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Does Free Trade Promote 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 with or without commitment, the following results are obtained. First, firms avoid the implementation of environmental tax by contracting technological transfer. Second, there is a case in which free trade is preferable to a tariff policy for both countries when there is no commitment to a tariff level. Third, free trade is not Pareto-preferred to a tariff policy when there is a commitment.

Keywords Environmental technology transfer · Free trade · Tariff protection
JEL Classification D43; F13; L13; Q56

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 (UN FCCC) includes provisions calling for the transfer of environmental technologies and know-how related to environmentally sound technologies. However, there seems to be disagreement on how this transfer can

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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.

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.[2] 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.[3]

It is important to note that these transfers of technology, either through licensing contracts or through the 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 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.[4] The main results can be summarized as follows. First, the existence of an environmental policy in the local country induces technology transfer from the foreign country. Second, free trade is preferable to a tariff

[2] In the negotiations for the post-Kyoto framework on climate change, developing countries proposed patent pooling, compulsory licensing of green technologies, excluding green technologies from patenting, and revoking existing patent rights on green technologies (UN FCCC, 2009; Hall and Helmers 2010). Compulsory licensing has to date only been authorized by the WTO TRIPS Agreement in emergency situations in the area of pharmaceutical patents.

[3] 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. These tariff rates are not prohibitively high compared to the tariff rates applied to some agricultural products. The trade data suggests that even in the low- and middle-income countries, the trade in climate-friendly technologies is growing and these countries continue to be net importers overall (World bank 2008, p.79).

[4] 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).

policy for both countries when the environmental damage is high. This has significant policy implications when one considers the claim that environmental degradation follows from trade liberalization. Third, technological transfer through licensing contracts decreases when higher environmental damage is expected, since the quantity of the local firm's product is smaller, while the 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 transboundary pollution under the reciprocal-markets model. He shows that a 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 impacts on 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 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.[5]

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 the 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: $SW_f^{j,k} = \pi_f^{j,k} - (\gamma/2)ED^{j,k}$.[6] The social welfare of the local country is the sum of the consumer surplus, the profit of the local firm, the environmental tax,[7] 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.[8] The evaluation of the environmental damage

[5] When we assume a fixed license fee instead of a per unit royalty, licensing contracts do not occur under free trade when higher environmental damage is expected. This is because the higher environmental tax rate leads to a larger difference between marginal cost of local firm with the license and that without it. Hence, the foreign firm prefers not to license and compete with the less efficient local firm. When there is a per unit royalty, the marginal cost of the local firm is the same regardless of the licensing contract. Hence, the foreign firm prefers to license and gain from the royalty.

[6] 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.

[7] We do not suppose Pigouvian tax in our analysis. This is justified from the following points of view. From the theoretical point of view, Pigouvian tax does not lead to optimal output under imperfect competition. From the practical point of view, it is easier to impose a tax on the quantity of pollutants than on damage since monitoring the amount of damage is costly.

[8] 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.

is denoted by $\gamma/2$.[9] Since the licensing contract eliminates the environmental damage, $ED^{j,L} = 0$. The Result with more general functional form is examined in the appendix.

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.[10] Recent studies suggest that this timing structure is useful to analyze the voluntary action taken by firms prior to the regulation by the government. For example, Conrad (2001) used a timing structure in which output and abatement decisions precede the setting of environmental policy instruments. Thus firms can recognize the impact of their decisions on the level of the emission tax chosen by the government Puller (2006) used a similar timing structure to consider the strategic use of innovation to affect the level of environmental regulation.

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

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

[9] 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.

[10] Our model assumes that the government does not have to observe the private contract. It is necessary only to look at the amount of pollutants to decide whether to implement the environmental tax.

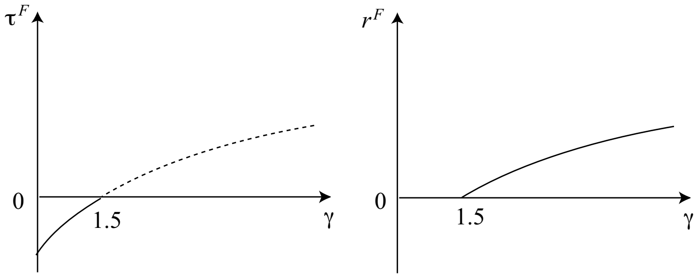

Fig. 1 The equilibrium environmental tax and license fee in free trade

If $\gamma > 1.5$, then $\tau^F > 0$. Since $\partial\tau^F/\partial\gamma > 0$, the local government increases the optimal environmental tax when higher environmental damage is expected. 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 following 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 deal with 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 a 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 a licensing contract. In contrast to the finding of Iida and Takeuchi (2010), licensing occurs even under free trade. This can be attributed to the fact that the model of Iida and Takeuchi (2010) does not assume the possibility of an environmental policy in the local country that gives 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 a contract is avoidance of regulation. When $\gamma \leq 1.5$, licensing does not occur and the local government subsidizes the polluting local firm.

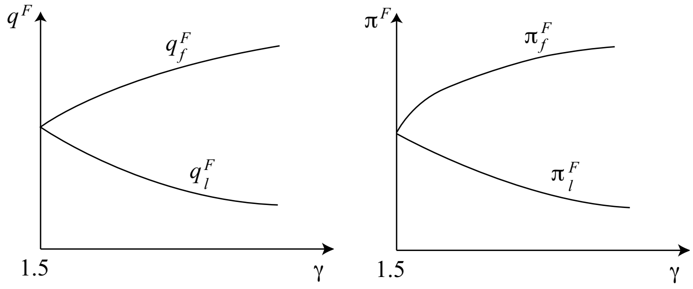

Fig. 2 The equilibrium quantity and profit in free trade

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.

Although a negative environmental tax is theoretically possible, it would be practically implausible and has less policy relevance. Therefore, we hereafter confine our analysis to the case when the environmental tax is positive, that is when $\gamma > 1.5$. 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, the import of environmentally efficient goods from the foreign country increases in γ.

When $\gamma > 1.5$, the local firm adopts the environmental technology and pays the license fee. Since a larger γ implies that the value of the environmental technology is higher, the license fee rises (Figure 1). This drawback to the local firm results in its 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, the consumer surplus decreases in γ. The social welfare of the local country decreases in γ while that 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 a tariff policy. While the optimal tariff will depend on whether or not the tariffs can be pre-committed before the licensing decisions, it is natural to assume that a government has an incentive to change a pre-announced tariff rate (Mukherjee and Pennings, 2006; Neary and Leahy,

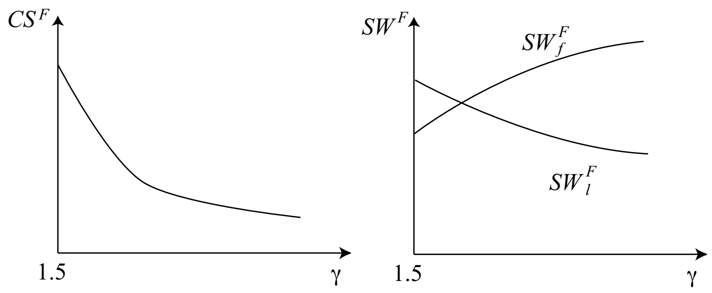

Fig. 3 The equilibrium consumer surplus and social welfare in free trade

2000). For this reason, 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 determines only 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

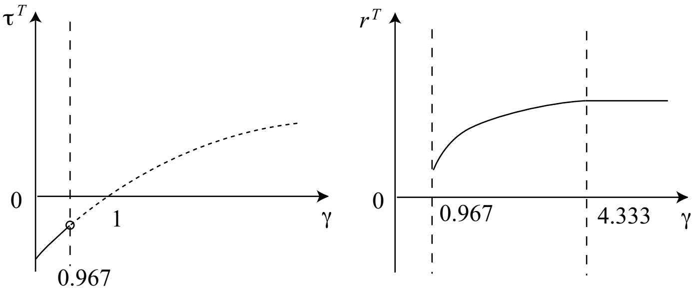

Fig. 4 The equilibrium environmental tax and license fee in a tariff policy

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 $\gamma > 4.333$. From this we obtain the next proposition.

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

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 licensing does not occur. The local firm receives a 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).

We assume $\gamma > 1.5$ to compare the case with free trade. The left and the right panels of Figure 6 show the equilibrium quantity and profit, respectively. The quantity and profit of the local firm decreases in γ. This is because the marginal cost of production increases in γ, as illustrated in Figure 4. 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, the con-

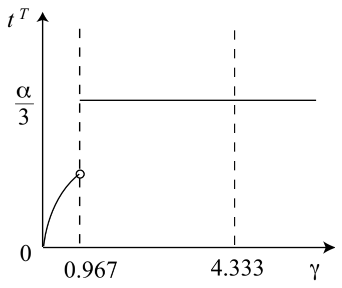

Fig. 5 The equilibrium tariff rate in a tariff policy

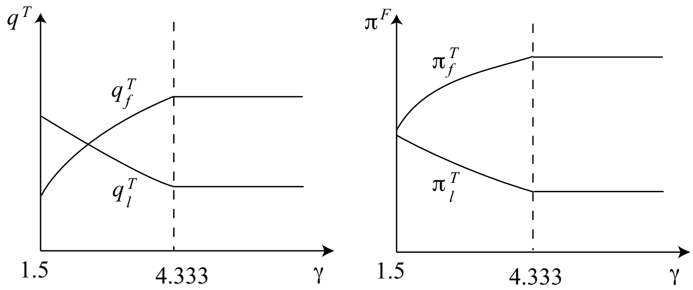

Fig. 6 The equilibrium quantity and profit in a tariff policy

sumer surplus decreases in γ because the reduction of the quantity of the local firm dominates the increase in the foreign firm's output. When $\gamma > 4.333$, the consumer surplus does not depend on γ.

The social welfare of the local country decreases in γ, while that for the foreign country increases in γ. This interpretation is similar to that for free trade. After a 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.

5 Discussions

5.1 Comparison

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

Previous studies on strategic environmental policies have pointed out that free trade lowers environmental regulation to compensate the domestic firm

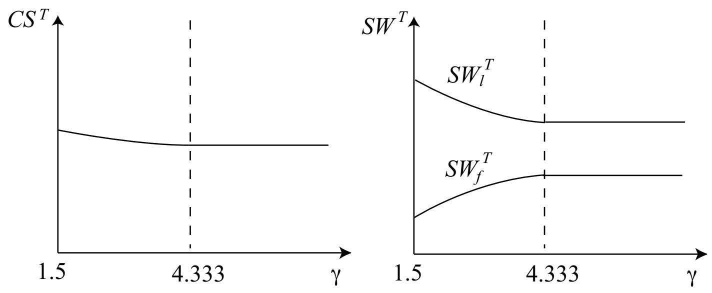

Fig. 7 The equilibrium consumer surplus and social welfare in a tariff policy

(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 a tariff policy, although it leads to weaker environmental regulation.

Proposition 4 *When* $\gamma \in (1.5, 4.301]$ *both countries prefer free trade to a tariff policy.*

Table 1 illustrates the situation by comparing the social welfare of each country. Initial T (F) means that a tariff policy (free trade) is preferred from the view point of the local country, the foreign country, or world welfare. When $\gamma > 1.5$, licensing occurs under both regimes. The foreign country prefers free trade to a tariff policy because there is no tariff payment. The local country also prefers free trade to a tariff policy as long as $\gamma \in (1.5, 4.301]$. This is because of the lower license fee under free trade. Since free trade promotes the diffusion of technology embodied in the product, the local government can impose a lower environmental tax. It means that the local firm has less incentive to adopt an innovative environmental technology under such a regime.

Table 1 Comparison between free trade and a tariff policy without commitment

	$1.5 < \gamma \leq 4.301$	$\gamma > 4.301$
Local Country	F	T
Foreign Country	F	
World Welfare	F	

When $\gamma > 4.301$, the local country prefers a tariff policy to free trade. Since higher γ implies a 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 a tariff policy. When $\gamma > 4.301$, this benefit exceeds the cost of the higher license fee and the local country prefers a 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 a tariff policy (see the right panel of Figure 7). Thus, the local country prefers a tariff policy to free trade when $\gamma > 4.333$. The foreign country prefers free trade because there is no tariff payment.

Aggregating the social welfare of both countries leads to the following proposition.

Proposition 5 *World welfare under free trade is always higher than that under a tariff policy, when $\gamma > 1.5$.*

Our main result can be summarized as follows. When the evaluation of the environmental damage (γ) is small, free trade is Pareto-preferred to a tariff policy. However, when the evaluation of the environmental damage is large, this no longer holds. While the foreign country still prefers free trade, the local country prefers a tariff policy since the licensing fee is too high. Free trade is potentially Pareto-Improving even when higher environmental damage is expected, though there should be side payments from the foreign country to the local country to attain it.

5.2 Commitment to a tariff

So far, the tariff rate has been 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, in contrast to the no-commitment case, free trade is not Pareto-preferred to a tariff policy when there is a commitment. 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 $\gamma \in (1.5, 1.823]$, 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 8 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 9. 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 9), the local government puts a lower tariff rate for higher γ when $\gamma \in (1.5, 1.823)$ (Figure 8). When $\gamma \in (1.5, 2.303)$, the tariff rate becomes negative and works as an import subsidy for the foreign firm.[11] 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 no longer beneficial for the local country to apply a negative tariff ($t^C < 0$). Although the license fee also increases, the local government increases the tariff rate to increase tariff revenue.

Table 2 compares the social welfare of each country. Initial C (F) means that a tariff policy (free trade) is preferred from the viewpoint of the local country, the foreign country, or world welfare.

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 a 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 a tariff policy with commitment. Hence, a comparison of the social welfare of each country leads to the following proposition.

Proposition 7 *When* $\gamma \in (1.5, 2.303)$*, both countries prefer commitment to free trade.*

Table 2 Comparison between free trade and a tariff policy with commitment

	$1.5 < \gamma < 2.303$	$\gamma \geq 2.303$
Local Country	C	
Foreign Country	C	F
World Welfare	C	F

Unlike the case of free trade or a tariff policy, there is a range in which the consumer surplus increases in γ (see Figure 10). This is because the optimal tariff decreases in γ when $\gamma \in (1.5, 1.823]$. 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 the consumer surplus, the social welfare of the local country initially increases in this range of γ.

By aggregating the social welfare of both countries, we compare the world welfare under free trade with that under commitment.

[11] An example of a subsidy applied also to foreign firms is the ‘eco-car’ subsidy program recently implemented in Japan. The program provided up to 250,000 yen (approximately 3000 US dollars) to people purchasing domestic or imported energy-efficient automobiles.

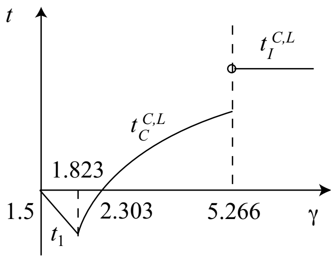

Fig. 8 The optimal tariff under commitment to a tariff

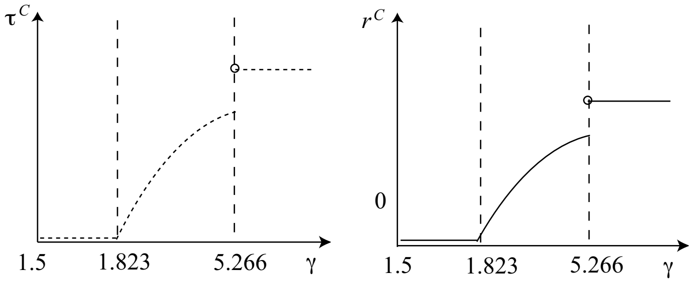

Fig. 9 The equilibrium environmental tax and license fee under commitment to a tariff

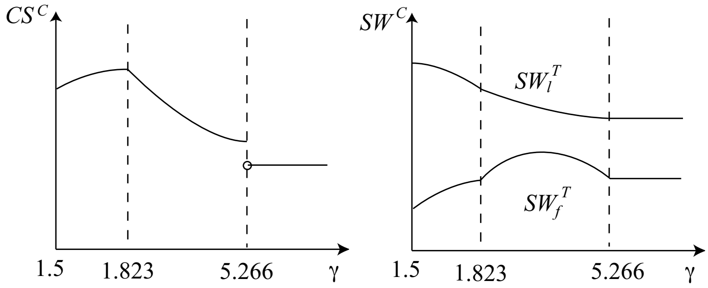

Fig. 10 The equilibrium consumer surplus and social welfare under commitment to a tariff

Proposition 8 *World welfare under commitment is higher than (resp. lower than or even with) that under free trade, when* $\gamma \in (1.5, 2.303)$ *(resp. otherwise).*

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

5.3 Comparison between commitment and no-commitment

We compare a tariff policy with and without commitment. The result is summarized in Table 3. Initial C (T) means that a tariff policy with commitment (without commitment) is preferred from the viewpoint of the local country, the foreign country, or world welfare. Because the local country can induce a lower license fee through the tariff rate, the local country always prefers commitment to no commitment. When $\gamma \in (1.5, 5.266)$, the benefit of the commitment case for foreign country is that the tariff rate is lower than in the no-commitment case. This benefit dominates the lower license fee that the foreign firm faces in the commitment case. So the foreign country prefers commitment to no-commitment when $\gamma \in (1.5, 5.266)$. When $\gamma > 5.266$, the tariff rate under the commitment case increases discontinuously and it exceeds the tariff rate under the no-commitment case. So the foreign country prefers no-commitment to commitment. From the perspective of total world welfare, because the higher tariff rate damages the consumer surplus, no-commitment is preferable when $\gamma \in (1.5, 5.266]$.

The range over which licensing occurs under a tariff policy with commitment is larger than that under free trade or under a 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. Thus licensing contracts are promoted by committing to a tariff rate. In the case of no commitment, the decision for a licensing contract is already made when the local government sets the tariff rate. If licensing does not occur, the local government sets a lower environmental tax to protect the local firm, and this discourages the agreements to have environmental technology transfer.

Table 3 Comparison between commitment and no-commitment

	$1.5 < \gamma \leq 5.266$	$\gamma > 5.266$
Local Country	C	
Foreign Country	C	T
World Welfare	C	T

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 local country cares less about the environmental damage, free trade is Pareto improving. If the concern of the country is high enough to conduct environmental protection, free trade is not preferred by it. While free trade promote technological transfer through import of the product, the quantity of production by the local firm decrease for higher γ. We need side payment from the foreign country to the local country to sustain a free trade regime that is potentially Pareto improving.

We have focused on the case where the local firm does not export its product to the foreign country. It would be useful to do further research on the case where the local firm does export to the foreign country and consider the possibility that the foreign country would also exercise trade policy.

Appendix

The equilibrium value under free trade

We obtain the following result for the case of free trade when $\gamma > 1.5$:

$$p^F = \frac{2\alpha\gamma}{3+4\gamma}, \quad q_f^F = \frac{2\alpha\gamma}{3+4\gamma}, \quad q_l^F = \frac{3\alpha}{3+4\gamma}, \tag{6}$$

$$\pi_f^F = \frac{\alpha^2\left(-9+6\gamma+4\gamma^2\right)}{(3+4\gamma)^2}, \quad \pi_l^F = \frac{9\alpha^2}{(3+4\gamma)^2}, \tag{7}$$

$$SW_f^F = \frac{\alpha^2\left(-9+6\gamma+4\gamma^2\right)}{(3+4\gamma)^2}, \quad SW_l^F = \frac{\alpha^2(27+12\gamma+4\gamma^2)}{2(3+4\gamma)^2}, \tag{8}$$

$$SW_w^F = \frac{3\alpha^2(3+8\gamma+4\gamma^2)}{2(3+4\gamma)^2}. \tag{9}$$

The equilibrium value under tariff policy without commitment

We obtain the following result for the case of tariff policy when $1.5 \leq \gamma \leq 4.333$:

$$p^T = \frac{\alpha+6\alpha\gamma}{6+9\gamma}, \quad q_f^T = \frac{\alpha(-1+3\gamma)}{6+9\gamma}, \quad q_l^T = \frac{2\alpha}{2+3\gamma}, \tag{10}$$

$$\pi_f^T = \frac{\alpha^2\left(-29+30\gamma+9\gamma^2\right)}{9(2+3\gamma)^2}, \quad \pi_l^T = \frac{4\alpha^2}{(2+3\gamma)^2}, \tag{11}$$

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

$$SW_w^T = \frac{\alpha^2\left(35+96\gamma+45\gamma^2\right)}{18(2+3\gamma)^2}. \tag{13}$$

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

$$p^T = \frac{3\alpha}{5}, \quad q_f^T = \frac{4\alpha}{15}, \quad q_l^T = \frac{2\alpha}{15}, \tag{14}$$

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

$$SW_f^T = \frac{2\alpha^2}{15}, \quad SW_l^T = \frac{14\alpha^2}{75}, \tag{16}$$

$$SW_w^T = \frac{8\alpha^2}{25}. \tag{17}$$

The equilibrium value under tariff policy with commitment

We obtain the following result for the case of commitment to a tariff when $\gamma \in (1.5, 1.823]$ where licensing occurs under the tariff rate $t_1 + \varepsilon$:

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

$$\pi_f^C = \frac{\alpha^2(1-2\gamma)^2}{(3+2\gamma)^2}, \quad \pi_l^C = \frac{4\alpha^2}{(3+2\gamma)^2}, \tag{19}$$

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

$$SW_w^C = \frac{\alpha^2\left(5+12\gamma+4\gamma^2\right)}{2(3+2\gamma)^2}. \tag{21}$$

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

$$p^C = \frac{2\alpha(-1+\gamma)}{3\gamma}, \quad q_f^C = \frac{\alpha\left(1+\gamma+\gamma^2\right)}{3\gamma(1+\gamma)}, \quad q_l^C = \frac{\alpha+2\alpha\gamma}{3\gamma+3\gamma^2}, \tag{22}$$

$$\pi_f^C = \frac{\alpha^2\left(-2-4\gamma+5\gamma^2+\gamma^3\right)}{9\gamma^2(1+\gamma)}, \quad \pi_l^C = \frac{(\alpha+2\alpha\gamma)^2}{9\gamma^2(1+\gamma)^2}, \tag{23}$$

$$SW_f^C = \frac{\alpha^2\left(-2-4\gamma+5\gamma^2+\gamma^3\right)}{9\gamma^2(1+\gamma)}, \quad SW_l^C = \frac{\alpha^2\left(4+\gamma+\gamma^2\right)}{6\gamma(1+\gamma)}, \tag{24}$$

$$SW_w^C = \frac{\alpha^2\left(-4+8\gamma+5\gamma^2\right)}{18\gamma^2}. \tag{25}$$

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

$$p^C = \frac{20\alpha}{33}, \quad q_f^C = \frac{25\alpha}{99}, \quad q_l^C = \frac{14\alpha}{99}, \tag{26}$$

$$\pi_f^C = \frac{47\alpha^2}{363}, \quad \pi_l^C = \frac{196\alpha^2}{9801}, \tag{27}$$

$$SW_f^C = \frac{47\alpha^2}{363}, \quad SW_l^C = \frac{37\alpha^2}{198}, \tag{28}$$

$$SW_w^C = \frac{689\alpha^2}{2178}. \tag{29}$$

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 $\gamma \in (1.5, 4.33]$ where licensing occurs in both cases and obtain the result

$$SW_w^F - SW_w^T = \frac{\alpha^2\left(3+10\gamma+6\gamma^2\right)\left(3+34\gamma+42\gamma^2\right)}{18(2+3\gamma)^2(3+4\gamma)^2} > 0. \tag{30}$$

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

$$SW_w^F - SW_w^T = \frac{\alpha^2(9+2\gamma)(9+22\gamma)}{50(3+4\gamma)^2} > 0. \qquad (31)$$

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 $\gamma \in (1.5, 4.333]$ and obtain

$$SW_f^F - SW_f^T = \frac{\alpha^2\left(-63-330\gamma-274\gamma^2+222\gamma^3+180\gamma^4\right)}{9(2+3\gamma)^2(3+4\gamma)^2} > 0, \qquad (32)$$

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

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

$$SW_f^F - SW_f^T = -\frac{\alpha^2\left(-153+42\gamma+28\gamma^2\right)}{15(3+4\gamma)^2} > 0, \qquad (33)$$

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 $\gamma \in (1.5, 4.333]$ and obtain

$$SW_l^F - SW_l^T = -\frac{\alpha^2\left(-45-264\gamma-344\gamma^2-60\gamma^3+36\gamma^4\right)}{6(2+3\gamma)^2(3+4\gamma)^2}. \qquad (34)$$

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

$$SW_l^F - SW_l^T = -\frac{\alpha^2\left(-1773-228\gamma+148\gamma^2\right)}{150(3+4\gamma)^2} < 0, \qquad (35)$$

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 $q_f^{C,L} = (\alpha + r - 2t)/3$, $q_l^{C,L} = (\alpha - 2r + t)/3$, $\pi_f^{C,L} = \left(\alpha^2 + 5\alpha r - 5r^2 - 4\alpha t - rt + 4t^2\right)/9$, 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

$$SW_l^{C,L} = \frac{1}{6}\left(2\alpha^2 - 4\alpha r + 3r^2 + 2\alpha t - 3t^2\right), \tag{36}$$

$$SW_l^{C,N} = \frac{\alpha^2(6-\gamma) - t^2(9+\gamma) + 2t(3+2\gamma)\tau - (3+4\gamma)\tau^2 + Z}{18}, \tag{37}$$

where $Z = \alpha(6t - 2t\gamma - 6\tau + 4\gamma\tau)$. In the fourth stage, when licensing does not occur, the local government determines the environmental tax rate to maximize (37). The equilibrium environmental tax rate is

$$\tau^C = \frac{t(3+2\gamma) - \alpha(3-2\gamma)}{3+4\gamma}. \tag{38}$$

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 $\pi_f^{C,L}(r_I^C) = \left(5\alpha^2 - 10\alpha t + 9t^2\right)/20$. 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,

$$SW_l^{C,L} = \frac{\alpha^2\left(27 + 12\gamma + 4\gamma^2\right) + 8\alpha t\left(-3 - \gamma + \gamma^2\right) - 12t^2\gamma(1+\gamma)}{2(3+4\gamma)^2} \tag{39}$$

when $t_1 < t \leq t_2$,

$$SW_l^{C,L} = \frac{\left(25\alpha^2 + 70\alpha t - 99t^2\right)}{200} \tag{40}$$

when $t > t_2$ and

$$SW_l^{C,N} = \frac{2\alpha t\gamma + \alpha^2(3+\gamma) - t^2(2+3\gamma)}{6+8\gamma} \tag{41}$$

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 (39) is

$$t_C^{C,L} = \frac{\alpha\left(-3 - \gamma + \gamma^2\right)}{3\gamma(1+\gamma)}. \tag{42}$$

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^C in 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 (40) is

$$t_I^{C,L} = \frac{35\alpha}{99}. \tag{43}$$

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 (41) is

$$t^{C,N} = \frac{a\gamma}{2+3\gamma}. \tag{44}$$

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 (39), respectively,

$$SW_l^{C,L}(t_C^{C,L}) = \frac{\alpha^2\left(4+\gamma+\gamma^2\right)}{6\gamma(1+\gamma)}, \tag{45}$$

$$SW_l^{C,L}(\bar{t}_C^{C,L}) = \frac{\alpha^2(3+4\gamma)^2\left(3+20\gamma-4\gamma^2\right)+B}{2(3+2\gamma)^2(3+4\gamma)^2}, \tag{46}$$

$$SW_l^{C,L}(\bar{t}_{C2}^{C,L}) = \frac{\alpha^2\left(-77+128\gamma+16\gamma^2\right)}{2(11+8\gamma)^2}, \tag{47}$$

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 (40), respectively,

$$SW_l^{C,L}(t_I^{C,L}) = \frac{37\alpha^2}{198}, \tag{48}$$

$$SW_l^{C,L}(\bar{t}_I^{C,L}) = \frac{100\alpha^2(-77+128\gamma+16\gamma^2)+D}{200(11+8\gamma^2)}, \tag{49}$$

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 (41), respectively,

$$SW_l^{C,N}(t^{C,N}) = \frac{\alpha^2(2+\gamma)}{4+6\gamma} \tag{50}$$

$$SW_l^{C,N}(\bar{t}^{C,N}) = \frac{\alpha^2\left(3+16\gamma-4\gamma^2\right)}{2(3+2\gamma)^2} \tag{51}$$

We compare the social welfare of the local firm where licensing occurs with that where licensing does not occur for $\gamma > 1.5$. There are four 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 $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (1, 1.823]$; (b) $SW_l^{C,L}\left(t_C^{C,L}\right)$, $SW_l^{C,L}\left(\bar{t}_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (1.823, 3.929]$; (c) $SW_l^{C,L}\left(t_C^{C,L}\right)$, $SW_l^{C,L}\left(t_I^{C,L}\right)$, and $SW_l^{C,N}\left(\bar{t}^{C,N}\right)$ when $\gamma \in (3.929, 6.808]$; and (d) $SW_l^{C,L}\left(\bar{t}_{C2}^{C,L}\right)$, $SW_l^{C,L}\left(t_I^{C,L}\right)$, 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): $1.5 < \gamma \leq 1.823$

In this case, because $\bar{t}^{C,N}$ is not the solution that maximizes $SW_l^{C,N}$, $SW_l^{C,N}(t^{C,N})$ $\geq SW_l^{C,N}(\bar{t}^{C,N})$.

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

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

If $\gamma \in [1.5, 2.840)$, $SW_l^{C,L}(\bar{t}_C^{C,L}) > SW_l^{C,L}(\bar{t}_I^{C,L})$. Next, we compare $SW_l^{C,L}(\bar{t}_C^{C,L})$ with $SW_l^{C,N}(\bar{t}^{C,N})$ and obtain

$$SW_l^{C,L}(\bar{t}_C^{C,L}) - SW_l^{C,N}(t^{C,N}) = -\frac{2\alpha^2\left(3-4\gamma-8\gamma^2+4\gamma^3\right)}{(3+2\gamma)^2(2+3\gamma)}. \quad (53)$$

If $\gamma \in (1.5, 2.293)$, $SW_l^{C,L}(\bar{t}_C^{C,L}) > SW_l^{C,N}(t^{C,N})$. To sum up, the local government chooses $\bar{t}_C^{C,L}$.

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

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

$$SW_l^{C,L}(t_C^L) - SW_l^{C,L}(\bar{t}_I^{C,L}) = \frac{2\alpha^2(-11-12\gamma+2\gamma^2)^2}{3\gamma(1+\gamma)(11+8\gamma)^2} > 0. \quad (54)$$

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

$$SW_l^{C,L}(t_C^{C,L}) - SW_l^{C,N}(\bar{t}^{C,N}) = \frac{2\alpha^2(9+12\gamma-5\gamma^2-5\gamma^3+4\gamma^4)}{3\gamma(1+\gamma)(3+2\gamma)^2} > 0, \quad (55)$$

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

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

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

$$SW_l^{C,L}(t_C^{C,L}) - SW_l^{C,L}(t_I^{C,L}) = -\frac{2\alpha^2\left(-33+\gamma+\gamma^2\right)}{99\gamma(1+\gamma)}. \quad (56)$$

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 (55), the local government chooses t_C^L, if $\gamma \in (3.929, 5.266]$. If $\gamma \in (5.266, 6.808]$, from results (55) and (56), the local government chooses t_I^L.

Case (d): $\gamma > 6.808$

In this case, because $SW_l^{C,L}(t^{C,L}) \geq SW_l^{C,L}(\bar{t}_{C2}^{C,L})$ and from result (56), we obtain $SW_l^{C,L}(t_I^{C,L}) > SW_l^{C,L}(\bar{t}_{C2}^{C,L})$. Moreover, from results (55) and (56), $SW_l^{C,L}(t_I^C) > SW_l^{C,N}(\bar{t}^N)$. 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

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 $\gamma \in (1.5, 1.823]$ and obtain

$$SW_f^F - SW_f^C = \frac{2\alpha^2(3-2\gamma)\left(-15-17\gamma+8\gamma^2+12\gamma^3\right)}{(3+2\gamma)^2(3+4\gamma)^2}. \tag{57}$$

When $\gamma > 1.5$, $(3-2\gamma)$ is negative and $\left(-15-17\gamma+8\gamma^2+12\gamma^3\right)$ 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

$$SW_f^F - SW_f^C = \frac{2\alpha^2\left(-3-\gamma+\gamma^2\right)\left(-3-13\gamma+3\gamma^2+10\gamma^3\right)}{9\gamma^2(1+\gamma)(3+4\gamma)^2}. \tag{58}$$

When $\gamma > 1.111$, $\left(-3-13\gamma+3\gamma^2+10\gamma^3\right)$ is always positive and $\left(-3-\gamma+\gamma^2\right)$ 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

$$SW_f^F - SW_f^C = \frac{10\alpha^2\left(-369+105\gamma+70\gamma^2\right)}{363(3+4\gamma)^2} > 0, \tag{59}$$

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 $\gamma \in (1.5, 1.823]$ and obtain

$$SW_l^F - SW_l^C = \frac{2\alpha^2(-3+2\gamma)\left(-18-27\gamma-\gamma^2+10\gamma^3\right)}{(3+2\gamma)^2(3+4\gamma)^2}. \tag{60}$$

When $\gamma > 1.5$, $(-3+2\gamma)$ is always positive and $\left(-18-27\gamma-\gamma^2+10\gamma^3\right)$ 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

$$SW_l^F - SW_l^C = -\frac{2\alpha^2\left(-3-\gamma+\gamma^2\right)^2}{3\gamma(1+\gamma)(3+4\gamma)^2} < 0. \tag{61}$$

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

$$SW_l^F - SW_l^C = \frac{2\alpha^2\left(585+75\gamma-49\gamma^2\right)}{99(3+4\gamma)^2}. \tag{62}$$

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

Q.E.D.

The proof of Proposition 8

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 $\gamma \in (1.5, 1.823]$ where licensing occurs in both cases and obtain the result

$$SW_w^F - SW_w^C = -\frac{2\alpha^2(1+\gamma)(3+\gamma)(-3+2\gamma)(1+2\gamma)}{(3+2\gamma)^2(3+4\gamma)^2} < 0, \qquad (63)$$

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

$$SW_w^F - SW_w^C = \frac{2\alpha^2\left(9+6\gamma-23\gamma^2-8\gamma^3+7\gamma^4\right)}{9\gamma^2(3+4\gamma)^2} < 0. \qquad (64)$$

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

$$SW_w^F - SW_w^C = \frac{2\alpha^2(30+7\gamma)(30+73\gamma)}{1089(3+4\gamma)^2} > 0. \qquad (65)$$

Q.E.D.

Effects of t and τ on q

In the case of tariff policy, the profit of the firms where licensing does not occurs are $\pi_f^{T,NL} = p(q) \cdot q_f - tq_f$ and $\pi_l^{T,NL} = p(q) \cdot q_l - \tau q_l$. In the final stage, firms engage in Cournot competiton. The FOCs yield,

$$p + p'(q) \cdot q_f - t = 0, \qquad (66)$$

$$p + p'(q) \cdot q_l - \tau = 0. \qquad (67)$$

From (66) and (67), the equilibrium quantity is obtained as $q_f^{T,NL}(t,\tau)$ and $q_l^{T,NL}(t,\tau)$.

Totally differentiating (66) and (67), we obtain

$$\begin{pmatrix} 2p'(q)+p''(q)\cdot q_f & p'(q)+p''(q)\cdot q_f \\ p'(q)+p''(q)\cdot q_l & 2p'(q)+p''(q)\cdot q_l \end{pmatrix} \begin{pmatrix} dq_f \\ dq_l \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} dt + \begin{pmatrix} 0 \\ 1 \end{pmatrix} d\tau. \qquad (68)$$

Therefore, we obtain following comparative statics,

$$\frac{\partial q_f}{\partial t} = \frac{2p'(q)+p''(q)\cdot q_l}{3(p'(q))^2+qp'(q)p''(q)} < 0, \quad \frac{\partial q_l}{\partial t} = \frac{-(p'(q)+p''(q)\cdot q_l)}{3(p'(q))^2+qp'(q)p''(q)} > 0, \qquad (69)$$

$$\frac{\partial q_f}{\partial \tau} = \frac{-(p'(q)+p''(q)\cdot q_f)}{3(p'(q))^2+qp'(q)p''(q)} > 0, \quad \frac{\partial q_l}{\partial \tau} = \frac{2p'(q)+p''(q)\cdot q_f}{3(p'(q))^2+qp'(q)p''(q)} < 0. \qquad (70)$$

where $2p'(q)+p''(q)\cdot q_i < p'(q)$ and $3(p'(q))^2+qp'(q)p''(q) > 0$, for $i = f, l$. This result is obtained by the stability condition of the oligopoly model (Ishikawa & Spencer, 1999).

Also, we obtain $\partial q/\partial t < 0$ and $\partial q/\partial \tau < 0$. For the crossing derivatives, $\partial^2 q_i/\partial t \partial \tau$, the sign is ambigious if the demand function is concave or convex. If the demand function is liner, $p''(q) = 0$ and $\partial^2 q_i/\partial t \partial \tau = 0$. This result is also obtained in the case where licesning occurs. In such a case, therefore, $\partial q_f/\partial r > 0$, $\partial q_l/\partial r < 0$, and $\partial q/\partial r < 0$.

Alternate functional forms

We have used a specific demand function and an environmental damage function. This section investigates whether our main finding holds under alternate assumptions on functional forms. We consider Proposition 5 that world welfare under free trade is always higher than that under tariff policy when there is no commitment to the tariff level. World welfare with a licensing contract is $SW_w^{F,L} = \int_0^X p\left(q(r^F)\right) dq$ under free trade and $SW_w^{T,L} = \int_0^X p\left(q(r^T, t^{T,L})\right) dq$ under a tariff policy, where $p(q)$ is the inverse demand function that satisfies $p' < 0$. Therefore, if $r^F < r^T$, $SW_w^{F,L}$ is higher than $SW_w^{T,L}$. We investigate what kind of assumption on functional form is necessary to have $r^F < r^T$.

Two factors lead to this result. First, the environmental tax under a tariff policy should be $\tau^F < \tau^T$ to enhance the incentive for the local firm to adopt the clean technology. Another factor is the tariff rate and it should be $t^{T,L} > t^{T,NL}$ to enhance the incentive for the local firm to adopt the technology.

We first discuss the environmental tax under free trade and a tariff policy without commitment. In the case of free trade, the social welfare of the local country without licensing consists of consumer surplus, producer surplus, environmental tax revenue, and the environmental damage.

$$\begin{aligned} SW_l^{F,NL} &= \int_0^X p(q)dq - p(q)\cdot(q_f + q_l) + (p(q) - \tau)q_l + \tau q_l - ED(q_l) \\ &= \int_0^X p(q)dq - p(q)\cdot q_f - ED(q_l), \end{aligned} \tag{71}$$

where $p(q)$ is the inverse demand function and $ED(q_l)$ is the environmental damage function. [12]

In the second stage, the local country determines the environmental tax to maximize (71). The FOC yields

$$\frac{\partial SW_l^{F,NL}}{\partial \tau} = p(q)\frac{\partial q}{\partial \tau} - p'(q)\frac{\partial q}{\partial \tau}q_f - p(q)\frac{\partial q_f}{\partial \tau} - ED'\frac{\partial q_l}{\partial \tau} = 0 \tag{72}$$

[12] Though we omit the evaluation parameter γ to simplify the argument of this subsection, it does not change the result. The size of ED' corresponds to that of γ.

From (72) and the FOC of the local firm ($\partial\pi_l/\partial q_l = p + p'(q)\cdot q_l - \tau = 0$), we obtain

$$\tau^F = ED' + \frac{p'(q)\cdot(\frac{\partial q_l}{\partial\tau}q_l + \frac{\partial q}{\partial\tau}q_f)}{\frac{\partial q_l}{\partial\tau}}. \quad (73)$$

The prime represents the derivatives of the function. Since we assume that the stability condition is satisfied, the second term is negative (see the end of the Appendix on the effects of t and τ on q). Therefore, $\tau^F < ED'$.

In the case of no-commitment to a tariff, the social welfare of the local country where licensing does not occur is

$$SW_l^{T,NL} = \int_0^X p(q)dq - p(q)\cdot q_f + tq_f - ED(q_l). \quad (74)$$

In the second-stage subgame, the local country determines the environmental tax to maximize (74). The FOC yields

$$\frac{\partial SW_l^{F,NL}}{\partial\tau} = p(q)\frac{\partial q}{\partial\tau} - p'(q)\frac{\partial q}{\partial\tau}q_f - p\frac{\partial q_f}{\partial\tau} + t\frac{\partial q_f}{\partial\tau} - \frac{\partial ED}{\partial q_l}\frac{\partial q_l}{\partial\tau} = 0 \quad (75)$$

From (75) and the FOC of the local firm ($\partial\pi_l^{T,NL}/\partial q_l = p + p'(q)\cdot q_l - \tau = 0$), we obtain

$$\tau^T = ED' + \frac{p'(q)\cdot(\frac{\partial q_l}{\partial\tau}q_l + \frac{\partial q}{\partial\tau}q_f)}{\frac{\partial q_l}{\partial\tau}} - t\frac{\frac{\partial q_f}{\partial\tau}}{\frac{\partial q_l}{\partial\tau}}. \quad (76)$$

When $t = 0$, $\tau^F = \tau^T$. Therefore, if $t^{T,NL} > 0$ and $\partial\tau^T/\partial t > 0$, then $\tau^T > \tau^F$.

Let us examine if $t^{T,NL}$ is positive. In the second stage, the local country also determines the tariff rate to maximize (74). The FOC yields

$$\begin{aligned}
\frac{\partial SW_l^{T,NL}}{\partial t} &= p\frac{\partial q}{\partial t} - p'(q)\frac{\partial q}{\partial t}q_f - p\frac{\partial q_f}{\partial t} + q_f + t\frac{\partial q_f}{\partial t} - ED'\frac{\partial q_l}{\partial t} \\
&= p(\frac{\partial q_f}{\partial t} + \frac{\partial q_l}{\partial t}) - p'(q)\frac{\partial q}{\partial t}q_f - p\frac{\partial q_f}{\partial t} + q_f + t\frac{\partial q_f}{\partial t} - ED'\frac{\partial q_l}{\partial t} \\
&= p\frac{\partial q_l}{\partial t} - p'(q)\frac{\partial q}{\partial t}q_f + q_f + t\frac{\partial q_f}{\partial t} - ED'\frac{\partial q_l}{\partial t} \\
&= (p - ED')\frac{\partial q_l}{\partial t} + (1 - p'(q)\frac{\partial q}{\partial t})q_f + t\frac{\partial q_f}{\partial t} = 0 \quad (77)
\end{aligned}$$

The optimal tariff rate $t^{T,NL}$ satisfies equation (77).

If $\frac{\partial SW_l^{T,NL}}{\partial t}|_{t=0} > 0$, then $t^{T,NL} > 0$. We obtain

$$\frac{\partial SW_l^{T,NL}}{\partial t}|_{t=0} = (p - ED')\frac{\partial q_l}{\partial t} + \left(1 - p'(q)\frac{\partial q}{\partial t}\right)q_f > 0. \quad (78)$$

The first term and the second term of (78) are positive. Therefore, $t^{T,NL} > 0$.

It is also necessary to examine the sign of $\partial\tau^T/\partial t$. We have already discussed in Section 4 that there is a complementary relation between τ^T and t when $\partial^2 SW_l^{T,NL}/\partial\tau\partial t$. We obtain

$$\begin{aligned}\frac{\partial^2 SW_l^{T,NL}}{\partial\tau\partial t} = \quad & (p'(q) - ED'')\frac{\partial q_l}{\partial t}\frac{\partial q_l}{\partial\tau} + (p - p'(q)\cdot q_f - ED')\frac{\partial^2 q_l}{\partial\tau\partial t} \\ & - p''(q)\cdot q_f\frac{\partial q}{\partial t}\frac{\partial q}{\partial\tau} + (t - p'(q)\cdot q_f)\frac{\partial^2 q_f}{\partial\tau\partial t} + (1 - p'(q)\frac{\partial q_f}{\partial t})\frac{\partial q_f}{\partial\tau}\end{aligned} \quad (79)$$

The sign of $\partial^2 SW_l^{T,NL}/\partial\tau\partial t$ depends on the functional form of the demand and the damage function. Let us assume the damage function is linear or convex and satisfies $ED'' \geq 0$. Then if demand function is linear, $\partial^2 SW_l^{T,NL}/\partial\tau\partial t > 0$, and $\partial\tau^T/\partial t > 0$. On the other hand, if demand function is convex or concave, the sign of $\partial^2 SW_l^{T,NL}/\partial\tau\partial t$ is ambiguous. Nevertheless, for the specific functional form, $P = 1 - Q^{\frac{1}{2}}$ or $P = 1 - Q^{1.5}$ and $ED = q_l^2$, we obtain $\partial^2 SW_l^{T,NL}/\partial\tau\partial t > 0$. It means that we should assume the demand function and the damage function that satisfy $\partial^2 SW_l^{T,NL}/\partial\tau\partial t > 0$ will derive the result obtained in Proposition 5.

From the result of $t^{T,NL} > 0$ and $\partial\tau^T/\ \partial t > 0$, we obtain $\tau^F < \tau^T$. Therefore, the local firm has a stronger incentive to adopt the environmental technology under a tariff policy than under free trade.

As another factor to derive our main result, it is necessary to discuss the tariff rate that affects the license fee r^T. In the case of free trade, a license fee is offered by the foreign firm such that

$$\begin{aligned}&\max_r \ \ \pi_f^{F,L}(r) \\ &\text{s.t} \qquad \pi_l^{F,L}(r) \geq \pi_l^{F,NL}(\tau^F).\end{aligned} \quad (80)$$

If τ^F is not so large, therefore if ED' is not so large, the constraint is binding and the optimal licensing fee is $r^F = \tau^F$. If the optimal license fee is interior, $r^F < \tau^F$. Therefore, in the case of free trade, $r^F \leq \tau^F$.

On the other hand, in the case of a tariff policy, the licensing fee is determined by

$$\begin{aligned}&\max_r \ \ \pi_f^{T,L}(r, t^L) \\ &\text{s.t} \qquad \pi_l^{T,L}(r, t^{T,L}) \geq \pi_l^{T,NL}(\tau^T, t^{T,NL}).\end{aligned} \quad (81)$$

If $t^{T,L} \geq t^{T,NL}$ holds, the incentive of the local firm to adopt the clean technology is enhanced and the optimal licensing fee becomes $r^T \geq \tau^T$. Then we obtain $r^F < r^T$ since $r^F = \tau^F < \tau^T$.

Let us examine if $t^{T,L} \geq t^{T,NL}$. We consider the range of r such that $\partial\pi_l^{T,L}(r, t^{T,L})/\partial r < 0$ to ensure the uniqueness of the solution. In the second stage where licensing does not occur, the local country determines the optimal tariff rate $t^{T,NL}$to maximize social welfare (74). From (77) and the FOC of the local firm ($\partial \pi_l^{T,NL}/\partial \tau = p + p'(q) \cdot q_l - \tau = 0$), we obtain

$$t^{T,NL}(\tau) = -\frac{1}{\frac{\partial q_f(\tau)}{\partial t}} \left\{ (\tau - ED'(\tau)) \frac{\partial q_l(\tau)}{\partial t} - p'(q) \cdot q_l(\tau) \frac{\partial q_l(\tau)}{\partial t} + \left(1 - p'(q) \frac{\partial q(\tau)}{\partial t} \right) \right\} \quad (82)$$

The first term in the brace represents the environmental externality caused by the local firm. If $\tau < ED'$, the environmental damage is not internalized. Therefore, the local firm lowers the tariff rate to promote environmental technology transfer via import.

Where licensing occurs, the social welfare of the local country is

$$SW_l^{T,L} = \int_0^X p(q)dq - p(q) \cdot q_f - rq_l + tq_f. \quad (83)$$

The local country determines the optimal tariff rate to maximize (83). The FOC yields

$$\frac{\partial SW_l^{T,L}}{\partial t} = p\frac{\partial q_l}{\partial t} - p'(q)\frac{\partial q}{\partial t}q_f - r\frac{\partial q_l}{\partial t} + q_f + t\frac{\partial q_f}{\partial t} = 0. \quad (84)$$

From (84) and the FOC of the local firm ($\pi_l^{T,L} = p + p'(q) \cdot q_l - r = 0$), we obtain

$$t^{T,L}(r) = -\frac{1}{\frac{\partial q_f(r)}{\partial t}} \left\{ -p'(r)q_l(r)\frac{\partial q_l(r)}{\partial t} + \left(1 - p'(r)\frac{\partial q(r)}{\partial t}\right) \right\}. \quad (85)$$

From (82) and (85), if $r = \tau$, then

$$t^{T,NL}(r) = t^{T,L}(r) - \frac{1}{\frac{\partial q_f(r)}{\partial t}} \left\{ (r - ED'(r))\frac{\partial q_l(r)}{\partial t} \right\}. \quad (86)$$

When $r > ED'$, the second term of (86) is positive and $t^{T,L} < t^{T,NL}$. If $r \leq ED'$, the second term of (86) is negative, in which case $t^{T,L} \geq t^{T,NL}$. Because there is no environmental damage when licensing occurs, the local government's only consideration when determining the tariff rate is protection of the local firm.

First, we consider the case where $r \leq ED'$. If $\tau \neq r$, the size of $t^{T,L}$ and $t^{T,NL}$ is ambiguous and depends on the sign of $\partial t^{T,L}/\partial r$. [13] The sign of $\partial t^{T,L}/\partial r$ is determined by the sign of $\partial^2 SW_l^{T,L}/\partial t \partial r$. We obtain

$$\begin{aligned} \frac{\partial^2 SW_l^{T,L}}{\partial t \partial r} &= \left(1 - p'(q)\frac{\partial q}{\partial t}\right)\frac{\partial q_f}{\partial r} - \left(1 - p'(q)\frac{\partial q}{\partial r}\right)\frac{\partial q_l}{\partial t} \\ &\quad + (p(q) - r)\frac{\partial^2 q_l}{\partial t \partial r} - p''(q) \cdot q_f\frac{\partial q}{\partial r}\frac{\partial q}{\partial t} - p'(q) \cdot q_f\frac{\partial^2 q}{\partial t \partial r} + t\frac{\partial^2 q_f}{\partial t \partial r}. \end{aligned} \quad (87)$$

[13] When $\partial t^{T,L}/\partial r \leq 0$, $t^{T,L} > t^{T,NL}$ for any r, where $r \leq ED'$. Therefore, in this case, the license fee is $r^T > \tau^T$. However, since $\partial t^{T,NL}/\partial \tau > 0$, if $\partial t^{T,L}/\partial r > 0$, it would happen that $t^{T,L} < t^{T,NL}$.

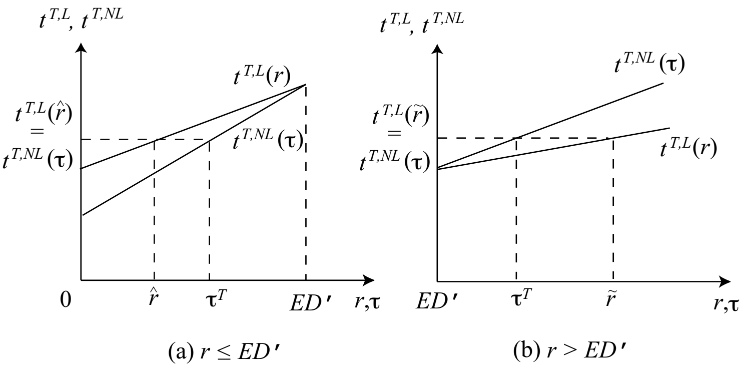

Fig. 11 The range of the optimal license fee

When the demand function is linear, $\partial^2 SW_l^{T,L}/\partial t\partial\tau = 0$, which leads to $\partial t^{T,L}/\partial r = 0$. Therefore, we obtain $t^{T,L} > t^{T,NL}$ for a linear demand function.

When the demand function is concave or convex, the sign is ambiguous. If $\partial t^{T,L}/\partial r > 0$, there exists $\hat{r}$ such that $t^{T,L}(\hat{r}) = t^{T,NL}\left(\tau^T\right)$ and $\hat{r} < \tau^T$ (see panel (a) of Figure 11).

If the license fee is $r^T = \hat{r}$, then $\pi_l^{T,L}\left(\hat{r}, t^L(\hat{r})\right) > \pi_l^{T,L}(\tau^T, t^{T,NL})$. Therefore in this case, if $\partial\pi_l^{T,L}/\partial r|_{r=\hat{r}} < 0$, $r^T \leq \hat{r}$ is not the optimal license fee. The optimal license fee is $r^T > \hat{r}$. [14] Moreover, when $\hat{r} < r^T \leq \tau^T$, since $t^{T,L}(r^T) > t^{T,NL}\left(\tau^T\right)$, $\pi_l^{T,L}\left(r, t^{T,L}(r)\right) > \pi_l^{T,L}(\tau^T, t^{T,NL})$. Thus, there is still room for the foreign firm to increase r. In this case, moreover, because $\pi_f^{T,L}(r^T, t^{T,L}) < \pi_f^{T,NL}(\tau^T, t^{T,NL})$, licensing does not occur. Eventually, the optimal license fee is $r^T > \tau^T$ such that $\pi_l^{T,L}\left(r, t^{T,L}(r)\right) = \pi_l^{T,L}(\tau^T, t^{T,NL})$ or $\pi_l^{T,L}\left(r, t^{T,L}(r)\right) > \pi_l^{T,L}(\tau^T, t^{T,NL})$ if t^T is an interior solution.

To sum up, when $r \leq ED'$, therefore when γ is larger, and the range of $\partial\pi_f^{T,L}/\partial r > 0$ is large enough such that $\partial\pi_f^{T,L}/\partial r_{|r=\hat{r}} > 0$, we obtain $r^F \leq \tau^F < \tau^T$ and $\tau^T < r^T$, therefore $r^F < r^T$.

Next we consider the case where $r > ED'$. In this case, $t^{T,L} < t^{T,NL}$ for any r if $\partial t^{T,L}/\partial r \leq 0$ holds. Therefore, the license fee must be $r^T < \tau^T$ to satisfy $\pi_l^{T,L}(r^T, t^{T,L}) \geq \pi_l^{T,NL}(\tau^T, t^{T,NL})$. Then if the environmental damage function is linear, we obtain $r^T > r^F$ since the marginal environmental damage is the same regardless of the trade policy and $r^F \leq \tau^F < ED'$ is satisfied. If the environmental damage function is convex, the magnitude relation between r^T and r^F is ambiguous.

If $\partial t^{T,L}/\partial r > 0$, there is $\tilde{r}$ such that $t^{T,L} = t^{T,NL}(\tau^T)$ (see panel (b) of Figure 11). When $r^T = \tau^T$, $\pi_l^{T,L}(r^T, t^{T,L}) < \pi_l^{T,NL}(\tau^T, t^{T,NL})$ since $t^{T,L}(r^T) < t^{T,NL}(\tau^T)$. Therefore, from the assumption that $\partial\pi_l^{T,L}/\partial r < 0$, the license fee is $r^T < \tau^T$ such that $\pi_l^{T,L}(r^T, t^{T,L}) \geq \pi_l^{T,NL}(\tau^T, t^{T,NL})$. In this case, because

[14] If the license fee is an interior solution, the license fee is r^T such that $\pi_l^{T,L} > \pi_l^{T,NL}$. In this case, because $r^T < \tau^T$, it is ambiguous if $r^T > r^F$.

$r^T < \tau^T$, it is ambiguous if $r^T > r^F$. However, if the environmental damage function is linear, $r^T > r^F$.

To sum up, when $r > ED'$, that is when γ is so small, we obtain $r^T > r^F$ for a linear environmental damage function. If environmental damage function is convex, it is ambiguous if $r^T > r^F$.

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