Rewards versus Intellectual Property Rights in Green Innovation: Incentive Design for Capacity Development

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Abstract

Prior economic analyses of reward systems and patent systems have given little attention to innovation research options and environmental externalities. Unlike those prior analyses, this paper examines reward systems and patent systems with the environmental externality in the context of research with two alternatives: normal innovation and green innovation. This paper describes the following: Under a patent system, the innovator never prefers green innovation research to normal innovation research. On the other hand, under a reward system, the innovator will prefer to pursue green innovation research unless environmental damage is sufficiently small. Furthermore, this paper shows what the incentive design for green innovation should be.

Keywords

Intellectual Property Rights, Green Innovation,
Law and Economics, Incentive Design

JEL classification

K39, O34
1 Introduction

Generally, a patent system creates incentives to innovate by conferring a right of monopolistic supply of innovations to their innovator. That is, a patent system promotes innovations in exchange for the deadweight loss of monopoly. In relation to the patent system and innovation, many studies exist.\(^2\)

Under a reward system, on the other hand, innovators are paid directly by the government for innovations; then the innovations pass into the public domain. That is, a reward system can create incentives to innovate without a market failure because of monopoly. With regard to such a reward system and innovation, few studies exist. Shavell and Van Ypersele (1999, 2001) compared a patent system to a reward system under asymmetric information by which the government cannot observe a potential demand of innovation, but the innovator can. These studies showed that either a patent system or a reward system might be superior to the other. Goto (2000) verified the results of Shavell and Van Ypersele (1999) from the point of view of the timing of the innovator’s observation, and considered the innovator’s reporting to the government.

However, these studies assumed that the innovation research is single and that it has no option. That is, these studies did not incorporate the research options that innovators can choose from. Innovation studies have presented many options. For instance, one innovation might have a large potential profit with negative externalities; another other might have a small potential profit with positive externalities. For that reason, this paper explains reward systems and intellectual property rights (patent systems) in the context of environmental technology innovation.

This paper is organized as follows: Section 2 presents the model; section 3 shows the first-best outcome in each research option case. Section 4 describes the patent system, whereas section 5 presents analysis of the reward system. Section 6 describes policy implications; section 7 presents salient conclusions.

2 The Model

According to Shavell and Van Ypersele (2001), consider a model of the following two players: a (potential) innovator and the government. Both players are risk neutral.

The innovator might invest in innovation research that will succeed with a probability that depends on the investment. The innovator has two research options: normal innovation research and green innovation research. In normal innovation research, investment \(k \in [0, \infty)\) succeeds with probability \(p(k)\), where \(p(k) \in [0, 1)\), \(p'(k) > 0\), \(p''(k) < 0\), \(p(0) = 0\), and \(\lim_{k \to \infty} p(k) = 1\). On the other hand, in green innovation research, investment \(k\) succeeds with probability \(\alpha p(k)\), where \(\alpha \in (0, 1)\) is positive constant; it implies relative difficulty in green R&D compared to normal R&D.

For simplicity, it is assumed that if an innovation exists, a new product is producible at zero cost per unit. However, normal innovative production causes

a constant environmental damage of $e > 0$ per unit. On the other hand, green innovative production causes no pollution.

Regarding the demand curve for the product, let $q$ denote the quantity of the product, where $d(q; t_i) \equiv t_i - q$ denotes inverse demand curve for the product, and $t_i$ is the demand parameter in $\{t_L, t_H\}$ and implies the market size of the product. Parameter $t_H$ is realized with probability $\mu \in (0, 1)$, and $t_L$ is realized with probability $1 - \mu$. It is assumed that the consumers are indifferent to the innovation property, either normal or green, because they are never damaged by purchasing the product.

Suppose that the function $p(\cdot)$, the environment damage $e$, the family of possible demand curves $d(q; t_i) \equiv t_i - q$, and the probability distribution of $t_i$ are common knowledge. The innovator can only observe the realized $t_i$, and decide the research option and the investment $k$ as private information. In addition, it is assumed that the government cannot observe the product’s quantity and the research option until the innovative products are sold.

The government has the following two policy alternatives: the patent system and the reward system. They are set up as a system to maximize the expected social welfare. The expected social welfare comprises the expected value of the utility individuals obtain from the innovative product, minus the total environmental damage, and minus research investment.

The timing of this model is as follows:

1. The government sets up the system.
2. The innovator chooses normal or green innovation research, and investment $k$.
3. The research outcome is realized.
4. According to the system and the research outcome, the utility individuals are decided.

3 First-Best Outcome

In this section, we consider the first-best outcome as the benchmark. First, presume that the demand parameter $t_i$, the research option and the investment $k$ all entail perfect information.

3.1 Normal Innovation

First, consider the normal innovation case. Let $q_n^{FB}(t_i)$ denote the first-best quantity of normal innovation products under any $t_i \in \{t_L, t_H\}$.

Next presume $e < t_i$, then $q_n^{FB}(t_i)$ must satisfy $d(q_n^{FB}(t_i); t_i) \equiv t_i - q_n^{FB}(t_i) = e$; thus,

$$q_n^{FB}(t_i) = t_i - e.$$  \hfill (1)

Next suppose that $e \geq t_i$; then $q_n^{FB}$ must satisfy $d(q_n^{FB}(t_i); t_i) \equiv t_i - q_n^{FB}(t_i) \leq e$. As a result,

$$q_n^{FB}(t_i) = 0.$$  \hfill (2)
Therefore, the social surplus is

$$s^\text{FB}_n(t_i) = \int_0^{q^\text{FB}(t_i)} [d(q; t_i) - e] dq = \begin{cases} \frac{[t_i-e]^2}{2} & \text{if } e < t_i \\ 0 & \text{if } e \geq t_i \end{cases}. \quad (3)$$

The first-best normal research investment $k^\text{FB}_n$ maximizes

$$p(k)s^\text{FB}_n(t_i) - k,$$

so $k^\text{FB}_n$ must satisfy

$$p'(k)s^\text{FB}_n(t_i) - 1 = 0 \quad \text{if } e < t_i, \quad (5)$$

$$k = 0 \quad \text{if } e \geq t_i. \quad (6)$$

Let $k(z)$ denote the $k$ that would be chosen if $z$ were the payoff from an innovation; then $k^\text{FB}_n$ can be written as

$$k^\text{FB}_n = k(s^\text{FB}_n(t_i)) = \begin{cases} k \left( \frac{[t_i-e]^2}{2} \right) & \text{if } e < t_i \\ 0 & \text{if } e \geq t_i \end{cases}. \quad (7)$$

Consequently, the first-best social welfare as a function of $t_i$ is given the following.

$$W^\text{FB}_n(t_i) = p(k(s^\text{FB}_n(t_i)))s^\text{FB}_n(t_i) - k(s^\text{FB}_n(t_i))$$

$$= \begin{cases} p \left( k \left( \frac{[t_i-e]^2}{2} \right) \right) \frac{[t_i-e]^2}{2} - k \left( \frac{[t_i-e]^2}{2} \right) & \text{if } e < t_i \\ 0 & \text{if } e \geq t_i \end{cases}. \quad (8)$$

### 3.2 Green Innovation

Similarly, we can consider the green innovation case. Let $q^\text{FB}_g(t_i)$ denote the first-best quantity of green innovation products under any $t_i$. It must satisfy $d(q^\text{FB}_g(t_i); t_i) \equiv t_i - q^\text{FB}_g(t_i) = 0$; therefore,

$$q^\text{FB}_g(t_i) = t_i. \quad (9)$$

Then, the social surplus is

$$s^\text{FB}_g(t_i) = \int_0^{q^\text{FB}_g(t_i)} d(q; t_i) dq = \frac{t_i^2}{2}. \quad (10)$$
Therefore, the first-best green research investment $k_{FB}^g$ maximizes

$$\alpha p(k)s_g^{FB}(t_i) - k,$$

so that $k_{FB}^g$ must satisfy

$$\alpha p'(k)s_g^{FB}(t_i) - 1 = 0.$$  \(12\)

Therefore, $k_{FB}^g$ can be written as

$$k_{FB}^g = k(\alpha s_g^{FB}(t_i)) = k\left(\frac{\alpha t_i^2}{2}\right).$$  \(13\)

Consequently, the first-best social welfare as a function of $t_i$ is given as

$$W_g^{FB}(t_i) = \alpha p(k(\alpha s_g^{FB}(t_i)))s_g^{FB}(t_i) - k(\alpha s_g^{FB}(t_i))$$

$$= p\left(k\left(\frac{\alpha t_i^2}{2}\right)\right)\left(\frac{\alpha t_i^2}{2} - k\left(\frac{\alpha t_i^2}{2}\right)\right).$$  \(14\)

### 3.3 First-Best Innovation Research

Comparing (8) with (14) yields the following relation for any $t_i \in \{t_L, t_H\}$.

$$W_n^{FB}(t_i) \leq W_g^{FB}(t_i) \iff \alpha \leq \frac{[t_i - e]^2}{t_i^2} \quad \text{if} \quad e < t_i,$$  \(15\)

$$W_n^{FB}(t_i) < W_g^{FB}(t_i) \quad \text{if} \quad e \geq t_i.$$  \(16\)

From (15) and (16), Fig. 2 is obtainable.

![Figure 2: First-best innovation research](image)

It implies that if $e$ or $\alpha$ is sufficiently high, green innovation research must be adopted; otherwise, normal innovation research must be adopted.
4 Patent system

Now consider the case in which the government cannot observe the demand parameter, the innovator’s research option, or the investment level. The patent system model must be established first. Under the patent system, the innovator has the exclusive right to sell the product resulting from an innovation. Therefore, if the innovator succeeds in the research, he will sell the monopoly quantity and obtain a monopoly profit.

4.1 Normal Innovation

First, consider the normal innovation case. Let $q_{n}^{M}(t_{i})$ denote the monopoly quantity of normal innovation products under any $t_{i} \in \{t_{L}, t_{H}\}$. Furthermore, let $\pi_{n}(t_{i})$ denote the monopoly profit of this case. The monopoly quantity $q_{n}^{M}(t_{i})$ must satisfy $\frac{\partial d(q_{n}^{M}(t_{i}); t_{i})}{\partial q_{n}^{M}(t_{i})} + d(q_{n}^{M}(t_{i}); t_{i}) = -q_{n}^{M}(t_{i}) + t_{i} - q_{n}^{M}(t_{i}) = 0$. Consequently,

$$q_{n}^{M}(t_{i}) = \frac{t_{i}}{2}. \quad (17)$$

Then, the monopoly profit is

$$\pi_{n}(t_{i}) = \frac{t_{i}^{2}}{4}. \quad (18)$$

On the other hand, the consumer surplus ($cs$) and the total environmental damage ($h$) are, respectively,

$$cs_{n}^{M}(t_{i}) = \frac{t_{i}^{2}}{8}, \quad \text{and} \quad (19)$$

$$h_{n}^{M}(t_{i}) = \frac{t_{i}e}{2}. \quad (20)$$

Therefore, the social surplus is given as

$$s_{n}^{M}(t_{i}) = cs_{n}^{M}(t_{i}) + \pi_{n}(t_{i}) - h_{n}^{M}(t_{i}) = \frac{3t_{i}^{2}}{8} - \frac{et_{i}}{2}. \quad (21)$$

Using (3) and (21), it can be derived that

$$s_{n}^{M}(t_{i}) \leq s_{n}^{FB}(t_{i}), \quad (22)$$
where the equal sign holds if and only if $e = \frac{t_i}{2}$.

The innovator will consider not $s_n^{FB}(t_i)$ but $\pi_n(t_i)$; therefore, he chooses $k$ to maximize

$$p(k)\pi_n(t_i) - k. \quad (23)$$

Then, the innovator will choose $k(\pi_n(t_i))$. Now, the following condition is obtainable.

$$\pi_n(t_i) \leq s_n^{FB}(t_i) \iff \frac{t_i^2}{4} > \frac{(t_i - e)^2}{2}$$

$$\iff 0 > 2e^2 - 4te + t_i^2$$

$$\iff e \leq t_i \left[1 - \frac{1}{\sqrt{2}}\right] \quad (24)$$

Therein, $e \in (0, t_L]$. Because $k(z)$ is an increasing function of $z$, it can be also obtained that

$$\pi_n(t_i) \leq s_n^{FB}(t_i) \iff k(\pi_n(t_i)) \leq k(s_n^{FB}(t_i)). \quad (25)$$

Consequently, from (22), (24) and (25), the following lemma can be derived.

**Lemma 1** Under the patent system, assuming that normal innovation research is adopted, the following are true.

(i) Inadequate investment and social surplus of innovation are realized if $0 < e < t_i \left[1 - \frac{1}{\sqrt{2}}\right]$.

(ii) The first-best investment and inadequate social surplus of innovation are realized if $e = t_i \left[1 - \frac{1}{\sqrt{2}}\right]$.

(iii) Excessive investment and inadequate social surplus of innovation are realized if $t_i \left[1 - \frac{1}{\sqrt{2}}\right] < e < \frac{t_i}{2}$.

(iv) Excessive investment and optimal social surplus of innovation are realized if $e = \frac{t_i}{2}$.

(v) Excessive investment and inadequate social surplus of innovation are realized if $e > \frac{t_i}{2}$.

### 4.2 Green Innovation

Next consider the green innovation case. Let $q_g^M(t_i)$ denote the monopoly quantity of green innovation products under any $t_i \in \{t_L, t_H\}$. Furthermore, let $\pi_g(t_i)$ denote the monopoly profit of this case. The monopoly quantity $q_g^M(t_i)$ must satisfy

$$\frac{\partial d(q_g^M(t_i); t_i)}{\partial q_g^M(t_i)} + d(q_g^M(t_i); t_i) = -q_g^M(t_i) + t_i - q_g^M(t_i) = 0; \text{ thus}$$

$$q_g^M(t_i) = \frac{t_i}{2}. \quad (26)$$
The green innovation case

Figure 4: Lemma 1

Then, the monopoly profit is

$$\pi_g(t_i) = \frac{t_i^2}{4}. \quad (27)$$

On the other hand, the consumer surplus and the total environmental damage are, respectively,

$$cs_g(t_i) = \frac{t_i^2}{8}, \quad (28)$$

$$h_g(t_i) = 0. \quad (29)$$

Therefore, the social surplus is given as

$$s_g(t_i) = cs_g(t_i) + \pi_g(t_i) - h_g(t_i) = \frac{3t_i^2}{8}. \quad (30)$$

Using (10) and (30), it can be derived that

$$s_g(t_i) < s_{FB}^B(t_i) \quad \text{for any} \quad t_i \in \{t_L, t_H}\]. \quad (31)$$
The innovator will consider not $s_g^{FB}(t_i)$ but $\pi_g(t_i)$; therefore, he chooses $k$ to maximize
\[ \alpha p(k) \pi_g(t_i) - k. \] (32)
Then, the innovator will choose $k(\alpha \pi_g(t_i))$. It follows that $\alpha \pi_g(t_i) < s_g^{FB}(t_i)$, and then
\[ k(\alpha \pi_g(t_i)) < k(s_g^{FB}(t_i)). \] (33)
Consequently, from (31) and (33), the following lemma is obtained.

**Lemma 2** Under the patent system, assume that green innovation research is adopted. Then, inadequate investment and social surplus of innovation are realized.

### 4.3 Normal Innovation Research vs. Green Innovation Research

Under the patent system, in the normal innovation research case, the innovator’s expected profit is
\[ V_n^M(t_i) = p(k(\pi_n(t_i))\pi_n(t_i) - k(\pi_n(t_i))) \]
\[ = p \left( k \left( \frac{t_i^2}{4} \right) \right) t_i^2 - k \left( \frac{t_i^2}{4} \right). \] (34)
Similarly, in the green innovation research case, the innovator’s expected profit is
\[ V_g^M(t_i) = p(k(\alpha \pi_g(t_i))\alpha \pi_g(t_i) - k(\alpha \pi_g(t_i))) \]
\[ = p \left( k \left( \frac{\alpha t_i^2}{4} \right) \right) \alpha t_i^2 - k \left( \frac{\alpha t_i^2}{4} \right). \] (35)
Now, from the definition of $k(z)$, it can be derived that
\[ \frac{\partial p(k(z))z - k(z)}{\partial z} = p(k(z)) + \frac{\partial k(z)}{\partial z} [p'(k(z))z - 1] = p(k(z)) > 0. \] (36)
Therefore, $t_i^2 > \frac{\alpha t_i^2}{4}$ for any $\alpha \in (0, 1)$ implies that
\[ V_n^M(t_i) > V_g^M(t_i) \text{ for any } t_i \in \{t_L, t_H\}. \] (37)
Consequently, the following proposition is obtained.

**Proposition 1** Under the patent system, the innovator will prefer normal innovation research to green innovation research.

## 5 Reward system

Next, consider the case in which the government cannot observe the demand parameter, the innovator’s research option, and the investment level.

Under the reward system, the government buys out the innovation from the innovator if the research succeeds. It is assumed that the innovation information is placed in the public domain and made available to a competitive production industry. Therefore, the product will be sold at a price of zero, so that zero profit will be made from production sales and the total quantity produced will be $q_g^{FB}(t_i) = t_i$, in either research option case.
5.1 Normal Innovation

First, consider the normal innovation case. The consumer surplus and the total environmental damage are, respectively,

\[ \text{cs}_n(t_i) = \frac{t_i^2}{2}, \quad \text{and} \]
\[ h_n(t_i) = et_i. \]

Therefore, the social surplus is given as

\[ s_n(t_i) = \text{cs}_n(t_i) - h_n(t_i) = t_i \left[ \frac{t_i}{2} - e \right] \geq 0. \]

Let \( r_n \) denote the reward paid by the government for normal innovation. Because the innovator earns zero profit from the production sales, the incentive to innovate is attributable entirely to the reward. The innovator therefore chooses \( k \) to maximize

\[ p(k) r_n - k. \]

Then, the innovator will choose \( k(r_n) \).

For the assumption that the government cannot observe \( t_i \), the reward \( r_n \) must be fixed and independent of \( t_i \). The social welfare as a function of \( r_n \) is

\[ W_n(r_n) = p(k(r_n)) \left[ \mu s_n^R(t_H) + (1 - \mu) s_n^R(t_L) \right] - k(r_n) \]
\[ = p(k(r_n)) \left[ \mu \left[ \frac{t_H^2}{2} - et_H \right] + (1 - \mu) \left[ \frac{t_L^2}{2} - et_L \right] \right] - k(r_n) \]
\[ = p(k(r_n)) E(s_n^R) - k(r_n), \]

where \( E(s_n^R) \equiv \mu \left[ \frac{t_H^2}{2} - et_H \right] + (1 - \mu) \left[ \frac{t_L^2}{2} - et_L \right]. \)

Now suppose that \( E(s_n^R) > 0 \), where

\[ E(s_n^R) > 0 \quad \Leftrightarrow \quad e < \frac{\mu t_H^2 + (1 - \mu) t_L^2}{2[\mu t_H + (1 - \mu) t_L]}. \]

Consider that \( p(k) E(s_n^R) - k \) is maximized over \( k \) if \( k = k(E(s_n^R)) \), it then follows that (42) is maximized if \( r_n = E(s_n^R) \). Therefore, the reward is the expected
social surplus from normal innovation. Consequently, if \( e < \frac{\mu t_H^2 + (1 - \mu) t_L^2}{2[\mu t_H + (1 - \mu) t_L]} \), then the innovator invests \( k(E(s^R_n)) \).

Next presume \( E(s^R_n) \leq 0 \), where

\[
E(s^R_n) \leq 0 \iff e \geq \frac{\mu t_H^2 + (1 - \mu) t_L^2}{2[\mu t_H + (1 - \mu) t_L]}.
\] (44)

It then follows that (42) is maximized if \( r_n = 0 \). Therefore, the reward is zero. Consequently, if \( e \geq \frac{\mu t_H^2 + (1 - \mu) t_L^2}{2[\mu t_H + (1 - \mu) t_L]} \), then the innovator never invests.

On the other hand, if the true demand parameter is \( t_i \) \((i = L, H)\), it is socially desirable that the investment \( k \) depend on \( s^R_n(t_i) \), where

\[
s^R_n(t_i) \geq 0 \iff e \leq \frac{t_i}{2},
\] (45)

and

\[
s^R_n(t_L) < E(s^R_n) < s^R_n(t_H) \text{ for any } e \in (0, \frac{t_H + t_L}{2}).
\] (46)

Furthermore, it can be readily obtained that

\[
t_L < \frac{\mu t_H^2 + (1 - \mu) t_L^2}{\mu t_H + (1 - \mu) t_L} < t_H.
\] (47)

Using (43), (44), (45), (46), (47), and the above reward analysis, the following lemma can be derived.

**Lemma 3** Under the reward system, assume that normal innovation research is adopted. In those conditions, the following are true.
(i) If the true $t_i$ is $t_L$ and $0 < e < \mu(t_H - t_L) \left[ \sqrt{1 + \frac{t_H + t_L}{\mu(t_H - t_L)}} - 1 \right]$,

(a) the government sets up a reward $r^*_n = E(s^R_n)$, and

(b) excessive investment and inadequate social surplus of innovation are realized.

(ii) If the true $t_i$ is $t_L$ and $e = \mu(t_H - t_L) \left[ \sqrt{1 + \frac{t_H + t_L}{\mu(t_H - t_L)}} - 1 \right]$,

(a) the government sets up a reward $r^*_n = E(s^R_n)$, and

(b) the first-best investment and the inadequate social surplus of innovation are realized.

(iii) If the true $t_i$ is $t_L$ and $\mu(t_H - t_L) \left[ \sqrt{1 + \frac{t_H + t_L}{\mu(t_H - t_L)}} - 1 \right] < e < \frac{\mu^2(e_h + (1 - \mu)t^2_L)}{2[\mu(t_H + (1 - \mu)t_L)]}$,

(a) the government sets up a reward $r^*_n = E(s^R_n)$, and

(b) inadequate investment and social surplus of innovation are realized.

(iv) If the true $t_i$ is $t_L$ and $\frac{\mu^2(e_h + (1 - \mu)t^2_L)}{2[\mu(t_H + (1 - \mu)t_L)]} \leq e < t_L$,

(a) the government sets up a reward $r^*_n = 0$, and

(b) inadequate (no) investment and (no) social surplus of innovation are realized.

(v) If the true $t_i$ is $t_L$ and $e \geq t_L$,

(a) the government sets up a reward $r^*_n = 0$, and

(b) the first-best (no) investment and (no) social surplus of innovation are realized.

(vi) If the true $t_i$ is $t_H$ and $0 < e < \frac{\mu^2(e_h + (1 - \mu)t^2_L)}{2[\mu(t_H + (1 - \mu)t_L)]}$,

(a) the government sets up a reward $r^*_n = E(s^R_n)$, and

(b) inadequate investment and social surplus of innovation are realized.

(vii) If the true $t_i$ is $t_H$ and $\frac{\mu^2(e_h + (1 - \mu)t^2_L)}{2[\mu(t_H + (1 - \mu)t_L)]} \leq e < t_H$,

(a) the government sets up a reward $r^*_n = 0$, and

(b) inadequate (no) investment and (no) social surplus of innovation are realized.

(viii) If the true $t_i$ is $t_H$ and $e \geq t_H$,

(a) the government sets up the reward $r^*_n = 0$, and

(b) the first-best (no) investment and (no) social surplus of innovation are realized.
5.2 Green Innovation

Next, we consider the green innovation case. The consumer surplus and the total environmental damage are, respectively,

\[ cs_g^R(t_i) = \frac{t_i^2}{2}, \text{ and } \]

\[ h_g^R(t_i) = 0. \] \hspace{1cm} (48) \hspace{1cm} (49)

Therefore, the social surplus is given as

\[ s_g^R(t_i) = cs_g^R(t_i) = s_g^{FB}(t_i). \] \hspace{1cm} (50)

Let \( r_g \) denote the reward paid by the government for the green innovation. Again, because the innovator earns zero profit from the sales of production, the incentive to innovate is attributable entirely to the reward. The innovator therefore chooses \( k \) to maximize

\[ \alpha p(k) - k. \] \hspace{1cm} (51)

Then, the innovator will choose \( k(\alpha r_g) \).

For the assumption that the government cannot observe \( t_i \), the reward \( r_g \) must be fixed and independent of \( t_i \). The social welfare as a function of \( r_g \) is

\[ W_g^R(r_g) = \alpha p(k(\alpha r_g)) \left[ \mu s_g^R(t_H) + (1 - \mu) s_g^R(t_L) \right] - k(\alpha r_g) \]

\[ = p(k(\alpha r_g)) \alpha \left[ \mu \left[ \frac{t_H^2}{2} \right] + (1 - \mu) \left[ \frac{t_L^2}{2} \right] \right] - k(\alpha r_g) \]

\[ = p(k(\alpha r_g)) \alpha E(s_g^R) - k(\alpha r_g), \] \hspace{1cm} (52)

where \( E(s_g^R) = \mu \left[ \frac{t_H^2}{2} \right] + (1 - \mu) \left[ \frac{t_L^2}{2} \right] > 0 \). It then follows that (52) is maximized if \( r_g = E(s_g^R) \). Therefore, the reward is the expected social surplus from the green innovation. Consequently, the innovator invests \( k(\alpha E(s_g^R)) \).

On the other hand, if the true demand parameter is \( t_i (i = L, H) \), it is socially desirable that the investment \( k \) depend on \( s_g^R(t_i) \), where

\[ s_g^R(t_L) < E(s_g^R) < s_g^R(t_H). \] \hspace{1cm} (53)

Using (50), (53) and the above reward analysis, the following lemma is obtained.
Lemma 4 Under the reward system, assume that green innovation research is adopted. In such conditions, the following are true.

(i) If the true \( t_i \) is \( t_L \),
   
   (a) the government sets up a reward \( r_g^* = E(s_g^R) \), and
   
   (b) excessive investment and the first-best social surplus of innovation are realized.

(ii) If the true \( t_i \) is \( t_H \),
   
   (a) the government sets up the reward \( r_g^* = E(s_g^R) \), and
   
   (b) inadequate investment and the first-best social surplus of innovation are realized.

5.3 Normal Innovation Research vs. Green Innovation Research

Under the reward system, in the normal innovation research case, the innovator’s expected profit is

\[
V_n^R(r_n^*) = \begin{cases} 
0 & \text{if } e < \frac{\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L} \\
 p(k(E(s_n^R))-k(E(s_n^R))) & \text{if } e \geq \frac{\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L}
\end{cases}
\]  

(54)

Similarly, in the green innovation research case, the innovator’s expected profit is

\[
V_g^R(r_g^*) = p(k(\alpha E(s_g^R))) - k(\alpha E(s_g^R)).
\]  

(55)

Now, the following condition is obtainable:

\[
E(s_n^R) \leq \alpha E(s_g^R)
\]

\[
\Leftrightarrow \mu \left( \frac{t_H^2}{2} - c t_H \right) + (1-\mu) \left( \frac{t_L^2}{2} - c t_L \right) \leq \alpha \left[ \mu \left( \frac{t_H^2}{2} \right) + (1-\mu) \left( \frac{t_L^2}{2} \right) \right]
\]

\[
\Leftrightarrow e \geq \frac{(1-\alpha)\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L}.
\]  

(56)

Equations (36), (54), (55), and (56) yield

\[
V_n^R(t_i) \leq V_g^R(t_i) \text{ for any } t_i \in \{t_L, t_H\} \Leftrightarrow e \geq \frac{(1-\alpha)\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L}.
\]  

(57)

Hence, the following proposition is obtained.

Proposition 2 Under the reward system, the following pertain.

(i) If \( 0 < e < \frac{(1-\alpha)\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L} \), the innovator will prefer normal innovation research to green innovation research.

(ii) If \( e \geq \frac{(1-\alpha)\mu t_H^2 + (1-\mu) t_L^2}{2\mu t_H + (1-\mu) t_L} \), the innovator will prefer green innovation research to normal innovation research.
6 Policy Implication

Proposition 1 implies that, under the patent system, the expected social welfare is

\[ W^M_n = \mu \left[ p(k(\pi_n(t_H)))s^M_n(t_H) - k(\pi_n(t_H)) \right] \]

\[ + (1 - \mu) \left[ p(k(\pi_n(t_L)))s^M_n(t_L) - k(\pi_n(t_L)) \right], \tag{58} \]

where

\[ \pi_n(t_i) = \frac{t_i^2}{4} \quad \text{for any} \quad t_i \in \{t_L, t_H\}, \tag{59} \]

\[ s^M_n(t_i) = \frac{3t_i^2}{8} - \frac{et_i^2}{2} \quad \text{for any} \quad t_i \in \{t_L, t_H\}. \tag{60} \]

Proposition 2 implies that, under the reward system, the expected social welfare is: if \( 0 < e < \frac{(1 - \alpha)(\mu t_H^2 + (1 - \mu)t_L^2)}{2[\mu t_H + (1 - \mu)t_L]} \), then

\[ W^R_n(r^*_n) = p(k(E(s^R_n)))E(s^R_n) - k(E(s^R_n)), \tag{61} \]

if \( e \geq \frac{(1 - \alpha)(\mu t_H^2 + (1 - \mu)t_L^2)}{2[\mu t_H + (1 - \mu)t_L]} \), then

\[ W^R_g(r^*_g) = p(k(\alpha E(s^R_g)))\alpha E(s^R_g) - k(\alpha E(s^R_g)), \tag{62} \]

where

\[ E(s^R_n) \equiv \mu \left[ \frac{t_H^2}{2} - et_H \right] + (1 - \mu) \left[ \frac{t_L^2}{2} - et_L \right], \tag{63} \]

\[ E(s^R_g) \equiv \mu \left[ \frac{t_H^2}{2} \right] + (1 - \mu) \left[ \frac{t_L^2}{2} \right]. \tag{64} \]

Therefore, the following proposition is obtained.

**Proposition 3** With regard to strategic policy setting for green innovation, the following pertain.
(i) If \[ 0 < e < \frac{(1-\alpha)[\mu(H_t) + (1-\mu)L_t]}{2\mu(H_t) + (1-\mu)L_t} \], the government should compare \( W^M_n \) with \( W^R_n(r^*_n) \) and choose the system that realizes the better expected social welfare. In either case, green innovation research will not be realized.

(ii) If \[ e \geq \frac{(1-\alpha)[\mu(H_t) + (1-\mu)L_t]}{2\mu(H_t) + (1-\mu)L_t} \], the government should compare \( W^M_n \) with \( W^R_g(r^*_g) \) and choose the system that realizes the better expected social welfare. Then, the larger \( e \) is, the more green research will be realized.

7 Concluding Remarks

Prior economic analyses of patent systems and reward systems have given little attention to innovation research options. Unlike prior works, this paper presented examination of the patent system and the reward system in the context of the research with the option of environmental technology innovation. Using a model presented by Shavell and van Ypersele (2001), this paper analyzes each system and its innovation from the perspective of efficiency. Three propositions were clarified by results of those analyses.

First, under the patent system, the innovator will prefer normal innovation research to green innovation research. Therefore, if the government sets up a patent system, the green innovation research will never be carried out. Second, under a reward system, if environmental damage is sufficiently small, the innovator will prefer normal innovation research to green research; otherwise, the innovator will prefer the green innovation research to the normal one. Third, the incentive system for innovation must be set up with consideration to the level of environmental externality. That is, if environmental damage is small, the government should set up a system to champion normal innovation research; otherwise, the government should set up a system to support green innovation research.

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