Environmental Regulation and Choice of Innovation in Oligopoly

Iwata, Hiroki

25 March 2016

Environmental Regulation and Choice of Innovation in Oligopoly

Hiroki Iwata*

Abstract

This study investigates the effect of an environmental regulation on the innovation choice of firms in an oligopoly. Most existing studies on environmental regulations and innovations examine the optimal behavior of firms when one innovation project is feasible. In our model, firms are allowed to choose from multiple types of innovation projects. Our main contributions are that we derive the conditions under which environmentally friendly and cost reducing innovations are selected in Bertrand competition and we show how environmental regulation affects innovation choice.

Keywords: environmental regulation; innovation; the Porter hypothesis
JEL: D21, Q55, Q58

* Faculty of Human Environmental Studies, Hiroshima Shudo University, 1-1-1, Ozukahigashi, Asaminami-ku, Hiroshima 731-3195, Japan

1. Introduction

Environmental issues are increasing and resolving these has been a major social challenge in recent years. On the other hand, the introduction of regulations that aims to resolve such issues would incur additional cost to firms and reduce their profits. In general, the relationship between firms' profit and environmental burden reduction is considered to be a trade-off. Therefore, many studies assert that it is difficult to realize simultaneously an increase in firms' profit and a reduction of environmental burden. By contrast, the Porter hypothesis (Porter, 1991; Porter and van der Linde, 1995) asserts that under strict environmental regulation, firms would accelerate innovations and could increase their profits.

Given that the Porter hypothesis suggests the possibility of compatibility between environmental protection and economic development, many studies, such as Palmer et al. (1995), are skeptical because the hypothesis has some contradictions in terms of the rational behavior of firms. For example, if firms can increase their profits by innovation, profit-maximizing firms are supposed to implement the innovation without an environmental regulation. Therefore, the Porter hypothesis cannot explain why environmental regulations are needed to implement the innovation. Beyond that, this hypothesis presents nothing more than some success examples.

On the other hand, some recent studies analyze the conditions under which the Porter hypothesis is supported (Xepapadeas and de Zeeuw, 1999; Schmutzler, 2001; Ambec and Barla, 2002; Feichtinger et al., 2005; André et al., 2009). Most existing studies that examine the Porter hypothesis assume that firms have only one type of innovation project and that these firms decide the level of investment in the project to maximize their expected profits: that is, the innovation itself is given in those studies. However, to improve the generality of the analysis, we have to demonstrate why an innovation project is selected. In practice, firms have multiple innovation projects from among which they choose one. In addition, they might decide not to implement any of these projects; that is, firms choose the status quo. This situation will arise when the expected profit after conducting innovation is smaller than the initial profit. Therefore, in this study, we introduce situations in which firms have multiple innovation projects. Furthermore, this study includes the case where firms decide not to implement any project.

In existing studies, the type of innovation varies. For example, Innes and Bial (2002) employed the innovation (Research and Development project) that lowers the pollution abatement cost; Xepapadeas and de Zeeuw (1999), Schmutzler (2001), Ambec and Barla (2002), and Feichtinger et al. (2005) employed the notion that newer technologies (or machines) are less polluting. Bonato and Schmutzler (2000) analyzed three types of innovations. Their innovations consist of: (1) pure cost reducing innovation, (2) pure environmental innovation, and (3) environmental innovation with cost reducing effects. Bonato and Schmutzler (2002) examined the firm's choice of an innovation under the setting of a fixed output level and price. Although this study also analyzes the choice of an innovation, we introduce the effect of strategic interdependence between firms into our model.

In the next place, the innovation's success or failure is generally uncertain in advance. Although environmental innovation with cost reducing effects is adopted in many existing studies (Xepapadeas and de Zeeuw, 1999; Schmutzler, 2001; Bonato and Schmutzler, 2002), reducing environmental burden might not always accompany the cost-reducing effect. Therefore, we introduce this uncertainty into our analysis. We assume that reducing environmental burden does not always accompany the cost reducing effect but the effect will stochastically generate. Introducing this uncertainty would extend the generality of the analysis.

2. The model

We consider a homogeneous duopoly market, in which two firms engage in a Bertrand competition. Both firms produce the same good with a common marginal cost c, and their production activities generate environmental burden D_H. Each firm i $(i = 1, 2)$ simultaneously chooses one innovation project from among three. The three projects are X, Y, and N.

Innovation project X reduces the marginal cost from c to c_x ($c > c_x \geq 0$). Innovation project Y reduces the environmental burden from D_H to D_L ($D_H > D_L \geq 0$). Generally, innovation project Y increases the marginal cost of the firm from c to c_y ($c_y > c$). However, project Y generates an innovation with probability s $(0 < s < 1)$. If an innovation occurs, the firm can reduce its marginal cost to c_x. The magnitude of s is the same between the firms. In addition, information about s is common knowledge. Therefore, innovation project Y can reduce both the environmental burden and its marginal cost with probability s and can reduce the environmental burden and increase the marginal cost with probability $1-s$. Innovation Y, therefore, shares the characteristics of the innovation in existing studies on the Porter hypothesis. On the other hand, innovation project X does not have any uncertainty. Accordingly, if a firm chooses investment project X, then the firm definitely can reduce its marginal cost. To implement investment project X or Y, firms have to incur investment cost $k\,(>0)$ where the cost is the same between X and Y. Further, project N means the status quo, that is, the firm does not implement any investment project.

Based on the above setting, we make a comparison of firms' behavior between an unregulated and a regulated situation. Particularly, our focus is to analyze the conditions that both firms select innovation Y, since it is considered to have a strong relationship with the realization of the Porter hypothesis.

3. Unregulated game

First, we investigate the situation in which environmental regulation is not introduced. Each firm chooses from three projects in the Bertrand competition. In the initial situation, both firms obtain 0 profits because the goods of both firms cannot be differentiated and their marginal costs are same.

If both firms choose innovation project X (or N), then their marginal costs are always equivalent. In this case, the profits of both firms are 0. If their marginal costs are not equivalent, then the market is monopolized by the firm with lower marginal cost. For example, if firm 1 chooses X and firm 2 chooses Y and the innovation does not occur in Y, then firm 1's marginal cost is c_x and firm 2's is c_y. In the result, firm 1 monopolizes the market and earns monopoly profit π^M [i]. This monopoly profit corresponds to the marginal cost c_x. Next, π^m $(\pi^m < \pi^M)$ means the monopoly profit that corresponds to the marginal cost c. π^m accrues if firm i chooses Y and the innovation is not generated. If the latter is true, then firm i's marginal cost is c_y and the other firm chooses N with its marginal cost being c. In this case, the market is monopolized by the latter firm.

If the Nash equilibrium of this game is $(firm1's\,choice, firm2's\,choice) = (Y, Y)$ and the expected profit is positive, then the market without environmental regulation could realize the win-win situation. This situation negates the Porter hypothesis because both firms increase their expected profit and reduce environmental burden without environmental regulations. In this case, the expected profit of firm i is described as follows.

$$E\pi^{YY}{}_i = s(1-s)\pi^M - k \tag{1}$$

Table 1 shows the payoff matrix of this game. Equation (1) is always smaller than

$(1-s)\pi^M - k$. $(1-s)\pi^M - k$ is the expected profit of firm i when it chooses innovation X and the other firm chooses innovation Y. Thus, the Nash equilibria of this game are as follows[ii].

(Firm1's choice, Firm 2's choice)= $(N, X), (X, N)$

As a result, in the case of the unregulated game, both firms do not reduce their environmental burden. Therefore, the innovation project Y that provides the reduction of the environmental burden and cost reducing innovation is not selected.

In addition, even assuming $s-1$, innovation Y surely brings about a reduction in environmental burden; thus, reducing marginal cost (Y, Y) is not a Nash equilibrium. The probability of $s=1$ means that both firms' marginal costs coincide at c_x and both firms acquire the expected profit $-k$.

Table 1 : unregulated game				
	Firm 2			
		X	Y	N
Firm 1	X	$-k, -k$	$(1-s)\pi^M - k$, $-k$	$\pi^M - k$, 0
	Y	$-k$, $(1-s)\pi^M - k$	$s(1-s)\pi^M - k$, $s(1-s)\pi^M - k$	$s\pi^M - k$, $(1-s)\pi^m$
	N	0, $\pi^M - k$	$(1-s)\pi^m$, $s\pi^M - k$	0, 0

3. Regulated game

Next, we analyze the market with environmental regulation. The environmental regulation is as follows. The government imposes an environmental lump-sum tax or a basic penalty $t(>0)$ on an environmentally unfriendly firm. Environmentally unfriendly means emitting a high level of pollution, that is, D_H. If a firm's emission is D_H, then this firm has to pay an environmental tax t and if the emission level is D_L, then an environmental tax is not imposed. The payoff matrix of this game is in table 2.

In this game, (Y, Y) can be a Nash equilibrium. The condition is the following.

$$s(1-s)\pi^M - k > \max\{(1-s)\pi^M - k - t, (1-s)\pi^m - t\} \qquad (2)$$

From (2), we obtain the following conditions.

$$(1-s)^2\pi^M < t \cap (1-s)(\pi^M - \pi^m) \geq k \qquad \text{if } (1-s)\pi^M - k - t \geq (1-s)\pi^m - t \quad (3)$$

$$k-(1-s)(s\pi^M - \pi^m) < t \cap (1-s)(\pi^M - \pi^m) < k \qquad \text{if } (1-s)\pi^M - k - t < (1-s)\pi^m - t \quad (4)$$

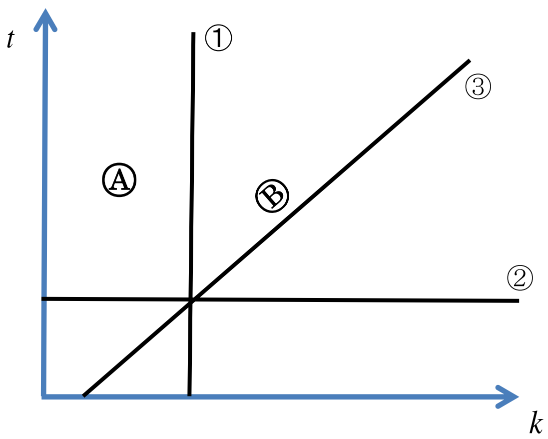
From (3), the conditions that (Y,Y) is a Nash equilibrium are investment cost k having an upper bound, that is, $k \leq (1-s)(\pi^M - \pi^m)$ and the level of environmental tax having a lower bound, that is, $(1-s)^2\pi^M < t$. The existence of the lower bound on the tax level means that the Porter hypothesis might be appropriate since it claims that to realize the win-win situation, the environmental regulation should be strictly enforced. Similarly, (4) means the existence of a lower bound on the environmental tax level, that is, $k-(1-s)(s\pi^M - \pi^m) < t$. Table 2 depicts the payoff matrix of a regulated game. In Figure 1, (Y,Y) is Nash equilibrium in areas A and B. Area A is derived from inequality (3) and B is derived from (4).

As a result, the introduction of an environmental regulation can redirect the firm's innovation choices to those that are more environmentally friendly. On the other hand, an increase in the expected profits is not guaranteed by the introduction of an environmental regulation[iii].

Table 2 : Regulated game

		Firm 2		
		X	Y	N
Firm 1	X	$-k-t$, $-k-t$	$(1-s)\pi^M - k - t$, $-k$	$\pi^M - k - t$, $-t$
	Y	$-k$, $(1-s)\pi^M - k - t$	$s(1-s)\pi^M - k$, $s(1-s)\pi^M - k$	$s\pi^M - k$, $(1-s)\pi^m - t$
	N	$-t$, $\pi^M - k - t$	$(1-s)\pi^m - t$, $s\pi^M - k$	$-t, -t$

Figure 1: The area of (Y, Y) is N-E



① : $k = (1-s)(\pi^M - \pi^m)$

② : $t = (1-s)^2 \pi^M$

③ : $t = k - (1-s)(s\pi^M - \pi^m)$

4. Different investment cost

In this section, we extend the previous analysis. In previous sections, the investment cost to implement innovation X and Y is k with it being the same between innovations X and Y. Thus, we introduce the different investment costs between X and Y. We then postulate the following situation. To implement innovation X (or Y), firms have to incur investment costs k_x (or k_y) where $k_y, k_x > 0$.

In this case, (Y, Y) can be the Nash equilibrium of the unregulated game. Table 3 depicts the payoff matrix of this game. The conditions are the following.

$$s(1-s)\pi^M - k_y > \max\{(1-s)\pi^M - k_x, (1-s)\pi^m\} \tag{5}$$

From (5), we acquire the following conditions.

$$k_x - k_y > (1-s)^2 \pi^M \qquad \text{if } (1-s)(\pi^M - \pi^m) \geq k_x \tag{6}$$

$$(1-s)(s\pi^M - \pi^m) > k_y \qquad \text{if } (1-s)(\pi^M - \pi^m) < k_x \tag{7}$$

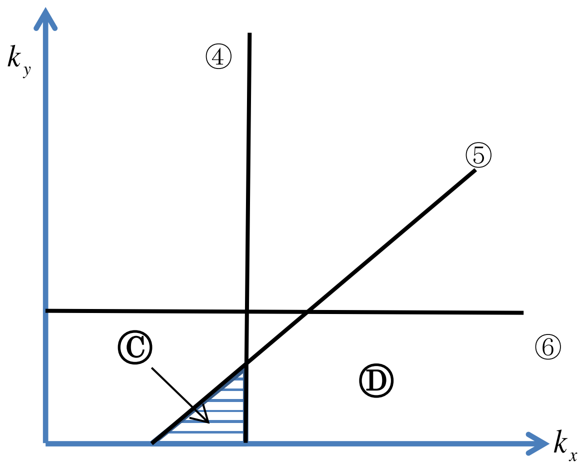
Figure 2 illustrates the areas where (Y, Y) is the Nash equilibrium. The conditions that these areas exist are given by the following in equality.

$$\frac{\pi^m}{\pi^M} < s < 1 \tag{8}$$

Equation (8) means that to realize this Nash equilibrium, the probability of the innovation in innovation Y has the lower bound $\frac{\pi^m}{\pi^M}$.

Table 3 : unregulated game (different investment costs)				
	Firm 2			
Firm 1		X	Y	N
	X	$-k_x, -k_x$	$(1-s)\pi^M - k_x$, $-k_y$	$\pi^M - k_x$, 0
	Y	$-k_y$, $(1-s)\pi^M - k_x$	$s(1-s)\pi^M - k_y$, $s(1-s)\pi^M - k_y$	$s\pi^M - k_y$, $(1-s)\pi^m$
	N	0, $\pi^M - k_x$	$(1-s)\pi^m$, $s\pi^M - k_y$	$0, 0$

Figure 2: The area of (Y, Y) is Nash Equilibrium



④ : $k_x = (1-s)(\pi^M - \pi^m)$

⑤ : $k_x - k_y = (1-s)^2 \pi^M$

⑥ : $k_y < k - (1-s)(s\pi^M - \pi^m)$

Next, we analyze the case where an environmental regulation is introduced in this game. The introduction of an environmental tax t shifts the ⑤ upward if $(1-s)(\pi^M - \pi^m) \geq k_x$ and shifts the ⑥ upward if $(1-s)(\pi^M - \pi^m) < k_x$ in Figure 2. As a result, the existence of an environmental regulation will extend the area where (Y, Y) is a Nash equilibrium.

5. Concluding Remarks

This study theoretically analyzed the choice of firms' innovation and the manner in which an environmental regulation affects their innovation choices. Many studies analyze the relationship between environmental regulations and innovations, treating an innovation as given. However, our analysis demonstrated that if firms have various innovation projects, they do not always choose an innovation that existing studies have employed. Even when the probability of a innovation is 1, in the absence of environmental regulations, the environmentally friendly and cost reducing innovations are not necessarily the choice of the other firm.

Additionally, our conclusion partially supports the Porter hypothesis. Environmental regulations would generate or extend the area where an environmentally friendly and cost reducing (stochastically) innovation is selected. On the other hand, we are not sure that the firms' choices increase their expected profits under environmental regulations because they do not always increase by the reduction of their marginal costs.

Finally, our analysis was limited to a homogeneous good and Bertrand competition. A comparison with Cournot competition and the introduction of an innovation that conducts product differentiation could be subjects of future research.

References

Ambec, S. and P. Barla (2002) A theoretical foundation of the Porter hypothesis. *Economic Letters*, 75(3), 355－360.

André, F. J., P. González and N. Porteiro (2009) Strategic quality competition and the Porter hypothesis. *Journal of Environmental Economics and Management*, 57(2), 182－194.

Bonato, D. and A. Schmutzler (2000) When do firms benefit from environmental regulations? A simple microeconomic approach to the Porter controversy. *Swiss Journal of Economics and Statistics*, 136(4), 513－530.

Feichtinger, G., R. F. Hartl, P. M. Kort and V. M. Veliov (2005) Environmental policy, the Porter hypothesis and the composition of capital: effects of learning and technological progress. *Journal of Environmental Economics and Management*, 50(2), 434－446.

Innes, R. and J. J. Bial (2002) Inducing innovation in the environmental technology of oligopoly firms. *Journal of Industrial Economics*, 50(3), 265－287.

Palmer, K., W. E. Oates and P. R. Portney (1995) Tightening environmental standards: the benefit-cost or no-cost paradigm? *Journal of Economic Perspectives*, 9(4), 119－132.

Porter, M. E. (1991) America's green strategy, *Scientific America*, 264(4).

Porter, M. E. and C. van der Linde (1995) Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 9(4), 97－118.

Schmutzler, A. (2001) Environmental regulations and managerial myopia. *Environmental and Resource Economics*, 18(1), 87－100.

Xepapadeas, A. and A. de Zeeuw (1999) Environmental policy and competitiveness: the Porter hypothesis and the composition of capital. *Journal of Environmental Economics and Management*, 37(2), 65－182.

---

[i] We postulate $\pi^M - k > 0$.

[ii] We restrict the analysis to a pure strategy Nash equilibrium.

[iii] Our main focus is to demonstrate the conditions under which (Y,Y) configure the Nash equilibrium. Therefore, this study does not address the issue of whether (Y,Y) is a unique Nash equilibrium of this game.