and Takeno (2007) and Regibeau and Gallegos (2004).

can be summarized as follows. First, the existence of an environmental policy in a local country induce technology transfer from a foreign county. Second, free trade is preferable to a tariff policy for both country when the environmental damage is high. This has significant policy implications when one considers the claim for environmental degradation caused by trade liberalization. Third, technological transfer through licensing contract decrease for higher environmental damage by the decrease in quantity of the local firm's product. On the other hand, import of environmentally efficient goods from the foreign country increases.

The impact of strategic trade and environmental policies has been previously investigated by several authors. Walz and Wellisch (1997) compare free trade and export subsidies with a third-market model in the context of local pollution. They show that free trade (which means a ban on export subsidies) enhances the social welfare of symmetric exporting countries. Although reducing the export subsidy lowers the environmental tax to compensate the firm, the compensation is less than the export subsidy reduction. Therefore, free trade raises the price of the final product and extracts rent from consumers of the third market. The exporting countries benefit from this. However, because the higher price of the product lowers the consumer surplus of the third market, free trade is not preferable from the perspective of world welfare.

Tanguay (2001) extends the analysis to trans-boundary pollution under the reciprocal-markets model. He shows that tariff is preferable to free trade. In the case of free trade, the government sets the environmental tax rate lower than that under a tariff policy to protect its own firm. Moreover, because of transboundary pollution, the government does not have an incentive to set a higher environmental tax in order to shift the pollution activity to another country. Therefore, free trade leads to a lower environmental tax rate and worsens the social welfare.

Although many other studies have investigated the interaction between trade and environmental policies (see, e.g., Burguet and Sempere, 2003; Lai and Hu, 2008; Ohori, 2006; Ray Chaudhuri and Baksi, 2009; Riveiro, 2008), to our knowledge there is no study that analyzes the interaction regarding the impact on environmental technology transfer. The most important contribution of our study is that we consider the role of licensing contracts. The earlier studies argue that the strength of an environmental

policy resulting from a trade policy significantly impacts on environmental damage. Therefore, if free trade leads to a lower environmental tax, it lowers social welfare through deterioration of the environment. In contrast, we show that the strength of an environmental policy resulting from a trade policy significantly affects the level of license fees. If licensing occurs and eliminates environmental damage, the environmental impact of free trade can be mitigated. We show that there is a possibility that free trade is better than a tariff policy for both countries even though free trade lowers the environmental tax rate.

The remainder of this paper is organized as follows. In Section 2, we present an international duopoly model with global pollution. In Section 3, we investigate a free trade policy. In Section 4, we investigate a tariff policy without a commitment to the tariff level. In Section 5, we compare free trade with no commitment from the viewpoint of equilibrium quantity and revenue, and social welfare. The case of tariff policy with pre-commitment is also examined. The final section concludes.

2 The model

We consider a duopoly model with one foreign and one local firm. We suppose the goods are homogeneous except for their environmental properties. The goods produced by the local firm generate global external diseconomy. The foreign firm has clean technology and 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.

The profits of the foreign firm and the local firm are $\pi_f^{j,k} = (p^{j,k} - t^k)q_f^{j,k} + r^j q_l^{j,k}$ and $\pi_l^{j,k} = (p^{j,k} - \tau^j - r^j)q_l$, 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, τ^j is the environmental tax rate imposed on one unit of pollution, 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 $p^{j,k} = \alpha - q_f^{j,k} - q_l^{j,k}$, and standardize the marginal private cost of production to zero. The social welfare of the foreign country is the sum of the producer surplus minus the environmental damage: $SW_f^{j,k} = \pi_f^{j,k} - (\gamma/2)ED^{j,k}$.[4] The social welfare of the local country is the sum of the consumer surplus, the profit of the local firm, the environmental tax, and the tariff revenue minus the environmental damage: $SW_l^{j,k} = (q_f^{j,k}+q_l^{j,k})^2/2+\pi_l^{j,k}+\tau^j q_l^{j,k}+t^k q_f^{j,k}-(\gamma/2)ED^{j,k}$. We assume that one unit of production generates one unit of pollution. The environmental damage is represented as $ED^{j,k} = (q_l^{j,k})^2$ and is common for both countries.[5] The evaluation of the environmental damage is denoted by $\gamma/2$.[6] Since the licensing contract eliminates the environmental damage, $ED^{j,L} = 0$.

3 Free Trade

First, we consider the free trade case. The timing of the game is as follows. In the first stage, the foreign firm offers royalty r to the local firm. In the second stage, the local firm decides to accept the offer. In the third stage, if licensing does not occur in the previous stage, the local government determines environmental tax rate τ. In the final stage, the firms engage in quantity competition. The equilibrium concept is SPE. The game is solved backwards.

To clarify the effect of the tariff policy on technology transfer, we consider only the case in which the local government determines the optimal environmental tax after the licensing contract. Recent studies have pointed out that the regulator may change the pre-committed environmental standard because of a lack of credibility (see, e.g., Conrad 2001; Puller 2006).

In the final stage, each firm determines its output. The equilibrium quantity and

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

[5]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.

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

profit with and without licensing are $q_f^{F,L} = (\alpha + r)/3$, $q_l^{F,L} = (\alpha - 2r)/3$, $\pi_f^{F,L} = \left(q_f^{F,L}\right)^2 + rq_l^{F,L}$ and $\pi_l^{F,L} = \left(q_l^{F,L}\right)^2$; and $q_f^{F,N} = (\alpha + \tau)/3$, $q_l^{F,N} = (\alpha - 2\tau)/3$, $\pi_f^{F,N} = \left(q_f^{F,N}\right)^2$ and $\pi_l^{F,N} = \left(q_l^{F,N}\right)^2$, where superscripts F, L and N represent free trade, licensing, and no licensing, respectively.

In the third stage, if the local firm has not accepted a licensing contract, the local government imposes an environmental tax on the local firm. The social welfare of the local country in the third stage is $SW_l^{F,N} = \left(Q^{F,N}\right)^2/2 + \pi_l^{F,N} + \tau q_l^{F,N} - (\gamma/2)\left(q_l^{F,N}\right)^2$ where $Q^{F,N} = q_f^{F,N} + q_l^{F,N}$. The optimal environmental tax that maximizes $SW_l^{F,N}$ is

$$\tau^F = \frac{\alpha(-3 + 2\gamma)}{3 + 4\gamma}. \tag{1}$$

If $\gamma > 1.5$, then $\tau^F > 0$. Since $\partial\tau^F/\partial\gamma > 0$, the local government increases the optimal environmental tax for higher environmental damage. The equilibrium quantity and profit without licensing are $q_f^{F,N} = 2\alpha\gamma/(3 + 4\gamma)$, $q_l^{F,N} = 3\alpha/(3 + 4\gamma)$, $\pi_f^{F,N} = \left(q_f^{F,N}\right)^2$ and $\pi_l^{F,N} = \left(q_l^{F,N}\right)^2$.

In the licensing stage, the foreign firm offers the license fee r^F, which maximizes its profit subject to $\pi_l^{F,L} \geq \pi_l^{F,N}$. The optimal license fee is a corner solution and is derived as $r^F = \tau^F$ such that $q_l^{F,L} = q_l^{F,N}$. Then, if $\pi_f^{F,L}(r^F) \geq \pi_f^{F,N}$, the foreign firm licenses its environmental technology to the local firm. Because $q_f^{F,L}(r^F) = q_f^{F,N}$, the profit of the foreign firm is denoted as $\pi_f^{F,L} = \pi_f^{F,N} + r^F q_l^{F,L}$. Therefore, the foreign firm licenses its technology to the local firm if $r^F > 0$, and in turn $\tau^F > 0$. We obtain the next proposition.

Proposition 1. When $\gamma > 1.5$, licensing occurs. Otherwise, licensing does not occur.

We depict the equilibrium environmental tax and license fee in Figure 1. The left and the right panels of the figure are the equilibrium environmental tax and license fee, respectively. The vertical axis of the left panel is the environmental tax rate and that of the right panel is the license fee, and the horizontal axes are the evaluation of the environmental damage. When $\gamma \leq 1.5$, the environmental tax rate is negative and the local firm receives the subsidy ($\tau^F < 0$). When $\gamma > 1.5$, the local firm incurs the license fee to avoid the tax payment. The dotted line in the left panel implies that the environmental tax is avoided by the licensing contract. In contrast to the

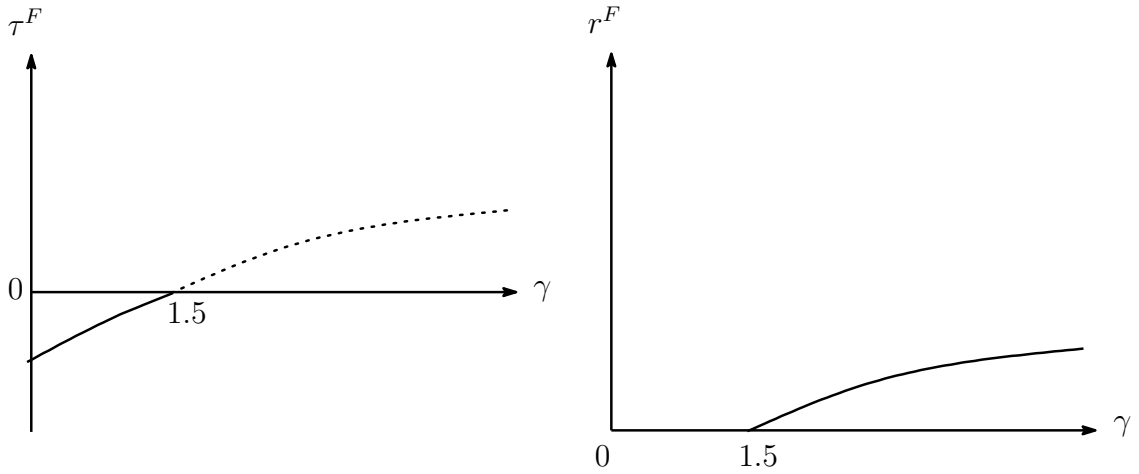

Figure 1: The equilibrium environmental tax and license fee in free trade

finding of Iida and Takeuchi (2010), licensing occurs even under free trade. This can be attributed to the existence of an environmental policy in the local country that gives a local firm an incentive to adopt the environmental technology. Indeed, if $\tau^F > 0$, licensing occurs. This obviously means that the incentive for the local firm to accept the contract is avoidance of regulation. When $\gamma \leq 1.5$, licensing does not occur and the local government subsidizes the polluting local firm.

Corollary 1. When $\gamma \leq 1.5$, the local government subsidizes the polluting local firm, therefore, $\tau^F \leq 0$.

Under the free trade regime, the local government does not have the means to protect the local firm directly. The government, therefore, uses an environmental tax as an instrument to protect the local firm.

Figure 2 shows the equilibrium value of quantity (the left panel) and profit (the right panel). The quantity and profit of the local firm decrease, and those of the foreign firm increase in γ. On the other hand, import of environmentally efficient goods from the foreign country increases in γ.

When $\gamma \leq 1.5$, because the local firm receives a subsidy ($\tau^F < 0$), the quantity of the local firm is larger than that of the foreign firm. When $\gamma > 1.5$, the local firm adopts the environmental technology and pay the license fee. Since a larger γ implies that the value of the environmental technology is higher, the license fee rises (Figure

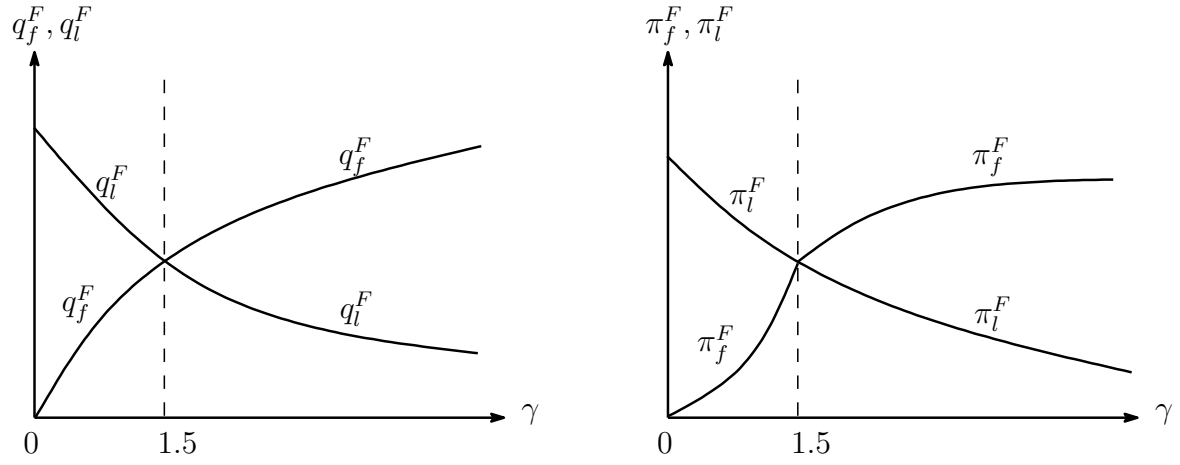

Figure 2: The equilibrium quantity and profit in free trade

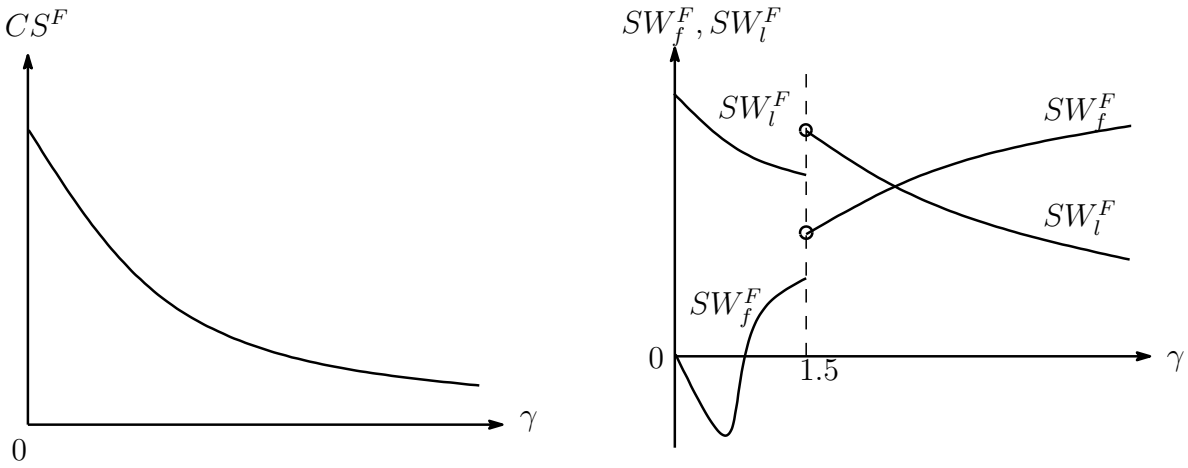

Figure 3: The equilibrium consumer surplus and social welfare in free trade

1). This drawback to the local firm results in an equilibrium quantity being less than that of the foreign firm.

Figure 3 shows the equilibrium consumer surplus (the left panel) and the social welfare (the right panel). Although the quantity of the foreign firm increases in γ, the reduction of the quantity of the local firm dominates. Therefore, consumer surplus decreases in γ.

When $\gamma < 1.5$, because the licensing contract does not occur, the social welfare of the local country decreases in γ. While the profit of the foreign firm increases, the environmental damage also increases in γ. The social welfare of the foreign country

depends on these two effects. When γ is small, the effect of environmental damage dominates that of the profit. As a result, the social welfare of the foreign country initially decreases and then begins to increase in γ. At $\gamma = 1.5$, the social welfare of both countries increases discontinuously. This is because licensing eliminates the environmental damage. After the licensing contract, there is no tariff revenue and the social welfare of the local country decreases. The social welfare of the foreign country becomes equal to the profit of the foreign firm and increases in γ.

4 Tariff policy

Next, we consider the case of tariff policy. While the optimal tariff will depend on whether the tariffs can be pre-committed before the licensing decisions, it is natural to assume that a government has the incentive to change a pre-announced tariff rate (Mukherjee and Pennings, 2006; Neary and Leahy, 2000). Thus, we analyze a no-commitment regime as a probable tariff policy.

In this case, the timing of the game is as follows. In the first stage, the foreign firm offers a licensing contract with royalty r^T to the local firm. In the second stage, the local firm decides to accept the offer. In the third stage, if licensing does not occur in the previous stage, the local government determines the tariff rate $t^{T,N}$ and environmental tax rate τ^T. If licensing does occur, the local government only determines the tariff rate $t^{T,L}$. In the final stage, the firms engage in quantity competition. The equilibrium concept is SPE. The game is solved backwards.

In the final stage, each firm determines its output. The equilibrium quantity and profit with and without licensing are $q_f^{T,L} = (\alpha + r - 2t^{T,L})/3$, $q_l^{T,L} = (\alpha - 2r + t^{T,L})/3$, $\pi_f^{T,L} = \left(q_f^{T,L}\right)^2 + rq_l^{T,L}$, and $\pi_l^{T,L} = \left(q_l^{T,L}\right)^2$; and $q_f^{T,N} = (\alpha - 2t^{T,N} + \tau)/3$, $q_l^{T,N} = (\alpha + t^{T,N} - 2\tau)/3$, $\pi_f^{T,N} = \left(q_f^{T,N}\right)^2$, and $\pi_l^{T,N} = \left(q_l^{T,N}\right)^2$, respectively. The social welfare of the local country with and without licensing is $SW_l^{T,L} = \left(Q^{T,L}\right)^2 + \pi_l^{T,L} + t^{T,L}q_f^{T,L}$ and $SW_l^{T,N} = \left(Q^{T,N}\right)^2 + \pi_l^{T,N} + \tau^T q_l^{T,N} + t^{T,N}q_f^{T,N} - (\gamma/2)\left(q_l^{ET,N}\right)^2$, respectively. In the third stage, when licensing does not occur, the local government determines the

environmental tax rate and the tariff rate to maximize $SW_l^{T,N}$. The FOCs yield

$$\hat{\tau}^{T,N} = \frac{t^{T,N}(3+2\gamma)-\alpha(3-2\gamma)}{3+4\gamma}, \tag{2}$$

$$\hat{t}^{T,N} = \frac{\tau^{T,N}(3+2\gamma)+\alpha(3-\gamma)}{9+\gamma}. \tag{3}$$

Since $\partial^2 SW_l^{T,N}/\partial\tau\partial t > 0$, there is a complementary relationship between $\tau^{T,N}$ and $t^{T,N}$. When the tariff rate is high, the environmentally friendly goods produced by the foreign firm cannot be diffused. Thus, the local government sets a high environmental tax while protecting the competitiveness of the local firm by setting a high tariff. On the other hand, when the tariff rate is lower, the local government sets a lower environmental tax. The lower environmental tax protects the local firm from competition with the foreign firm. From (2) and (3), we obtain the equilibrium environmental tax rate and tariff rate;

$$\tau^{T,N} = \frac{2\alpha(-1+\gamma)}{2+3\gamma}, \tag{4}$$

$$t^{T,N} = \frac{\alpha}{3} - \frac{2\alpha}{3(2+3\gamma)}. \tag{5}$$

When $\gamma < 1$, the environmental tax rate takes a negative value and the local government actually subsidizes the local firm, despite the pollution caused by it.

The optimal tariff rate takes its effect on the environment into account. This is confirmed by $t^{T,N} = \alpha/3 - 2\alpha/3(2+3\gamma) = \alpha/3 - (\partial(\gamma/2)ED^{T,N}/\partial q_l - \tau^{T,N})\partial q_l/\partial t$. The last term of the above equation corresponds to the environmental damage caused by the marginal increase in the tariff rate.

When licensing occurs, the optimal tariff rate is $t^{T,L} = \alpha/3$. We obtain the next proposition.

Proposition 2. The optimal tariff is higher with licensing than without licensing: $t^{T,L} > t^{T,N}$.

When licensing does not occur, the local government must consider protecting both the environment and the local firm. On the other hand, the local country can concentrate on protecting the local firm when licensing occurs and environmental damage is internalized. The difference leads to a higher optimal tariff under the no licensing

regime. The relationship between the difference in tariffs, $t^{T,L}-t^{T,N}$, and the evaluation of environmental damage is as follows.

Corollary 2. The difference between the tariff rate with and without licensing is smaller when γ is higher: $\partial[t^{T,L}-t^{T,N}]/\partial\gamma<0$

The local government enhances its regulation when environmental damage is large. Therefore, from (2), (3), the tariff rate $t^{T,N}$ is also enhanced to protect the local firm, which reduces the difference $t^{T,L}-t^{T,N}$. In contrast, when the implementation of environmental tax is restricted as in Iida and Takeuchi (2010), it sets a lower tariff rate for higher γ to diffuse the environmentally friendly goods produced by the foreign firm.

The third stage equilibrium quantity and profit with and without licensing are $q_f^{T,L}=(3r+\alpha)/9$, $q_l^{T,L}=2(2\alpha-3r)/9$, $\pi_f^{T,L}=\left(\alpha^2+42r\alpha-45r^2\right)/81$, and $\pi_l^{T,L}=\left(q_l^{T,L}\right)$; and $q_f^{T,N}=\alpha\gamma/(2+3\gamma)$, $q_l^{T,N}=2\alpha/(2+3\gamma)$, $\pi_f^{T,N}=\left(q_f^{T,N}\right)^2$, and $\pi_l^{T,N}=\left(q_l^{T,N}\right)$, respectively.

In the licensing stage, the foreign firm offers a license fee r^T that maximizes its profit subject to $\pi_l^{T,L}\geq\pi_l^{T,N}$. When $\gamma\leq 4.333$, the optimal license fee is a corner solution and is derived as $r_C^T=\alpha(-5+6\gamma)/(6+9\gamma)$ such that $q_l^{T,L}=q_l^{T,N}$.

When $\gamma>4.333$, the interior solution is derived as $r_I^T=7\alpha/15$. When γ is small, because environmental damage is small, the value of the environmental technology (the license fee) is also small; therefore, when $\gamma\leq 4.333$, the optimal license fee is derived as a corner solution. However, when γ is large, because the value of the environmental technology is higher, r_C^T is larger than r_I^T, which is independent of γ. Since the foreign firm incurs a tariff payment that increases the marginal cost of its product, it is no longer beneficial to require as large a license fee as possible when $\gamma>4.333$.

The profit of the foreign firm licensing the environmental technology to the local firm is $\pi_f^{T,L}(r_C^T)=\alpha^2\left(-29+30\gamma+9\gamma^2\right)/9(2+3\gamma)^2$ (when $\gamma\leq 4.333$) and $\pi_f^{T,L}(r_I^T)=2\alpha^2/15$ (when $\gamma>4.333$). When $\gamma\geq 0.967$, $\pi_f^{T,L}(r_C^T)\geq\pi_f^{T,N}$ and the foreign firm licenses the technology to the local firm. Moreover, since $\pi_f^{T,L}(r_I^{T,L})\geq\pi_f^{T,L}(r_C^{T,L})$, $\pi_f^{T,L}(r_I^{T,L})>\pi_f^{T,N}$ when $\gamma>4.333$. Hence, we obtain the next proposition.

Proposition 3. When $\gamma\geq 0.967$, licensing occurs. Otherwise, licensing does not occur.

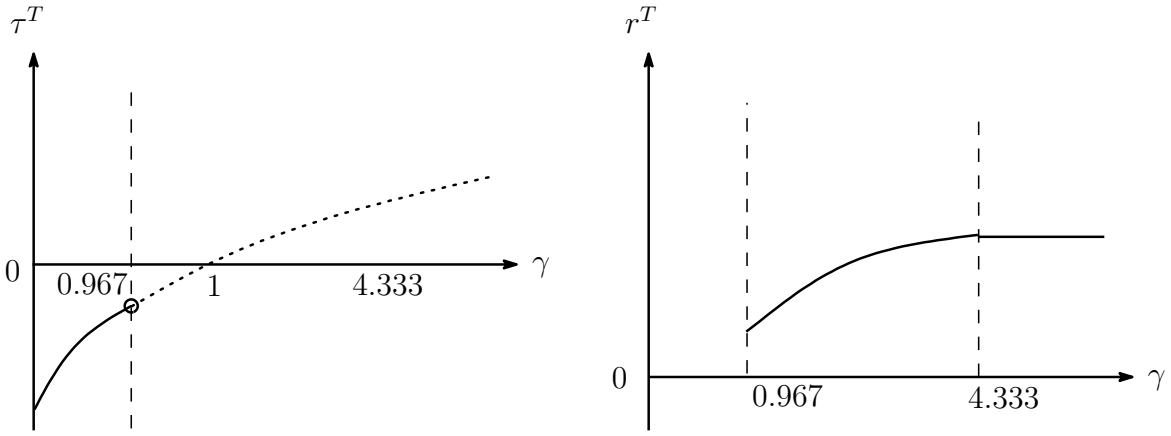

Figure 4: The equilibrium environmental tax and license fee in tariff policy

We depict the equilibrium environmental tax and license fee in Figure 4. The left and the right panels of the figure are the equilibrium environmental tax and license fee, respectively. The vertical axis of the left panel is the environmental tax rate and that of right is the license fee, and the horizontal axis is the evaluation of environmental damage. The dotted line is the environmental tax rate if the licensing does not occur. The local firm receives the subsidy ($\tau^T < 0$) when $\gamma < 0.967$. The local firm pays the license fee when $\gamma \geq 0.967$. The environmental tax rate and license fee are the marginal cost of production for the local firm, and increase in γ.

As we have already examined, the optimal tariff rate is $t^{T,L} = \alpha/3$ under a licensing contract (Figure 5).

The left and the right panels of Figure 6 show the equilibrium quantity and profit, respectively. The quantity of the local firm decreases in γ. This is because the marginal cost of production increases in γ, as illustrated in Figure 4. Since the license fee is determined such that $q_l^{T,L} = q_l^{T,N}$, the quantity decreases continuously in spite of a discontinuous increase in the marginal cost of production at $\gamma = 0.967$.

Although the tariff rate increases in γ when $\gamma < 0.967$, the quantity of the foreign firm increases. This is because the local government increases the environmental tax rate more than the tariff rate. Consequently, there is a larger downward shift in the reaction function of the local firm than that of the foreign firm. It decreases the quantity of the local firm and increases that of the foreign firm. At $\gamma = 0.967$, where licensing

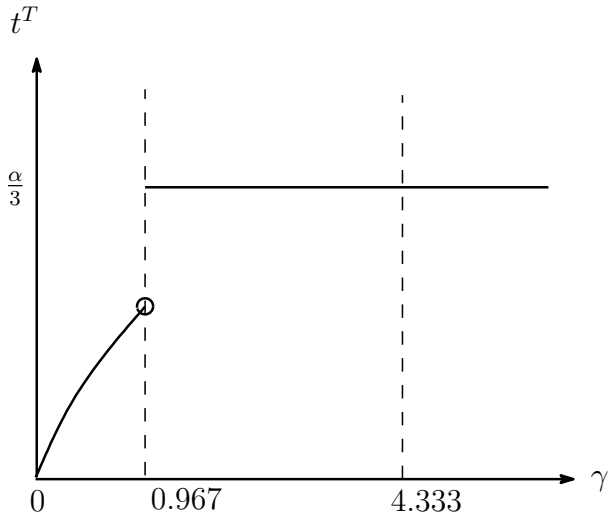

Figure 5: The equilibrium tariff rate in tariff policy

occurs, there is a discontinuous increase in the tariff rate and the quantity of the foreign firm drops down. However, because of the license revenue, the profit of the foreign firm keeps increasing in γ. When $\gamma > 4.333$, the license fee and therefore each firm's quantity do not depend on γ.

We depict the equilibrium consumer surplus (the left panel) and social welfare (the right panel) in Figure 7. As is in the case of free trade, consumer surplus decreases in γ because the reduction of the quantity of the local firm dominates the increase in the foreign firm's output. At $\gamma = 0.967$, consumer surplus drops off because of a discontinuous decrease in the quantity of the foreign firm. When $\gamma > 4.333$, consumer surplus does not depend on γ.

The social welfare of the local country decreases in γ. The social welfare of the foreign country initially decreases, and then begins to increase in γ. This interpretation is similar to that of free trade. After the licensing contract, the social welfare of the local country decreases and the social welfare of the foreign firm (which equals the profit of the foreign firm) increases. However, unlike what happens in the case of free trade, the social welfare of the local country is always larger than that of the foreign country. This is because of the tariff revenue.

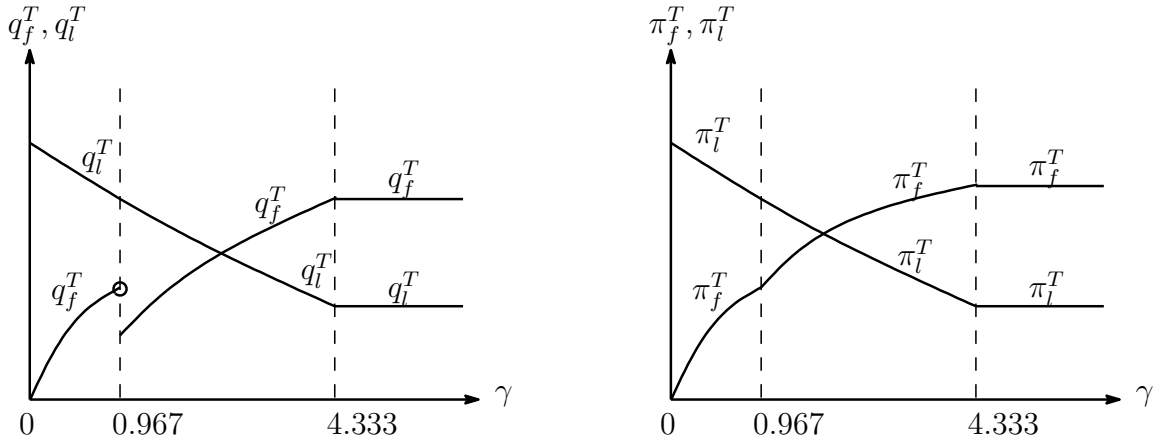

Figure 6: The equilibrium quantity and profit in tariff policy

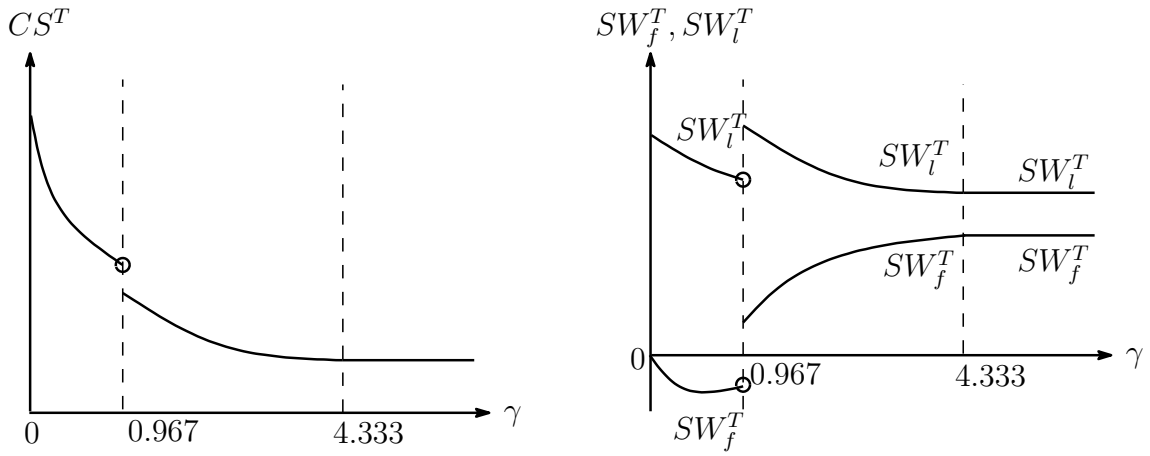

Figure 7: The equilibrium consumer surplus and social welfare in tariff policy

5 Discussions

5.1 Comparison

First, we compare free trade with tariff policy on the range where the licensing contract occurs. Licensing occurs when $\gamma > 1.5$ under free trade and $\gamma \geq 0.967$ under tariff policy. The range under tariff policy is larger than that under free trade.

Previous literature on the strategic environmental policies have pointed out that free trade lowers environmental regulation to compensate the domestic firm (Tanguay, 2001; Walz and Wellisch, 1997). Therefore, in such a case, the incentive of the local firm to adopt environmental technology may be weakened, and it may cause social welfare loss. However, we can show that there is a case where free trade is Pareto improving to tariff policy, although it leads to weaker environmental regulation.

Proposition 4. World welfare under tariff policy is higher than (resp. lower than or even with) that under free trade, when $\gamma \in (0, 0.203)$ and when $\gamma \in [0.967, 1.5]$ (resp. otherwise).

Figure 8 illustrates the situation by comparing the social welfare of each country. The upper part represents the policy preferred by the foreign country and the lower represents that by the local country. Initial T means tariff policy and F means free trade.

When $\gamma \in (0, 0.967)$, licensing does not occur under either regime. As a result, the foreign firm does not pay a tariff and the foreign country prefers free trade to tariff policy. On the other hand, the local country prefers tariff policy to free trade because of the tariff revenue. When $\gamma \in [0.967, 1.5]$, licensing occurs only under tariff policy. The foreign country prefers tariff policy in this case, because there is revenue from a license fee and no environmental damage. The local country also prefers tariff policy because of the tariff revenue. When $\gamma \in (1.5, 4.333]$, licensing occurs under both regimes. The foreign country prefers free trade to tariff policy because there is no tariff payment. The local country also prefers free trade to tariff policy as long as $\gamma \in (1.5, 4.301]$. This is because of the lower license fee under the free trade. Since free trade promote the diffusion of technology embodied in the product, the local government can place a

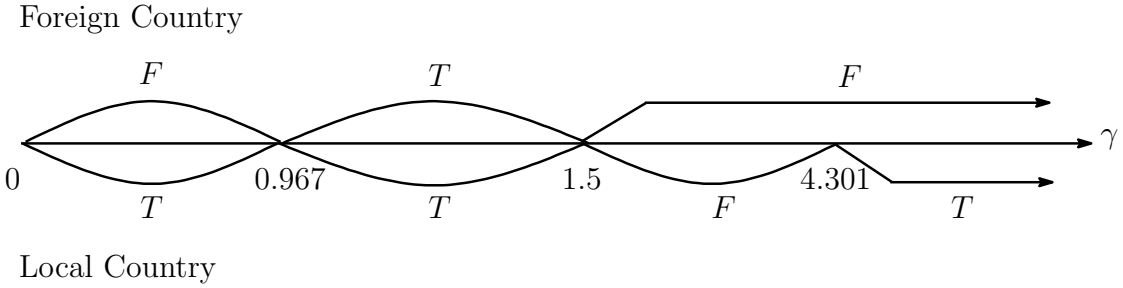

Figure 8: Comparison between each country's social welfare under free trade and tariff policy

lower environmental tax. It means that the local firm has less incentive to adopt an innovative environmental technology under such a regime.

When $\gamma > 4.301$, the local country prefers tariff policy to free trade. Since higher γ implies higher license fee, as illustrated in the previous section, the quantity of the local firm decreases and that of the foreign firm increases in γ (see the left panel of Figure 6). Consequently, the local country earns larger tariff revenue when γ is higher under tariff policy. When $\gamma > 4.301$, this benefit exceeds the cost of the higher license fee and the local country prefers tariff policy to free trade. Moreover, when $\gamma > 4.333$, the license fee is determined by interior solution and independent of γ. While the local country's social welfare decreases in γ under free trade (see the right panel of Figure 3), it is not affected under tariff policy (see the right panel of Figure 7). Thus, the local country prefers tariff policy to free trade when $\gamma > 4.333$. The foreign country prefers free trade because there is no tariff payment. To sum up, a comparison of the social welfare of each country under each regime leads to the following proposition.

Proposition 5. When $\gamma \in [0.967, 1.5]$ both countries prefer tariff policy to free trade. When $\gamma \in (1.5, 4.301]$ both countries prefer free trade to tariff policy.

Our main result can be summarized as follows. When the evaluation of the environmental damage (γ) is small, the tariff policy is useful to encourage the environmental technology transfer. However, when the evaluation of the environmental damage is large enough that the local country adopts environmental regulation, free trade is beneficial for the world welfare.

5.2 Commitment to a tariff

So far, the tariff rate is assumed to be determined after the licensing contract. If the regulator could commit itself in advance to a specific tariff rate, how does the previous result change? In this subsection, we consider the case of commitment to a tariff. We show that our main result does not change, except that there is a situation where the local country subsidizes the foreign firm to lower the license fee. Here we show only the result. The proof is in the Appendix.

We obtain the first stage equilibrium where the local government determines the optimal tariff rate as follows.

Proposition 6. When $\gamma \in (0, 0.5]$, the optimal tariff rate is $t^{C,N}$ and licensing does not occur. When $\gamma \in (0.5, 1.823]$, the optimal tariff rate is $\bar{t}_C^{C,L}$ and licensing occurs. When $\gamma \in (1.823, 5.266]$, the optimal tariff rate is $t_C^{C,L}$ and licensing occurs. When $\gamma > 5.266$, the optimal tariff rate is $t_I^{C,L}$ and licensing occurs.

Figure 9 illustrates Proposition 6. The vertical axis is the tariff rate and the horizontal axis is the evaluation parameter of environmental damage. We also depict the equilibrium environmental tax and license fee in Figure 10. The left and the right panels of the figure are the equilibrium environmental tax and the license fee, respectively. The dotted line is the environmental tax rate when licensing contracts are not entered into. In the case of commitment, the local government can induce licensing contracts through the tariff rate. Because the license fee is equal to the environmental tax rate ($r^C = \tau^C$) and $\partial\tau^C/t > 0$, the local government lowers the tariff rate to suppress the license fee. Moreover, because $\partial\tau^C/\gamma > 0$, to suppress the license fee to low levels (almost zero; see the left panel of Figure 10), the local government puts a lower tariff rate for higher γ when $\gamma \in (0.5, 1.823)$ (Figure 9). When $\gamma > 1.5$, the tariff rate becomes negative and works as an import subsidy for the foreign firm. We obtain the next corollary.

Corollary 3. When $\gamma \in (1.5, 2.303)$, the optimal tariff rate is negative.

When $\gamma > 1.823$, it is not beneficial for the local country to apply a negative tariff ($t^C < 0$) anymore. Although the license fee also increase, the local government increases the tariff rate to increases tariff revenue. We compare the world welfare under free trade with that under commitment.

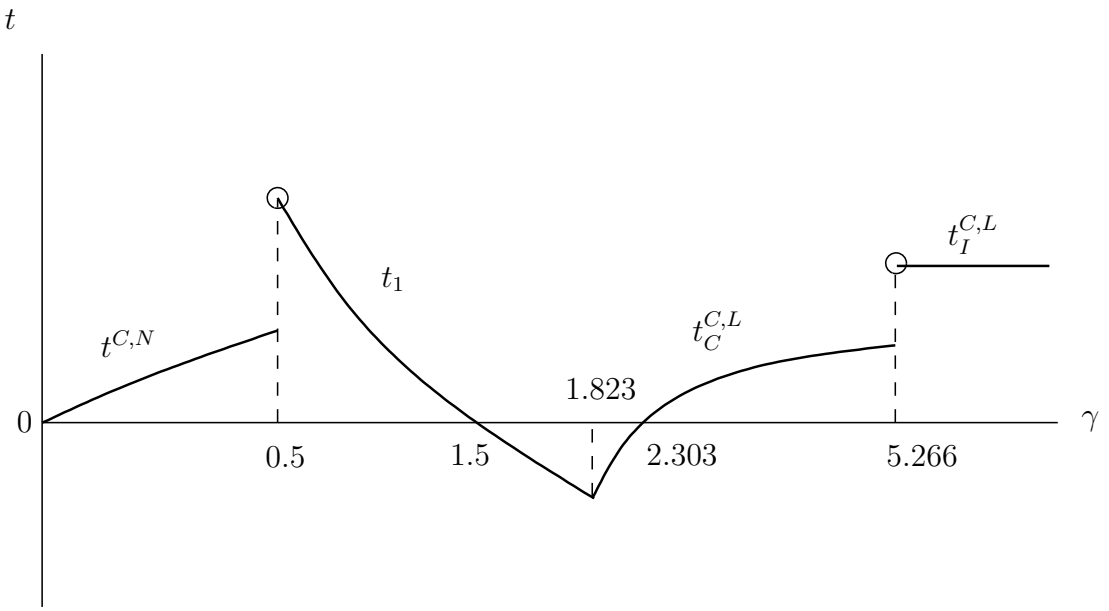

Figure 9: The optimal tariff under commitment to a tariff

Proposition 7. World welfare under commitment is higher than (resp. lower than or even with) that under free trade, when $\gamma \in (0, 0.203)$ and when $\gamma \in (0.5, 2.303)$ (resp. otherwise).

Therefore, free trade is preferable to a tariff policy with commitment when the evaluation of the environmental damage is high (when $\gamma \geq 2.303$).

Figure 12 compares the social welfare of each country. Interpretation of the figure is mostly the same as that of the no commitment case, except for $\gamma > 1.5$, where licensing occurs under both cases. If the local government can commit itself to a tariff, it sets a tariff rate that attracts the lowest possible license fee. Therefore, the local country always prefers commitment to free trade. When $\gamma \in (1.5, 2.303)$, the foreign firm receives a subsidy in the form of negative tariff. So the foreign country also prefers commitment to free trade. When $\gamma \geq 2.303$, the foreign firm incurs a positive tariff again and prefers free trade to tariff policy with commitment. Hence, a comparison of the social welfare of each country leads to the following proposition.

Proposition 8. When $\gamma \in (0.5, 2.303)$ both countries prefer commitment to free trade.

Unlike the case of free trade or tariff policy, there is a range where consumer surplus increases in γ (see Figure 11). This is because the optimal tariff decreases in γ when

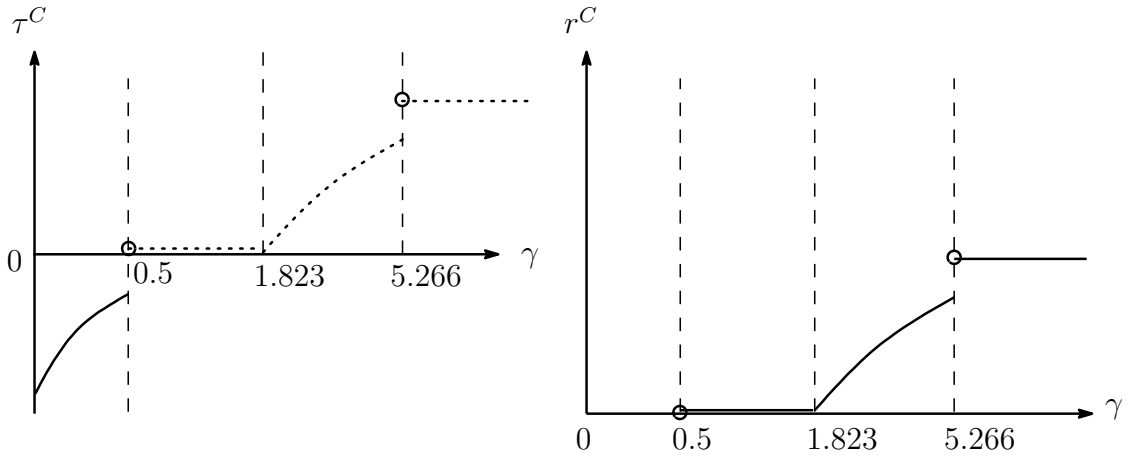

Figure 10: The equilibrium environmental tax and license fee under commitment to a tariff

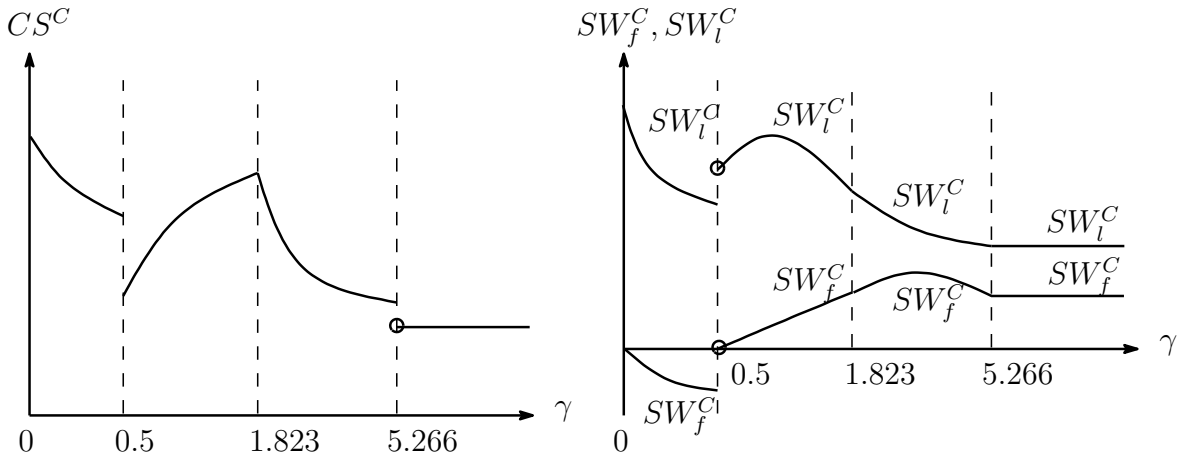

Figure 11: The equilibrium consumer surplus and social welfare under commitment to a tariff

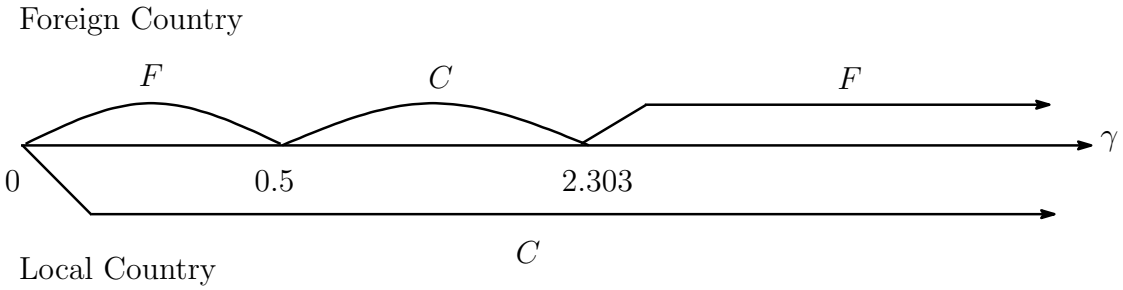

Figure 12: Comparison between each country's social welfare under free trade and commitment to a tariff

$\gamma \in (0.5, 1.823]$. Consequently, the increase in the foreign firm's output dominates the decrease in the local firm's output. The profit of the local firm decreases and the subsidy to the foreign firm ($t^C < 0$) increases in γ. Since these costs are less than the increase in consumer surplus, the social welfare of the local country initially increases in this range of γ.

The range over which licensing occurs under tariff policy with commitment is larger than that under free trade or under tariff policy without commitment. Through its commitment, the local government can encourage licensing contracts by its tariff policy. The local government sets the environmental tax rate higher than it would under no commitment, thereby inducing licensing contracts. Therefore, licensing contracts are promoted by committing to a tariff rate. In the case of no commitment, the decision of the licensing contract is already made when the local government sets the tariff rate. Therefore, if licensing does not occur, the local government sets a lower environmental tax to protect the local firm, which discourages the agreement of environmental technology transfer.

6 Conclusion

This paper has examined the welfare implications of a free trade regime and a licensing agreement within a framework of international duopoly involving global pollution. We have shown that although free trade lowers environmental regulation relative to a tariff policy, free trade is preferable to a tariff policy for world welfare when the evaluation of the environmental damage is higher. Moreover, we have shown that there is a possibility

that free trade dominates a tariff policy in the Paretian sense when the environmental damage is within a certain range. The cost of free trade for the local country is that there is no tariff revenue. The benefit is the lower license fee that is the result of lower environmental regulation. When the environmental damage is within a certain range, the benefit dominates the cost, and the local country prefers free trade to a tariff policy.

When the developing country cares less about the environmental damage, a tariff policy is beneficial to transferring environmental technology and enhancing the world welfare. If the concern of the developing country is high enough to conduct environmental regulation, free trade is preferable to a tariff policy for world welfare.

Appendix

The equilibrium value under free trade

We obtain the following result for the case of free trade when $0 < \gamma \leq 1.5$ where licensing does not occur as follows:

$$
\begin{aligned}
p^F &= \frac{2\alpha\gamma}{3+4\gamma}, \quad q_f^F = \frac{2\alpha\gamma}{3+4\gamma}, \quad q_l^F = \frac{3\alpha}{3+4\gamma}, && (6)\\
\pi_f^F &= \frac{4\alpha^2\gamma^2}{(3+4\gamma)^2}, \quad \pi_l^F = \frac{9\alpha^2}{(3+4\gamma)^2}, && (7)\\
SW_f^F &= \frac{\alpha^2\gamma(-9+8\gamma)}{2(3+4\gamma)^2}, \quad SW_l^F = \frac{\alpha^2(3+\gamma)}{6+8\gamma}, && (8)\\
SW_w^F &= \frac{3\alpha^2(3+2\gamma+4\gamma^2)}{2(3+4\gamma)^2}. && (9)
\end{aligned}
$$

When $\gamma > 1.5$, the result where licensing occurs is denoted as follows:

$$
\begin{aligned}
p^F &= \frac{2\alpha\gamma}{3+4\gamma}, \quad q_f^F = \frac{2\alpha\gamma}{3+4\gamma}, \quad q_l^F = \frac{3\alpha}{3+4\gamma}, && (10)\\
\pi_f^F &= \frac{\alpha^2\left(-9+6\gamma+4\gamma^2\right)}{(3+4\gamma)^2}, \quad \pi_l^F = \frac{9\alpha^2}{(3+4\gamma)^2}, && (11)\\
SW_f^F &= \frac{\alpha^2\left(-9+6\gamma+4\gamma^2\right)}{(3+4\gamma)^2}, \quad SW_l^F = \frac{\alpha^2(27+12\gamma+4\gamma^2)}{2(3+4\gamma)^2}, && (12)\\
SW_w^F &= \frac{3\alpha^2(3+8\gamma+4\gamma^2)}{2(3+4\gamma)^2}. && (13)
\end{aligned}
$$

The equilibrium value under tariff policy without commitment

We obtain the following result for the case of tariff policy when $0 < \gamma < 0.967]$ where licensing does not occur as follows:

$$
\begin{aligned}
p^T &= \frac{2\alpha\gamma}{2+3\gamma}, \quad q_f^T = \frac{\alpha\gamma}{2+3\gamma}, \quad q_l^T = \frac{2\alpha}{2+3\gamma}, && (14)\\
\pi_f^T &= \frac{\alpha^2\gamma^2}{(2+3\gamma)^2}, \quad \pi_l^T = \frac{4\alpha^2}{(2+3\gamma)^2}, && (15)\\
SW_f^T &= \frac{\alpha^2(-2+\gamma)\gamma}{(2+3\gamma)^2}, \quad SW_l^T = \frac{\alpha^2(2+\gamma)}{4+6\gamma}, && (16)\\
SW_w^T &= \frac{\alpha^2\left(4+4\gamma+5\gamma^2\right)}{2(2+3\gamma)^2}. && (17)
\end{aligned}
$$

When $0.967 \leq \gamma \leq 4.333$, the result where licensing occurs is denoted as follows:

$$p^T = \frac{\alpha + 6\alpha\gamma}{6 + 9\gamma}, \quad q_f^T = \frac{\alpha(-1 + 3\gamma)}{6 + 9\gamma}, \quad q_l^T = \frac{2\alpha}{2 + 3\gamma}, \tag{18}$$

$$\pi_f^T = \frac{\alpha^2 \left(-29 + 30\gamma + 9\gamma^2\right)}{9(2 + 3\gamma)^2}, \quad \pi_l^T = \frac{4\alpha^2}{(2 + 3\gamma)^2}, \tag{19}$$

$$SW_f^T = \frac{\alpha^2 \left(-29 + 30\gamma + 9\gamma^2\right)}{9(2 + 3\gamma)^2}, \quad SW_l^T = \frac{\alpha^2 \left(31 + 12\gamma + 9\gamma^2\right)}{6(2 + 3\gamma)^2}, \tag{20}$$

$$SW_w^T = \frac{\alpha^2 \left(35 + 96\gamma + 45\gamma^2\right)}{18(2 + 3\gamma)^2}. \tag{21}$$

When $\gamma > 4.333$, the result where licensing occurs is denoted as follows:

$$p^T = \frac{3\alpha}{5}, \quad q_f^T = \frac{4\alpha}{15}, \quad q_l^T = \frac{2\alpha}{15}, \tag{22}$$

$$\pi_f^T = \frac{2\alpha^2}{15}, \quad \pi_l^T = \frac{4\alpha^2}{225}, \tag{23}$$

$$SW_f^T = \frac{2\alpha^2}{15}, \quad SW_l^T = \frac{14\alpha^2}{75}, \tag{24}$$

$$SW_w^T = \frac{8\alpha^2}{25}. \tag{25}$$

The equilibrium value under tariff policy with commitment

We obtain the following result for the case of commitment to a tariff when $\gamma \in (0, 0.5]$ where licensing does not occur as follows:

$$p^C = \frac{2\alpha\gamma}{2 + 3\gamma}, \quad q_f^C = \frac{\alpha\gamma}{2 + 3\gamma}, \quad q_l^C = \frac{2\alpha}{2 + 3\gamma}, \tag{26}$$

$$\pi_f^C = \frac{\alpha^2\gamma^2}{(2 + 3\gamma)^2}, \quad \pi_l^C = \frac{4a^2}{(2 + 3\gamma)^2}, \tag{27}$$

$$SW_f^C = \frac{\alpha^2(-2 + \gamma)\gamma}{(2 + 3\gamma)^2}, \quad SW_l^C = \frac{\alpha^2(2 + \gamma)}{4 + 6\gamma}, \tag{28}$$

$$SW_w^C = \frac{\alpha^2 \left(4 + 4\gamma + 5\gamma^2\right)}{2(2 + 3\gamma)^2}. \tag{29}$$

When $\gamma \in (0.5, 1.823]$, the result where licensing occurs under the tariff rate $t_1 + \varepsilon$ is denoted as follows:

$$p^C = \frac{2\alpha}{3+2\gamma}, \quad q_f^C = \frac{\alpha(-1+2\gamma)}{3+2\gamma}, \quad q_l^C = \frac{2\alpha}{3+2\gamma}, \tag{30}$$

$$\pi_f^C = \frac{\alpha^2(1-2\gamma)^2}{(3+2\gamma)^2}, \quad \pi_l^C = \frac{4\alpha^2}{(3+2\gamma)^2}, \tag{31}$$

$$SW_f^C = \frac{\alpha^2(1-2\gamma)^2}{(3+2\gamma)^2}, \quad SW_l^C = \frac{\alpha^2\left(3+20\gamma-4\gamma^2\right)}{2(3+2\gamma)^2}, \tag{32}$$

$$SW_w^C = \frac{\alpha^2\left(5+12\gamma+4\gamma^2\right)}{2(3+2\gamma)^2}. \tag{33}$$

When $\gamma \in (1.823, 5.266]$, the result where licensing occurs under the tariff rate $t_C^{C,L}$ is denoted as follows:

$$p^C = \frac{2\alpha(-1+\gamma)}{3\gamma}, \quad q_f^C = \frac{\alpha\left(1+\gamma+\gamma^2\right)}{3\gamma(1+\gamma)}, \quad q_l^C = \frac{\alpha+2\alpha\gamma}{3\gamma+3\gamma^2}, \tag{34}$$

$$\pi_f^C = \frac{\alpha^2\left(-2-4\gamma+5\gamma^2+\gamma^3\right)}{9\gamma^2(1+\gamma)}, \quad \pi_l^C = \frac{(\alpha+2\alpha\gamma)^2}{9\gamma^2(1+\gamma)^2}, \tag{35}$$

$$SW_f^C = \frac{\alpha^2\left(-2-4\gamma+5\gamma^2+\gamma^3\right)}{9\gamma^2(1+\gamma)}, \quad SW_l^C = \frac{\alpha^2\left(4+\gamma+\gamma^2\right)}{6\gamma(1+\gamma)}, \tag{36}$$

$$SW_w^C = \frac{\alpha^2\left(-4+8\gamma+5\gamma^2\right)}{18\gamma^2}. \tag{37}$$

When $\gamma > 5.266$, the result where licensing occurs under the tariff rate $t_I^{C,L}$ is denoted as follows:

$$p^C = \frac{20\alpha}{33}, \quad q_f^C = \frac{25\alpha}{99}, \quad q_l^C = \frac{14\alpha}{99}, \tag{38}$$

$$\pi_f^C = \frac{47\alpha^2}{363}, \quad \pi_l^C = \frac{196\alpha^2}{9801}, \tag{39}$$

$$SW_f^C = \frac{47\alpha^2}{363}, \quad SW_l^C = \frac{37\alpha^2}{198}, \tag{40}$$

$$SW_w^C = \frac{689\alpha^2}{2178}. \tag{41}$$

The proof of Proposition 4

We compare world welfare in the case of free trade with that in the case of tariff policy. We compare SW_w^F with SW_w^T when $\gamma \in (0, 0.967)$ where licensing does not occur in

either case, and obtain

$$SW_w^F - SW_w^T = \frac{\alpha^2\gamma^2\left(-2+7\gamma+14\gamma^2\right)}{(2+3\gamma)^2(3+4\gamma)^2}. \tag{42}$$

Solving $(-2+7\gamma+14\gamma^2)=0$ with respect to γ, we obtain $\gamma \approx 0.203$. Therefore, $SW_w^F < SW_w^T$ if $\gamma \in (0, 0.203)$ and $SW_w^F \geq SW_w^T$ if $\gamma \in [0.203, 0.967)$.

We compare SW_w^F with SW_w^T when $\gamma \in [0.967, 1.5]$ where licensing occurs only in the case of tariff policy and obtain the result

$$SW_w^F - SW_w^T = \frac{\alpha^2\left(9-516\gamma-1460\gamma^2-834\gamma^3+252\gamma^4\right)}{18(2+3\gamma)^2(3+4\gamma)^2} > 0, \tag{43}$$

if $\gamma \in [0.966, 1.5]$.

We compare SW_w^F with SW_w^T when $\gamma \in (1.5, 4.33]$ where licensing occurs in both cases and obtain the result

$$SW_w^F - SW_w^T = \frac{\alpha^2\left(3+10\gamma+6\gamma^2\right)\left(3+34\gamma+42\gamma^2\right)}{18(2+3\gamma)^2(3+4\gamma)^2} > 0. \tag{44}$$

We compare SW_w^F with SW_w^T when $\gamma > 4.333$ where licensing occurs in both cases and obtain the result

$$SW_w^F - SW_w^T = \frac{\alpha^2(9+2\gamma)(9+22\gamma)}{50(3+4\gamma)^2} > 0. \tag{45}$$

Q.E.D.

The proof of Proposition 5

First, we compare the foreign country's social welfare in the case of free trade with that in the case of tariff policy. We compare SW_f^F with SW_f^T when $\gamma \in (0, 0.967)$ and obtain

$$SW_f^F - SW_f^T = \frac{\alpha^2\gamma^2\left(2+31\gamma+40\gamma^2\right)}{2(2+3\gamma)^2(3+4\gamma)^2} > 0. \tag{46}$$

We compare SW_f^F with SW_f^T when $\gamma \in [0.967, 1.5]$ and obtain

$$SW_f^F - SW_f^{ET} = \frac{\alpha^2\left(522+528\gamma-1358\gamma^2-1257\gamma^3+360\gamma^4\right)}{18(2+3\gamma)^2(3+4\gamma)^2} < 0, \tag{47}$$

if $\gamma \in [0.967, 1.5]$.

We compare SW_f^F with SW_f^T when $\gamma \in (1.5, 4.333]$ and obtain

$$SW_f^F - SW_f^T = \frac{\alpha^2 (-63 - 330\gamma - 274\gamma^2 + 222\gamma^3 + 180\gamma^4)}{9(2+3\gamma)^2(3+4\gamma)^2} > 0, \tag{48}$$

if $\gamma \in (1.5, 4.333]$.

We compare SW_f^F with SW_f^T when $\gamma > 4.333$ and obtain

$$SW_f^F - SW_f^T = -\frac{\alpha^2 (-153 + 42\gamma + 28\gamma^2)}{15(3+4\gamma)^2} > 0, \tag{49}$$

if $\gamma > 4.333$.

Next, we compare the local country's social welfare in the case of free trade with that in the case of tariff policy. We compare SW_l^F with SW_l^T when $\gamma \in (0, 0.967)$ and obtain

$$SW_l^F - SW_l^T = -\frac{\alpha^2\gamma^2}{2(2+3\gamma)(3+4\gamma)} < 0. \tag{50}$$

We compare SW_l^F with SW_l^T when $\gamma \in [0.967, 1.5]$ and obtain

$$SW_l^F - SW_l^T = -\frac{\alpha^2 (57 + 40\gamma - 42\gamma^2 + 9\gamma^3)}{6(2+3\gamma)^2(3+4\gamma)} < 0, \tag{51}$$

if $\gamma \in [0.967, 1.5]$.

We compare SW_l^F with SW_l^T when $\gamma \in (1.5, 4.333]$ and obtain

$$SW_l^F - SW_l^T = -\frac{\alpha^2 (-45 - 264\gamma - 344\gamma^2 - 60\gamma^3 + 36\gamma^4)}{6(2+3\gamma)^2(3+4\gamma)^2}. \tag{52}$$

Solving $(-45 - 264\gamma - 344\gamma^2 - 60\gamma^3 + 36\gamma^4) = 0$ with respect to γ, we obtain $\gamma \approx 4.301$. Therefore, $SW_w^F \geq SW_w^T$ if $\gamma \in (1.5, 4.301)$ and $SW_w^F < SW_w^T$ if $\gamma \in (4.301, 4.333]$.

We compare SW_l^F with SW_l^T when $\gamma > 4.333$ and obtain

$$SW_l^F - SW_l^T = -\frac{\alpha^2 (-1773 - 228\gamma + 148\gamma^2)}{150(3+4\gamma)^2} < 0, \tag{53}$$

if $\gamma > 4.333$.

Q.E.D.

Commitment to a tariff

In the case of commitment to a tariff, the timing of the game is as follows; in the first stage, the local government determines the tariff rate t^C; in the second stage, the foreign firm offers a licensing contract with royalty r^C to the local firm; in the third stage, the local firm decides whether to accept the offer; in the fourth stage, if licensing does not occur in the previous stage, the local government determines the environmental tax rate τ^C; and in the final stage, the firms engage in quantity competition. The equilibrium concept is SPE. The game is solved backwards.

In the final stage, each firm determines its output. The equilibrium quantity and profit with and without the licensing contract are $q_f^{C,L} = (\alpha + r - 2t)/3$, $q_l^{C,L} = (\alpha - 2r + t)/3$, $\pi_f^{C,L} = (\alpha^2 + 5\alpha r - 5r^2 - 4\alpha t - rt + 4t^2)/9$, and $\pi_l^{C,L} = (q_l^{C,L})^2$; and $q_f^{C,N} = (\alpha - 2t + \tau)/3$, $q_l^{C,N} = (\alpha + t - 2\tau)/3$, $\pi_f^{C,N} = (q_f^{C,N})^2$, and $\pi_l^{C,N} = (q_l^{C,N})^2$, respectively. The social welfare of the local country, with and without licensing respectively, is

$$SW_l^{C,L} = \frac{1}{6}\left(2\alpha^2 - 4\alpha r + 3r^2 + 2\alpha t - 3t^2\right), \tag{54}$$

$$SW_l^{C,N} = \frac{\alpha^2(6-\gamma) - t^2(9+\gamma) + 2t(3+2\gamma)\tau - (3+4\gamma)\tau^2 + \alpha(6t - 2t\gamma - 6\tau + 4\gamma\tau)}{18}. \tag{55}$$

In the fourth stage, when licensing does not occur, the local government determines the environmental tax rate to maximize (55). The equilibrium environmental tax rate is

$$\tau^C = \frac{t(3+2\gamma) - \alpha(3-2\gamma)}{3+4\gamma}. \tag{56}$$

When $t > \alpha(3-2\gamma)/(3+2\gamma) \equiv t_1$, $\tau^C > 0$. The fourth stage equilibrium quantity and profit where licensing does not occur are $q_f^{C,N} = (2\alpha\gamma - t - 2t\gamma)/(3+4\gamma)$, $q_l^{C,N} = (3\alpha - t)/(3+4\gamma)$, $\pi_f^{C,N} = \left(q_f^{C,N}\right)^2$ and $\pi_l^{C,N} = \left(q_l^{C,N}\right)^2$.

In the licensing stage, the foreign firm offers a license fee r^C that maximizes its profit subject to $\pi_l^{C,L} \geq \pi_l^{C,N}$. The optimal license fee is a corner solution when $t \leq 15\alpha/(11+8\gamma) \equiv t_2$ and is derived as $r_C^C = \tau^C$ such that $q_l^{C,L} = q_l^{C,N}$. Hence, if $t > t_1$, the local firm has an incentive to innovate environmental technology. So, if $\pi_f^{C,L}(r_C^C) \geq \pi_f^{C,N}$, the foreign firm licenses environmental technology to the local firm. Because $q_f^{C,L}(r_C^C) = q_f^{C,N}$, the profit of the foreign firm when it licenses the technology

is denoted as $\pi_f^{C,L} = \pi_f^{C,N} + r_C^C q_l^{C,L}$. Therefore, the foreign firm licenses its technology to the local firm when $r_C^C > 0$, and in turn $t > t_1$. The optimal license fee is an interior solution when $t > t_2$ and is $r_I^C = (5\alpha - t)/10$. When t is higher, because $\partial\tau^C/\partial t > 0$, the license fee r_C^C rises. Moreover, the higher tariff increases the production cost of the foreign firm. Therefore when $t > t_2$, the interior solution r_I^C emerges. Then the profit of the foreign firm is $\pi_f^{C,L}(r_I^C) = (5\alpha^2 - 10\alpha t + 9t^2)/20$. Because $t_2 > t_1$, $\pi_f^{C,L}(r_I^C) \geq \pi_f^{C,L}(r_C^C)$ and $\pi_f^{C,L}(r_C^I) > \pi_f^{C,N}$ when $t > t_1$, $\pi_f^{C,L}(r_I^C) > \pi_f^{C,N}$ when $t > t_2$. To sum up, the foreign firm licenses its technology when $t > t_1$

The second stage equilibrium social welfare of the local country when licensing occurs under the license fees r_C^C and r_I^C and that when licensing does not occur are, respectively,

$$SW_l^{C,L} = \frac{\alpha^2(27 + 12\gamma + 4\gamma^2) + 8\alpha t(-3 - \gamma + \gamma^2) - 12t^2\gamma(1 + \gamma)}{2(3 + 4\gamma)^2} \tag{57}$$

when $t_1 < t \leq t_2$,

$$SW_l^{C,L} = \frac{(25\alpha^2 + 70\alpha t - 99t^2)}{200} \tag{58}$$

when $t > t_2$ and

$$SW_l^{C,N} = \frac{2\alpha t\gamma + \alpha^2(3 + \gamma) - t^2(2 + 3\gamma)}{6 + 8\gamma} \tag{59}$$

when $t \leq t_1$.

The optimal tariff rate

In the first stage, the local government determines the optimal tariff rate. We must consider the tariff rate that is compatible with the licensing decision of stage 2. This means there are three cases. Case 1 is that the local government determines tariff rate $t^{C,L}$ such that $t_1 < t^{C,L} \leq t_2$, and then licensing occurs under the license fee r_C^C. Note that we assumed $t \leq \alpha/2$ and because $t_1 \geq \alpha/2$ when $\gamma \leq 0.5$, there is no t such that $t > t_1$. So when $\gamma \leq 0.5$, licensing does not occur. Case 2 is that the local government determines tariff rate $t^{C,L}$ such that $t^{C,L} > t_2$, and then licensing occurs under the license fee r_I^C. Case 3 is that the local government determines tariff rate $t^{C,N}$ such that $t^{C,N} \leq t_1$, and then licensing does not occur.

Case 1: licensing occurs under the license fee r_C^C in the next stage

First, we consider Case 1, in which the local government determines the tariff rate that will maximize social welfare in the local country, in anticipation of a next stage in which licensing will occur. The optimal tariff rate that maximizes (57) is

$$t_C^{C,L} = \frac{\alpha\left(-3-\gamma+\gamma^2\right)}{3\gamma(1+\gamma)}. \tag{60}$$

If $\gamma \in (1.823, 6.808]$ then $t_1 < t_C^{C,L} \leq t_2$. Therefore, if $\gamma \in (1.823, 6.808]$, $t_C^{C,L}$ is the equilibrium tariff rate that is compatible with the licensing stage decision. Otherwise, $t_C^{C,L}$ is incompatible with the licensing decision. However, if the local government determines a tariff rate such that $\bar{t}_C^{C,L} = t_1 + \varepsilon$ where $\varepsilon > 0$ is small enough, then licensing occurs under the tariff rate $\bar{t}_C^{C,L}$. Moreover, if the local government determines the tariff rate such that $\bar{t}_{C2}^{C,L} = t_2$, then licensing occurs under the tariff rate $\bar{t}_{C2}^{C,L}$.

Case 2: licensing occurs under the license fee r_I^Cin the next stage

Next, we consider Case 2, in which the local government determines the tariff rate that will maximize social welfare in the local country, in anticipation of a next stage in which licensing will occur. The optimal tariff rate that maximizes (58) is

$$t_I^{C,L} = \frac{35\alpha}{99}. \tag{61}$$

If $\gamma > 3.929$ then $t_I^{C,L} > t_2$. Therefore, if $\gamma > 3.929$, $t_I^{C,L}$ is the equilibrium tariff rate that is compatible with the licensing stage decision. Otherwise, $t_I^{C,L}$ is incompatible with the licensing decision. However, if the local government determines a tariff rate such that $\bar{t}_I^{C,L} = t_2 + \varepsilon$ where $\varepsilon > 0$ is small enough, then licensing occurs under the tariff rate $\bar{t}_I^{C,L}$.

Case 3: licensing does not occur in the next stage

Finally, we consider Case 3, in which the local government determines a tariff rate in anticipation of a next stage in which licensing will not occur. The optimal tariff rate that maximizes (59) is

$$t^{C,N} = \frac{a\gamma}{2+3\gamma}. \tag{62}$$

If $\gamma \leq 1$ then $t^{C,N} \leq t_1$. Therefore, if $\gamma \leq 1$, $t^{C,N}$ is the equilibrium tariff rate that is compatible with the licensing stage decision. Othewise, $t^{C,N}$ is incompatible with the next stage decision. However, when $\gamma > 1$, if the local government determines a tariff rate such that $\bar{t}^{C,N} = t_1$, then licensing does not occur under the tariff rate $\bar{t}^{C,N}$.

The local government will choose a tariff rate that will induce the largest social welfare. If the local government wants to obtain this result when licensing occurs, it will set the optimal tariff rate at $t_C^{C,L}$ or $\bar{t}_C^{C,L}$ or $\bar{t}_{C2}^{C,L}$ or $t_I^{C,L}$ or $\bar{t}_I^{C,L}$. If it does not, it will set the optimal tariff rate at $t^{C,N}$ or $\bar{t}^{C,N}$. From the above, we obtain Proposition 6.

The equilibrium environmental tax when licensing does not occur is $\tau^C(t^{C,N}) = 2\alpha(-1+\gamma)/(2+3\gamma)$. The equilibrium license fee when $t^C = t_C^{C,L}$ and that when $t^C = t_I^{C,L}$ are $r_C^C(t_C^{C,L}) = \alpha\left(-3-2\gamma+2\gamma^2\right)/3\gamma(1+\gamma)$, and $r_I^C(t_I^{C,L}) = 46\alpha/99$, respectively.

The decision of the optimal tariff rate

The social welfare of the local country, under a tariff rate when $t = t^{C,L}$, when $t = \bar{t}_C^{C,L}$, and when $t = t_{C2}^{C,L}$ is obtained from (57), respectively,

$$SW_l^{C,L}(t_C^{C,L}) = \frac{\alpha^2\left(4+\gamma+\gamma^2\right)}{6\gamma(1+\gamma)}, \tag{63}$$

$$SW_l^{C,L}(\bar{t}_C^{C,L}) = \frac{\alpha^2(3+4\gamma)^2\left(3+20\gamma-4\gamma^2\right)+B}{2(3+2\gamma)^2(3+4\gamma)^2}, \tag{64}$$

$$SW_l^{C,L}(\bar{t}_{C2}^{C,L}) = \frac{\alpha^2\left(-77+128\gamma+16\gamma^2\right)}{2(11+8\gamma)^2}, \tag{65}$$

where $B = 8\alpha(-27-72\gamma-42\gamma^2+20\gamma^3+16\gamma^4)\varepsilon - 12\gamma(1+\gamma)(3+2\gamma)^2\varepsilon^2$.

The social welfare of the local country, under a tariff rate when $t = t_I^{C,L}$ and that when $t = \bar{t}_I^{C,L}$ is obtained from (58), respectively,

$$SW_l^{C,L}(t_I^{C,L}) = \frac{37\alpha^2}{198}, \tag{66}$$

$$SW_l^{C,L}(\bar{t}_I^{C,L}) = \frac{100\alpha^2(-77+128\gamma+16\gamma^2)+D}{200(11+8\gamma^2)}, \tag{67}$$

where $D = 40\alpha(-605-286\gamma+112\gamma^2)\varepsilon - 99(11+8\gamma)^2\varepsilon^2$.

The social welfare of the local country, under a tariff rate when $t = t^{C,N}$ and, that

when $t = \bar{t}^{C,N}$ is obtained from (59), respectively,

$$SW_l^{C,N}(t^{C,N}) = \frac{\alpha^2(2+\gamma)}{4+6\gamma} \tag{68}$$

$$SW_l^{C,N}(\bar{t}^{C,N}) = \frac{\alpha^2\left(3+16\gamma-4\gamma^2\right)}{2(3+2\gamma)^2} \tag{69}$$

We compare the social welfare of the local firm where licensing occurs with that where licensing does not occur for $\gamma > 0.5$. There are five cases that we must consider depending on the size of γ: (a) $SW_l^{C,L}\left(\bar{t}_C^{C,L}\right)$, $SW_l^{C,L}\left(\bar{t}_I^{C,L}\right)$, and $SW_l^{C,N}\left(t^{C,N}\right)$ when $\gamma \in (0.5, 1]$; (b) $SW_l^{C,L}\left(\bar{t}_C^{C,L}\right)$, $SW_l^{C,L}\left(\bar{t}_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (1, 1.823]$; (c) $SW_l^{C,L}\left(t_C^{C,L}\right)$, $SW_l^{C,L}\left(\bar{t}_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (1.823, 3.929]$; (d) $SW_l^{C,L}\left(t_C^{C,L}\right)$, $SW_l^{C,L}\left(t_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (3.929, 6.808]$; and (e) $SW_l^{C,L}\left(\bar{t}_{C2}^{C,L}\right)$, $SW_l^{C,L}\left(t_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma > 6.808$. Note that we consider ε small enough, therefore, the case in which $\varepsilon \to 0$.

Case (a): $0.5 < \gamma \leq 1$

We compare $SW_l^{C,L}(\bar{t}_C^{C,L})$ with $SW_l^{C,L}(\bar{t}_I^{C,L})$ and obtain the result

$$SW_l^{C,L}\left(\bar{t}_C^{C,L}\right) - SW_l^{C,L}\left(\bar{t}_I^{C,L}\right) = -\frac{16\alpha^2(1+\gamma)\left(-33-52\gamma-6\gamma^2+10\gamma^3\right)}{\left(33+46\gamma+16\gamma^2\right)^2}. \tag{70}$$

If $\gamma \in [0, 2.840)$, $SW_l^{C,L}(\bar{t}_C^{C,L}) > SW_l^{C,L}(\bar{t}_I^{C,L})$. Next, we compare $SW_l^{C,L}(\bar{t}_C^{C,L})$ with $SW_l^{C,N}(\bar{t}^{C,N})$ and obtain

$$SW_l^{C,L}(\bar{t}_C^{C,L}) - SW_l^{C,N}(t^{C,N}) = -\frac{2\alpha^2\left(3-4\gamma-8\gamma^2+4\gamma^3\right)}{(3+2\gamma)^2(2+3\gamma)}. \tag{71}$$

If $\gamma \in (0.444, 2.293)$, $SW_l^{C,L}(\bar{t}_C^{C,L}) > SW_l^{C,N}(t^{C,N})$. To sum up, if $\gamma \in (0.5, 1]$, the local government chooses $\bar{t}_C^{C,L}$.

Case (b): $1 < \gamma \leq 1.823$

In this case, because $\bar{t}^{C,N}$ is not the solution that maximizes $SW_l^{C,N}$, $SW_l^{C,N}(t^{C,N}) \geq SW_l^{C,N}(\bar{t}^{C,N})$, from the results of (70) and (71), the local government chooses $\bar{t}_C^{C,L}$.

Case (c): $1.823 < \gamma \leq 3.929$

We compare $SW_l^{C,L}(t_C^L)$ with $SW_l^{C,L}(\bar{t}_I^{C,L})$ and obtain the result

$$SW_l^{C,L}(t_C^L) - SW_l^{C,L}(\bar{t}_I^{C,L}) = \frac{2\alpha^2(-11-12\gamma+2\gamma^2)^2}{3\gamma(1+\gamma)(11+8\gamma)^2} > 0. \tag{72}$$

We also compare $SW_l^{C,L}(t_C^{C,L})$ with $SW_l^{C,N}(\bar{t}^{C,N})$ and obtain the result

$$SW_l^{C,L}(t_C^{C,L}) - SW_l^{C,N}(\bar{t}^{C,N}) = \frac{2\alpha^2(9+12\gamma-5\gamma^2-5\gamma^3+4\gamma^4)}{3\gamma(1+\gamma)(3+2\gamma)^2} > 0, \tag{73}$$

for any $\gamma > 0$. Consequently, the local government chooses $t_C^{C,L}$.

Case (d): $3.929 < \gamma \leq 6.808$

We compare $SW_l^{C,L}(t_C^{C,L})$ with $SW_l^{C,L}(t_I^{C,L})$ and obtain

$$SW_l^{C,L}(t_C^{C,L}) - SW_l^{C,L}(t_I^{C,L}) = -\frac{2\alpha^2\left(-33+\gamma+\gamma^2\right)}{99\gamma(1+\gamma)}. \tag{74}$$

When $\gamma \leq 5.266$, $SW_l^{C,L}(t_C^{C,L}) \geq SW_l^{C,L}(t_I^{C,L})$. Moreover, from result (73), the local government chooses t_C^L, if $\gamma \in (3.929, 5.266]$. If $\gamma \in (5.266, 6.808]$, from results (73) and (74), the local government chooses t_I^L.

Case (e): $\gamma > 6.808$

In this case, because $SW_l^{C,L}(t^{C,L}) \geq SW_l^{C,L}(\bar{t}_{C2}^{C,L})$ and from result (74), we obtain $SW_l^{C,L}(t_I^{C,L}) > SW_l^{C,L}(\bar{t}_{C2}^{C,L})$. Moreover, from results (73) and (74), $SW_l^{C,L}(t_I^C) > SW_l^{C,N}(\bar{t}^N)$. Hence, the local government chooses $t_I^{C,L}$ when $\gamma > 6.808$.

From the above, we obtain Proposition 6.

The proof of Proposition 7

We compare world welfare in the case of free trade with that in the case of commitment. We compare SW_w^F with SW_w^C when $\gamma \in (0, 0.5]$ where licensing does not occur in either case and obtain

$$SW_w^F - SW_w^C = -\frac{\alpha^2\gamma^2\left(2-7\gamma-14\gamma^2\right)}{\left(6+17\gamma+12\gamma^2\right)^2}. \tag{75}$$

Solving $(2-7\gamma-14\gamma^2)=0$ with respect to γ, we obtain $\gamma \approx 0.203$. Therefore, $SW_w^F < SW_w^C$ if $\gamma \in (0, 0.203)$ and $SW_w^F \geq SW_w^C$ if $\gamma \in [0.203, 0.5]$.

We compare SW_w^F with SW_w^C when $\gamma \in (0.5, 1.5]$ where licensing occurs under only commitment to a tariff and obtain the result

$$SW_w^F - SW_w^C = -\frac{\alpha^2\left(-18+33\gamma+94\gamma^2+60\gamma^3+8\gamma^4\right)}{\left(9+18\gamma+8\gamma^2\right)^2} < 0, \tag{76}$$

if $\gamma \in (0.5, 1.5]$.

We compare SW_w^F with SW_w^C when $\gamma \in (1.5, 1.823]$ where licensing occurs in both cases and obtain the result

$$SW_w^F - SW_w^C = -\frac{2\alpha^2(1+\gamma)(3+\gamma)(-3+2\gamma)(1+2\gamma)}{(3+2\gamma)^2(3+4\gamma)^2} < 0, \tag{77}$$

if $\gamma \in (1.5, 1.823]$.

We compare SW_w^F with SW_w^C when $\gamma \in (1.823, 5.266]$ and obtain the result

$$SW_w^F - SW_w^C = \frac{2\alpha^2\left(9+6\gamma-23\gamma^2-8\gamma^3+7\gamma^4\right)}{9\gamma^2(3+4\gamma)^2} < 0. \tag{78}$$

Solving $(9+6\gamma-23\gamma^2-8\gamma^3+7\gamma^4)=0$ with respect to γ, we obtain $\gamma \approx 2.303$. Therefore, $SW_w^F < SW_w^C$ if $\gamma \in (1.822, 2.303)$ and $SW_w^F \geq SW_w^C$ if $\gamma \in [2.303, 5.266]$.

We compare SW_w^F with SW_w^C when $\gamma > 5.266$ and obtain the result

$$SW_w^F - SW_w^C = \frac{2\alpha^2(30+7\gamma)(30+73\gamma)}{1089(3+4\gamma)^2} > 0. \tag{79}$$

Q.E.D.

The proof of Proposition 8

First, we compare the foreign country's social welfare in the case of free trade with that in the case of commitment. We compare SW_f^F with SW_f^C when $\gamma \in (0, 0.5]$ and obtain

$$SW_f^F - SW_f^C = \frac{\alpha^2\gamma^2\left(2+31\gamma+40\gamma^2\right)}{2\left(6+17\gamma+12\gamma^2\right)^2} > 0. \tag{80}$$

We compare SW_f^F with SW_f^C when $\gamma \in (0.5, 1.5]$ and obtain

$$SW_f^F - SW_f^C = -\frac{\alpha^2\left(18+57\gamma-52\gamma^2+4\gamma^3+96\gamma^4\right)}{2(3+2\gamma)^2(3+4\gamma)^2} < 0. \tag{81}$$

We compare SW_f^F with SW_f^C when $\gamma \in (1.5, 1.823]$ and obtain

$$SW_f^F - SW_f^C = \frac{2\alpha^2(3-2\gamma)\left(-15-17\gamma+8\gamma^2+12\gamma^3\right)}{(3+2\gamma)^2(3+4\gamma)^2}. \tag{82}$$

When $\gamma > 1.5$, $(3-2\gamma)$ is negative and $(-15-17\gamma+8\gamma^2+12\gamma^3)$ is positive if $\gamma > 1.255$. Therefore, if $\gamma \in (1.5, 1.822]$, $SW_f^F < SW_f^C$.

We compare SW_f^F with SW_f^C when $\gamma \in (1.823, 5.266]$ and obtain

$$SW_f^F - SW_f^C = \frac{2\alpha^2\left(-3-\gamma+\gamma^2\right)\left(-3-13\gamma+3\gamma^2+10\gamma^3\right)}{9\gamma^2(1+\gamma)(3+4\gamma)^2}. \tag{83}$$

When $\gamma > 1.111$, $(-3-13\gamma+3\gamma^2+10\gamma^3)$ is always positive and $(-3-\gamma+\gamma^2)$ is positve if $\gamma > 2.303$. Therefore, when $\gamma \in (1.823, 2.303)$, $SW_f^F < SW_f^C$ and $SW_f^F \geq SW_f^C$ when $\gamma \in [2.303, 5.266]$.

We compare SW_f^F with SW_f^C when $\gamma > 5.266$ and obtain

$$SW_f^F - SW_f^C = \frac{10\alpha^2\left(-369+105\gamma+70\gamma^2\right)}{363(3+4\gamma)^2} > 0, \tag{84}$$

when $\gamma > 5.266$.

Next, we compare the local country's social welfare in the case of free trade with that in the case of commitment. We compare SW_l^F with SW_l^C when $\gamma \in (0, 0.5]$ and obtain

$$SW_l^F - SW_l^C = -\frac{\alpha^2\gamma^2}{2(2+3\gamma)(3+4\gamma)} < 0. \tag{85}$$

We compare SW_l^F with SW_l^C when $\gamma \in (0.5, 1.5]$ and obtain

$$SW_l^F - SW_l^C = \frac{\alpha^2\left(18-27\gamma-44\gamma^2+20\gamma^3\right)}{2(3+2\gamma)^2(3+4\gamma)} < 0, \tag{86}$$

if $\gamma \in (0.5, 1.5]$.

We compare SW_l^F with SW_l^C when $\gamma \in (1.5, 1.823]$ and obtain

$$SW_l^F - SW_l^C = \frac{2\alpha^2(-3+2\gamma)\left(-18-27\gamma-\gamma^2+10\gamma^3\right)}{(3+2\gamma)^2(3+4\gamma)^2}. \tag{87}$$

When $\gamma > 1.5$, $(-3+2\gamma)$ is always positive and $(-18-27\gamma-\gamma^2+10\gamma^3)$ is negative if $\gamma \in (1.5, 1.823]$. Therefore, $SW_f^F < SW_f^C$.

We compare SW_l^F with SW_l^C when $\gamma \in (1.823, 5.266]$ and obtain

$$SW_l^F - SW_l^C = -\frac{2\alpha^2\left(-3-\gamma+\gamma^2\right)^2}{3\gamma(1+\gamma)(3+4\gamma)^2} < 0. \tag{88}$$

We compare SW_l^F with SW_l^C when $\gamma > 5.266$ and obtain

$$SW_l^F - SW_l^C = \frac{2\alpha^2\left(585+75\gamma-49\gamma^2\right)}{99(3+4\gamma)^2}. \tag{89}$$

When $\gamma > 4.304$, $(585 + 75\gamma - 49\gamma^2)$ is negative. Therefore, $SW_l^F < SW_l^C$.

Q.E.D.

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