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Environmental Technology Licensing Under Emission-Equivalent Environmental Taxes and Standards

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Abstract: We use a two-stage game with an outsider patentee and n homogeneous firms to study the effects of environmental taxes and standards under an equivalent emission on environmental technology licensing behavior. Counter to the intuition, a stricter environmental policy hinders technology licensing since a stricter environmental regulation weakens the licensee's payment ability. When the innovation size is small, there exists a preference inconsistency on the environmental instrument between the government and the patentee. The patent owner has a higher incentive to license under an environmental standard than under an emission tax with an equivalent emission amount.

Keywords: Environment instrument, licensed proportion, preference inconsistency.

INTRODUCTION

Environmental policy and environmental technology licensing are useful ways for reducing environmental pollution, whereby the government applies the environmental policy and the firm uses environmental technology to protect the earth. In facing the international environmental problems such as global warming, the transfer of superior environmental technologies to less-advanced firms has been considered an effective environmental regime. By the transfer of clean technologies, the environment and welfare may improve in the country through the decreases in pollution. Actually, we look forward to seeing that the transfers of environmental technologies can lead to Pareto-improving outcomes. In order to enhance environmental technology transfer, some large laboratories, such as Los Alamos National Laboratory, some multi-national corporations, such as Dow Chemical, and some universities also publish information about environmental technology licensing in order to inform firms and let them realize environmental technologies [1-3]. It is a trend globally for governments to encourage environmental technology licensing and to adopt an environmental policy to reduce pollutants. This paper performs an investigation on the influence of environment instruments on environmental technology licensing.

The automotive industry has many cases of technology licensing and environmental standards. For example, in Europe, the average fuel economy is regulated at 45 miles per gallon (mpg). A target in 2012 is over 50mpg and the CO2 average emission standard is 130 grams per kilometer. However, China's average fuel economy is 35mpg [4]. Under the structure of the Kyoto Protocol with a CO2 emission standard, China may need technology licensing for its automotive industry. We are interested in this question: is an environmental standard more helpful to the technology transfer than an emission tax?

An emission tax and environmental standard, generally speaking, are two main instruments to use for protecting the environment. The literature about comparing various environmental instruments in different market structures is vast. The classic paper comparing environmental instruments shows quantity control may have a higher social welfare than price control in the presence of uncertainty [5]. Helfand [6] defines an environmental standard as the ratio of total emission to total output. According to this definition, Helfand [6] presents that a tightening environmental standard may increase pollution, because firms obey a stricter environmental standard by increasing output rather by decreasing emission. Thus, Helfand [6] thinks an emission tax may be emission-superior to an environmental standard.

Ulph [7, 8] compares an emission tax and an environmental standard when two firms and two governments have strategic interactions. Ulph [7] finds an environmental standard is Pareto-superior to an emission tax, but there is not an obvious result in a more general setting [8]. Spulber [9] shows that an emission tax is more efficient than an environmental standard in the case where by firms can free entry and exit. Lahiri and Ono [10] compare the effects of an emission tax and an environmental standard on social welfare and pollution level. Lahiri and Ono [10] find that there is better social welfare with an environmental standard than that by an emission tax in the case where the number of firms is fixed. At the same case, there is a better pollution level with an environment tax than that by an environmental standard. However, for the case when firms can free entry and exit and the demand function is concave, the results are just the opposite.

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Aside from an abundant amount of literature that focuses on comparing with different environmental instruments, there is also a large body of literature to discuss one kind of environmental instrument in various model settings. Ebert [11] examines the effect of pollution abatement technology on the optimal tax rate under different oligopoly models. Ebert [12] analyzes the effect of an environmental standard in a Cournot oligopoly model with symmetric firms. Katsoulacos and Xepapadeas [13] offer the effect of an emission tax in the presence and absent of free entry and exit. Katsoulacos and Xepapadeas [13] find that the optimal emission tax causes pollution externality to over-internalize under the case of free entry and exit. However, the result of over-internalization may not occur when the case of free entry and exit is absent. Kayalica and Lahiri [14] analyze a government's environmental policy on an environmental standard in the case of foreign direct investment. Kayalica and Lahiri [14] show that a host country employs a stricter environmental standard than the other country in the case when the number of foreign direct investment firms is fixed. However, when the foreign direct investment firms can free entry and exit, a host country may employ a less strict environmental standard.

Many countries with rapid economic growth need to acquire new technologies by licensing, in order to improve their production processes, and need to enact an environmental policy to abate pollution levels. Since these papers above only compare two environmental instruments, but do not consider technical licenses, they cannot provide a complete suggestion of environmental policy to a country with rapid economic growth such as China. This paper combines the issues of environmental policy and technology licensing and compares the effects of an emission tax and an environmental standard on social welfare, pollution level, producer surplus, and licensed proportion.

This paper is organized as follows. Following this introduction, Section 2 is the basic model. Section 3 solves the model by backward induction to obtain the Nash equilibria under an emission tax and an environmental standard with the equivalent emission. Section 4 compares the effects of an emission tax and an environmental standard with the equivalent emission. Section 5 concludes this paper.

THE MODEL-SETUP

There are n homogeneous firms exporting products to the foreign country. The patent owner is characterized as an environmental technology innovator and an outsider patentee. There is a two-stage game with n firms and an outsider patentee. In stage 0, the government chooses the environmental instrument as either an emission tax or an environmental standard. In stage 1, the innovator adopts the fixed-fee licensing method to choose the licensed proportion $\phi \in [0, 1]$, i.e., the proportion of firms that a patentee sells the license to.[1] Hence, there are $n\phi$ firms using a new technology and $(n - \phi)$ firms using an old technology. In stage 2, n firms play a Cournot competition. The sub-game perfect Nash equilibrium of this two-stage game is obtained by backward induction.

[1]Kamien and Tauman [15] show that the outsider patentee always prefers the fixed fee licensing contract.

Each firm's per unit emission is $e > 0$ before getting a license. The parameter e is normalized to 1. However, a new environmental technology can reduce per unit emission from 1 to $1-\varepsilon$, where $0 < \varepsilon < 1$. If the patentee decides a licensed proportion is ϕ, then there are $n\phi$ firms with lower per unit emission $1 - \varepsilon$ and $n(1-\phi)$ firms with higher per unit emission 1.

The parameters with a '*' are hereafter those case with the environmental standard, and the parameters without a '*' are those under the emission tax. Consider the case where the government's environment instrument is environmental standard z; that is, the maximum allowance of pollutant per unit of output. Since licensees' per unit emission amount is $1-\varepsilon$, an abatement level of per output for each licensee is $(1-\varepsilon)-z$. Consider the other case where the government's environmental instrument is an emission tax which the government charges tax according to the emission quantities. In the emission tax case, a non-licensee's per unit emission cost is $c_0 = t$ and a licensee's per unit emission cost is $c_1 = t(1-\varepsilon)$. In the environmental standard case, we assume that per unit abatement cost is θ. Thus, a non-licensee's per unit output cost is $c_0^* = \theta(1-z)$ and a licensee's per unit output cost is $c_1^* = \theta(1-\varepsilon-z)$. For simplification, the parameter θ is normalized to 1. We also assume the manner that per unit production cost is normalized to zero.

MODEL SOLUTION

In this section we use backward introduction to solve the sub-game perfect Nash equilibrium in this model. The equilibrium solutions in the emission tax case and in the environmental standard are in sections 3.1 and 3.2, respectively.

The Emission Tax

The given inverse demand function that firms face in the foreign market is $p = 1 - Q$. The parameters p and Q are respectively the price and the total demand quantity in the foreign market. The parameter $Q = n(1-\phi)x_0 + n\phi x_1$, where x_0 and x_1 are the non-licensee's output and licensee's output, respectively. In stage 2 the equilibrium outputs are determined from a Cournot game of $n\phi$ firms with low cost c_1 and $n(1-\phi)$ firms with high cost c_0 as follows:

$$x_0 = \frac{1-(n\varphi+1)t+n\varphi t(1-\varepsilon)}{n+1}, \tag{1a}$$

$$x_1 = \frac{1-[n(1-\varphi)+1]t(1-\varepsilon)+n(1-\varphi)t}{n+1}, \tag{1b}$$

where $x_1 - x_0 = t\varepsilon > 0$.

Arrow [16] maintains that if the magnitude of innovation (ε) is large enough and the licensee cannot get a license from the patent owner, then non-licensees will be kept out of market, i.e., $x_0 = 0$. This case is called a drastic innovation. On the contrary, if the magnitude of innovation is not large enough, then firms without licensing can still survive in the market, i.e., $x_0 > 0$. This is called a non-drastic innovation case. If there are k firms without a new technology that are kicked out of the market, then it is called a k-drastic innovation, where $k < n$. The drastic innovation condition and the non-drastic innovation condition are shown respectively as $\varepsilon > \varepsilon_0$ and $0 < \varepsilon < \varepsilon_0$, where $\varepsilon_0 = (1 - t) / (n\phi t)$.

From the result in stage 2, it is found that:

$$\frac{dx_0}{dt} = \frac{-1 - n\varphi\varepsilon}{n+1} < 0, \tag{2a}$$

$$\frac{dx_0}{d\varphi} = \frac{dx_1}{d\varphi} = \frac{-nt\varepsilon}{n+1} < 0, \tag{2b}$$

$$\frac{dx_1}{dt} = \frac{-1 + \varepsilon[n(1-\varphi)+1]}{n+1} < 0,$$

$$\text{if } 0 < \varepsilon < \varepsilon_1, \tag{2c}$$

where $\varepsilon_1 = 1/[n(1-\phi) + 1]$. It shows that an increase in an emission tax causes the non-licensee's output to decrease. There is an uncertain effect on the licensee's output when an emission tax increases. Since an increasing emission tax causes a rise in the marginal production cost, licensees' outputs decrease. However, a new technology decreases the licensee's marginal production cost, and hence the licensee's output increases. When $0 < \varepsilon < \varepsilon_1$, the effect of the production cost decreasing is smaller than the effect of the production increasing, thus inducing the licensees' outputs to decrease. When a patent owner's licensed proportion increases, the non-licensee's output and licensee's output decrease, because the number of firms with low marginal production cost increases to a decrease in the degree of market competition.

Kamien and Tauman [15] find that if the patent holder is a non-producer, then the fixed-fee licensing method is superior to the royalty licensing method. Since the innovator is a non-producer in this study, we follow the concept of Kamien and Tauman [15] to set the patent owner as using the fixed-fee licensing method. Under this licensing method, the optimal fixed fee will be exactly the difference between the profit after being licensed and the profit without licensing; i.e., $F = \pi_1 - \pi_0 = (x_1)^2 - (x_0)^2$. Since $\pi_1 - F \geq \pi_0$, the licensees accepts the patent owner's licensing contract. Thus, the licensor charging a fixed licensing fee is $F = (x_1)^2 - (x_0)^2$. The patent owner chooses a licensed proportion to maximize its own licensing revenue. The licensing revenue function for the patent owner is $R = n\phi F$. Thus, the optimal licensed proportion in stage 1 is:

$$\phi = \frac{tn\varepsilon + t\varepsilon + 2 - 2t}{4tn\varepsilon} > 0. \tag{3}$$

Differentiating the optimal licensed proportion with respect to t and ε yields:

$$\frac{d\varphi}{dt} = \frac{-1}{2t^2 n\varepsilon} < 0, \tag{4a}$$

$$\frac{d\varphi}{d\varepsilon} = \frac{-2(1-t)}{4tn\varepsilon^2} < 0. \tag{4b}$$

The results of the competitive static analysis show that the licensed proportion and two variables, emission tax and the innovation size, have an inverse relation. This implies that a strict emission tax will hinder a technology transfer. If the innovator size is large, then there exists a low licensed proportion. This means that if the patentee has a large innovation size, then the patentee can increase licensing revenue by decreasing a licensed proportion.

We now formulate the social welfare function under the emission tax case. Since all products are exported to the foreign market, the social welfare function (SW) is composed of producer surplus (PS), pollution tax revenue (T), and environmental damage (D), where $D' > 0$ and $D'' > 0$ [10, 14]. The social welfare function in this case is expressed as $SW = PS + T - D$. Producer surplus is the sum of n firms' profits; i.e., $PS = n(1 - \phi)(x_0)^2 + n\phi(x_1)^2$.[2] The government's pollution tax revenue is $T = tE$, where $E = n(1 - \phi)x_0 + (1 - \varepsilon)n\phi x_1$. The environmental damage is a function of the total emission, i.e., $D = (1/2)E^2$. Hence, we have:

$$\frac{dPS}{dt} = n(x_1^2 - x_0^2)\frac{d\varphi}{dt} + 2n(1-\phi)x_0\frac{dx_0}{dt}$$

$$+2n\phi x_1\frac{dx_1}{dt} < 0, \tag{5a}$$

$$\frac{dE}{dt} = n[(1-\varepsilon)x_1 - x_0]]\frac{d\varphi}{dt} + n\phi(1-\varepsilon)\frac{dx_1}{dt}$$

$$+n(1-\phi)\frac{dx_0}{dt}. \tag{5b}$$

There is a negative relation between the emission tax and producer surplus, showing that a firm's profit will decrease under a strict environmental policy. However, there exists an ambiguous relation between the emission tax and the amount of emission. This result comes from an ambiguous affect on the licensee's output by the emission tax.

The Environmental Standard

Following the same process in Section 3.1, we analyze the effect of the environmental standard on technology licensing. Given the inverse demand function that firms face in the foreign market is $p^* = 1 - Q^*$, the parameters p^* and Q^* are the price and the total demand quantity in the foreign market, where $Q^* = n(1 - \phi^*)x_0^* + n\phi^* x_1^*$. Moreover, x_0^* (x_1^*) and ϕ^* are the outputs of a firm without (with) a license and the licensed proportion. In stage 2, the equilibrium outputs for firms without and with a licensee can be determined as follows, respectively:

$$x_0^* = \frac{1 + n\varphi^*(1 - z - \varepsilon^*) - (n\varphi^* + 1)(1 - z)}{n+1}, \tag{6a}$$

$$x_1^* = \frac{1 - [n(1-\varphi^*)+1](1 - z - \varepsilon^*) + n(1-\varphi^*)(1-z)}{n+1} \tag{6b}$$

where $x_1^* - x_0^* = \varepsilon^* > 0$. Here, we consider the cases of a drastic innovation and a non-drastic innovation, and thus two conditions are respectively $\varepsilon^* > \varepsilon_0^*$ and $0 < \varepsilon^* < \varepsilon_0^*$, where $\varepsilon_0^* = z / (n\phi^*)$. Some comparative static analyses on the equilibrium outputs with respect to the parameters z and ϕ^* are shown as follows:

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[2]The firms in our model include $n\phi$ licensed firms, $n(1 - \phi)$ no-licensed firms, and one outside patent owner. The revenue of outsider patent owner is a fixed licensing fee F which was paid by those $n\phi$ licensed firms. Therefore, the producer surplus in our model is $PS = n(1 - \phi)(x_0)^2 + [n\phi(x_1)^2 - F] + F$ which can be simplified as $PS = n(1 - \phi)(x_0)^2 + n\phi(x_1)^2$.

$$\frac{dx_0^*}{dz} = \frac{dx_1^*}{dz} = \frac{1}{n+1} > 0, \quad (7a)$$

$$\frac{dx_0^*}{d\varphi^*} = \frac{dx_1^*}{d\varphi^*} = \frac{-n\varepsilon^*}{n+1} < 0. \quad (7b)$$

Since the parameter z decreases to induce a firm's cost-up on emission abatement, a low z stands for a strict environmental standard. On the contrary, a high z stands for a not so strict environmental standard. Therefore, we find that both of the licensees' and non-licensees' equilibrium outputs will decrease when the government adopts a strict environmental standard. Moreover, both licensing and no-licensing equilibrium outputs will also decrease when a licensed proportion increases. This shows that the degree of market competition decreases when the number of firm with a new technology increases.

In stage 1, the patent owner chooses the optimal licensed proportion to maximize its licensing revenue. Since the patent owner charging the licensees' maximum fixed fee is $F^* = (x_1^*)^2 - (x_0^*)^2$, the patentee owner's total licensing revenue is $R^* = n\phi^* F^*$. The optimal licensed proportion in stage 1 is:

$$\phi^* = \frac{n\varepsilon + 2z + \varepsilon}{4n\varepsilon}. \quad (8)$$

Comparative static analyses based on the licensed proportion with respect to the environmental standard are:

$$\frac{d\varphi^*}{dz} = \frac{1}{2n\varepsilon} > 0, \quad (9a)$$

$$\frac{d\varphi^*}{d\varepsilon} = \frac{-2z}{4n\varepsilon^2} < 0. \quad (9b)$$

The implication from the results of competitive static analysis is the same as the case of an emission tax: (1) a strict environmental standard hinders technology licensing; (2) the licensed proportion is low when the innovation is large.

Following the framework in Section 3.1, we formulate the social welfare function under the environmental standard case. In this way, the social welfare (SW^*) function is the sum of producer surplus (PS^*), less the environmental damage D. The social welfare function is expressed as $SW^* = PS^* - D$. Producer surplus is the sum of n firms' profits, i.e., $PS^* = n(1 - \phi^*)(x_0^*)^2 + n\phi^* (x_1^*)^2$. The environmental damage is a function of the total emission; i.e., $D(E^*) = (1/2)E^{*2}$, where $E^* = z[n(1 - \phi^*)x_0^* + n\phi^* x_1^*]$. Thus, we find:

$$\frac{dPS^*}{dz} = n[(x_1^*)^2 - (x_0^*)^2]\frac{d\varphi^*}{dz} + 2n(1-\phi^*)x_0^*\frac{dx_0^*}{dz} + 2n\phi^* x_1^*\frac{dx_1^*}{dz} > 0, \quad (10a)$$

$$\frac{dE^*}{dz} = Q^* + z[n(x_1^* - x_0^*)\frac{d\varphi^*}{dz} + n(1-\phi^*)\frac{dx_0^*}{dz} + n\phi^*\frac{dx_1^*}{dz}] > 0. \quad (10b)$$

Both the producer surplus and the amount of emission decrease with a strict environmental standard.

EMISSION-EQUIVALENCE

In this section we study the effects of licensed proportion, social welfare, and licensing incentive under different environment policies.

Environment Instrument and Licensed Proportion

The emission-equivalent is defined as the emission levels of two environment instruments being the same. Here, we discuss the licensing incentive in the case of an emission-equivalent. Let $E = E^*$ and we obtain a relation between z and t:

$$z_E = \frac{1}{4t(2n+1)}\{-t\varepsilon(n+1) + \sqrt{\begin{matrix}[t\varepsilon(n+1)]^2 + 8t^2(3t\varepsilon - 2\varepsilon + 4)(2n^2+3n+1) \\ -6t^3\varepsilon^2(2n^3+5n^2+4n+1) - 8t^3(8n^2+10n+3) - 8t(2n+1)\end{matrix}}\}. \quad (11)$$

Since z_E is an environmental standard, it is reasonable for us to assume that Equation (11) is always positive. Substituting Equation (11) into Equation (8) and deducting Equation (3), we have the licensed proportion difference in two environmental instruments:

$$\phi^* - \phi = \frac{n\varepsilon + 2z_E + \varepsilon}{4n\varepsilon} - \frac{tn\varepsilon + t\varepsilon + 2 - 2t}{4tn\varepsilon}. \quad (12)$$

We can employ a figure to illustrate the implication in Equation (12).[3]

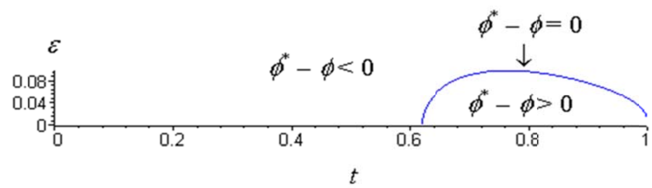

Fig. (1). Environmental Instrument and Licensed Proportion (n = 100).

The combination (t, ε) on the curve in Fig. (**1**) makes the licensed proportion between two kinds of environmental instruments be indifferent. The area below (above) the curve standards for the licensed proportion for the environmental standard is larger (smaller) than the licensed proportion for the emission tax. It implies that the licensed proportion under the case of an emission tax is low (high) when the government charges a high (low) emission tax. The reason is very clear in that a heavy emission tax induces the licensees' revenue to decrease significantly, and the revenue loss cannot be recovered by using a new technology. Thus, a high

[3]In the part of numerical simulation, the reason why we assume a large firm number is to depict a more competitive licensing market. The most of industrial organization studies always assume the market structure to be oligopoly. In order to depict a more competitive licensing market, here we do not restrict the number of firm in the theoretical analysis section and use a large firm's number in the numerical simulation section.

emission tax decreases the licensees' willingness to purchase a new technology. On the contrary, a low emission tax induces a not so significant decrease on the licensees' revenue, and the revenue loss can be recovered by purchasing a new technology. Thus, a low emission tax increases the licensees' willingness to purchase a new technology.

Fig. (**2**) shows the result on the environmental instrument and licensed proportion when the number of licensees is a variable. The area where the licensed proportion in the case of an environmental standard is larger than the licensed proportion in the case of an emission tax will become small when the number of firms becomes greater. This implies that when the number of licensees increases, the licensed proportion under the case of an emission tax is higher than the licensed proportion under the case of an environmental standard given a heavy emission tax and a small innovation size. In other words, the patentee will license new technology to more firms when the government adopts an emission tax under a heavy emission tax, a large innovation size, and an increase on the number of firms. The reason is that the market competition is fierce when the number of firms increases and the government adopts the emission tax as an environment instrument. Firms need a large technology innovation size to recover the revenue loss from an emission tax. Thus, there is a high licensed proportion under the case of the emission tax with a heavy emission tax, a large innovation size, and an increase on the number of firms.

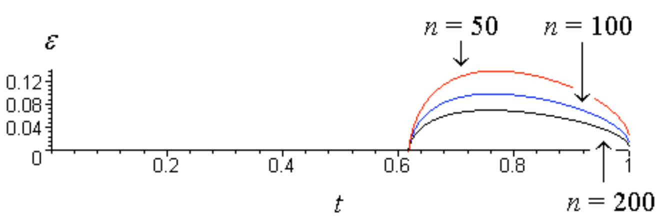

Fig. (2). Environmental Instrument and Licensed Proportion (n = 50, 100, 200).

Environment Instrument and Social Welfare

We employ Equation (11) to find the social welfare for two kinds of environmental instruments under the emission-equivalent case. In Fig. (**3**), we use curves SW =0 and SW^* = 0 to divide the t-ε plane into five regimes. In regimes I and II (III and IV), the social welfare for an environmental standard is always higher (lower) than the social welfare under an emission tax. Due to not having a real number solution in regime V, we use the symbol "NA" to represent we cannot calculate the difference of social welfare in two environmental instruments.

Based on Fig. (**3**), we find that when the innovation size is small, the social welfare in the case of an emission tax is higher than the social welfare in the case of an environmental standard. In contrast, if the innovation size is large, then we have an inverse result that we have maintained in the case of a small innovation size. Under the emission-equivalent case, when we compare the social welfare difference between the case of an emission tax and the case of an environmental standard, the emission tax revenue (T) is a critical point. The emission revenue has a positive relation with the output level, and thus a small innovation size induces a high output level for fierce market competition. It also induces more emission tax revenue. However, the k-drastic innovation appears in the case of a large innovation size. This means that some firms without a new technology will get kicked out of the market when the innovation size is large. Since the number of firms becomes less, the existing firms can obtain a high profit for a high price and a low output. Since the emission tax revenue is less in the k-drastic innovation case and producer surplus in the case of an environmental standard (PS^*) is an only factor to decide the size of the social welfare given $E = E^*$, we conclude that when the innovation size is large, the optimal environmental instrument is an environmental standard.

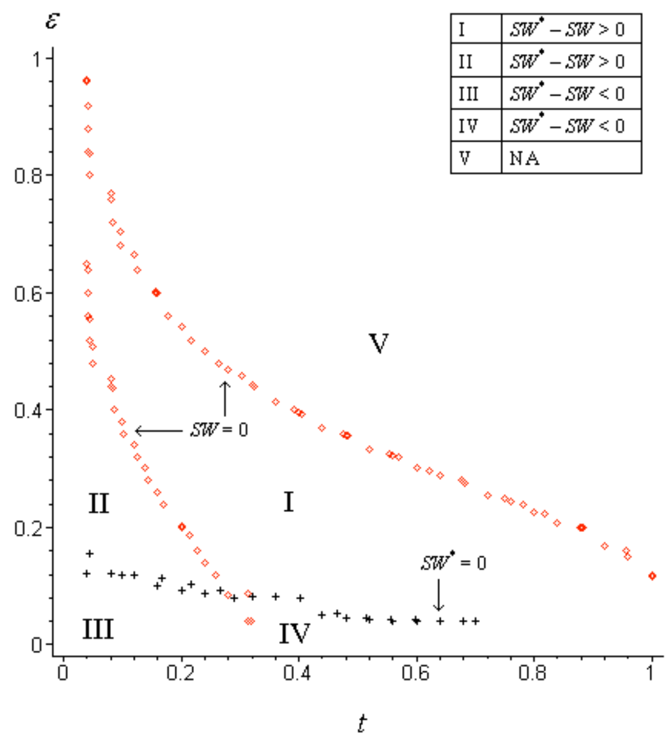

Fig. (3). Environmental Instrument and Social Welfare (n = 100).

Environment Instrument and Licensing Incentive

An environmental instrument always affects the patentee's licensing incentive. Here, we examine which environmental instrument has a strong licensing incentive for the patentee in the case of an emission-equivalent. We compare the revenue difference for two kinds of environmental instruments; i.e., $R^*(z_E) - R(t)$. The result of $R^*(z_E) - R(t)$ is drawn on the t-ε plane as Fig. (**4**).

Proposition 1 *The patentee has a higher incentive to license when the government adopts an environmental standard than an emission tax under the equivalent emission.*

From Figs. (**1**, **2**), we find that the licensed proportion in the case of an environmental standard is always lower than the licensed proportion in the case of an emission tax in a large part of the feasible area. This induces that the licensee has a stronger monopoly power in the case of an environmental standard than in the case of an emission tax. Thus, the patentee can charge a higher licensing fee from the licensee in the case of environmental standard than in the case of an emission tax. It is one reason that the patentee has a strong licensing incentive in the case of an environmental standard.

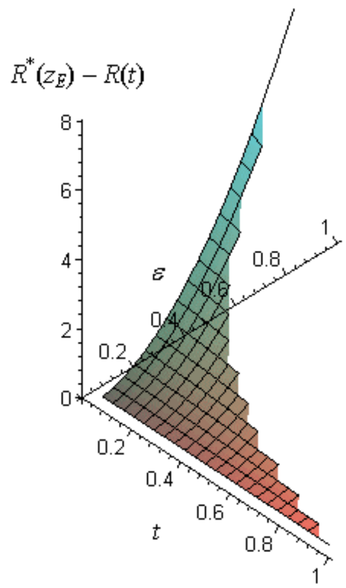

Fig. (4). Environmental Instrument and Licensing Incentive (n = 100).

We next compare the results in subsections 4.2 and 4.3. The result in subsection 4.2 shows that the government prefers the emission tax rather than the environmental standard as an environmental instrument when the innovation size is small. However, the government prefers the environmental standard as an environmental instrument when the innovation size is large. The result in section 4.3 tells us the innovator always prefers the government to adopt the environmental standard as an environmental instrument. Hence, we have a proposition as follows.

Proposition 2 *There exists a preference inconsistency (consistency) between the innovator and the government when the innovation size is small (large).*

Strict Environmental Policy Forbids Technology Licensing

We have shown above that $d\phi/dt < 0$ and $d\phi^*/dz > 0$. This result tells us that the licensed proportion will decrease when the government practices a strict environmental policy no matter in the case of an emission tax or in the case of an environmental standard. Hence, a strict environmental policy will hinder the new technology to expand. A strict environmental policy increases a firm's marginal cost, it makes a firm's profit decrease, and then a firm's ability at purchasing new technology becomes weak. To maximize the licensing revenue, the outsider patentee will decrease the licensed proportion in order to differentiate a firm's marginal cost and increase a firms' ability to purchase new technology. With the above discussion, we have the following proposition.

Proposition 3 *A stricter environmental policy hinders technology licensing under the emission-equivalent emission tax and environmental standard.*

Equations (5a) and (10a) show that $dPS/dt < 0$ and $dPS^*/dz > 0$. This result tells us that a stricter environmental policy will decrease the producer surplus. We can decompose Equations (5a) and (10a) as $dPS/dt = (\partial PS/\partial\phi)(\partial\phi/\partial t) + (\partial PS/\partial x_0)(\partial x_0/\partial t) + (\partial PS/\partial x_1)(\partial x_1/\partial t) < 0$ and $dPS^*/dz = (dPS^*/d\phi^*)(d\phi^*/dz) + (dPS^*/dx_0^*)(dx_0^*/dz) + (dPS^*/dx_1^*)(dx_1^*/dz) > 0$. We make sure that $dPS/d\phi > 0$ and $dPS^*/d\phi^* > 0$ due to $d\phi/dt < 0$ and $d\phi^*/dz > 0$. In other words, an increase in the licensed proportion makes the number of efficient firm increase and then it induces the producer surplus to increase.

CONCLUDING REMARKS

We employ a two-stage game model including an outside patent owner and n manufacturing firms to discuss the effect of an emission tax and environmental standard under the case of an emission-equivalent. A stricter environmental policy hinders technology licensing under emission taxes and environmental standards with an equivalent emission. The outsider patentee has a higher licensing incentive in the case of an environmental standard than in the case of an emission tax.

The government prefers to take the emission tax as an environmental instrument when the innovation size is small. On the contrary, when the innovation size is large, the government prefers to use the emission tax. There is a preference inconsistency on an environmental instrument between the government and the innovator when the innovation size is small. However, they will show consistency on an environmental instrument when the innovation size is large.

The licensed proportion in the case of an emission tax is always larger than that in the case of an environmental standard when the emission tax rate is low. If the government imposes a high emission tax rate, then the licensed proportion in the case of an environmental standard is larger than that in the case of an emission tax. When the number of firms increases, the area whereby the licensed proportion in the case of an environmental standard is higher than the licensed proportion in the case of an emission tax will shrink.

The licensor here is an outside patentee and does not join a production action. Hence, the licensing behavior of the licensor is not affected by a competitive impact. It will be an interesting issue in the future to consider the licensor as an industry-inside patentee.

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