International technology transfer, environmental pollution, and domestic welfare

Ray-Yun Chang[a], Ping-Sing Kuo[b], Yan-Shu Lin[b], Jin-Li Hu[c,*]

[a] Department of Economics, Chinese Culture University

Center for Research in Econometric Theory and Applications, National Taiwan University, Taipei, Taiwan R.O.C.

[b] Department of Economics, National Dong Hwa University

[c] Institute of Business and Management, National Chiao Tung University

[*] Corresponding author. 118, Sec, 1, Chung-Hsiao W. Rd., Taipei City 10044, Taiwan. Email: jinlihu@mail.nctu.edu.tw. FAX: +886-2-23494922. URL: http://jinlihu.tripod.com.

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Abstract

This article constructs a two-stage game model to explore the impact of international green technology licensing on the environment and social welfare. Results show that the total amount of pollution under licensing may be larger than that under no licensing whereas the social welfare under licensing may be smaller than that under no licensing. This implies that foreign technology transfer may not be socially preferred and harmful to the domestic environment. In addition, trade liberalization may help reduce the environmental harm when the import tariff is moderate.

Keywords: International Technology Transfer; Environmental Pollution; Two-Part Tariff; Welfare

JEL Classifications: D43, D44, D45, L13

1. Introduction

In the modern world, pollution has accompanied industrial development, and its resultant damage to the environment has help spur greater environmental consciousness advocating for environmental protection in many developed countries. Firms with inferior technologies can acquire advanced technologies by technology transfers from foreigners, even though they are market competitors. However, these more advanced technologies may not be environmentally friendly. Take China as an example: Since 1980s China has been importing retired dirty technology from the developed economies and hence becomes a world factory as well as a pollution heaven (Lu, 2008). Although China's government has regulated the automobile industry for environmental improvement in the major cities, firms in the industry are negotiating with and learning from foreign firms so as to adhere to those regulations (Gallagher, 2003; Nguyen et al., 2014).

On the hand, there is an argument that trade liberalization can be beneficial to environmental protection. This is because the World Trade Organization (WTO) and regional trade agreements (RTA) facilitate environmentally trade policies and international coordination to protect the environment (Ketchell, 2018). Therefore, there are good as well as bad effects of international technology transfer, which have to be taken into account at the same time.

Better technology may benefit domestic firms and consumers, but the cost paid to the foreign patent holder is a loophole to domestic welfare. In order to evaluate the necessity and effectiveness of policies that encourage the adoption of advanced foreign environmental technologies, policymakers must understand how the foreign technology is paid, how domestic welfare is affected, and the amount of pollution that is changed. Therefore, the purpose of this article is to examine how the licensing of an international green technology influences pollution and social welfare in the presence of trade and environment policies. For simplicity, we confine the study to pollution generated by consumption, which accounts for a significant portion of total emissions (World Bank and IHME 2016).

This study delves into research in the fields of trading in intellectual property rights (IPR), economic development, and the environment, and interactions between each of them. In the past few decades, the rapid growth in IPR trading in world markets has led to a significant increase in technology licensing among firms.[1] The literature on technology transfer and international trade is quite extensive; some focus on the policy implications of technology licensing, such as Kabiraj and Marjit (2003), Mukherjee and Pennings (2006), Mukherjee (2007), Horuchi and Ishikawa (2009), Hwang *et al.* (2016), and Kabiraj and Kabiraj (2017).

Kabiraj and Marjit (2003) consider a duopoly model with a three-stage game to show that a tariff increase can induce the foreign firm to license its inferior technology and thus make social welfare better. Mukherjee and Pennings (2006) discover that a domestic government can use a tax policy to influence the foreign firm's decision to license. Mukherjee (2007) aims to figure out the optimal licensing contract when firms realize effective cost differences between each other and then finds that the optimal licensing contract is a royalty (fixed fee) when the aforementioned cost is low (high). Horuchi and Ishikawa (2009) indicate that a tariff increase (decrease) leads to a tariff-jumping effect (entry-deterring effect), thus inducing the foreign firm to license its technology. Hwang *et al.* (2016) note that if a foreign firm's R&D is endogenized, then trade liberalization policies result in better technology being transferred to the domestic firm. Kabiraj and Kabiraj (2017) consider a duopolistic trade model with technology transfer to show that a tariff can be chosen so as to induce fee licensing and to maximize both consumer surplus and domestic welfare.

There is a tremendous body of literature addressing issues on economic development and environment. Some of them analyze the effect of trade liberalization on pollution, where the government uses environmental regulations to internalize pollution externalities, such as Krutilla (1991). Some of them consider negative externalities connected with production, such as Markusen (1975) and Burguet and Sempere (2003). Others just consider negative externalities connected with consumption, like Krutilla (1991), Bommer and Schulze (1999), Damania *et al.* (2003), and Lai (2004). Ishikiwa and Okubo (2010) investigate the effects of environmental and trade policies with negative consumption externalities in an international duopoly model and show that tariffs could reduce externalities more effectively than emission taxes. Chen and Wang (2010) examine the effects of trade liberalization on environmental taxes in an international mixed duopoly, showing that a bilateral reduction in tariffs is beneficial to the global environment, but its impact on welfare is

[1] Please refer to Kamien (1992) for a survey.

ambiguous. Kawasaki and Ohno (2014) consider cross-border consumption and trans-boundary air pollution in the context of environmental taxes and tariffs to demonstrate that the environmental tax rate with a tariff is lower than without it, and that a tariff is not always necessary from the viewpoint of social welfare.

Many interesting questions can be asked from combining these two branches: Is foreign green technology transfer by licensing always beneficial to the domestic environment? Is it always good for the domestic welfare? Is there a possible conflict between the domestic environment and welfare? What is the impact of trade liberalization on pollution? Our answers are as follows. The total amount of pollution under the licensing regime may be larger than that under the no-licensing regime. The social welfare under licensing might be smaller than that under no-licensing. Hence, in some circumstances there exists a convergence of interests between pollution amount and social welfare, but some do not present this convergence. Finally, when an import tariff is moderate, trade liberalization decreases total pollution under licensing.

To examine how green technology transfer affects the environment, we decompose into two component effects: technology upgrading effect and total output effect. The "technology upgrading effect" refers to technology transfer leading to improvements in pollution abatement technologies, such that the production or consumption of goods and services generates less pollution. The "total output effect" refers to the impact on the environment through increased output or economic activity resulting from technology transfer.

Most traditional studies in international technology transfer ignore the environmental effect. On the contrary, Iida and Takeuchi (2011) examine how trade policies affect environmental technology transfer in an international duopoly model with global pollution. Asano and Matsushima (2014) investigate the effect of an environmental tax imposed by the home government on the incentives of a foreign technology transfer. Kim *et al.* (2018) examine how privatization policies affect the number of licensed firms and domestic welfare in a polluting mixed duopoly. It should be noted that these three articles assume the licensing contract eliminates all the environmental damage. Conversely, we assume that superior technology innovation can reduce a partial amount of pollution only. Therefore, we examine the effects of technology transfer on environmental pollution and social welfare in an international environment. More recently, Glachant et al. (2017) analyze the North's incentives to accept technology transfer in the international polluting goods market. Gersbach et al. (2019) examine the double free-riding problem by constructing a multi-country model with an international market of tradeable emission permits and licenses for abatement technologies. However, both of these two articles do not take into account how optimal licensing contract affect environmental pollution and social welfare.

The remainder of this article is organized as follows: Section 2 outlines the basic model and solves the equilibrium without licensing. Section 3 then solves the equilibrium under licensing. Section 4 compares the results in the two previous sections. Section 5 analyzes the impacts of policies under licensing regimes. Finally, Section 6 concludes this article.

2. The equilibrium without licensing

Firms 1 and 2, located in countries 1 and 2, respectively, produce a homogenous good and compete *à la* Cournot in country 2, which imposes an import tariff τ. The quantity exported by firm 1 is q_1, and that produced by firm 2 is q_2. The inverse demand for the good is given by $p(Q) = a - Q$, where $Q = q_1 + q_2$. The marginal costs of these two firms are identical and can be assumed to be zero without loss of generality.

Firm 1 has a better pollution abatement technology. Emissions intensity e (exhaust emissions per unit consumption),[2] unnoticed by the consumers,[3] is generated by Firm 2's product, and $e-\beta$ comes from Firm 1's.[4] Firm 1 can license its superior technology to Firm 2 and reduce its emissions intensity to $e-\beta$.

This technology innovation should be non-drastic throughout this article.[5] To discourage exhaust emissions, country 2 imposes an environmental tariff t on each unit of pollution and $t \in (0, \overline{t})$, where $\overline{t} = a/(e+\beta)$ is the upper bound for the domestic firm at τ=0. The pollution abatement technology has no value if t is

[2] Emissions intensity is the ratio of carbon dioxide emissions to measure economic output. http://www.nrdc.org/globalwarming/fintensity.asp.

[3] Generally, there are two types of green technologies used in the literature: end-of-pipe and cleaner production. The former type assumes that a firm can reduce gross emissions whereas outputs remain the same. On the contrary, the cleaner production technology affects the process of production, which reduces emissions per output unit (e.g., Petrakis and Xepapadeas, 1999 and Ulph and Ulph, 2007). We adopt the latter one.

[4] The setting of pollution here is considered as negative externalities connected with consumption, like by Krutilla (1991), Bommer and Schulze (1999), and Lai (2004).

[5] Wang (1998) shows that the licensor would never license the technology innovation to its rivals with drastic innovation.

non-positive.

The no-licensing case is set up as a benchmark model. Given the above assumptions, the profit functions of Firms 1 and 2 can be expressed as follows:

$$\pi_1(q_1,q_2)=\left(p-t\left(e-\beta\right)-\tau\right)q_1, \tag{1}$$

$$\pi_2(q_1,q_2)=(p-te)q_2. \tag{2}$$

By differentiating (1) and (2) with respect to q_1 and q_2, respectively, and solving simultaneously, we can derive the equilibrium quantities produced by each firm under the no-licensing regime,[6] which are:

$$q_1^N=\left(\frac{a-te+2t\beta-2\tau}{3}\right), \tag{3}$$

$$q_2^N=\left(\frac{a-te-t\beta+\tau}{3}\right), \tag{4}$$

where the superscript "N" denotes no licensing. The comparative statics are:

$$\frac{\partial q_1^N}{\partial t}=-\frac{e-2\beta}{3}<0,\frac{\partial q_2^N}{\partial t}=-\frac{e+\beta}{3}<0,\frac{\partial q_1^N}{\partial \tau}=\frac{-2}{3}<0,\frac{\partial q_2^N}{\partial \tau}=\frac{1}{3}>0.$$

First, the effect of t on Firm 1's output is ambiguous, which depends on the magnitude between e and 2β. Here, we assume $e-2\beta>0$ so that $\partial q_1^N/\partial t$ and $\partial q_2^N/\partial t$ are negative, and that a higher environmental tariff results in a smaller quantity of Firms 1 and 2's output. Second, duty τ is negative on q_1^N and positive on q_2^N intuitively. The total output under no licensing is:

$$Q^N=\left(\frac{2a-2te+t\beta-\tau}{3}\right). \tag{5}$$

The total amount of pollution in country 2 is:

$$D^N=\left(e-\beta\right)\cdot q_1^N+e\cdot q_2^N=\left(e-\beta\right)\left(\frac{a-te+2t\beta-2\tau}{3}\right)+e\left(\frac{a-te-t\beta+\tau}{3}\right). \tag{6}$$

Domestic welfare consists of consumer surplus, $cs^N=\left(q_1^N+q_2^N\right)^2/2$, Firm 2's profit, π_2^N, tariff revenue, τq_1^N, and net pollution revenue (the pollution tax revenue minus the environmental damage), $\left(t-\gamma\right)D^N$, where γ is the damage costs per unit

[6] The first-order conditions are $\partial\pi_1^N/\partial q_1=p-q_1-t(e-\beta)-\tau=0$ and $\partial\pi_2^N/\partial q_2=p-q_2-te=0$. The second-order conditions and the stability condition are satisfied.

pollution.[7] In summary, domestic welfare is:

$$\mathrm{SW}^{N} = \pi_2^{N} + cs^{N} + \tau q_1^{N} + \left(t-\gamma\right)D^{N}. \tag{7}$$

3. The equilibrium with licensing

This section considers a two-stage game theoretical model of technology licensing. In the first stage, Firm 1 (hereafter, the licensor firm) needs to decide a two-part tariff licensing contract - a fixed fee F and a royalty rate r - to Firm 2 (hereafter, the licensee firm), or to not license at all; Firm 2 needs to decide to accept the contract or not if Firm 1 offers it. The two firms compete in Cournot fashion in the second stage.

We proceed by backward induction. In case licensing occurs, the profit functions of Firms 1 and 2 change as follows:

$$\pi_1^{L}(q_1,q_2) = \left(p - t(e-\beta) - \tau\right)q_1 + rq_2 + F, \tag{8}$$

$$\pi_2^{L}(q_1,q_2) = \left(p - t(e-\beta) - r\right)q_2 - F. \tag{9}$$

Solving the Cournot duopoly model we derive the equilibrium quantities produced by each firm under the licensing regime with a two-part tariff contract (r,F),[8] which are:

$$q_1^{L}\left(r\right) = \frac{a + r - te + t\beta - 2\tau}{3}, \tag{10}$$

$$q_2^{L}\left(r\right) = \frac{a - 2r - te + t\beta + \tau}{3}, \tag{11}$$

where the superscript "L" denotes licensing.

The comparative statics are shown below:

$$\frac{\partial q_1^{L}}{\partial t} = -\frac{e-\beta}{3} < 0, \frac{\partial q_2^{L}}{\partial t} = -\frac{e-\beta}{3} < 0; \frac{\partial q_1^{L}}{\partial \tau} = \frac{-2}{3}, \frac{\partial q_2^{L}}{\partial \tau} = \frac{1}{3}.$$

These results are analogous to those from the previous section. Raising the environmental duty hurts both firms, and Firm 2 benefits from a higher custom tariff.

Substituting (10) and (11) into (8) and (9), we have the equilibrium profit functions of Firm 1 and Firm 2 in stage 2, which are:

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[7] We assume that environmental damage is a linear function of total emissions, such as those in Chiou and Hu (2001), Lai (2004), Abe and Zhao (2005), and Yang and Hu (2012).

[8] The first-order conditions are:

$$\partial \pi_1^{L} / \partial q_1 = p - q_1 - t(e-\beta) - \tau = 0,\ \partial \pi_2^{L} / \partial q_2 = p - q_2 - t(e-\beta) - r = 0.$$

The second-order conditions and the stability condition are the same as those in Section 2.

$$\pi_1^L\left(q_1^L(r),q_2^L(r),r,F\right)=\left(p^L(r)-t(e-\beta)-\tau\right)q_1^L(r)+rq_2^L(r)+F,$$

$$\pi_2^L(r,F)=\left(p^L(r)-t(e-\beta)-r\right)q_2^L(r)-F.$$

Back to the first stage, the licensor firm has to choose the best two-part tariff (r,F) to maximize its profit in stage 2. Following the licensing literature, the optimal fixed fee is to extract the licensee firm's surplus from licensing, which is:

$$F(r)=\left(p^L(r)-t(e-\beta)-r\right)q_2^L(r)-\pi_2^N(q_1^N,q_2^N)=\frac{4(te+r-a-\tau)(r-t\beta)}{9}.$$

By antitrust legislation, we have the limitation that $0\le r\le t\beta$ and $F\ge 0$.[9] Now the licensor firm's optimal contract can be solved from the following maximization problem:

$$\max_r \pi_1^L\left(q_1^L(r),q_2^L(r),r,F(r)\right)=\left(p^L(r)-t(e-\beta)-\tau\right)q_1^L(r)+rq_2^L(r)+F(r),$$
$$\text{s.t. } F(r)\ge 0, 0\le r\le t\beta.$$

Ignoring the constraints for the moment, we can solve the optimal royalty rate by the first-order condition, which is:

$$r=\frac{a-te+t\beta-5\tau}{2}.$$

Coming back to those constraints, we know first that:

$$r\le t\beta \text{ if } \tau\ge(a-te-t\beta)/5\equiv\hat{\tau}(t),$$

such that the optimal r touches its upper bound $r=t\beta$ if $\tau<\hat{\tau}(t)$ and is also bundled with a non-negative optimal fixed fee $F(t\beta)=0$. Second, $r\ge 0$ implies $\tau\le(a-te+t\beta)/5\equiv\tilde{\tau}(t)$, such that the optimal r reaches its lower bound $r=0$ if $\tau>\tilde{\tau}(t)$ and is bundled with a non-negative optimal fixed fee $F(0)=4t\beta(a-te+\tau)/9$.

If $\hat{\tau}(t)<\tau<\tilde{\tau}(t)$, then the optimal royalty rate is an interior solution $r=(a-te+t\beta-5\tau)/2$, and we have the optimal fixed fee:

$$F=(5\tau-a+te+t\beta)(a-te-t\beta+7\tau)/9.$$

In summary, the optimal two-part tariff contract is:

[9] Here, we restricted the royalty and fixed fee to be non-negative in our model, and the optimal royalty should be weakly less than the degree of tax reducing $t\beta$ in order to make a non-negative fixed fee. Such a set-up is used in much of the theoretical literature (see Katz and Shapiro, 1985; Mukherjee, 2007; Poddar and Sinha, 2010 for using a similar assumption).

$$
(r,F)=\begin{cases}(t\beta,0) & 0\le\tau\le\hat{\tau},\\ \left(\dfrac{a-te+t\beta-5\tau}{2},\dfrac{(5\tau-a+te+t\beta)(a-te-t\beta+7\tau)}{9}\right) & \text{if}\quad \hat{\tau}<\tau<\tilde{\tau},\\ \left(0,\dfrac{4t\beta(a-te+\tau)}{9}\right) & \tilde{\tau}\le\tau<\bar{\tau},\end{cases}
$$

where $\bar{\tau}(t)=(a-te+t\beta)/2$ is the prohibitive import tariff.[10]

[Figure 1 inserts here.]

We use Figure 1 to illustrate the result of the optimal licensing contract. Given any pollution tax rate, t, the custom tariff rate will affect the pattern of the optimal two-part tariff licensing contract. When the tariff is very high, the licensor is at a disadvantage to compete with the licensee, and thus adopting a pure fixed fee can extract more rent from the domestic firm than adopting a two-part or pure royalty method. We read Figure 1 the other way. Given a certain range of tariff rate, τ, the optimal licensing contract is royalty, two-part tariff, and fixed fee when the pollution tax rate is low, medium, and high, respectively. When the pollution tax rate is high, although it reduces both firms' output, the licensor would like to increase total output, and thus adopting a pure fixed fee can yield more profits than the other methods.

Substituting the optimal licensing contract into $q_1^L(r)$ and $q_2^L(r)$, the equilibrium total output is:

$$
Q^L=\begin{cases}\dfrac{2a-2te+t\beta-\tau}{3}, & 0\le\tau\le\hat{\tau},\\ \dfrac{a-te+t\beta+\tau}{2}, & \text{if}\quad \hat{\tau}<\tau<\tilde{\tau},\\ \dfrac{2a-2te+2t\beta-\tau}{3}, & \tilde{\tau}\le\tau<\bar{\tau}.\end{cases}\tag{12}
$$

Abatement technology transfer through licensing complicates the impacts of government policies. Total pollution is proportional to total domestic consumption, which in turn is closely related to custom tariff and environmental tax. We have the equilibrium amount of pollution as $D^L=(e-\beta)Q^L$. In equilibrium, consumer surplus and social welfare in country 2 under the licensing regime can be derived as follows:

[10] From (10), we have $q_1^L\big|_{r=0}=\dfrac{a-te+t\beta-2\tau}{3}$. To hold the duopoly model, Firm 1's output must be positive, which means the import tariff has to be limited; hence, we get the prohibitive import tariff $\bar{\tau}$.

$$CS^L = \left(Q^L\right)^2 \big/ 2,$$

$$SW^L = \pi_2^N + CS^L + \tau q_1^L + (t-\gamma)D^L. \tag{13}$$

4. Licensing impact on pollution and welfare

This section compares the results obtained in Sections 2 and 3. By comparing (5) and (12), we can derive the difference in total output between the licensing and no licensing regimes as follows:

$$Q^L - Q^N = \begin{cases} 0, & 0 \le \tau \le \hat{\tau}, \\ \frac{a-te+t\beta+\tau}{2}, & \text{if} \quad \hat{\tau} < \tau < \tilde{\tau}, \\ \frac{2a-2te+2t\beta-\tau}{3}, & \tilde{\tau} \le \tau < \bar{\tau}. \end{cases} \tag{14}$$

The above result shows that $Q^N = Q^L$ if $0 \le \tau \le \hat{\tau}$, but $Q^L > Q^N$ otherwise. We next proceed to compare the total amount of pollution under the licensing and no-licensing regimes. The total amount of pollution under the no licensing and licensing regimes can be derived as follows:

$$D^N = (e-\beta)\cdot q_1^N + e\cdot q_2^N = (e-\beta)\cdot Q^N + \beta\cdot q_2^N, \tag{15}$$

$$D^L = (e-\beta)Q^L. \tag{16}$$

By subtracting (15) from (16), we further derive that:

$$D^L - D^N = (e-\beta)\left(Q^L - Q^N\right) - \beta\cdot q_2^N \gtreqless 0. \tag{17}$$

We see that the total amount of pollution may increase or decrease after licensing, depending on two effects: *total output effect* and *technology upgrading effect*. The *total output effect* measured by $(e-\beta)\left(Q^L - Q^N\right)$ is non-negative, showing that pollution may be higher, because of greater output after licensing. On the other hand, the *technology upgrading effect*, measured by $-\beta\cdot q_2^N$, is negative, showing that both firms get the green technology after licensing, therefore decreasing the total amount of pollution. By (4), (14), and (17), we can derive the difference in total pollution between the licensing and no licensing regimes as follows:

$$D^L - D^N = -\frac{(a-te-t\beta+\tau)\beta}{3} < 0, \qquad \text{if } 0 \le \tau \le \hat{\tau} \tag{18}$$

$$D^L - D^N = \frac{(5e-7\beta)\tau - (e+\beta)(a-te-t\beta)}{6} < (\ge) 0, \ \text{ if } \hat{\tau} < \tau < \tilde{\tau} \text{ and } \tau < (\ge)\, \tau_1, \tag{19}$$

$$D^L - D^N = -\frac{(a-2te+\tau)\beta}{3} < (\geq) 0, \qquad \text{if } \tilde{\tau} \leq \tau < \overline{\tau} \text{ and } \tau > (\leq) \tau_2, \qquad (20)$$

where $\tau_1 = \frac{(e+\beta)(a-te-t\beta)}{5e-7\beta}$ and $\tau_2 = 2te - a$.

From (18), the total amount of pollution under licensing is always smaller than that under no licensing. The reason is that their total outputs are the same, but both firms get the green technology after licensing, whereas only firm 1 has such green technology under no licensing. From (19), the total amount of pollution under licensing is smaller than that under no licensing if $\tau < \tau_1$. From (20), the total amount of pollution under licensing is smaller than that under no-licensing if $\tau > \tau_2$. This leads to Proposition 1 as follows.

Proposition 1. *The total amount of pollution under the licensing regime is larger than that under the no licensing regime when* $\tau_1 < \tau < \tau_2$.

As shown in Figure 1, there are two critical values τ_1 and τ_2, resulting in $D^L = D^N$. When $\tau \in (\tau_1, \tau_2)$, the total amount of pollution under the licensing regime is larger than that under the no-licensing regime. The intuition behind Proposition 1 is as follow. There exist two effects after licensing: *technology upgrading effect* and *total output effect*. The former decreases pollution, but the latter has an opposite effect. Eventually, the effect of licensing on total pollution depends on the magnitudes of the two effects. For $0 \leq \tau \leq \hat{\tau}$, there is no *total output effect* because Q^L and Q^N are the same, and the total amount of pollution is thus lower under the licensing regime. For $\hat{\tau} < \tau < \overline{\tau}$, when environmental tariff t is sufficiently high, q_2^N will also be low, resulting in a low $\beta \cdot q_2^N$, and it implies that the *technology upgrading effect* is weak and dominated by the *total output effect*. In this context, the total amount of pollution is higher under the licensing regime; otherwise, the reverse is true.

By subtracting (7) from (13), we derive the difference in social welfare between the licensing and no licensing regimes as follows:

$$\mathrm{SW}^L - \mathrm{SW}^N = \frac{1}{2}\left(\left(Q^L\right)^2 - \left(Q^N\right)^2\right) + \tau\left(q_1^L - q_1^N\right) + (t-\gamma)\left(D^L - D^N\right) \gtreqless 0. \qquad (21)$$

This shows that the impact of green technology licensing can be decomposed into three terms: the changes of consumer surplus, tariff revenue, and net pollution tax revenue. The first term $\left(\left(Q^L\right)^2-\left(Q^N\right)^2\right)/2$ indicates that the licensing will increase total output and thus consumer surplus, which is a positive component of social welfare. The second term $\tau\left(q_1^L-q_1^N\right)$ indicates that the licensing will lower the output of the licensor firm and decrease the tariff revenue, which is thus a negative component of social welfare. The third term $(t-\gamma)\left(D^L-D^N\right)$ indicates that the net pollution tax revenue depends on the change in the amount of pollution, which is an ambiguous term. In summary, the change of *SW* due to green technology licensing is ambiguous.

Finally, by (3), (5), (10), (12), and (17), we can further derive that:

$$SW^L-SW^N=-\frac{(t-\gamma)(a-te-t\beta+\tau)\beta}{3}>(\le)0, \quad \text{if} \quad 0\le\tau\le\hat{\tau} \quad \text{and} \quad t<(\ge)\gamma \quad ,$$

$$SW^L-SW^N=-\frac{(a-te-t\beta-5\tau)(7a-7te+5t\beta+\tau)}{72}+\frac{\tau(a-te-t\beta-5\tau)}{6}$$
$$+\frac{(t-\gamma)\left[(5e-7\beta)\tau-(e+\beta)(a-te-t\beta)\right]}{6}>(\le)0,$$
$$\text{if } \hat{\tau}<\tau<\tilde{\tau} \text{ and } \tau<(\ge)\tau_3 \text{ or } \tau>(\le)\tau_4,$$

$$SW^L-SW^N=\frac{t\beta(4a-4te+3t\beta-2\tau)}{18}-\frac{t\beta\tau}{3}-\frac{(t-\gamma)(a-2te+\tau)\beta}{3}>(\le)0,$$
$$\text{if } \tilde{\tau}\le\tau<\overline{\tau} \text{ and } \tau<(\ge)\tau_5,$$

where:

$$\tau_3=\frac{23a-30e\gamma+42\beta\gamma+7t(e-5\beta)+6\sqrt{\theta}}{55}, \tau_4=\frac{23a-30e\gamma+42\beta\gamma+7t(e-5\beta)-6\sqrt{\theta}}{55},$$

$$\tau_5=\frac{6a\gamma-2at-12te\gamma+8t^2e+3t^3\beta}{2(7t-3\gamma)},$$

and:

$$\theta=4a^2+25e^2\gamma^2+49\beta^2\gamma^2+9t^2e^2+60t^2\beta^2-30t\gamma e^2-100t\gamma\beta^2+20t^2e\beta+38et\beta\gamma+12ate$$
$$-60at\beta+72a\beta\gamma-20ae\gamma-70e\beta\gamma^2>0 .$$

For $0\le\tau\le\hat{\tau}$, because $q_1^L=q_1^N$, $Q^L=Q^N$, and $D^L<D^N$, when environmental tariff t is sufficiently high ($t>\gamma$), the negative pollution tax revenue is strong and dominates the environmental damage. Thus, we can show that

$\mathrm{SW}^L - \mathrm{SW}^N = (t-\gamma)\left(D^L - D^N\right) < 0$. Under such a circumstance, the no licensing regime is superior to licensing in terms of domestic social welfare.

For $\hat{\tau} < \tau < \tilde{\tau}$, the above result shows that the domestic social welfare under licensing is superior to that under no licensing when the import tariff τ is moderate. The intuition is as follows. Consumer surplus is higher, but also generates higher pollution under licensing, thus cancelling out exactly. Tariff revenue plays an important role in comparing welfare under with and without licensing. Note that because τ is the production cost of the licensor, the licensor would like Firm 2 to produce more and extract rent via licensing, resulting in lower tariff revenue and lower domestic social welfare under the licensing regime. On the other hand, the tariff revenue, τq_1 , is concave in τ . When τ is sufficiently high ($\tau > \tau_3$) or low ($\tau < \tau_4$), the tariff revenue τq_1 will be low, resulting in lower domestic social welfare under the licensing regime. This result is of some interest as it goes against the general outcome in the literature whereby licensing is welfare-enhancing (see for example, Wang (1998) and Kamien and Tauman (2002)).[11] On the contrary, the tariff revenue is higher if the import tariff τ is moderate.

For $\tilde{\tau} \leq \tau < \bar{\tau}$, the above result shows the domestic social welfare under no licensing superior to that under licensing when the import tariff τ ($\tau > \tau_5$) is higher. The intuition is as follows. When the import tariff is large enough, the licensor would like Firm 2 to produce more and extract rent via licensing, such that tariff revenue decreases dramatically, leading to lower welfare under the licensing regime. We conclude the above into Proposition 2 as follows.

Proposition 2. *For $0 \leq \tau \leq \hat{\tau}$, licensing results in lower social welfare than no licensing if $t > \gamma$. For $\hat{\tau} < \tau < \tilde{\tau}$, licensing results in lower social welfare than no licensing if τ is very high ($\tau > \tau_3$) or low ($\tau < \tau_4$). For $\tilde{\tau} \leq \tau < \bar{\tau}$, licensing results in lower social welfare than no licensing if τ is sufficiently high ($\tau > \tau_5$).*

By Propositions 1 and 2, we construct the following proposition.

[11] From different perspectives, Faulí-Oller and Sandonis (2002), Erkal (2005), Mukherjee (2005), Fillipini (2005), and Sinha (2010) also show that licensing may be welfare-reducing. However, their causes of the result are different from ours. In this article, technology licensing is welfare-reducing as it may lower the tariff revenue.

Proposition 3. *The total amount of pollution under licensing may be larger than that under no licensing, but the former one may be more socially preferred.*

The analytics show that the total amount of pollution and social welfare under licensing regime may be larger or smaller than that under the no-licensing regime. We provide some numerical examples to support the results in Proposition 3. In order to obtain numerical examples, we assume that $e = 2.5$, $\beta = 0.5$, $\gamma = 1$, $t = 0.62$, and $a = 2.5$ in Table 1. According to these results, we show that the total amount of pollution and social welfare under licensing are higher than those under no-licensing if the import tariff locates at $\tau_1 (\cong 0.2133) < \tau < \tau_5 (\cong 0.5838)$.

[Table 1 inserts here.]

5. Impacts of policies under licensing regimes

Conventional wisdom of protectionism suggests more stringent environmental regulation and less free international trade, as trade liberalization increases total output and hence deteriorates the environment. Freer trade can be characterized by a lower custom tariff rate, and a more stringent environmental regulation can be characterized by a higher environment tax. Before licensing, the impact of government policies on the environment can be identified by the comparative statics of total pollution, which are:

$$D_t^N = \frac{dD^N}{dt} = -\frac{2\left((e-\beta)^2 + \beta e\right)}{3} < 0,$$

$$D_\tau^N = \frac{dD^N}{d\tau} = -\frac{(e-2\beta)}{3} < 0,$$

where the subscripts refer to partial derivatives.

The equations above show that pollution decreases with both of the environmental tax and import tariff. This implies that a more stringent environment regulation or a more restrictive trade is beneficial to the environment - in accordance with conventional wisdom of environmental protectionism.

After licensing, the impacts of pollution tax and import tariff on total pollution also depend on regions cut by τ and t. There are three regions as follows.

Region I: $0 \leq \tau \leq \hat{\tau}(t)$

$$D_t^L = \frac{-(e-\beta)(2e-\beta)}{3} < 0, D_\tau^L = \frac{-(e-\beta)}{3} < 0.$$

Region II: $\hat{\tau}(t) < \tau < \tilde{\tau}(t)$

$$D_t^L = \frac{-(e-\beta)^2}{2} < 0, D_\tau^L = \frac{(e-\beta)}{2} > 0.$$

Region III: $\hat{\tau}(t) \le \tau \le \bar{\tau}(t)$

$$D_t^L = \frac{-2(e-\beta)^2}{3} < 0, D_\tau^L = \frac{-(e-\beta)}{3} < 0.$$

Figure 2 shows the relationship between total pollution D and custom tariff rate τ for any given environment tax rate t. It is worth noting that only Regions I and III are in accordance with the conventional wisdom of environment protectionism, and a reverse result occurs in Region II, where freer trade can improve environment. Proposition 4 summarizes the above results.

[Figure 2 inserts here.]

Proposition 4. *When licensing a green technology with a two-part tariff contract, trade liberalization improves the environment if* $\tau \in [\hat{\tau}, \tilde{\tau}]$.

Under the situation in which a foreign firm transfers its green technology by licensing, the domestic government can help reduce environmental harm provided that the tariff rate is moderate. The intuition can be explained as follows. The impacts of import tariff to total output in the licensing stage are $dQ^L/d\tau = \partial Q^L/\partial\tau + (\partial Q^L/\partial r)(\partial r/\partial\tau)$. The first term of right-hand side is the direct effect of the import tariff, which is negative apparently. If $\tau \in [\hat{\tau}, \tilde{\tau}]$, then the second term is the indirect effect, which indicates the import tariff influences total output by the royalty rate. Its sign is positive, because a higher import tariff reduces the royalty rate. The indirect effect is larger than the direct effect, and hence we get that total output increases with the import tariff. Trade liberalization leads to environmental improvement. However, if $\tau \in [0, \hat{\tau}]$ and $\tau \in [\tilde{\tau}, \bar{\tau}]$, then the second term is zero, and trade liberalization leads to worse environment.

A similar research by Lai (2004) points out that trade liberalization may reduce pollution via the pollution tax rising endogenously. We take the pollution tax as given and get the result by introducing international licensing.

6. Concluding remarks

This article builds up a two-stage game model to explore the impact of international green technology licensing on the environment and social welfare, showing that green technology transfer could be either beneficial or harmful to the environment of an import country, depending on the combination of environmental tariff and import tariff. The total amount of pollution after licensing is larger than that before licensing when the import tariff is moderate. Trade liberalization may cause environmental improvement with licensing. The technology licensing is welfare-reducing when the import tariff is large, as it may lower the tariff revenue. Furthermore, the total amount of pollution under the licensing regime may larger than that under the no-licensing regime, but the former may be socially preferred.

Although this article does not internalize the government's policy-making into the model, it conducts a comprehensive analysis under any reasonable given environmental tariff and import tariff. This study provides implications to governments such that when they make decisions on environment policy and trade policy they should take into account firms' strategic behavior, as technology licensing may be good or bad for the domestic environment. If the combinations of policies are bad for our environment, then a ban on technology transfer from foreign firms may be a better way for maintaining the environmental quality.

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Table 1: Comparisons between licensing and no-licensing regimes

τ	$D^L - D^N$	$SW^L - SW^N$
0.1	- 0.1233	0.0469
0.2	- 0.0200	0.0376
0.3	0.0500	0.0211
0.4	0.0333	0.0137
0.5	0.0167	0.0062[(b)]
0.59	0.0017[(a)]	-0.0005
0.62	- 0.0033	-0.0027

Notes: (a) $D^L > D^N$ if $\tau_1(\cong 0.2133) < \tau < \tau_2(\cong 0.5999)$. (b) $SW^L > SW^N$ if $\tau < \tau_5(\cong 0.5838)$.

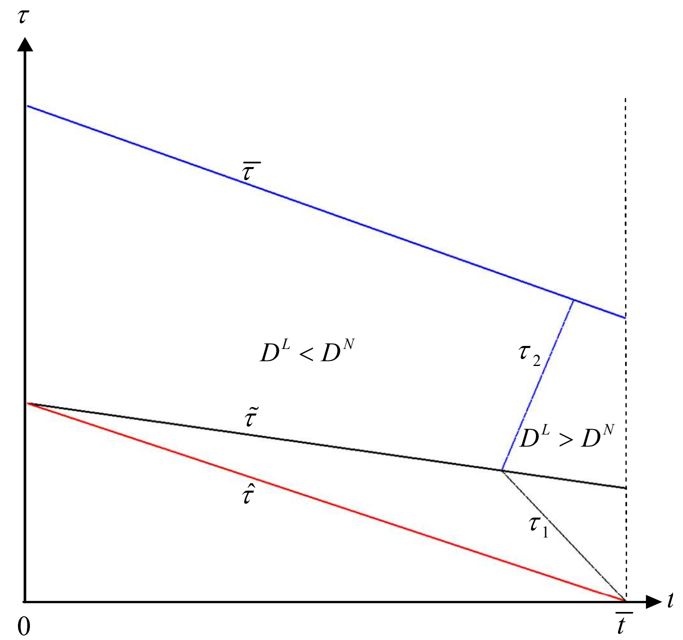

Figure 1. The effect of technology licensing on pollution

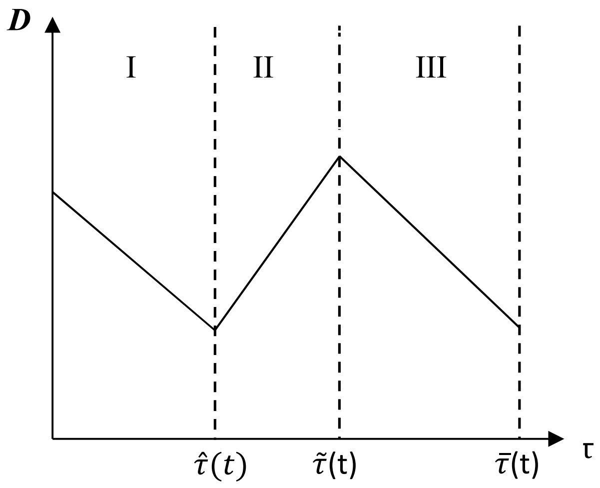

Figure 2. The impact of trade liberalization on pollution