Optimal tariffs with emissions taxes under non-restrictive two-part licensing strategies by a foreign eco-competitor

Kim, Seung-Leul and Lee, Sang-Ho

Kangwon National University, Chonnam National University

June 2021

Optimal tariffs with emissions taxes under non-restrictive two-part licensing strategies by a foreign eco-competitor

Seung-Leul Kim* and Sang-Ho Lee†

Abstract

This study considers eco-technology licensing strategy by a foreign innovator that competes with a polluting domestic firm in the home country. We examine and compare the two-part licensing contracts with and without non-negative constraints on the royalty or a fixed fee. We find that the licensor may choose either negative royalty or negative fixed fee, depending on the levels of emissions tax and tariff. We then examine the government's optimal tariff policies under the emissions tax and demonstrate that allowing a non-restrictive two-part licensing contract is better for domestic welfare than a restrictive licensing contract. We also reveal that the tariffs under the two-part licensing have a negative relationship with emissions taxes, but the tariff with non-restrictive licensing is higher than that with restrictive licensing.

JEL Classification: L13; D45; H23

Keywords: Eco-technology; tariff policies; emissions tax; non-restrictive two-part licensing; foreign innovated firm

1. Introduction

During the last generation, technology innovation and free trade stance have drastically expanded the volume of international trade and globalisation worldwide. However, owing to liberalisation and the deregulation of economic activities, the scope and nature of trade and environmental problems have also been diversified without being limited to a specific region or country.

For example, the global concern about climate change requires greenhouse gas (GHG) reduction plans and other environmental policies that have been implemented in polluting

* Assistant Professor, Department of Regional Economics, Kangwon National University, Samcheok, Gangwon, South Korea, E-mail: slkim@kangwon.ac.kr

† Corresponding author. Professor, Department of Economics, Chonnam National University, Gwangju, Chonnam, South Korea, E-mail: sangho@jnu.ac.kr

industries across the world.[1] The GHG reduction plans are primarily focused on industrial green R&D activities aimed at reducing emissions levels. Many countries and companies are eager to develop eco-friendly technologies and products to reach near-zero emissions by 2050. In addition, international organisations and research institutions are also emphasising the importance of the eco-technology industry to reduce global pollution emissions.

Conversely, as part of their trade protection policies, many countries are strengthening the introduction of technology barriers to trade (TBT). The industrial regulations and policies on environmental technology have become an international issue. In the rapidly changing global economy, the combined policy of trade and environmental issues caused by such globalisation is therefore one of the most important economic growth policies.

The interaction between trade policy and environmental regulation has been recently studied in the economics literature. Early studies focused on the interest of government revenue in adjusting tariffs and emissions taxes to improve welfare (see Copeland, 1994; Hatzipanayotou et al., 1994; Gulati and Roy, 2008). Recent works have examined the optimal policies and revealed that trade liberalisation results in less-stringent environmental regulations, which suggests that policies regulating trade and the environment are positively correlated.[2] However, Tsai and Chang (2015) demonstrated that a positive relationship between tariffs and environmental taxes may not be applicable under the eco-technology, which can fully abate pollution through environmental research and development (R&D). When both environmental taxes and tariffs are employed, Chao et al. (2012) found that welfare is maximised with the first-best optimal policy combination, which is free trade and a Pigouvian tax on consumption-based pollution.

One of the most important global phenomena is the significant increase in the volume and value of patent licensing in recent years (see Zuniga and Guellec, 2009). Patent licensing is an

[1] As part of the Paris COP21 agreement, several countries submitted independent nationally determined contributions along with environmental policies, including market-oriented mechanisms and stricter emissions standards. For example, many progressive countries have already adopted market-based environmental regulation by using emissions taxes, cap-and-trades, and pollution abatement (green R&D) subsidies. Recently, Burtraw and McCormack (2017), Garcia et al. (2018), and Lee and Park (2021) have provided some useful real-world discussions on climate change policy instruments in the United Nations and the United States.

[2] When the environmental damage is serious, the government should impose higher emissions tax on the polluting domestic firms while raising the tariff as domestic firms have a cost disadvantage from the emissions tax, which might increase the rent-extraction effect from the foreign competitors. However, when the environmental damage is not serious, the government may impose lower emissions tax and reduce the tariff to increase market competition. See Chao et al. (2012) for example.

important policy issue for improving social welfare as well as protecting the interests of innovators because patents can provide incentives for effective R&D to develop new products or technological innovations. Kabiraj and Marjit (2003) and Mukherjee and Tsai (2013) examined the effect of tariff or subsidy/tax policies on technology licensing decision and revealed that innovators license to domestic licensees in the presence of optimal policies. Kabiraj and Kabiraj (2017) also determined that the government can impose a positive tariff on importing goods under the two-part licensing contracts, which can induce fixed fee licensing of the foreign licensor and maximise domestic welfare.

The current study extends the analysis into the eco-technology licensing under trade policy with environmental problems [3] and examines the optimal tariffs with emissions taxes under the foreign firm's licensing strategies. In particular, we investigate strategic two-part licensing contracts by a foreign innovator, which competes with a polluting domestic firm in the home country, and examine policy relationships between tariffs and emissions taxes. Intuitively, a licensing contract of an eco-technology increases the production cost of domestic firms while a tariff policy raises the cost of foreign firms. Furthermore, as the emissions tax increases, domestic firms decrease output, but foreign firms produce more outputs and receive more licensing fee. Thus, social welfare depends not only on the effects of reducing pollution damage and increasing market outputs but also on the effect of extracting profit of the foreign firm.

We investigate and compare the restrictive contract with non-negative constraint on the royalty or fixed fee and the non-restrictive contract without non-negative constraint. [4] We find that the foreign eco-innovator may strategically choose either a negative royalty or a negative fixed fee, depending on the levels of emissions tax and tariff. We also examine the government's optimal tariff policies under the emissions tax and demonstrate that, in terms of domestic welfare, a non-restrictive two-part licensing contract is better than a restrictive licensing contract. This implies that the restriction on subsidy by a foreign innovator leads to a reduction in welfare. Hence, a tariff policy that allows non-restrictive licensing contract is

[3] Anand and Khanna (2000) empirically demonstrate that licensing of patents is quite high in the polluting industries such as chemicals, electronics, and pharmaceuticals.

[4] Our study differs from Kabiraj and Kabiraj (2017) and Yang et al. (2020) in that we allow the possibility of a negative royalty or a negative fixed fee under the licensing of eco-technology. Our approach is close to Lia and Sen (2005) and Hattori and Tanaka (2018), who considered a negative royalty and revealed that a subsidised royalty can be an equilibrium strategy of the inside innovator. However, they neither considered public policy nor environmental issues. For more discussion, see the literature review in Section 2.

always welfare-improving under the emissions taxes.[5] We also find that the optimal tariff policy under the two-part licensing has a negative relationship with emissions taxes, but the tariff under non-restrictive licensing is higher than that under restrictive licensing.

The remainder of this paper is organised as follows. In Section 2, we briefly introduce a literature review. We provide the basic model with environmental regulation and trade policy in Section 3. We examine the no licensing case in Section 4 and construct the two-part licensing contracts under the restrictive and non-restrictive cases in Sections 5 and 6, respectively. In Section 7, we compare the equilibrium outcomes under both restrictive and non-restrictive two-part licensing contracts. In Section 8, we discuss welfare consequences of the optimal tariffs policy under the two-part licensing contracts and explain the interaction between two policy instruments. The final section provides a conclusion.

2. Literature Review

In the theoretical literature on patent licensing, the innovators can give a license to licensees by means of different licensing contracts such as royalty, fixed-fee licensing, auctioning, two-part tariff licensing, among others. However, empirical evidence on licensing contracts reveals that most of the contracts include a positive royalty or combinations of up-front fees and royalties. For example, Rostoker (1984) determined that, among 37 corporations in the manufacturing industry, 46% used two-part tariff licensing (including royalty plus fixed fee), 39% used royalty alone, and 13% used fixed fee alone. Using French data covering a sample of 278 contracts, Bousquet et al. (1998) indicate that 225 (82%) include royalties, of which 216 (96%) are ad valorem. Vishwasrao (2007) also shows that patent licensors are empirically more likely to ask for royalties when sales are relatively high and involatile, but profits are low.

Early studies reveal that with outside innovation, fixed fee policy is superior to royalty (or auction) policy in perfect competition (Kamien and Tauman, 1984; Katz and Shapiro, 1985), homogenous oligopoly model (Kamien and Tauman, 1986; Katz and Shapiro, 1986; Kamien *et al.*, 1992), asymmetric Cournot industry (Stamatopoulos and Tauman, 2009), and eco-industry (Kim and Lee, 2014). However, there is still debate on these results since royalty is preferred to fixed-fee in the Bertrand model (Muto, 1993), product differentiation model

[5] The credibility of commitment in the tariff-induced technology transfer is a contemporary issue in the recent literature. For example, see Kabiraj and Marjit (2003), Mukherjee and Tsai (2013), and Kabiraj and Kabiraj (2017).

(Poddar and Sinha, 2004, Bagchi and Mukherjee, 2010), open economy (Mukherjee, 2007), and dynamic frameworks (Saracho, 2011).

Others have also focused on patent licensing regarding internal innovation. They demonstrate that royalty licensing is preferred to fixed-fee licensing in a Cournot duopoly with a homogeneous good (Wang, 1998), a differentiated Bertrand duopoly (Wang and Yang, 1999), incumbent innovators in a homogeneous Cournot oligopoly (Kamien and Tauman, 2002), and a leadership structure (Kabiraj, 2005). However, Wang (2002) reveals that fixed-fee licensing is preferred to royalty licensing for an internal patentee with a heterogeneous duopoly if the product differentiation is sufficiently large.

While previous literature mainly deals with royalty and fixed-fee licensing, recent research has also focused on two-part licensing, basically consisting of a fixed fee plus a per-unit royalty. Erutku and Richelle (2007) demonstrate that an outside innovator always prefers a fixed-fee plus a royalty contract, which gives profit a monopoly endowed with the innovation but can reduce social welfare. With inside innovation, Sen and Tauman (2007) examined homogenous oligopoly, Li and Yanagawa (2011) considered a leadership duopoly model with product differentiation, and Mukherjee and Balasubramanian (2001) and Fauli-Oller and Sandonis (2002) analysed differentiated Cournot-Bertrand duopolies. Fauli-Oller et al. (2012) highlight that the innovation is licensed to all firms under two-part tariff, regardless of the number of firms, the degree of product differentiation, and the type of patentee. Moreover, two-part tariff licensing can be developed by ad valorem royalties with a fee (Hernandez-Murillo and Liobet, 2006; Martin and Saracho, 2015).

Recent theoretical literature has also analysed the relationship between market structure and public policy. Mukererjee and Tsai (2013) examined a homogeneous oligopoly market in the presence of tax and subsidy policy. Regarding eco-technology licensing, Kim and Lee (2014, 2016a, 2016b) analysed an environmental policy with royalty or fixed fee and two-part licensing contracts, while Kim et al. (2018) investigated the privatisation policy in a mixed oligopoly with a foreign eco-innovator. Some studies examine trade policy with licensing. Kabiraj and Marjit (2003) and Mukherjee and Pennings (2006) emphasised the role of government in technology licensing under an open economy in which tariff policy induces fee licensing rather than royalty licensing. Wang et. al (2012) examined the relationship of strategic trade policy and welfare with consumer-friendly initiative of the foreign exporting firm. Further, it is revealed that a tariff can be chosen to induce fee licensing and maximise both consumers' surplus and domestic welfare in an international duopolistic model (Kabiraj and Kabiraj, 2017), foreign Stackelberg leadership model (Yang *et al.*, 2020). Our model is close to these studies wherein the government imposes a positive tariff on importing goods under two-part licensing. We analyse the welfare effect of two policy instruments that are tariff and emissions tax with eco-technology. We also extend the assumption of a restrictive two-part licensing into a non-restrictive case in which either a negative royalty or a negative fixed fee is possible. Our study differs from previous studies in that we allow the possibility of a subsidy under the eco-technology licensing when the government can commit to tariffs and environmental taxes.

3. Model

Consider a Cournot duopoly where a domestic firm and a foreign firm compete in a domestic market with homogenous products that may emit pollutants. The inverse demand function in the domestic market is given by $P = A - Q$, where $Q = q_d + q_f$ denotes market outputs and q_d and q_f are the outputs of the domestic and foreign firms, respectively. For simplicity, we assume that both firms have the same constant marginal cost, c.

While the domestic firm emits pollutants, the foreign firm is an eco-firm and has a patent of environmentally clean technology, that is, zero-pollution eco-technology that produces no emissions, for analytic convenience. The foreign firm can consider a technology licensing strategy where it can license its eco-technology to its rival firm by offering a licensing contract with a two-part scheme consisting of per-unit royalty and fixed-fee. If the domestic firm adopts the licensing contract, the licensed domestic firm can also reduce pollution (and expenditure on emissions tax if the government imposes emissions tax) while the non-licensed domestic firm will continue to emit pollution where its emissions function is defined as $E = q_d$.

We denote environmental damage as $D(E) = dE$, which is constant to the total emissions level. The social welfare function will be defined as the sum of consumer surplus, domestic firm's profit, and government total revenue minus environmental damage. We assume that the government maximises domestic welfare and imposes an emissions tax at the rate of t (> 0) on the domestic firm. Further, the government can impose an import tariff at the rate of τ

(>0) on foreign products. We assume that $0 \le \tau < (a-c+t)/2$ to assure the interior solutions in the analysis.

We examine two-part licensing contracts by the foreign licensor but compare the two cases: (i) a restrictive scheme with non-negative constraints on per-unit royalty and fixed-fee, and (ii) a non-restrictive scheme without non-negative constraints. We then examine the optimal government policies between emissions tax and tariff.

The timing of the game is as follows. In the first stage, for given emissions tax and tariff, the foreign firm announces the provision of eco-technology and decides a per-unit royalty and a fixed-fee. In the second stage, given the two-part licensing contract, the domestic firm decides whether to purchase a license. Finally, each domestic and foreign firm chooses output levels q_d and q_f in a Cournot-fashion in the last stage. The sub-game perfect Nash equilibrium will be divided by backward induction.

4. No licensing case

Under no licensing, a foreign firm faces an import tariff while a domestic firm faces an emissions tax in the output competition. The profit functions of a domestic firm and a foreign firm are as follows, respectively:

$$\pi_d^N = P(Q)q_d^N - cq_d^N - tq_d^N \quad \text{and} \quad \pi_f^N = P(Q)q_f^N - cq_f^N - \tau q_f^N \tag{1}$$

Then, the equilibrium quantities of the firms are as follows:

$$q_d^N = \frac{a-c-2t+\tau}{3} \quad \text{and} \quad q_f^N = \frac{a-c+t-2\tau}{3} \tag{2}$$

where the superscript N denotes the equilibrium under no licensing. It indicates that the relative size between t and τ determines the production and profitability. That is, $q_d^N \gtreqless q_f^N$ if $\tau \gtreqless t$.

In the following, to guarantee non-negative quantities of both firms at equilibrium, we assume the positive tariffs as follows:

$$\max[0, 2t+c-a] \le \tau < \frac{a-c+t}{2}. \tag{3}$$

Let us define $\tau_D = \dfrac{a-c+t}{2}$ and $\tau_M = 2t + c - a$. Then, the domestic firm will act as a monopolist if the tariff is prohibitive, that is, $\tau \ge \tau_D$, while the foreign firm will act as a monopolist if the emissions tax is very high, that is, $t > \dfrac{a+\tau-c}{2}$ (or $\tau \le \max[0, \tau_M]$).

The corresponding profits of the firms and the welfare are as follows:

$$\pi_d^N = \left(\frac{a-c-2t+\tau}{3}\right)^2 \quad \text{and} \quad \pi_f^N = \left(\frac{a-c+t-2\tau}{3}\right)^2 \tag{4}$$

$$\begin{aligned} W^N &= \int_0^Q P(u)du - cq_d + \tau q_f - dE \\ &= \frac{1}{6}\left[2(a-c)^2 - 2d(a+\tau-2t-c) + 2\tau(a+t-c) - t(2a-2c+t) - 3\tau^2\right] \end{aligned} \tag{5}$$

5. Restrictive two-part licensing case

We consider a two-part licensing contract $T(r, f)$ where r is a per-unit royalty and f is a fixed-fee. We impose a non-negativity constraint of the royalty and fee and construct an optimal two-part licensing contract.

The profit functions of a foreign firm and a licensed domestic firm are as follows, respectively:

$$\pi_d^T = P(Q)q_d - cq_d - rq_d - f \quad \text{and} \quad \pi_f^T = P(Q)q_f - cq_f - \tau q_f + rq_d + f \tag{6}$$

The equilibrium quantities of the firms are as follows:

$$q_d^T = \frac{a-c-2r+\tau}{3} \quad \text{and} \quad q_f^T = \frac{a-c+r-2\tau}{3} \tag{7}$$

where the superscript T denotes the equilibrium under the restrictive two-part licensing. Then, it indicates that the relative cost relationship between r and τ determines the efficiency of the firm and profitability. That is, $q_d^T \gtreqless q_f^T$ if $\tau \gtreqless r$. It is noteworthy that the foreign firm can strategically manipulate the royalty to increase (decrease) the output of licensee, which yields asymmetric cost between the firms, and then impose a fixed fee to retrieve the increased profit of the domestic firm into its profit.

The corresponding profits of the firms become as follows:

$$\pi_d^T = \left(\frac{a-c-2r+\tau}{3}\right)^2 - f \quad \text{and} \quad \pi_f^T = \left(\frac{a-c+r-2\tau}{3}\right)^2 + rq_d + f \tag{8}$$

where $r \geq 0$ and $f \geq 0$. To make a contract agreeable to the domestic firm, the fixed fee should be equal to the profit difference between accepting and rejecting the licensing offer, that is, $\pi_d^T - \pi_d^N = 0$ at equilibrium. It implies that the contract should ensure the incentive compatibility of the licensed domestic firm between the licensed and non-licensed case. Then, we have the following relations between the fixed fee and royalty:

$$f(r) = \frac{4}{9}(r-t)(r+c+t-a-\tau) \tag{9}$$

Note that the relationship between the fixed-fee and royalty is non-monotonic and U-shaped, that is, as the royalty increases, the fixed-fee decreases first and then increases later, given the policy parameters, that is, if $r \underset{<}{\overset{>}{}} \frac{a+\tau-c}{2}$, then $\frac{\partial f(r)}{\partial r} \underset{>}{\overset{<}{}} 0$ and $\frac{\partial^2 f(r)}{\partial r^2} > 0$. Then, given this constraint in (9), the foreign firm will determine the royalty to maximise the equilibrium profit function in (8):

$$\max_r \left(\frac{a-c+r-2\tau}{3}\right)^2 + rq_d^T + f(r) \quad \text{s.t} \quad f(r) \quad \text{in (9)} \tag{10}$$

From the first-order condition, we have the following optimal royalty:

$$r^* = r = \frac{a-c-5\tau}{2} \tag{11}$$

where the superscript * denotes the optimal decision of the foreign innovator under the restrictive two-part licensing. Note that r^* is decreasing in τ and positive if $\tau \leq \frac{(a-c)}{5}$.

Then, we can construct the optimal fixed fee f^* as follows:

$$f^* = f(r) = \frac{(5\tau - a + 2t + c)(a - 2t - c + 7\tau)}{9} \tag{12}$$

Note that f^* increases in t while it has U-shape relationship with τ, that is, $\frac{\partial f^*}{\partial t} > 0$ and $\frac{\partial f^*}{\partial \tau} \gtrless 0$ if $\tau \gtrless \frac{a-c-2t}{35}$ and $\frac{\partial^2 f^*}{\partial \tau^2} > 0$.

Let us define τ^R as a royalty level with zero fixed fee, which satisfies $f^* = 0$, and τ^F as a fixed fee level with zero royalty, which satisfies $r^* = 0$.

$$\tau^R = \frac{a-c-2t}{5} \quad \text{and} \quad \tau^F = \frac{a-c}{5} \tag{13}$$

Note that τ^R can be positive (if $t < \frac{(a-c)}{2}$) or negative (if $t > \frac{(a-c)}{2}$), while τ^F is always positive.

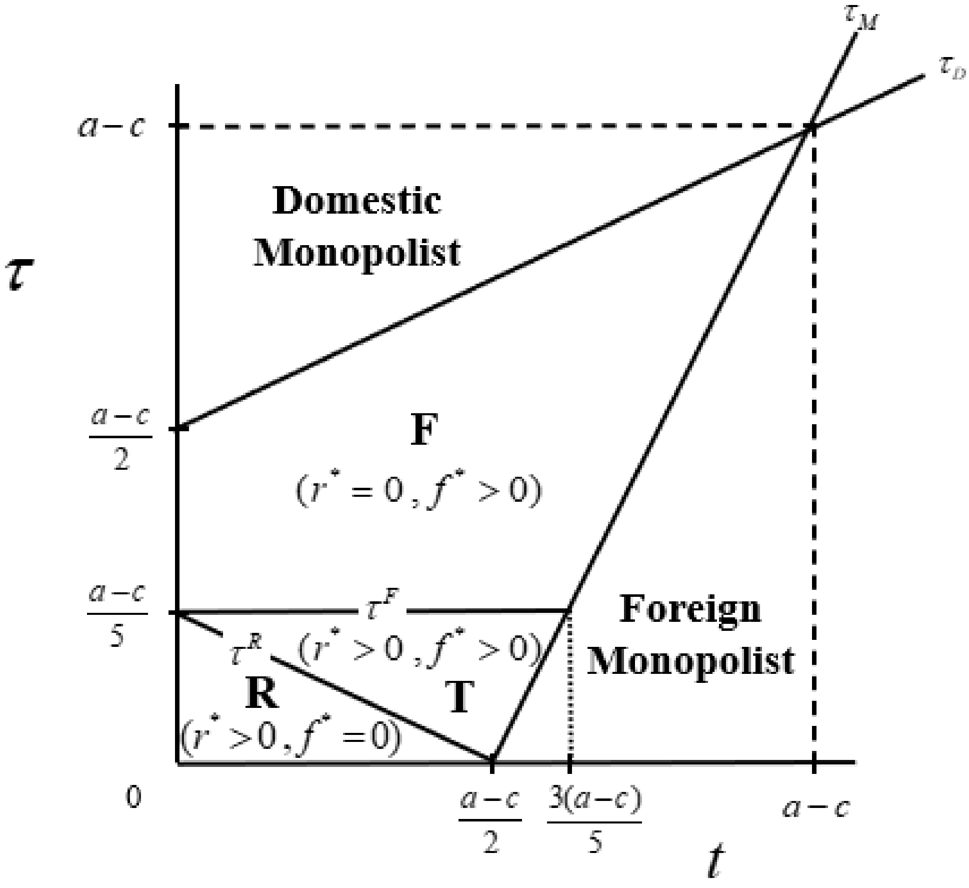

Fig. 1. Optimal licensing strategies with restrictions

Fig. 1 provides the relationships of the findings, where τ^R and τ^F are the boundaries of duopolistic competition. That is, if the tariff is very high ($\tau \geq \tau_D$), only domestic firm exists in the market, and if emissions tax is very high ($\tau < \tau_M$), only foreign firms exist in the market. With non-negative constraints on royalty and fee, the following proposition then defines the optimal licensing contracts.

Proposition 1. With non-negative constraints on royalty and fixed fee, the optimal two-part licensing contract is as follows:

(a) $r^* = t$, $f^* = 0$ if $\tau \leq \dfrac{a-c-2t}{5}$,

(b) $r^* = \dfrac{a-c-5\tau}{2}$, $f(r^*) = \dfrac{(5\tau - a + 2t + c)(a - 2t - c + 7\tau)}{9}$ if $\dfrac{a-c-2t}{5} < \tau \leq \dfrac{a-c}{5}$,

(c) $r^* = 0$, $f(0) = \dfrac{4t(a + \tau - t - c)}{9}$ if $\tau > \dfrac{a-c}{5}$.

This proposition implies that optimal royalty depends on the levels of tariff and emissions tax and it affects the size of fixed fee. Fig. 1 also provides the optimal contracts, which are described by R (royalty) or T (two-part), or F (fixed fee). It states that the foreign eco-innovator can choose either (i) royalty only (Case a) or (ii) fixed fee only (Case c). Otherwise, two-part licensing contracts have positive royalty and fixed fee (Case b). In particular, if tariff and emissions tax are low, only royalty is the optimal contract, $r^* > 0$. If these are moderate, a two-part licensing contract is optimal, $r^* > 0$ and $f(r^*) > 0$. However, if the tariff level is sufficiently high, only fixed-fee licensing is optimal.

Putting r^* and f^* into the profits of both firms in (8), we have the following profits under the optimal licensing contracts.

Under royalty licensing, the profits of the domestic firm and the foreign firm are as follows:

$$\pi_d^R = \left(\frac{a-c-2t+\tau}{3}\right)^2 \text{ and } \pi_f^R = \frac{(a-c)(a-c+5t-4\tau)+4\tau^2 - t\tau - 5t^2}{9} \tag{14}$$

Under pure fixed-fee licensing, the profit of a licensed domestic firm and a foreign firm are as follows:

$$\pi_d^F = \left(\frac{a-c-2t+\tau}{3}\right)^2 \text{ and } \pi_f^F = \frac{(a-c)(a-c+4t-4\tau)+4(\tau^2-t^2+\tau t)}{9} \quad (15)$$

Under two-part licensing, the profit of a licensed domestic firm and a foreign firm are as follows:

$$\pi_d^T = \left(\frac{a-c-2t+\tau}{3}\right)^2 \text{and } \pi_f^T = \frac{(a-c)(5a-5c-26\tau)+41\tau^2+16t(a-c-t+\tau)}{36} \quad (16)$$

We can show that a foreign innovator has incentive to sell a license to a domestic firm through all types of licensing:[6] $\pi_f^R > \pi_f^N$, $\pi_f^F > \pi_f^N$ and $\pi_f^T > \pi_f^N$ for any τ and t.

Finally, to provide policy implications with regards to tariff policy and emissions taxation, we compare welfare functions under the two-part licensing strategies. Under two-part licensing, the social welfare function can be defined by

$$W^L = \int_0^Q P(u)du - cq_d - pq_f + \tau q_f - rq_d - f$$

The resulting welfare from a licensing strategy with r and f is as follows:

$$W^R = W^R\{r^*, f=0\} = \frac{1}{6}\left[2(a-c)(a-c-2t+\tau)+3(t^2-\tau^2)\right] \quad (17)$$

$$W^F = W^F\{r^*=0, f(0)\} = \frac{1}{18}\left[6(a-c)(a-c+\tau)-8t(a+\tau-c-t)-9\tau^2\right] \quad (18)$$

$$W^T = W^T\{r^*, f(r^*)\} = \frac{1}{72}\left[17(a-c)^2+70\tau(a-c)-32t(a+\tau-c-t)-91\tau^2\right] \quad (19)$$

We now focus on the welfare effect of the tariff by assuming that $t=d$ where emissions tax is based on the Pigouvian level in the following analysis.[7]

---

[6] Note that the profit of domestic firm is the same under no licensing, that is, $\pi_d^N = \pi_d^R = \pi_d^F = \pi_d^T$. It implies that the domestic firm will accept the offered license by a foreign firm because the latter can construct two-part licensing contracts by taking the incentive compatibility constraint of the domestic firm, and thus, it can offer a favourable (discounted) contract to the domestic firm.

[7] To focus on the tariff effect, we consider a Pigouvian tax on pollution damage level, which is the same as Chao et al. (2012). Lee (1999) also examined the optimal emissions tax under imperfect competition and determined that the tax level depends on the number of firms and the curvature of demand functions. In particular, if the demand function is linear with the endogenous market structure, the emissions tax is exactly same with marginal damage level.

Proposition 2. Suppose that $t = d$. Then, (i) $W^R = W^N$, (ii) $W^T > W^N$, and (iii) $W^F \gtrless W^N$ if $\tau \lessgtr \tau_w^*$ where $\tau_w^* = \dfrac{4(a-c)-t}{8}$ satisfies $W^F = W^N$.

This proposition indicates that two-part licensing with a restrictive constraint always improves welfare while royalty licensing cannot improve welfare, compared with non-licensing. However, fixed-fee licensing can increase (decrease) welfare when $\tau < \tau_w^* (\tau > \tau_w^*)$. Thus, fixed-fee licensing may yield welfare losses under the optimal choices of the domestic firm. Fig. 2 illustrates that the optimal choices may not be socially desirable with response to tariff and emissions tax under the fixed-fee licensing. That is, welfare losses exist, comparing the welfares between fixed-fee licensing and non-licensing, indicated by $W^F < W^N$ in shaded areas in Fig. 2 in which non-licensing can induce higher welfare.

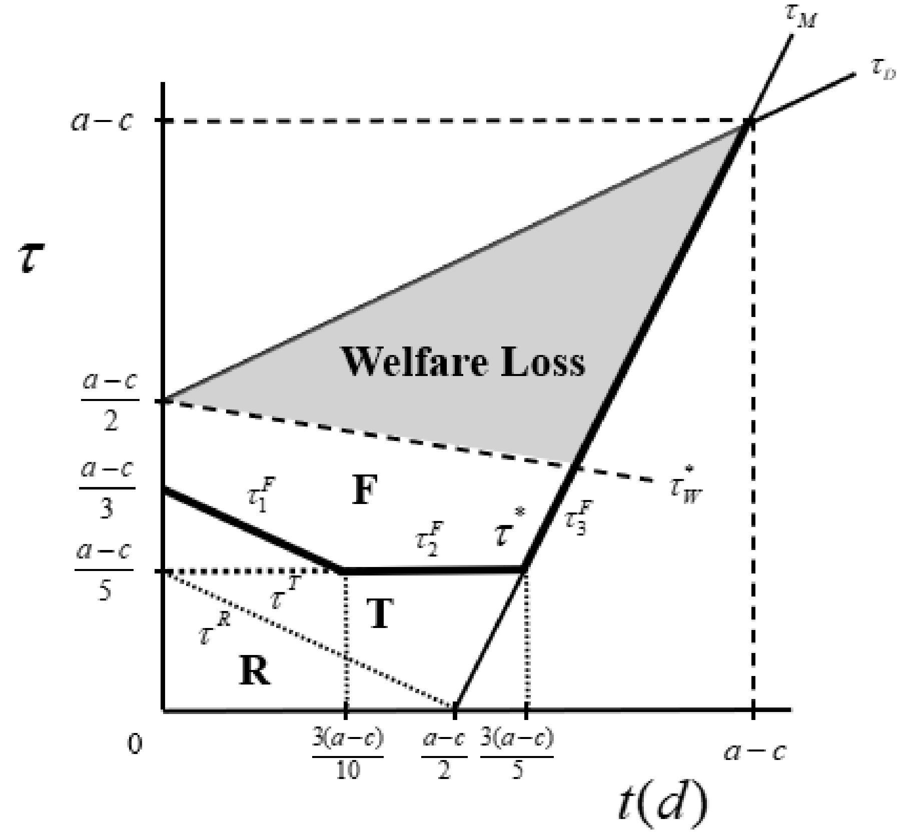

Fig. 2. Welfare losses and optimal tariff with restrictions

Finally, we examine the optimal tariff schedules and provide policy implications on the licensing strategies of eco-technology. We first find the optimal tariff schedules given the licensing contracts, and then compare the welfare consequences.

Lemma 1. Given the licensing contracts, the optimal tariff schedules are as follows: [8]

(i) Royalty licensing: $\tau^R = \frac{a-2t-c}{5}$ where $0 \le t < \frac{a-c}{2}$,

(ii) Two-part licensing: $\tau^T \approx \frac{a-c}{5}$ where $0 \le t < \frac{3(a-c)}{5}$,

(iii) Fixed-fee licensing: $\tau_1^F = \frac{3(a-c)-4t}{9}$ where $0 \le t < \frac{3(a-c)}{10}$,

$$\tau_2^F = \frac{a-c}{5} \text{ where } \frac{3(a-c)}{10} \le t < \frac{3(a-c)}{5}, \text{ and}$$

$$\tau_M = \tau_3^F = 2t + c - a \text{ where } \frac{3(a-c)}{5} \le t < (a-c).$$

In Fig. 2, optimal tariff schedules are also shown by the bold line τ^S where $S \equiv R, F, T$ (R: Royalty licensing, F: Fixed-fee Licensing, and T: Two-part licensing). First, under royalty licensing, when emissions tax increases, the royalty increases and the outflow of profits to foreign firm increases; thus, the domestic welfare decreases. The optimal tariffs must be levied as much as possible to offset. Therefore, the optimal tariff under royalty licensing has a negative relationship with the environmental tax. Second, under two-part licensing, the increase in emissions tax reduces royalty and increases the fee in proportion to the decrease in royalty. Thus, for increasing domestic welfare, the optimal tariffs should be closely imposed to τ^T. Finally, under fixed-fee licensing, as the increase in emissions tax, the optimal tariff first falls, then is constant, and finally increases. In the areas where tariffs are relatively low, raising the environmental tax will increase the cost burden on a domestic firm and raising the tariff will also increase the amount of adjustments to be paid. Thus, it is necessary to gradually reduce the tariff.

Lemma 2. $W^{F*} > W^{T*} > W^{R*}$.

[8] Some necessary proofs of lemmas and propositions are provided in the Appendix.

Lemma 2 states that welfare is maximised with optimal tariff under fixed-fee licensing which is higher than either that of royalty or two-part licensing. This confirms a general finding that firm's profit is higher under two-part licensing, while social welfare is greater under fixed-fee licensing. For example, Kabiraj and Kabiraj (2017) demonstrated that the government can impose a tariff under the two-part licensing contracts and induce fixed fee licensing of the foreign licensor to maximise domestic welfare.[9]

Proposition 3. Under the restrictive two-part licensing, the optimal tariff schedules τ^* are as follows:

$$\tau^* = \left\{ \begin{array}{lll} \tau_1^F & if & 0 \le t < \dfrac{3(a-c)}{10} \\ \tau_2^F & if & \dfrac{3(a-c)}{10} \le t < \dfrac{3(a-c)}{5} \\ \tau_M & if & \dfrac{3(a-c)}{5} \le t < (a-c) \end{array} \right\}$$

Proposition 3 implies that the optimal tariffs should induce fixed fee licensing to obtain maximised overall welfare. In Fig 2., the overall optimal tariff is indicated with the thick line. With increase in emissions tax, the optimal tariff first reduces, then is constant, and finally increases. There is a trade-off between reducing damaging effect and rent-leaking effect. Thus, if the government plans to make a tighter emissions tax policy, then it should lower the tariff to obtain maximizing welfare. Thus, when both environmental taxes and tariffs are employed, these two policies may be strategic substitutes. This implies that the strategic policy relationship between trade policy and environmental policy could be negative. This is contrary to the positive traditional policy relationship between the environmental tax and tariff under imperfect competition because there exists a trade-off between environmental damage and allocative inefficiency.[10] However, if the eco-technology innovation is involved, the policy relationship may be reversed. This is contrary to the traditional relationship where increasing tariff increases a domestic firm's profits and decreases a foreign firm's profits. However, with the licensing strategy by a foreign innovator, the domestic firm pays more fees to the foreign

[9] Mukherjee and Tsai (2013) also indicated that both firms and society may prefer two-part tariff licensing contract under costly technology transfer when the quality of licensed technology is endogenously chosen.
[10] For example, see Chao et al. (2012) and Tsai and Chang (2015).

firm with increasing fee, which can be induced by either increasing emissions tax or tariff. (Note that $\frac{\partial f^*}{\partial t} > 0$ and $\frac{\partial f^*}{\partial \tau} \gtrless 0$ if $\tau \gtrless \frac{a-c-2t}{35}$). Therefore, if the government wants to protect domestic industry by increasing tariffs, it can be achieved by inducing lower output and higher price, rather than decreasing welfare.

6. Non-restrictive two-part licensing case

Until now, we have analysed two-part licensing strategies with non-negative royalty and fixed fee. However, it is possible for the patentee to consider a negative royalty or a negative fixed fee under the two-part licensing.[11] In this section, we consider a two-part licensing contract without a non-negative constraint on r and f .

Then, from same profit maximisation problems for the foreign eco-innovated firm, we have the same optimal royalty as (11):

$$r^{**} = r^* = \frac{a-c-5\tau}{2} \tag{11}$$

where the superscript ** denotes the optimal decision of the foreign innovator under the non-restrictive two-part licensing. Note that $r^{**} = r^*$ is decreasing in τ, but it can be positive or negative, that is, $r \gtrless 0$ if $\tau \gtrless \frac{(a-c)}{5}$. Then, we also have the same optimal fixed-fee $f^{**} = f^*$ in (12), which can even be negative. Thus, we have the same with τ^R and τ^F in (13).

Then, without non-negative constraints on royalty and fee, the following proposition then defines the optimal licensing contracts.

Proposition 4. Without non-negative constraints on royalty and fixed fee, the optimal two-part licensing contract is as follows:

(a) $r^{**} = t$, $f^{**} = 0$ if $\tau = \tau^R$,

(b) $r^{**} = 0$, $f(0) = \frac{4t\{6(a-c)-5t\}}{45}$ if $\tau = \tau^F$,

[11] Liao and Sen (2005) and Hattori and Tanaka (2018) introduced subsidy in licensing with combinations of upfront fee and negative royalty and determined that a subsidised royalty can be an equilibrium strategy of the inside innovator.

(c) $r^{**} = \dfrac{a-c-5\tau}{2} > 0$, $f(r^{**}) = \dfrac{(5\tau - a + 2t + c)(a - 2t - c + 7\tau)}{9} < 0$ if $\tau < \tau^R$,

(d) $r^{**} = \dfrac{a-c-5\tau}{2} < 0$, $f(r^{**}) = \dfrac{(5\tau - a + 2t + c)(a - 2t - c + 7\tau)}{9} > 0$ if $\tau > \tau^F$,

(e) $r^{**} = \dfrac{a-c-5\tau}{2} > 0$, $f(r^{**}) = \dfrac{(5\tau - a + 2t + c)(a - 2t - c + 7\tau)}{9} > 0$ if $\tau^R < \tau < \tau^F$.

The relationships of the findings, where τ^R and τ^F are the boundaries of duopolistic competition, are illustrated in Fig. 3. It provides the optimal contracts that are described by R (royalty) or T (two-part), or F (fixed-fee). We can have either (i) royalty only (case A) or (ii) fixed fee only (case B). Further, we also have either (i) two-part licensing with negative royalty (case D) or (ii) two-part licensing with negative fixed fee (case C). Otherwise, two-part licensing contracts have positive royalty and fixed fee (case E).

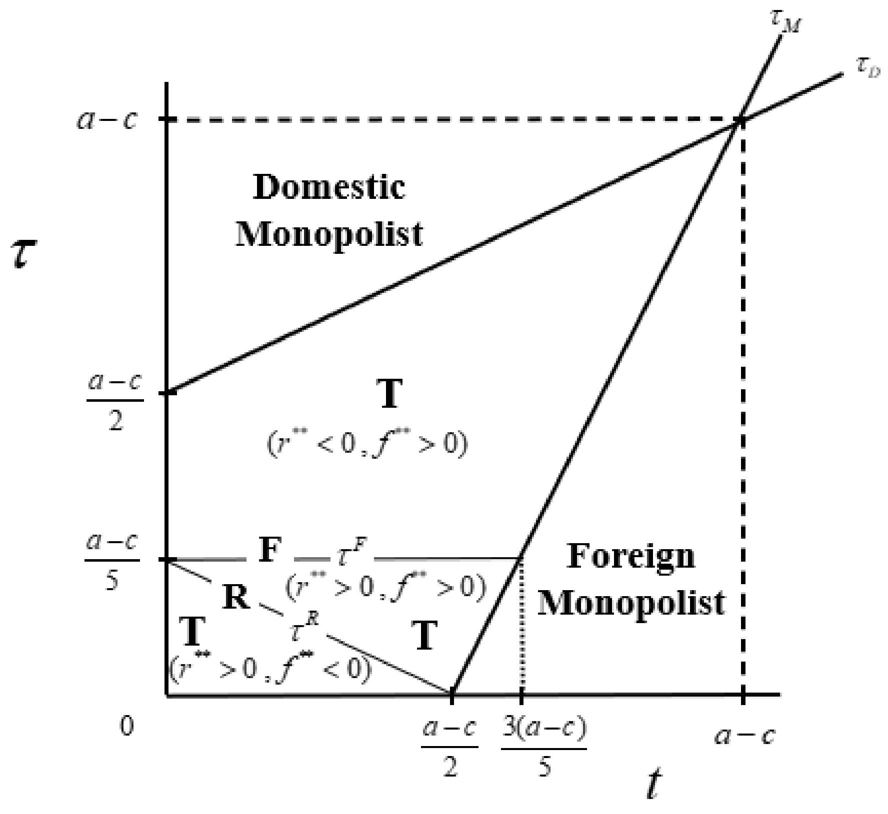

Fig. 3. Optimal licensing strategies of foreign firms without restrictions

This proposition implies that optimal licensing strategies depend on levels of tariff and emissions tax. In particular, if the tariff is moderate between $\tau^R < \tau < \tau^F$, the two-part licensing contract with positive royalty and fixed fee is optimal. Otherwise, non-negative constraints are essential to construct two-part licensing contracts.

On the one hand, if tariff and emissions tax are low, that is, $\tau < \tau^R$, the optimal royalty is always positive while the optimal fixed fee will be negative. Note that if we impose a non-negative constraint of fixed fee, only royalty is an optimal contract, that is, $r^* > 0$ and $f^* = 0$. In such a case that the government policy is soft to both firms, their competition becomes a typical licensing model of internal innovation between the firms with asymmetric cost.[12] However, if the non-negative fixed fee is available, a lower tariff raises the royalty and reduces the fixed fee to a negative value. This is because the foreign firm can induce the domestic firm to take a contract by providing a negative fixed fee (subscription subsidy) and then impose royalty to have relative cost advantage, which will return its loss from the subsidy to its ex-post profit.

On the other hand, if the tariff is high, that is, $\tau > \tau^F$, the optimal fixed fee is always positive while the optimal royalty will be negative.[13] Thus, if the tariff makes it hard for the foreign firm to enter the domestic market, a higher tariff raises fixed fee and reduces royalty to a negative value. This is because the foreign firm can induce the domestic firm to take a contract by providing a negative royalty (usage subsidy), which causes its rival to have cost advantage and increase outputs but impose a higher fixed fee to retrieve the increased profit of the domestic firm into its profit. This result is in contrast to the results of Kabiraj and Kabiraj (2017) and Yang et al. (2020), who imposed a non-negative royalty and demonstrated that fixed-fee licensing could dominate two-part licensing when import tariff rate is high.

[12] In a standard patent licensing with internal innovation, it is shown that royalty licensing is preferred to fixed-fee licensing in a Cournot duopoly with a homogeneous good (Wang, 1998), a differentiated Bertrand duopoly (Wang and Yang, 1999), incumbent innovators in a homogeneous Cournot oligopoly (Kamien and Tauman, 2002), and a leadership structure (Kabiraj, 2005).

[13] Note that if we impose a non-negative constraint of royalty, only fixed fee is an optimal contract, that is, $r^* = 0$ and $f^* > 0$.

Note that a foreign innovator has incentive to sell a license to a domestic firm through non-restrictive two-part licensing, that is, we have $\pi_f^T - \pi_f^N = \dfrac{(a-c-5\tau)^2 + 4t\,[2(a-c)-5t+8\tau]}{36} > 0$ for any τ and t.[14]

Finally, we examine and compare the welfares between non-licensing and two-part licensing strategies from Eqs. (5) and (19).

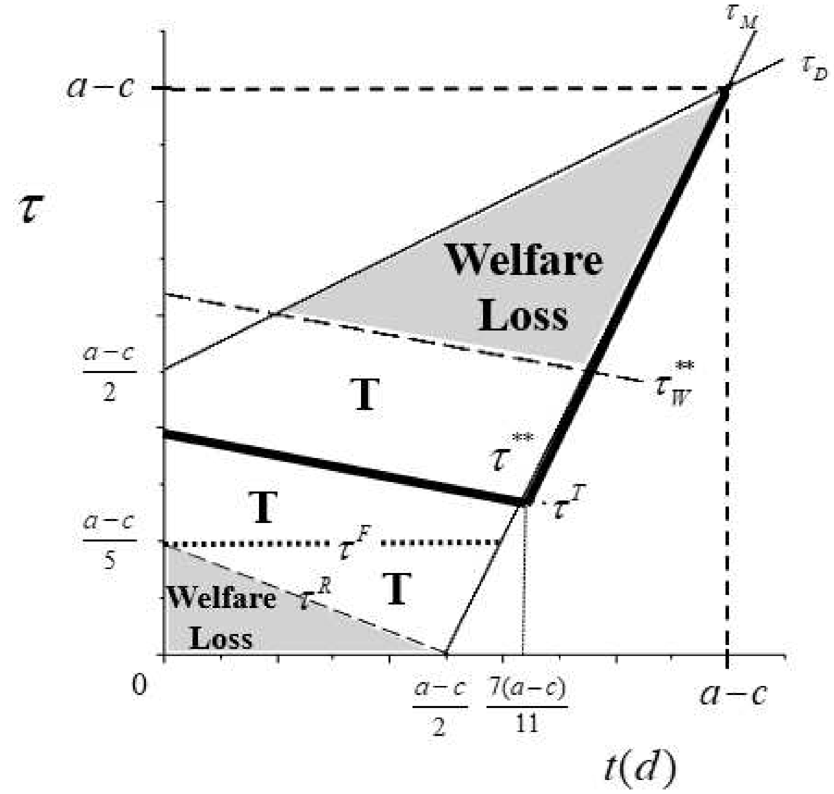

Fig. 4. Welfare losses and optimal tariff with non-restriction

Proposition 5. Suppose that $t = d$. Then, (i) $W^T < W^N$ if either $\tau > \tau_W^{**}$ or $\tau < \tau^R$, (ii) $W^T \geq W^N$ if $\tau^R \leq \tau \leq \tau_W^{**}$ where $\tau^R = \dfrac{a-2t-c}{5}$ and $\tau_W^{**} = \dfrac{7(a-c)-2t}{11}$ satisfies $W^T = W^N$.

[14] Note also that the profit of domestic firm is the same under no licensing, that is, $\pi_d^N = \pi_d^T$, but the domestic firm will accept the offered license by a foreign firm.

This proposition states that two-part licensing may improve the welfare if the tariff is sufficiently high, but yield welfare loss otherwise. That is, if the tariff is either very high or low, the welfare-improving effect (from the elimination of emissions) under the licensing will be outweighed by the welfare-distorting effect (from rent-leakage effect to the foreign firm). Fig. 4 shows that the optimal choices may not be socially desirable with response to tariff and emissions tax under the two-part licensing. That is, welfare losses exist in the shaded areas in Fig. 4, in which non-licensing can induce higher welfare.

Finally, we consider that the government determines the optimal tariff. Then, from the first-order condition of (19), we have $\frac{\partial W^T}{\partial \tau} = \frac{35(a-c)-16t-91\tau}{36}$ =0. Then, we can obtain the optimal tariff schedule τ^T as follows:

$$\tau^T = \frac{35(a-c)-16t}{91} \tag{22}$$

Proposition 6. Under the non-restrictive two-part licensing, the optimal tariff schedules by τ^{**} are as follows:

$$\tau^{**} = \begin{Bmatrix} \tau^T & if \ \ 0 \le t < \frac{7(a-c)}{11} \\ \tau_M & if \ \ t \ge \frac{7(a-c)}{11} \end{Bmatrix}$$

Fig. 4 also shows the comparisons between τ^{**} and τ_W^{**}. First, it shows that $\tau^F < \tau^{**} < \tau_W^{**}$ for any t. This implies that when the government imposes the optimal tariff, the foreign firm implements the two-part licensing contract with a negative royalty and a positive fixed fee, which always improves the domestic welfare, compared to no licensing. Second, it is shown that τ^{**} decreases as the emissions tax increases, that is, $\frac{\partial \tau_T}{\partial t} < 0$. This also implies that the strategic policy relationship between trade policy and environmental policy could be negative. This is because the eco-technology innovation can induce the government to replace emissions tax with tariff policy. For example, if the environmental damage is serious and thus the emissions tax rate is high, it is desirable to eliminate the welfare loss from the pollutants. In that case, the optimal tariff should be low to induce the eco-foreign firm to enter the domestic market with cost advantage when eco-technology licensing contract is forthcoming. However, if the environmental damage is not serious and thus the emissions tax rate is low, it is desirable to make domestic firm at a cost advantage. In that case, the rent leakage effect is more serious than the pollution effect, and thus, the optimal tariff should be higher when eco-technology licensing contract is forthcoming.

7. Comparisons

In this section, we compare the results of between restrictive and non-restrictive two-part licensing contracts. First, we examine whether the foreign innovated competitor has a strategic incentive to choose either a negative royalty or a negative fixed fee under two-part licensing. Then, we compare the profit functions of two cases from Eqs. (14) to (16), then, we obtain $\pi_f^T(r^{**}, f^{**}) - \pi_f^F(r^*, f^*) = \frac{(a-c-5\tau)^2}{36} > 0$ and $\pi_f^T(r^{**}, f^{**}) - \pi_f^R(r^*, f^*) = \frac{(a-c-2t-5\tau)^2}{36} > 0$ for any τ and t. This implies that a foreign competitor prefers non-restrictive two-part licensing to the restrictive licensing contract.

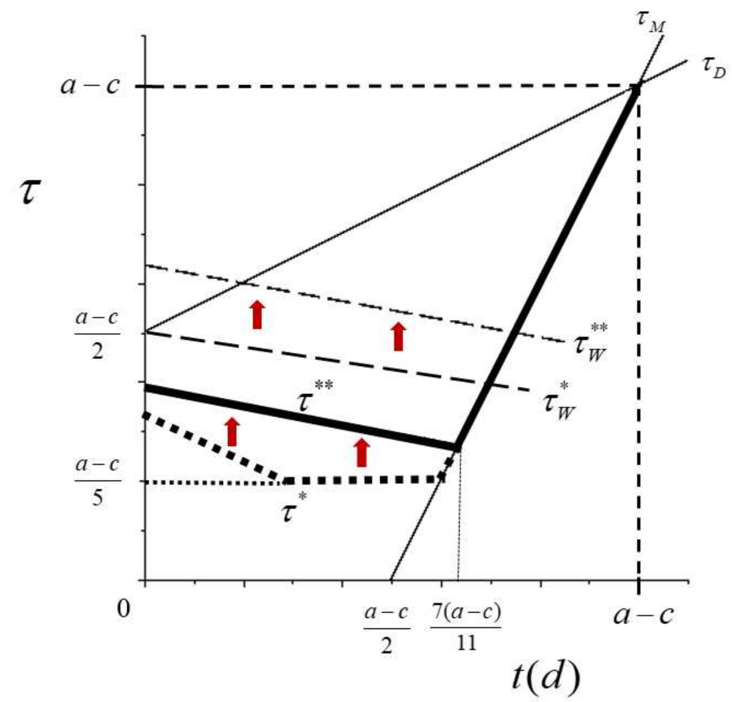

Fig. 5. Optimal tariffs between restrictive and non-restrictive two-part licensing

Second, from Propositions 2 and 5, we have that $\tau_w^{**} - \tau_w^{*} = \frac{3(a-c)+7t}{22} > 0$ for all t. This implies that the government can raise tariffs under the non-restrictive two-part licensing compared to the restrictive licensing contract. Fig. 5 compares the overall optimal tariffs between restrictive and non-restrictive two-part licensing contracts.

Finally, comparing the welfare between the two cases yields the following:

***Proposition** 7*. The foreign competitor prefers non-restrictive licensing to restrictive licensing, which increases not only the optimal tariff level but the resulting social welfare, compared to the restrictive licensing.

This proposition implies that when the optimal tariff is imposed, welfare is higher under non-restrictive than under restrictive licensing. That is, if the government expects that the foreign licensor can impose a negative royalty (subsidy), it should impose higher tariffs to improve social welfare. This is because under the non-restrictive two-part licensing, the foreign eco-innovator sets a negative royalty to subsidise the domestic firm, which pays neither emissions tax nor tariff; thus, it can escape the protection by a tariff but return back the losses by imposing a higher positive fixed fee. Hence, it is possible to obtain more profits by first subsidising and then taking them back as fixed rather than taking them all with only the fixed fee. Consequently, the increases in a negative royalty (subsidy) induce an increase in the fixed fee, which also increases the rent-extraction effect to the foreign competitor. Therefore, the optimal tariff rate should be increased under non-restrictive two-part licensing. However, by giving subsidies via a negative royalty in the domestic market, it is possible to produce more and decrease market price. Thus, the government can increase welfare by imposing a higher tariff under the subsidy. Therefore, a Pareto-improving outcome exists under the non-restrictive two-part licensing contract.[15]

---

[15] Without considering the optimal tariff schedules, we can also see that the non-restrictive two-part licensing contract can lessen the welfare loss when $\tau_w^{*} < \tau_w^{**}$, while it can increase welfare loss when $\tau < \tau^R$. This implies that without considering the optimal tariff, the range of welfare losses can be reduced in the absence of restriction of two-part licensing. However, if tariffs and environmental taxes are very low, it may cause welfare losses under the non-restrictive case. This means that royalty licensing of restrictive two-part licensing is better for the society than two-part licensing with non-restrictive licensing contract.

8. Conclusion

We examined the two-part licensing contracts of eco-technology by a foreign innovator that competes with a polluting domestic firm in a home country and investigated the government's optimal tariffs facing with an emissions tax. We compared the two-part licensing contracts with and without restrictive constraints and showed that the foreign eco-innovator will choose the non-restrictive two-part licensing contracts with a negative royalty or a fixed fee, depending on the levels of emissions tax and tariff. We also revealed that for domestic welfare, the non-restrictive two-part licensing contract is better than the restrictive two-part licensing contract. Therefore, when tariffs are committed before the firms have made their licensing agreements, allowing non-restrictive licensing contracts is welfare-improving under the emissions taxes. Finally, we showed that the optimal tariff policy under the non-restrictive licensing contract is higher than that under the restrictive one and that both contracts have negative relationships with emissions taxes.

In future research, the possible extensions will be to analyse trade policy and emission regulation with the leader–follower model and the asymmetric cost model in the international oligopolistic competition.

References

Anand, B.N. & Khanna, T. (2000). The structure of licensing contracts. *Journal of Industrial Economics*, *48*, 103-135.

Bagchi, A., & Mukherjee, A. (2010). Licensing and patent protection. *Economics Bulletin*, *30* (3), 2010-2016.

Bousquet, A., Cremer, H., Ivaldi, M., & Wolkovicz, M. (1998). Risk sharing in licensing. *International Journal of Industrial Organization*, *16*, 534-554.

Burtraw, D., & McCormack, K. (2017). Consignment auctions of free emissions allowances. *Energy Policy*, *107*, 337–344.

Chao, C-C., Laffargue, J-P. & Sgro, P. M. (2012). Tariff and environmental policies with product standards. *Canadian Journal of Economics*, *45*, 978-995.

Copeland, B. R., (1994) International trade and the environment: policy reform in a polluted small open economy. *Journal of Environmental Economics and Management*, *26*, 44-65.

Erutku, C., & Richelle, Y. (2007). Optimal licensing contracts and the value of a patent. *Journal of Economics and Management Strategy*, *16,* 407-436.

Fauli-Oller, R., & Sandonis, J. (2002). Welfare reducing licensing. *Games and Economic Behavior*, *41*, 192-205.

Fauli-Oller, R., Gonzalez, X., & Sandonis, J. (2012). Optimal two-part tariff licensing contracts with differentiated goods and endogenous R&D. *Manchester School*, *81,* 803-827.

Hattori. M. & Tanaka Y. (2018). License and entry strategies for an outside innovator under duopoly with combination of royalty and fixed-fee. *Journal of Industry, Competition and Trade*, *18*, 485-502.

Hatzipanayotou, P., Michael S., & Miller, S. M. (1994). Win-win indirect tax reform. *Economics Letters*, *44*, 147-51.

Hernandez-Murillo, R., & Llobet, G. (2006). Patent licensing revisited: Heterogeneous firms and product differentiation. *International Journal of Industrial Organization*, *24,* 149-175.

Garcia, A., Leal, M., & Lee, S. H. (2018). Time-inconsistent environmental policies with a consumer-friendly firm: tradable permits versus emission tax. *International Review of Economics & Finance*, *58*, 523-537.

Gulati, S. & Roy D. (2008). National treatment and the optimal regulation of environmental externalities. *Canadian Journal of Economics*, *41*, 1445-71.

Kabiraj, A., & Kabiraj, T. (2017). Tariff induced licensing contracts, consumers, surplus and welfare. *Economic modelling*, 60, 439-447.

Kabiraj, T., & Marjit, S. (2003). Protecting consumers through protection: The role of tariff-induced technology transfer. *European Economic Review*, *47*, 113-124.

Kabiraj, T. (2005). Technology transfer in Stackelberg structure: licensing contracts and welfare. *Manchester School*, *73*, 1-28.

Kamien, M., & Tauman, Y. (1984). The private value of a patent: A game theoretic analysis. *Journal of Economics*, *4,* 93-118.

Kamien, M., Oren, S., Tauman, Y. (1992). Optimal licensing of cost-reducing innovation. *Journal of Mathematical Economics*, *21,* 483-508.

Kamien, M. and Y. Tauman (2002). Patent licensing: the inside story. *Manchester School*, *70*, 7–15.

Katz, M., & Shapiro, C. (1985). On the licensing of innovations. *RAND Journal of Economics*, *16,* 504-520.

Katz, M., & Shapiro, C. (1986). How to license intangible property. *Quarterly Journal of Economics, 101,* 567-590.

Kim, S. L., & Lee, S. H. (2014). Eco-technology licensing under emission tax: royalty vs. fixed-fee. *Korean Economic Review, 30,* 273-300.

Kim, S. L., & Lee, S. H. (2016a). Environmental policy on the fixed-fee licensing of eco-technology under foreign penetration. *Economics Bulletin, 36*, 1364-1370.

Kim, S. L., & Lee, S. H. (2016b). The licensing of eco-technology under emission taxation: Fixed-fee vs. auction. *International Review of Economics & Finance, 45*, 343-357.

Kim, S. L., & Lee, S. H. (2018). Eco-technology licensing by a foreign innovator and privatization policy in a polluting mixed duopoly. *Asia-Pacific Journal of Accounting and Economics, 25*, 433-448.

Lee, S.H. (1999). Optimal taxation for polluting oligopolists with endogenous market structure. *Journal of Regulatory Economics*, *15*, 293-308.

Lee, S. H., & Park, C. H. (2021). Environmental Regulations in Private and Mixed Duopolies: Taxes on Emissions versus Green R&D Subsidies. *Economic Systems*, *45*(1), 100852.

Liao, C. H., & Sen, Debapriay (2005). Subsidy in licensing: optimal and welfare implications. *Manchester School*, *73*, 281-299.

Li, Y., & Yanagawa, T. (2011). Patent licensing of Stackelberg manufacturer in a differentiated product market. *International Journal of Economic Theory*, *7,* 7-20.

Martin, M., & Saracho, A. I. (2015). Optimal two-part tariff licensing mechanisms. *Manchester School*, *83,* 288-306.

Mukherjee, A. (2007). Optimal licensing contract in an open economy. *Economics Bulletin*, *12,* 1-6.

Mukherjee, A., & Balasubramanian, N. (2001). Technology transfer in a horizontally differentiated product market. *Research in Economics*, *55,* 257-274.

Mukherjee, A., & Tsai, Y. (2013). Technology licensing with strategic tax policy. *Journal of Economics*, *108,* 231-247.

Mukherjee, A., & Pennings, E. (2006). Tariffs, licensing and market structure. *European Economic Review*, *50*, 1699-1707.

Muto, S. (1993). On licensing policies in Bertrand competition. *Games and Economic behavior*, *5,* 257-267.

Poddar, S., & Sinha, U. B. (2004). On patent licensing and spatial competition. *Economic Record*, *80,* 208-218.

Rostoker, M. (1984). A survey of corporate licensing. *IDEA: The Journal of Law and Technology*, *24,* 59-92.

Saracho, A.I. (2011). Licensing information goods. *International Journal of Industrial Organization*, *29,* 187-199.

Sen, D., & Tauman, Y. (2007). General licensing schemes for a cost-reducing innovation. *Games and Economic Behavior*, *59,* 163-186.

Stamatopoulos, G., & Tauman, T. (2009). On the superiority of fixed fee over auction in asymmetric markets. *Games and Economic Behavior*, *67,* 331.333.

Tsai, T. H., & Chang, Y. M. (2015). Tariffs and Environmental Taxes in the Presence of Environmental R&D, *Environmental and Resource Economics*, *60*, 413–431.

Vishwasrao, S. (2007). Royalty vs. fees: How do firms pay for foreign technology? *International Journal of Industrial Organization*, *25,* 741-759.

Wang, L. F. S., Wang, Y. C., & Zhao, L. (2012). Tariff policy and welfare in an international duopoly with consumer-friendly initiative. *Bulletin of Economic Research*, *64*, 56-64.

Wang, X.H. (1998). Fee versus royalty licensing in a Cournot duopoly model. *Economic Letters*, *60*, 55-62.

Wang, X.H. (2002). Fee versus royalty licensing in a differentiated Cournot duopoly. *Journal of Economics and Business*, *54*, 253-266.

Wang, X.H. and B. Yang (1999). On licensing under Bertrand competition. *Australian Economic Papers*, *38*, 106-119.

Yang, L., Yan, Q., Balezentis, T., Li, M. (2020). Licensing strategy and tariff policy in an international trade model with foreign Stackelberg leadership. *Transformations in Business & Economics*, *19*, 284-305.

Zuniga, M. P., & Guellec, D. (2009). Who licenses out patents and why? Lessons from a business survey. *STI working paper,* OECD.

Appendix

Proof of Lemma 1.

The optimal tariff schedules are derived as follows:

(i) Given t, $\frac{\partial W^R}{\partial \tau} = \frac{a-c-3\tau}{3}$ and then we have $\tau = \frac{a-c}{3} > \tau_R$. Thus, the optimal tariff schedule of royalty licensing is $\tau_R^* = \frac{a-2t-c}{5}$ for $0 \le t < \frac{a-c}{2}$.

(ii) Given t, $\frac{\partial W^T}{\partial \tau} = \frac{35(a-c)-16t-91\tau}{36}$ and then we have $\tau = \frac{35(a-c)-16t}{91} > \tau_T = \frac{a-c}{5}$ for all t. Thus, the optimal tariff of two-part tariff licensing is close to $\tau_T = \frac{a-c}{5}$ for $0 \le t < \frac{3(a-c)}{5}$ where $t = \frac{3(a-c)}{50}$ which satisfies $\tau^T = \tau_M$.

(iii) Given t, $\frac{\partial W^F}{\partial \tau} = \frac{3(a-c)-4t-9\tau}{9}$ and then we have $\tau = \frac{3(a-c)-4t}{9} > 0$ which is decreasing in t. Thus, the optimal tariff schedules of fixed-fee licensing are

(a) $\tau_1^F = \frac{3(a-c)-4t}{9}$ for $0 \le t < \frac{3(a-c)}{10}$ where $t = \frac{3(a-c)}{10}$ which satisfies $\tau^T = \tau_1^F$,

(b) $\tau_2^F = \frac{a-c}{5}$ for $\frac{3(a-c)}{10} \le t < \frac{3(a-c)}{5}$ where $t = \frac{3(a-c)}{5}$ which satisfies $\tau^T = \tau_M$,

(c) $\tau_M = \tau_3^F = 2t+c-a$ for $\frac{3(a-c)}{5} \le t < a-c$.■

Proof of Lemma 2.

From the optimal tariff schedules of proposition 6, we can derive the following welfares:

$$W^{R*} \equiv W^R(\tau_R) = \frac{19(a-c)^2}{50} + t\left(\frac{21}{50}t - \frac{18(a-c)}{25}\right) \tag{A1}$$

$$W^{T*} \equiv W^T(\tau_T) = \frac{19(a-c)^2}{50} + \left(\frac{4}{9}t - \frac{8(a-c)}{15}\right) \tag{A2}$$

$$W^{F*} \equiv W^F(\tau_1^F) = \frac{7(a-c)^2}{18} + t\left(\frac{44}{81}t - \frac{16(a-c)}{27}\right) \tag{A3}$$

We have $W^{T*} - W^{R*} = \frac{t}{450}\left(84(a-c)+11t\right) > 0$ from (A1) and (A2), and $W^{F*} - W^{T*} = \frac{2(3a-3c-10t)^2}{2025} > 0$ from (A3) and (A2). Thus, $W^{F*} > W^{T*} > W^{R*}$.■

Proof of Proposition 3.

From lemma 1 and 2, we have the overall optimal tariffs which are (i) τ_1^F if $0 \le t < \frac{3(a-c)}{10}$ since $W^{F*} > W^{T*} > W^{R*}$, (ii) τ_2^F if $\frac{3(a-c)}{10} \le t < \frac{3(a-c)}{5}$ since $W^{F*} = W^{T*} > W^{R*}$, and (iii) τ_M if $t \ge \frac{3(a-c)}{5}$ since $W^{F*} > W_F^M$ where $W_F^M = \frac{3}{8}(a-c-\tau)^2$ represents the welfare of foreign monopoly.■

Proof of Proposition 7.

We get that

(i) $W^T(\tau^{**}) - W^F(\tau^* = \tau_1^F) = \frac{4(a-c)^2}{117} - \frac{8t[21(a-c)+55t]}{7371} > 0$ for $0 \le t < \frac{3(a-c)}{10}$,

(ii) $W^T(\tau^{**}) - W^F(\tau^* = \tau_2^F) = \frac{2[21(a-c)-20t]^2}{20475} > 0$ for $\frac{3(a-c)}{10} \le t < \frac{3(a-c)}{5}$, and

(iii) $W^T(\tau^{**}) - W^F(\tau^* = \tau_3^F) = \frac{12(a-c)^2}{13} - \frac{2t[1344(a-c)+1199t]}{819} > 0$ for $0 \le t < a-c$.■