Eco-technology licensing by a foreign innovator and the privatization policy in a polluting mixed duopoly

SEUNG-LEUL KIM[*]

SANG-HO LEE[†]

TOSHIHIRO MATSUMURA[‡]

This article investigates the strategic fixed-fee licensing contract in a mixed duopoly where public and private firms may purchase eco-technology from a foreign innovator. We examine the welfare consequences of exclusive licensing and a privatization policy, and show that the foreign innovator chooses either exclusive or non-exclusive licensing contract according to not only the cost gap between the two firms but also the environmental damage of pollutants. Thus, privatization improves social welfare when both cost gap and environmental damage are large, privatization can improve social welfare. Otherwise, either exclusive or non-exclusive contract without privatization might be better to the society. Finally, when the government can restrict the foreign innovator to only non-exclusive contracts, privatization mostly improves social welfare except in the case where both cost gap and environmental damage are small.

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[*] Economics Department, Chonnam National University, Korea. E-mail: slkim@jun.ac.kr

[†] Corresponding author, Economics Department, Chonnam National University, Korea. E-mail: sangho@jun.ac.kr This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF—2014S1A2A2028188)

[‡] Institute of Social Science, University of Tokyo, Japan. E-mail: matsumur@iss.u-tokyo.ac.jp

1. Introduction

The eco-industry provides environment-friendly goods and services, such as cleaner technologies, green products, and pollution abatement services, which polluting firms increasingly purchase to reduce environmental risk and to minimize pollution and resource use.[1] Stricter environmental laws and regulations have recently contributed to the development of this eco-industry. However, as most eco-technologies are likely to be patented, the eco-industry is now characterized by the monopolistic situation. Then, given the exclusiveness of eco-patents, it is critical to examine how the patent licensing strategy of eco-technology affects the incentives of licensees who emit environmental pollutants.

According to the Environmental Business International (2012), it is reported that the global market size of eco-industry is expected to expand by US$992 billion by 2017. The database of PTC (Patent Cooperation Treaty) indicates that well-developed countries invented general environmental management technologies which are comprised over 60% of total patents in these technologies all over the world. Meanwhile, developing countries tend to import eco-technology from foreign innovator[2] to reduce GHS (Green House Gas). In Korean eco-industry market, for example, the environmental technology is increasingly imported with the amount of 22% from public sector and 78% from private sector in 2012. Recently, many governments in advanced countries also play a strong role and invest R&D in the creation of eco-technology such as CleanTECH San Diego in USA, LAKES (Lahti Regional Development Company) in Finland, Solar Valley Mitteldeutschland in Germany, Water Cluster in Israel and so on.

In the literature on the industrial economics of R&D innovation activity, many works have studied the patent licensing of cost-reducing innovations.[3] In particular, traditional studies with

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[1] The importance of the eco-industry has been recognized by numerous reports from national and international institutions such as OECD (1996), Berg et al. (1998), ERCL (2002), and Kennett and Steenblik (2005). The economic analysis on the eco-industry was introduced by Feess and Muehlheusser (2002) and David and Sinclair-Desgagne (2005). Canton et al. (2008, 2012) and Nimubona and Sinclair-Desgagne (2010) examined the effect of emission tax on the activity of polluting oligopolistic firms toward the eco-industry. Lee and Park (2011) also incorporated the subsidy on abatement goods produced in the eco-industry under free entry market structure.

[2] Eco-innovators, maintaining its leadership position on eco-technology, include Clean Tech Delta, CLEAN, Eco World Styria (Austria), Ecotech Quebec (Canada), Green Cape, Lombardy Energy Cluster (Italy), SSCA (Sakishima Smart Community Alliance, Japan), Tenerrdis (France) and so on.

[3] Besides the strategic issue of patent licensing, many works have studied on the R&D activities as an endogenous variable in private or/and public R&D competitions (Matsumura and Matsushima, 2004; Ishibashi and Matsushima, 2006; Gil-Molto et al., 2011). Meanwhile, recent works also consider eco-R&D investment to analyze eco-R&D activities under environmental regulation (Chiou and Hu 2001, Poyago-Theotoky 2007, Mcdonald and Payogo-Theotoky 2014).

an outsider innovator have focused on market structure and regulatory policy and compared the efficiencies of some types of licensing.[4] Concerning eco-technology, for example, Kim and Lee (2014) showed that the innovator provides a non-exclusive license under the royalty contract, while it might exclude polluting firms under the fixed-fee licensing contract, and compared with royalty licensing, an exclusive fixed-fee contract would increase the welfare, with the welfare effect dependent on the level of emission tax.

On the other hand, several economists are interested in patent licensing issues in a mixed market.[5] Ye (2012) investigated optimal licensing strategies in a mixed oligopoly where the innovator is a public firm and found out that fixed fee is superior to royalty for the innovator. Later, three different types of technology licensing contracts were examined in a horizontal mixed oligopoly with an innovator private firm (Chen et al., 2014). More recently, Niu (2015) analyzed the international licensing policy for a foreign R&D institution and found that a fully nationalized public firm is never the best choice in the presence of an international licensing contract.

This paper contributes to public policy on privatization by considering eco-technology and the strategic exclusive licensing contract. Specifically, this paper examines a model of patent licensing strategies between a foreign eco-innovator and a polluting mixed duopoly, where polluters may purchase a license of pollution abatement technology from a patentee under fixed-fee licensing[6]. In the presence of emission tax, we consider the cost gap between the public firm

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[4] Early work shows that with outside innovation, the 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). However, there are still debates on these results because royalty is preferred to fixed fee in the Bertrand model (Muto, 1993), spatial competition model (Poddar and Sinha, 2004; Heywood and Ye, 2012), strategic tax policy (Mukherjee and Tsai, 2010), and dynamic frameworks (Saracho, 2011).

[5] The studies on the mixed market show that full (or partial, possibly) privatization of welfare maximizing public firms may improve social welfare (De Fraja and Delbono, 1989, 1990; Matsumura, 1998; Bennett and Maw, 2003). Since then, there have been substantial studies concerning the welfare effect of privatization on trade policy (Fjell and Pal, 1996; Pal and White, 1998), market structure (Fjell and Heywood, 2004), free-entry market (Wang and Chen, 2010), impact of foreign penetration (Wang and Chen, 2011), and tariffs and environmental taxes (Xu and Lee, 2015). In particular, concerning the environmental issues, Bárcena-Ruiz and Garzón (2006) showed how the decision on whether to privatize a public firm interacts with the environmental policy. Beladi and Chao (2006) proved that privatization paradoxically exerts a negative effect on the environment. In the same line, Pal and Saha (2015) examined whether privatization improves the environment in a mixed oligopolistic model.

[6] Earlier works show that regardless of the industry size and/or magnitude of the innovation, a fixed-fee licensing and auctioning is superior to royalty licensing under perfect competition (Kamien and Tauman, 1984), homogenous oligopoly (Kamien and Tauman, 1986; Katz and Shapiro, 1986), leadership structure

and the private firm, and analyze how this cost gap affects both patent licensing strategies of an eco-innovator and the welfare effect of privatization policy. Furthermore, we also analyze international licensing in a mixed market and examine how privatization evokes an exclusive contract, which might cause welfare loss.

In traditional literature, the impact of a privatizing public firm on domestic welfare is shown to contain three effects: (i) an output substitution effect, which usually negatively affects welfare because privatization decreases the total production of the final good for consumption; (ii) a cost-saving effect resulting from a decrease in production of the inefficient public firm; and (iii) a rent-leakage effect associated with the foreign private firm. This paper adds the other impact of privatization, which eliminates the incentive of exclusion from the foreign innovator. Depending on these four different effects, the optimal policy toward the public firm is either privatization or nationalization.

In this paper, we emphasize the non-exclusion effect of licensing contract under privatization. Privatization switches the optimal choice of foreign innovator from exclusive licensing to a non-exclusive licensing strategy. It causes the removal of damage by zero-pollution technology when both cost gap and damage are large. However, when both cost gap and damage are low, a mixed market under exclusive licensing is better because the negative rent-leakage effect dominates this damage-reducing effect from non-exclusive contract.

We show that in a mixed market, the foreign innovator prefers exclusive contract when both cost gap and environmental damage are either small or large, while it prefers non-exclusive contract when those are intermediate. We also show that in a private market, the foreign innovator prefers the non-exclusive contract when the cost gap is small, while it prefers the exclusive contract when the cost gap is large. Finally, we show that the welfare effect of the privatization policy depends not only on the cost gap but also on the environmental damage level. In particular, when the cost gap and environmental damage are large, the privatization policy can improve the social welfare. However, when both cost gap and environmental damage are small, the exclusive contract under nationalization is better to the society. Finally, when the cost gap and damage level are intermediate, the non-exclusive contract under nationalization is better to the society.

The organization of this paper is as follows. Section 2 constructs the basic duopoly model of eco-technology licensing. We analyze fixed-fee licensing strategies of an innovator in a mixed market in Section 3 and that of a private market in Section 4. Section 5 examines the welfare

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(Kabiraj, 2004), and Cournot duopoly with network externality (Wang et al. 2012).

effect of privatization under the optimal licensing strategy and discusses a regulatory effect when government restricts foreign innovator to non-exclusive contracts. The final section provides a conclusion.

2. The Basic Model

Consider a Cournot duopoly market where a public firm (firm 0) and a private firm (firm 1) compete in homogeneous products that emit pollutants from the production process. The inverse demand function for final goods is given by $P(Q) = A - Q$, where $Q = q_0 + q_1$ is the market output level of final goods, in which q_0 and q_1 are the output of the public firm and the private firm, respectively. Then, consumer surplus is defined as $CS = \frac{Q^2}{2}$. We assume that the production cost is constant, c_i, but the private firm is more efficient than the public firm, where the production cost of the private firm is zero, that is, $c_0 \geq c_1 = 0$. To assure the interior solutions, we also assume that $c_0 < \frac{A}{2}$ in the analysis.[7]

Each unit of output entails one unit of emission, in which the emission function is defined as $e_i = q_i$. Let $E = e_0 + e_1$ be the total emission level and $D(E) = dE$ denote the environmental damages, where $d > 0$ is marginal environmental damage, which is constant to the total emission level. We assume that the level of emissions is restricted by environmental regulation in the form of emission taxes or carbon permits with the carbon price of $t > 0$. We assume that the emission market is perfectly competitive, which implies that the emission tax or carbon price should be same with the marginal social damage, that is, $t = d$. The sum of the emission expenditures of the firms are $T(E) = tE$.

Suppose that there is a foreign innovator that licenses clean eco-technology with the contract of fixed-fee licensing to one or both firms. When this innovator licenses its technology to *k (= 1,2)* firms, the licensed firms can reduce the pollution and thereby emission (tax or carbon price) expenditures. For analytical simplicity, we assume a zero-pollution eco-technology in which the licensed firm can clearly eliminate all the pollutants from this technology and thus produce no emission during production.[8]

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[7] If $c_0 \geq A/2$, it is possible for private firm to set monopoly price which lead public firm to exit from the market. It is a trivial case and thus, we exclude this case.

[8] Note that although we incorporate non-zero pollution eco-technology in the model, the qualitative implications of the analysis are not directly relevant with regard to this form of abatement technology.

The profit functions of a licensed firm and a non-licensed firm are determined with the fixed fee, *f(k)*, and the announced number of the licensed firm, *k*, as follows:

$$\pi_i^L(k) = P(Q)q_i^L - c_i q_i^L - f\ (k), \tag{1}$$

$$\pi_i^N(k) = P(Q)q_i^N - c_i q_i^N - de_i^N, \tag{2}$$

where q_i^L or q_j^N is the firm's output level supplied as a licensee or a non-licensee, respectively, $i = 0, 1$.

The foreign innovator's profit function is defined by[9]

$$R(k) = kf\ (k). \tag{3}$$

We assume that the public firm maximizes the domestic social welfare, which is defined as the sum of consumer surplus, each firm's profit, and the revenue from emission expenditures minus the environmental damage of emissions:

$$W(k) = CS + \pi_0 + \pi_1 + T - D(E) = \int_0^Q P(u)du - c_0 q_0 - dE(k) - R(k). \tag{4}$$

There are four cases in defining the welfare in (4):

(i) when *k = 0 and* $E = e_0 + e_1$, that is, when both public and private firms are non-licensed firms, then $W(0)$;

(ii) when *k = 1* and $E = e_1$, that is, when the public firm is licensed but the private firm is non-licensed, then $W_0(1)$;

(iii) when *k = 1* and $E = e_0$, that is, when the private firm is licensed but the public firm is non-licensed, then $W_1(1)$;

(iv) when *k = 2* and $E = 0$, that is, when both public and private firms are licensed, then $W_0(2)$ (when the fixed fee is determined by the public firm's willingness-to-pay); or $W_1(2)$ (when the fixed fee is determined by the private firm's willingness-to-pay).

The timing of the game is as follows. In the first stage, under environmental regulation, a foreign innovator announces a licensing contract to provide *k* number of licenses upon charging

[9] Note that the production cost of the innovator to provide abatement goods or services does not change the qualitative implications of licensing strategies by the innovator under the fixed-fee licensing contract. However, when the production cost of the innovator is present, loyalty licensing contract dominates the fixed-fee licensing under lower production cost, while two-part licensing contract dominates it under higher production cost. See Kim and Lee (2014, 2015) for more discussions on royalty and two-part tariff contracts with the eco-industry.

a fixed fee, *f(k)*. In the second stage, given the licensing contract, the polluting public and private firms simultaneously decide whether to purchase a license. In the third stage, when the number of k licensees are contracted, the duopoly firms choose their output levels in a Cournot fashion. Then, the sub-game perfect Nash equilibrium is derived by a backward induction.

3. Mixed Duopoly

In this section, we analyze fixed-fee licensing contracts in a mixed duopoly, in which public and private firms coexist in the market and the innovator decides whether it licenses to public or private firm or both firms.

3.1 Benchmark: *k = 0*

As a benchmark, we consider the no-licensing case where both public and private firms do not purchase a license. Under Cournot competition, the first order conditions of objective function in (2) and (4) are, respectively, as follows:

$$\frac{\partial W}{\partial q_0} = A - q_0 - q_1 - c_0 - d = 0, \tag{5}$$

$$\frac{\partial \pi_1^N}{\partial q_1} = A - q_0 - 2q_1 - d = 0. \tag{6}$$

Solving these first-order conditions simultaneously, we have $q_0 = A - 2c_0 - d$, $q_1 = c_0$, $Q = A - c_0 - d$, and $P = c_0 + d$ at equilibrium. Then, using the outputs and price in equilibrium, the profits of public and private firms are $\pi_0^N(0) = 0$ and $\pi_1^N(0) = c_0{}^2$, respectively.

The resulting welfare under mixed duopoly is

$$W^M(0) = \int_0^Q P(u)du - c_0 q_0^N - dq_0^N - dq_1^N = \frac{1}{2}\{A(A - 2c_0 - 2d) + c_0(3c_0 + 2d) + d^2\}. \tag{7}$$

3.2 When the innovator sells a license to only one firm: *k = 1*

Next, consider a fixed-fee licensing case with *k = 1*. We can consider two cases: one with a public licensed firm and another with a private licensed firm. Then, we need to compare the profits of the innovator in each case.

3.2.1 Licensed public firm and non-licensed private firm

First, consider that a licensed public firm and a non-licensed private firm produce final goods in a Cournot competition. Solving first-order conditions (2) and (4) simultaneously, we get $q_0 = A - 2c_0 + d$, $q_1 = c_0 - d$, $Q = A - c_0$, and $P = c_0$. In particular, if $c_0 > d$, $q_1 > 0$. However, if $c_0 \le d$, $q_1 = 0$, which is the case of public monopoly[10]. We consider only the case of $c_0 > d$ to assure the interior solutions in the analysis.

Under the assumption of $c_0 > d$ and using the outputs and price in equilibrium, we have the profits of the private firm, $\pi_1^N(1) = (c_0 - d)^2$. Then, the welfare, which is the objective of the licensed public firm, is defined as

$$W_0(1) = \int_0^Q P(u)du - c_0 q_0^L - dq_1^N - \pi_0^M(1) = \frac{1}{2}\{A(A-2c_0) + 3c_0^{\,2} + 2d^2 - 4c_0 d\} - f_0(1). \tag{8}$$

The fixed fee should be equal to the maximum welfare difference of the public licensee between accepting and rejecting the licensing offer, given the other firm is not accepting it at Nash equilibrium. That is, $f_0(1)$ should satisfy that $W_0(1) - W^M(0) = 0$ in (7) and (8). Then, the public firm's maximum willingness-to-pay is derived as follows:

$$f_0(1) = (A - 3c_0)d + \frac{1}{2}d^2. \tag{9}$$

This gives

$$W_0(1) = \frac{1}{2}\{A(A - 2c_0 - 2d) + c_0(3c_0 + 2d) + d^2\} \tag{10}$$

and $\pi_1^N(1) = (c_0 - d)^2$. (11)

3.2.2. Non-Licensed public firm and licensed private firm

Second, consider that a public firm and a licensed private firm produce final goods in a Cournot competition. Solving first-order conditions (1) and (4) simultaneously, we can derive $q_0 = A - 2c_0 - 2d$, $q_1 = c_0 + d$, $Q = A - c_0 - d$, and $P = c_0 + d$. In particular, if $c_0 < \frac{A-2d}{2}$, $q_0 > 0$. However, if $c_0 \ge \frac{A-2d}{2}$, $q_0 = 0$, which is the case of private monopoly in the mixed market. To assure the interior solutions, we deal with only the situation where both public and private firms produce positive output in the market.

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[10] With the condition of $c_0 \le d$, which constructs public monopoly and solving first-order condition (4), we can get $q_0 = A - c_0$, $q_1 = 0$, $Q = A - c_0$, and $P = c_0$.

Then, using the outputs and price in equilibrium, we have the profits of the private firm, $\pi_1^L(1) = (c_0 + d)^2 - f_1(1)$. Then, the welfare, which is the objective of licensed public firm, is defined as

$$W_1(1) = \int_0^Q P(u)du - c_0 q_0^N - d q_0^N - R_1^M(1) = \frac{1}{2}\{A(A - 2c_0 - 2d) + 3(c_0{}^2 + d^2) + 6c_0 d\} - f_1(1). \quad (12)$$

The fixed fee should be equal to the maximum profit difference of the private licensee between accepting and rejecting the licensing offer, given the other firm is not accepting it at Nash equilibrium. That is, $f_1(1)$ should satisfy that $\pi_1^L(1) - \pi_1^N(0) = 0$. Then, the private firm's maximum willingness-to-pay is derived as follows:

$$f_1(1) = d(2c_0 + d). \quad (13)$$

This gives

$$W_1(1) = \frac{1}{2}\{A(A - 2c_0 - 2d) + c_0(3c_0 + 2d) + d^2\} \quad (14)$$

and $\pi_1^L(1) = (c_0 + d)^2 - f_1(1)$. (15)

Let $c_S(1) = \frac{2A - d}{10}$, which satisfies $f_0(1) = f_1(1)$ in (9) and (13).

Lemma 1. In a mixed duopoly with $k = 1$, the optimal fixed fee is $f_0(1)$ and the public firm (i.e., firm 0) gets a license if $c_0 < c_S(1)$, but it is $f_1(1)$ and the private firm (i.e., firm 1) gets the license if $c_0 > c_S(1)$.

Proof. From (9) and (13), we have $c_S(1) = \frac{2A - d}{10}$. Then, we can derive $f_0(1) - f_1(1) = \frac{d}{2}(2A - d - 10c_0) \gtrless 0$. Since $f_0(1) - f_1(1) \gtrless 0$, the innovator determines the optimal fixed fee by *max* [$f_0(1)$, $f_1(1)$]. Thus, if $c_0 \lessgtr c_S(1)$, then $f_0(1) \gtrless f_1(1)$. Therefore, the optimal fixed fee with k = 1 is $f_0(1)$ or $f_1(1)$. ■

Then, from (9) and (13), the profit of the innovator under fixed-fee licensing is as follows:

$$R^M(1) = \begin{cases} R_0^M(1) = (A - 3c_0)d + \frac{1}{2}d^2 & \text{if } c_0 < c_S(1). \quad (16) \\ R_1^M(1) = d(2c_0 + d) & \text{if } c_0 > c_S(1). \quad (17) \end{cases}$$

The resulting welfare is

$$W^M(1) = \begin{cases} W_0(1) = \int_0^Q P(u)du - c_0 q_0 - dq_1 - R_0^M(1) & \text{if } c_0 < c_S(1). \\ W_1(1) = \int_0^Q P(u)du - c_0 q_0 - dq_0 - R_1^M(1) & \text{if } c_0 > c_S(1). \end{cases}$$

Note that in a mixed duopoly with k = 1, the welfare level is irrelevant to the exclusive licensing strategy of the innovator. That is, $W_0(1) = W_1(1) = W^M(1)$.

$$W^M(1) = W_0(1) = W_1(1) = \frac{1}{2}\{A(A - 2c_0 - 2d) + c_0(3c_0 + 2d) + d^2\}. \tag{18}$$

3.3 When the innovator sells licenses to both firms: *k = 2*

We now consider the fixed-fee licensing case with *k = 2*, where the innovator charges the same fixed fee, *f*, without discrimination. In this case, we have two different maximum willingness-to-pay values for fixed fee: (i) $2f_0(2)$ from $W_0(2) - W_1(1) = 0$ and (ii) $f_1(2)$ from $\pi_1^L(2) - \pi_1^N(1) = 0$.

From the first-order conditions from the objective functions of the licensed private and licensed public firms in (1) and (4), we have $q_0 = A - 2c_0$, $q_1 = c_0$, $Q = A - c_0$, and $P = c_0$ at equilibrium. Then, using the outputs and price in equilibrium, we have the profits of private firm, $\pi_1^L(2) = c_0{}^2 - f_1(2)$. Thus, the welfare, which is the objectives of licensed public firm, is defined as

$$W_0(2) = \int_0^Q P(u)du - c_0 q_0^L - R_0^M(2) = \frac{1}{2}(A^2 - 2Ac_0 + 3c_0{}^2) - 2f_0(2). \tag{19}$$

Then, each firm's maximum willingness-to-pay for fixed fee can be calculated as follows:

$$f_0(2) = \frac{1}{2}d(A - c_0 - \frac{1}{2}d), \tag{20}$$

$$f_1(2) = d(2c_0 - d). \tag{21}$$

Note that $c_S(2) = \frac{1}{5}(A + \frac{3}{2}d)$ satisfies $f_0(2) = f_1(2)$ in (20) and (21) for any d.

Lemma 2. In a mixed duopoly with *k = 2*, the optimal fixed fee is $f_1(2)$ if $c_0 < c_S(2)$, but it is $f_0(2)$ if $c_0 > c_S(2)$.

Proof. The innovator determines the optimal fixed fee at $\min[f_0(2), f_1(2)]$. Thus, if $c_0 \lessgtr c_S(2)$, then $f_0(2) \overset{>}{\underset{<}{}} f_1(2)$. Therefore, the optimal fixed fee with k = 2 is $f_1(2)$ if $c_0 < c_S(2)$ but $f_0(2)$ if $c_0 > c_S(2)$. ■

Then, the profit of the innovator is as follows:

$$R^M(2) = \begin{cases} R_1^M(2) = 2 \cdot f_1(2) = 2d(2c_0 - d) & \text{if } c_0 < c_S(2). \quad (22) \\ R_0^M(2) = 2 \cdot f_0(2) = d(A - c_0 - \frac{1}{2}d) & \text{if } c_0 > c_S(1). \quad (23) \end{cases}$$

The resulting welfare is

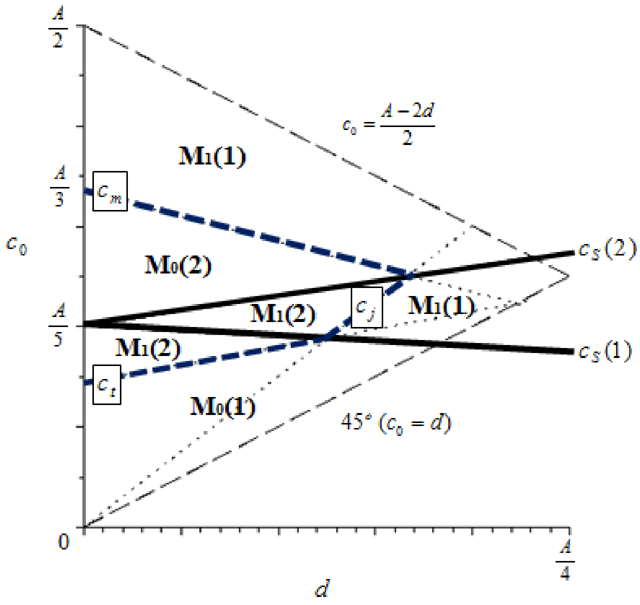
$$W^M(2) = \begin{cases} W_0(2) = \int_0^Q P(u)du - c_0 q_0 - R_0^M(2) = \frac{1}{2}\{A(A - 2c_0 - 2d) + c_0(3c_0 + 2d) + d^2\} & \text{if } c_0 > c_s(2) \quad (24) \\ W_1(2) = \int_0^Q P(u)du - c_0 q_0 - R_1^M(2) = \frac{1}{2}\{A(A - 2c_0) + 3c_0^2 - 4d(2c_0 - d)\} & \text{if } c_0 < c_s(2) \quad (25) \end{cases}$$

3.4 The optimal choice of the innovator: Comparison between *k = 1* and *k = 2*

In a mixed duopoly, we compare the fixed-fee between exclusive licensing (*k = 1*) and non-exclusive licensing (*k = 2*) and examine whether public or private firm is the licensee when *k = 1*.

Proposition 1. In a mixed duopoly, (i) for $c_0 < c_s(1)$, the innovator licenses to both public and private firms, and charges $f_0(1)$ if $c_0 < c_t$ but licenses to public firm with $f_1(2)$ if $c_0 > c_t$; (ii) for $c_s(1) < c_0 < c_s(2)$, the innovator licenses to both public and private firms and charges $f_1(2)$ if $c_0 > c_j$ but the innovator licenses to only private firm and charges $f_1(1)$ if $c_0 < c_j$; and (iii) for $c_0 > c_s(2)$, the innovator licenses to both public and private firms and charges $f_0(2)$ if $c_0 < c_m$ but the innovator licenses to only private firm and charges $f_1(1)$ if $c_0 > c_m$.

Proof. First, from $R_0^M(1)$ and $R_1^M(2)$ in (16) and (22), we define $c_t \equiv \frac{1}{7}(A + \frac{5}{2}d)$ which satisfies $R_0^M(1) - R_1^M(2) = 0$. Thus, if $c_0 \overset{<}{\underset{>}{}} c_t$, then $R_0^M(1) \overset{>}{\underset{<}{}} R_1^M(2)$. Second, from $R_1^M(2)$ and $R_1^M(1)$ in (17) and (22), we have $c_j \equiv \frac{3}{2}d$, which satisfies $R_1^M(2) - R_1^M(1) = 0$. Thus, if $c_0 \overset{<}{\underset{>}{}} c_j$, then $R_1^M(2) \overset{<}{\underset{>}{}} R_1^M(1)$. Third, from $R_1^M(1)$ and $R_0^M(2)$ in (17) and (23), we have $c_m \equiv \frac{1}{3}A - \frac{1}{2}d$, which satisfies $R_1^M(1) - R_0^M(2) = 0$. Thus, if $c_0 \overset{<}{\underset{>}{}} c_m$, then $R_1^M(1) \overset{<}{\underset{>}{}} R_0^M(2)$. ■



<Fig. 1 Optimal choices of the eco-innovator in a mixed duopoly market>

Figure 1 shows the optimal decisions of the innovator in the mixed market where $c_S(1)$, $c_S(2)$, c_m, c_j and c_t are determined by the profit comparisons with response to the cost gap and environmental damage in Proposition 1. The optimal choices on the number of licensees in a mixed market are described by $\mathrm{M_i}(k)$, where k represents the optimal number of licensees and $i = 0$ (public firm) or $i = 1$(private firm) represents the optimal fixed fee charged to each firm. Then, there are four optimal strategies of the -innovator, indicated by $\mathrm{M}_0(1)$, $\mathrm{M}_1(1)$, $\mathrm{M}_0(2)$, and $\mathrm{M}_1(2)$. First, consider the case of $c_0 < c_s(1)$, where if the cost gap is smaller than c_t, the innovator prefers exclusive licensing but if it is larger than c_t, the innovator prefers non-exclusive licensing. That is because with increasing cost gap, the public firm's willingness-to-pay decreases, while with increasing output production, the private firm's willingness-to-pay increases. Next, in the case of $c_s(1) < c_0 < c_s(2)$, the choices of the innovator depend on the damage level. When the damage level is higher than c_j, the innovator gives a license to only the private firm, but when the damage level is lower than c_j, both firms get licenses. Since the cost gap is high enough, as the damage level increases, the public firm decreases its output while private firm increases outputs, which means the private firm's willingness-to-pay becomes large. Finally, in the case of $c_0 > c_s(2)$, when both cost gap and damage level are smaller than c_m, the innovator gives licenses to both firms, but when these are larger than c_m, only the private firm gets a license. When the cost gap is very high, the public firm can pay a small amount for getting the license because its production decreases with the increasing cost gap and damage level. Therefore, in a mixed market, when cost gap is small or large, the foreign innovator prefers the exclusive licensing contract to a non-exclusive licensing one, but when it is intermediate, it prefers the non-exclusive licensing contract.

Proposition 2. In a mixed duopoly, non-exclusive licensing is always more desirable than exclusive licensing.

Proof. From (24) and (18), we have $W_0(2) - W(1) = 0$ and from (25) and (18), we have $W_1(2) - W(1) = (\frac{3}{2}d + A - 5c_0)d > 0$. ■

This proposition states that the non-exclusive fixed-fee licensing contract improves social welfare in a mixed duopoly market. Under fixed-fee licensing, as the environmental damage increases, the foreign innovator has an incentive to exclude polluting firms to increase its profits, while the domestic private firm pays more to the foreign innovator under the exclusive licensing contract. Therefore, the regulator can consider restricting the exclusive fixed-fee licensing contract to increase welfare. Alternatively, the government can consider privatization policy to reduce the incentive of the exclusive licensing contract, which will be examined in the next section.

4. Private Duopoly

We analyze the effect of the privatization policy. For the purpose of comparison between mixed and private markets, we assume that $d < c_0 < \frac{A-2d}{2}$, where both firms exist in the mixed market.

4.1 Benchmark: *k = 0*

Again, as a benchmark, we consider no-licensing case where both private firms do not purchase a license. Under Cournot competition, the first-order conditions of objective functions in (2) are, respectively, as follows:

$$\frac{\partial \pi_0^N}{\partial q_0} = A - 2q_0 - q_1 - c_0 - d = 0, \tag{26}$$

$$\frac{\partial \pi_1^N}{\partial q_1} = A - q_0 - 2q_1 - d = 0. \tag{27}$$

Solving these first-order conditions simultaneously, we have $q_0 = \dfrac{A-2c_0-d}{3}$, $q_1 = \dfrac{A+c_0-d}{3}$, $Q = \dfrac{2A-c_0-2d}{3}$, and $P = \dfrac{A+c_0+2d}{3}$ at equilibrium. Then, using the outputs and price in equilibrium, the profits of the public and private firms are $\pi_0^N(0) = \left(\dfrac{A-2c_0-d}{3}\right)^2$ and $\pi_1^N(0) = \left(\dfrac{A+c_0-d}{3}\right)^2$.

The resulting welfare is

$$W^P(0) = \int_0^Q P(u)du - c_0 q_0^N - dq_0^N - dq_1^N = \frac{1}{9}\{4A(A-c_0-2d) + \frac{11}{2}c_0{}^2 + d(4c_0+4d)\}. \tag{28}$$

4.2 When the innovator sells a license to only one firm: *k = 1*

We now consider the fixed-fee licensing case with $k = 1$. Then, the fixed fee should be equal to the maximum profit difference of each licensee between accepting and rejecting the licensing offer, given the other firm is not accepting it at Nash equilibrium. That is, $f_i(1)$ should satisfy that $\pi_i^L(1) - \pi_i^N(0) = 0$.

First, consider that an efficient licensed private firm and an inefficient non-licensed private firm produce final goods in a Cournot competition. From (1), the first-order conditions yield $q_0^N = \dfrac{A-2c_0-2d}{3}$, $q_1^L = \dfrac{A+c_0+d}{3}$, $Q = \dfrac{2A-c_0-d}{3}$, and $P = \dfrac{1}{3}(A+c_0+d)$ at equilibrium[11]. Then, the efficient firm's maximum willingness-to-pay is derived as follows:

$$f_1(1) = \frac{4d(A+c_0)}{9}. \tag{29}$$

Second, consider that an inefficient licensed private firm and an efficient non-licensed private firm produce final goods in a Cournot competition. From (2), the first-order conditions yield $q_0^L = \dfrac{A-2c_0+d}{3}$, $q_1^N = \dfrac{A+c_0-2d}{3}$, $Q = \dfrac{2A-c_0-d}{3}$, and $P = \dfrac{1}{3}(A+c_0+d)$ at equilibrium. Then, the inefficient firm's maximum willingness-to-pay is derived as follows:

$$f_0(1) = \frac{4d(A-2c_0)}{9}. \tag{30}$$

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[11] Since $A > 2c_0$, the equilibrium outputs are positive, and thus, we have $\dfrac{\partial q_1^L}{\partial d} > 0 > \dfrac{\partial q_0^N}{\partial d}$.

Finally, since $f_1(1) - f_0(1) > 0$, the innovator determines the optimal fixed fee at $f_1(1)$, *max* [$f_0(1)$, $f_1(1)$].

This gives $\pi_0^N(1) = \left(\frac{A-2(c_0+d)}{3}\right)^2$ and $\pi_1^L(1) = \left(\frac{A+c_0+d}{3}\right)^2 - f_1(1)$. Then, the profit of the innovator under fixed-fee licensing is as follows:

$$R(1) = \frac{4d(A+c_0)}{9}. \tag{31}$$

Lemma 3. In a private duopoly with *k = 1*, the optimal fixed fee is $f(1) = f_1(1)$ and the efficient firm (i.e., firm 1) gets a license.

In fixed-fee licensing, when the innovator plans on selling the license to only one firm, it aims to maximize its profit and thus charges the maximum possible fee to the efficient firm. Thus, the efficient firm willingly accepts the asked fee to buy a license.

The resulting welfare is

$$W^P(1) = \int_0^Q P(u)du - c_0 q_0^N - dq_0^N - R(1) = \frac{1}{9}\{4A(A - c_0 - 2d) + \frac{11}{2}c_0{}^2 + d(7c_0 + \frac{11}{2}d)\}. \tag{32}$$

4.3 When the innovator sells licenses to both firms: *k = 2*

When *k = 2*, two different maximum willingness-to-pay for fixed fee can be obtained from $\pi_i^L(2) - \pi_i^N(1) = 0$. Thus, from the profit functions of the two licensed firms in (1), we have $q_0^L = \frac{A-2c_0}{3}$, $q_1^L = \frac{A+c_0}{3}$, $Q = \frac{2A-c_0}{3}$, and $P = \frac{A+c_0}{3}$ at equilibrium[12]. Then, using the outputs in equilibrium, each firm's maximum willingness-to-pay for fixed fee can be produced as follows:

$$f_0(2) = \frac{4d(A-2c_0-d)}{9}, \tag{33}$$

$$f_1(2) = \frac{4d(A+c_0-d)}{9}. \tag{34}$$

Then, the innovator determines the optimal fixed fee at $\min[f_0(2), f_1(2)]$. Since $f_1(2) > f_0(2)$, the optimal fixed fee is the inefficient firm's maximum willingness-to-pay for fixed fee, $f(2) = f_0(2)$. The profit of the licensed public firm is $\pi_0^L(2) = \left(\frac{A-2c_0}{3}\right)^2 - f_0(2)$ and that of the licensed private firm is $\pi_1^L(2) = \left(\frac{A+c_0}{3}\right)^2 - f_0(2)$.

[12] Notice that the equilibrium outputs are positive and independent of the level of emission tax.

Then, the profit of the innovator is as follows:

$$R(2) = \frac{8d(A - 2c_0 - d)}{9}. \tag{35}$$

The resulting welfare is

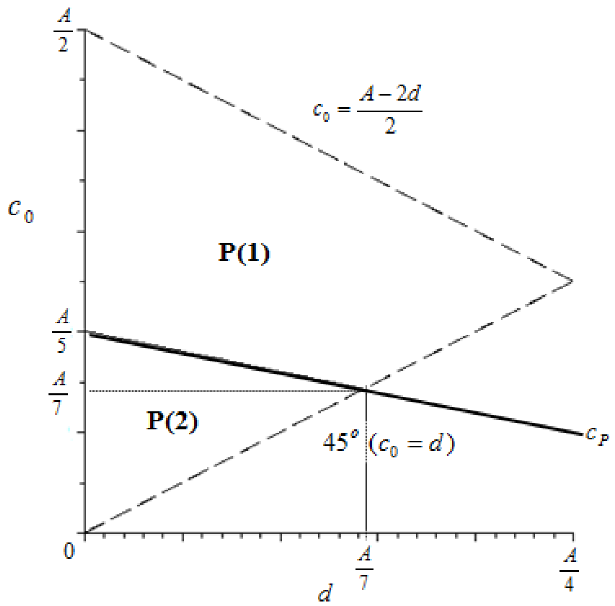
$$W^P(2) = \int_0^Q P(u)du - c_0 q_0^L - R(2) = \frac{1}{9}\{4A(A - c_0 - 2d) + \frac{11}{2}c_0^{\,2} + d(16c_0 + 8d)\}. \tag{36}$$

4.4 The optimal choice of the innovator: Comparison between *k = 1* and *k = 2*

Let $c_P = \frac{A-2d}{5}$, which satisfies $R(1) = R(2)$ in (31) and (35).

Proposition 3. In a pure duopoly, the innovator licenses to both firms if $c_0 \le c_P$, but only to the efficient firm if $c_0 > c_P$.

Proof. From (31) and (35), we have $c_P = \frac{A-2d}{5}$. Thus, if $c_0 \lesseqgtr c_P$, then $R(1) \lesseqgtr R(2)$. ■



<Fig. 2 Optimal choices of the eco-innovator in a private duopoly market>

Figure 2 shows the optimal choices of the eco-innovator in a private duopoly market. The optimal choices in the private market are described by $\mathrm{P}(k)$. Depending on the damage level and cost gap, the innovator decides the optimal number of licensees. In particular, the optimal choice on the upper region of of c_P is to sell a license to only one firm and the optimal choice on the lower region of c_P is to sell licenses to both firms. Specifically, regardless of the damage, the foreign innovator prefers a non-exclusive fixed-fee licensing strategy when the cost gap between both firms is small ($c_0 < \frac{A}{7}$), while the innovator prefers exclusive licensing when the cost gap is large ($c_0 > \frac{A}{5}$). However, when the cost gap is intermediate ($\frac{A}{7} < c_0 < \frac{A}{5}$), the optimal licensing strategy depends on both damage level and cost gap. This implies that with increasing cost gap and damage level, the efficient firm is willing to pay more licensing fee. Thus, when the cost gap and environmental damages are large, the innovator prefers exclusive fixed-fee licensing, while when these are small, the innovator prefers non-exclusive fixed-fee licensing. Consequently, in the eco-industry, increasing cost gap and damage result in exclusion effect on licensing.

Proposition 4. In a private duopoly market, non-exclusive licensing is always more desirable than exclusive licensing.

Proof. Note that from (28), (32), and (36), $W^P(2) - W^P(1) = (c_0 + \frac{5}{18}d)d > 0$ and $W^P(1) - W^P(0) = \frac{1}{6}(2c_0 + d)d > 0$. Thus, we have $W^P(0) < W^P(1) < W^P(2)$. ■

This proposition states that a non-exclusive fixed-fee licensing contract improves social welfare. Under fixed-fee licensing in a private duopoly market, with increasing cost gap and damage level, the foreign innovator has an incentive to exclude polluting firms to increase its profits, while domestic polluting firms pay more to the foreign innovator under the exclusive licensing contract. Therefore, post-privatization the regulator should still consider the restriction of the exclusive fixed-fee licensing contract.

5. Welfare Comparisons between Mixed and Private Markets

5.1 Discussions on welfare analysis

In this section, we examine how the welfare consequences arise from the foreign innovator's optimal decision of fixed-fee licensing in private and mixed markets. Note that its decision depends on the levels of environmental damage and cost gap. Thus, we need to compare the different cost thresholds. Since $c_P < c_S(2)$, we have three cases.

First, consider the case of $c_0 < c_P$.

Lemma 4. Suppose that $c_0 < c_P$ and $c_0 < c_t$. Then, the existence of the public firm is more socially desirable to the society if $c_0 < c_K$, but privatization improves social welfare if $c_0 > c_K$

because it induces the innovator to sell to both firms.

Proof. Note that $W_0(1)=W_1(1)=W^M(1)$. From (18) and (36), if $c_0 \lesseqgtr c_K$, then $W^M(1) \gtreqless W^P(2)$, where $c_K = \frac{1}{16}(5A+7d-\sqrt{9A^2+102dA+161d^2})$. ■

Lemma 5. Suppose that $c_0 < c_P$ and $c_0 > c_t$. Then, privatization improves social welfare because it induces the innovator to sell to both firms.

Proof. From (25) and (36), if $c_0 \lesseqgtr c_D$, then $W_1(2) \gtreqless W^P(2)$, where $c_D = \frac{1}{16}(5A+52d-\sqrt{9A^2+264dA+2384d^2})$. However, $c_0 > c_D$ if $c_0 < c_P$ and $c_0 > c_t$. Thus, $W_1(2) < W^P(2)$. ■

Second, consider the case of $c_P < c_0 < c_S(2)$.

Lemma 6. Suppose that $c_P < c_0 < c_S(2)$ and either $c_0 < c_t$ or $c_0 < c_j$ holds. Then, privatization always improves social welfare because it induces the innovator to sell to only the efficient private firm.

Proof. From (18) and (32), if $c_0 \lesseqgtr c_E$, then $W^M(1) \gtreqless W^P(1)$, where $c_E = \frac{1}{16}(5A-2d-\sqrt{9A^2+12dA+36d^2})$. However, c_0 is always greater than c_E when c_0 is either $c_0 < c_t$ or $c_0 < c_j$ in $c_P < c_0 < c_S(2)$. Thus, $W^M(1) < W^P(1)$. ■

Lemma 7. Suppose that $c_P < c_0 < c_S(2)$ and neither $c_0 < c_t$ nor $c_0 < c_j$ holds. Then, the existence of the public firm is more socially desirable to the society if $c_0 < c_F$, but privatization improves social welfare if $c_0 > c_F$ because it induces the innovator to sell to only the efficient private firm.

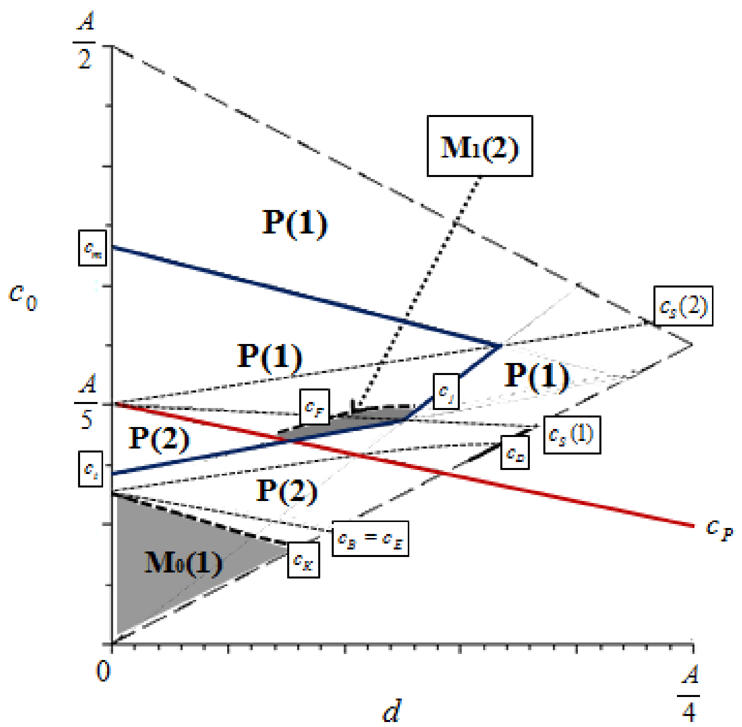
Proof. From (25) and (32), if $c_0 \lesseqgtr c_F$, then $W_1(2) \gtreqless W^P(1)$, where $c_F = \frac{1}{16}(5A+43d-\sqrt{9A^2+174dA+1449d^2})$. ■

Finally, consider the case of $c_0 > c_S(2)$.

Lemma 8. Suppose that $c_0 > c_S(2)$. Then, privatization always improves social welfare because it induces the innovator to sell to only the efficient firm.

Proof. From (24) and (32), if $c_0 \lesseqgtr c_B$, then $W_0(2) \gtreqless W^P(1)$, where $c_B = \frac{1}{16}(5A-2d-\sqrt{9A^2+12dA+36d^2})$. However, it is always $c_0 > c_B$ if $c_0 > c_S(2)$; then, we have $W_0(2) < W^P(1)$. From lemma 6, we know that $W^M(1) < W^P(1)$ if $c_0 > c_S(2)$. Thus, $W^P(1) > W^M(1) \& W_0(2)$ for $c_0 > c_S(2)$. ■

Proposition 5. With a foreign innovator, the domestic welfare effect of privatization policy depends not only on the cost gap but also on the environmental damage level. In particular, (i) privatization policy can improve the social welfare when cost gap and environmental damage are large; (ii) when both cost gap and environmental damage are small, the exclusive contract under nationalization is better; and (iii) when damage level is intermediate, it is possible to increase social welfare by nationalization under the non-exclusive contract.



<Fig. 3 Domestic welfare comparison of privatization under the optimal licensing contract>

Figure 3 shows the welfare effect of privatization policy when the foreign innovator uses the fixed-fee licensing contract. Note that c_z, where z = s, t, m, j, and p represents the locus of optimal choices by the innovator and z = B, D, F, E, and K represents the locus of the welfare comparisons between mixed and private markets with a different number of fixed-fee licensees. It is worthwhile to notice that the optimal decision on privatization under fixed-fee licensing depends not only on the cost gap but also on the environmental damage level. The shaded area in Figure 3 indicates that the mixed market is better to the society, while the non-shaded area suggests that privatization can improve social welfare.

On the one hand, in the case of $c_0 < c_P$, the innovator prefers the non-exclusive licensing strategy in the private market, while it prefers exclusive licensing in the mixed duopoly market. Thus, when cost gap or damage is large, privatization can improve social welfare, while the mixed market is better to the society when both cost gap and damage are small, although the innovator prefers exclusive licensing strategy in the mixed market. That is, the role of the public firm in increasing the welfare is still effective when both cost gap and damage are small.

As a matter of fact, there are three effects of privatization on domestic welfare in the literature: (i) output substitution effect, which is negative to the society because privatization decreases the production of total outputs; (ii) cost-saving effect, which is positive to the society because private firms produce more with cheaper cost; and (iii) rent-leaking effect, which is negative to the society because private firms become more competitive to produce output and as a result, increase the payment of goods to the foreign innovator. We can add one more effect of privatization on the welfare, that is, non-exclusion effect of licensing. Policy change from the mixed market to the private market causes the switch of the optimal choice of the foreign innovator from exclusive licensing to non-exclusive licensing strategy. Further, it causes the removal of damage by zero-pollution technology when both cost gap and damage are large. However, when both cost gap and damage are low, the mixed market under exclusive licensing is better to the society because negative rent-leaking effect dominates this damage-reducing effect from the non-exclusive contract.

On the other hand, in the other case of $c_0 > c_P$, the innovator prefers exclusive licensing strategy in the private market, while it prefers non-exclusive licensing in the mixed duopoly market. When both cost gap and damage are large, the rent-leaking effect is mostly greater than the damage effect. Thus, although pollution increases, privatization can save the amount of licensing fee leaks to the foreign innovator. In the case where these are intermediate, the presence of the public firm is still more desirable to the society when the damage-reducing effect from the non-exclusive contract dominates the rent-leakage effect (i.e., the shaded area of $\mathrm{M}_1(2)$ in the figure 3). Therefore, appropriate government policies between mixed and private markets could enhance the welfare effect of technology licensing on the society.

5.2 Discussions on the restriction of exclusive licensing

In the context of licensing contract where the non-exclusive contract is deterministic in welfare comparisons, the restriction of exclusive licensing might be beneficial to the society. We now examine the welfare effect of privatization under the restriction of exclusive licensing contract. When the government restricts foreign innovator to only non-exclusive licensing, the profits of the innovator in mixed and private markets should be positive to adopt non-exclusive licensing.

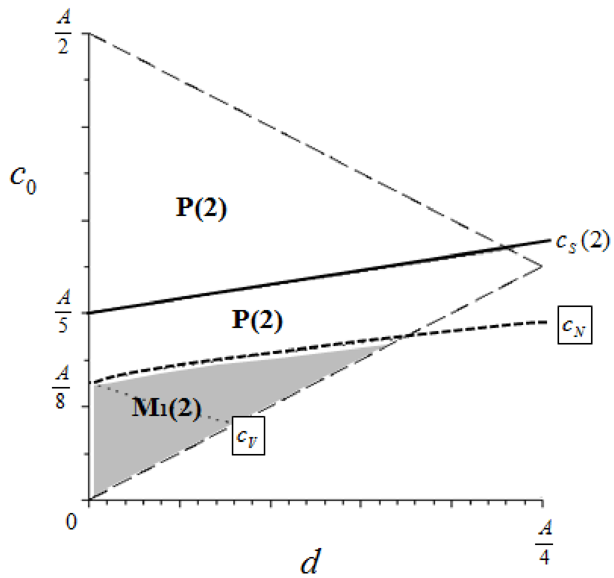
Considering the constraints of the cost gap, (i) $c_0 < \frac{A-d}{2}$ for $R(2) > 0$ from (14); (ii) $c_0 > \frac{d}{2}$ for $R_1^M(2) > 0$ from (33); and (iii) $c_0 > A - \frac{d}{2}$ for $R_0^M(2) > 0$ from (34), we have the following lemmas.

Lemma 9. Suppose that $c_0 < c_S(2)$. Under non-exclusive licensing regulation, the mixed market is more desirable to the society if $c_0 < c_N$, while the private market is more desirable to the society if $c_0 > c_N$.

Proof. From (15) and (36), if $c_0 \lesseqgtr c_N$, then $W_1(2) \gtreqless W^P(2)$, where $c_N = \frac{1}{16}(5A + 52d - \sqrt{9A^2 + 264dA + 2384d^2})$. ■

Lemma 10. Suppose that $c_0 > c_S(2)$. Under non-exclusive licensing regulation, the private market can always improve the social welfare.

Proof. From (15) and (35), if $c_0 \lesseqgtr c_V$, then $W_0(2) \gtreqless W^P(2)$, where $c_V = \frac{1}{16}(5A + 7d - \sqrt{9A^2 + 102dA + 161d^2})$. However, $c_0 > c_V$ if $c_0 > c_S(2)$. Thus, $W_0(2) < W^P(2)$. ■



<*Fig. 4 Privatization policy under non-exclusive licensing regulation*>

Figure 4 shows the optimal choice on privatization under the non-exclusive licensing contract. Note that c_S is the locus of optimal choice of the innovator in the mixed market, while c_z, where z = N, V represents the locus of the welfare comparisons under the non-exclusive fixed-fee licensing regulation. Then, the optimal privatization policy under the non-exclusive licensing regulation depends crucially on the cost gap. This shows that the mixed market is better to the society when the cost gap is small (shaded area), while the private market can improve social welfare when the cost gap is large (non-shaded area). Therefore, the restriction of exclusive licensing can expand the superiority of the mixed market.

6. Concluding Remarks

This article investigates the welfare effect of privatization policy when a foreign innovator decides an eco-technology licensing strategy in a polluting mixed duopoly market. Under a fixed-fee licensing contract, we examine the strategic choice on an exclusive licensing contract of the innovator and the welfare effect of privatization. In a mixed market, the innovator prefers the exclusive contract when both cost gap and damage are small or large, while it prefers the non-exclusive contract when those are intermediate. In a private market, the innovator prefers the non-exclusive contract when the cost gap is small, while it prefers the exclusive contract when the cost gap is large. Thus, the innovator's strategy on the exclusive licensing is influential to determine the welfare effect of privatization, which depends not only on cost gap between polluting firms but also on environmental damage. In particular, privatization can improve social welfare when both cost gap and damage are large, while the exclusive contract under the mixed market is better to the society when both cost gap and environmental damage are small. Importantly, when the cost gap and damage level are intermediate, the non-exclusive contract in a mixed market is better to the society. Therefore, the government should consider the welfare effect of exclusive licensing contract in the process of privatization and construct an appropriate non-exclusion regulation to improve the social welfare.

As for future research, the analysis should incorporate some important real issues in eco-technology licensing. First, it is important to consider the sub-licensing issue in which the licensed public firm can give sub-license to the private firm (Miao, 2013). Second, it is natural to investigate the other types of licensing contract, such as royalty, auctioning, and two-part tariff licensing strategies (Chen et al., 2014). Finally, it is worthwhile to incorporate different bargaining powers between the innovator and the polluting firms in mixed and private markets.

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