Effects of competition forms and market structure on green innovation incentives

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Abstract

This paper analyzes the effects of environmental policy on green innovation. We compare the incentives for green innovation in both the Cournot and Bertrand competition. It is shown that positive incentives for green innovation exist in both competition models. When environmental regulations are imposed, the effects of the probability of success on green innovation incentives differ between the Bertrand and Cournot competition. Additionally, we clarify the conditions necessary for the establishment of the Porter hypothesis in both competition models.

Keywords: Cournot and Bertrand competition, Green innovation, Porter hypothesis

JEL classifications: L13, Q52, Q55

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1. Introduction

In this paper, we analyze the effects of environmental regulation on firms' incentives for green innovation. This study focuses on the effects of market structure (i.e., the number of firms) and form of competition (i.e., Cournot or Bertrand) on incentives for innovation. Also, considering the probability of success of the said innovation, this study clarifies what kind of green innovation occurs under what kind of market situations.

In recent years, green innovations that drastically reduce the environmental burden have been coveted. Environmentally-friendly technologies are desired in goal 9 (Industry, innovation, and infrastructure) of the United Nation's Sustainable Development Goals (SDGs). The United Nations insists on target 9.4 of the SDGs that states: "*By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.*"[2] For that reason, green innovations have to be carried out to achieve the targets.

On the contrary, although firms develop and deploy environmentally-friendly technologies as a result of green innovations, and which might be desirable from a social welfare point of view, it is not always favorable to each firm's profit maximization goals. This is because firms incur research and development (R&D) expenses in relation to innovations that may not succeed. Furthermore, consumers may not value innovations if the prices of goods rise as a result. For that reason, this study focuses on the situation

[2] Quoted from the following website
https://unstats.un.org/sdgs/metadata/?Text=&Goal=9&Target=9.4

in which consumers do not value the environmental performance of firms.[3] In such a situation, firms do not intend to carry out green innovations because such innovations may reduce their expected profits even if the innovations succeed. It is necessary to analyze whether environmental regulations by the government encourages green innovations. Normally, environmental policies aim to correct external diseconomies. However, if environmental policies promote technological progress as a side effect, it can achieve more socially desirable outcomes. The conditions necessary to carry out green innovations have been analyzed in environmental economics literature so far. Many existing studies have used the Bertrand and Cournot models to examine what kind of environmental regulations (e.g., direct controls, environmental tax, and marketable permits) lead to green innovations and have compared their effects on social welfare. (e.g., Milliman and Prince, 1989; Requate, 1998; Innes and Bial, 2002; Montero 2002; Montero, 2002; Fischer et al., 2003; Perino and Requate, 2012; D'Amato and Dijkstra, 2015; Cao et al., 2016; Lambertini et al., 2017). When incurring R&D costs, some green innovations are more likely to succeed than others. In other words, the probabilities of success vary widely. In existing studies, Innes and Bial (2002) consider the probability of success regarding green innovation. Innes and Bial (2002) analyze the effect of environmental policy on stochastic green innovations in a Bertrand duopoly market. Following their study, we introduce stochastic green innovations in our model. Moreover, it is assumed that the response to environmental regulations will be different depending on both the forms of competition and the number of competing firms. Montero (2002a) examined innovation incentives by using two forms of competition (i.e., Bertrand and Cournot). However, his study deals with a duopoly and does not take

[3] Existing studies consider the situation in which consumers value the environmental performance of firms (e.g., Arora and Gangopadhyay, 1995; André et al., 2009).

stochastic innovations into account. The main contribution of our study to the literature is that we extend an existing framework to the Bertrand and Cournot models by generalizing the number of firms as m.[4] Moreover, we demonstrate the difference between different types of innovation by introducing stochastic green innovations. As a result, we can show that incentives for green innovations exist in both the Cournot and Bertrand competition. We found that under the Cournot competition, green innovation incentives increase even if the probability of success of innovation is 0.5 or more. On the contrary, under Bertrand competition model, innovation incentives always decline if the probability is in that range (0.5 or more). Additionally, our results are related to Porter's hypothesis (Porter, 1991; Porter and van der Linde, 1995) on environmental regulations and innovations. Our model includes a case in which green innovations brought about by environmental regulations can increase firms' expected profits. We present established conditions for weak and strong versions of the hypothesis in the Cournot and Bertrand competition.

The rest of the paper is structured as follows. In the next section, we describe the basic model and explain the incentives for green innovation in each market structure. In section 3, we analyze the impact of environmental regulation levels, the probability of innovation success, and the number of firms on green innovation incentives. In section 4, we discuss the relationship between our results and the Porter hypothesis. Section 5 summarizes the results.

2. Model

[4] Although our study focuses on the interaction between symmetric firms, some existing studies, such as Perino and Requate (2012) and Cao et al. (2016), consider a heterogeneous case. Their papers analyze the effect of environmental regulation on R&D investment without the uncertainty of abatement technology.

We consider a two-stage model. Here, the market is composed of m ex-ante symmetric firms $(i=1,2,\cdots,m)$. In stage 1, each firm i decides whether to conduct green innovations. In our model, each firm i has to incur R&D costs $K(>0)$ when implementing green innovations. In stage 2, the market competition stage, each firm chooses either output or price to maximize profits. Therefore, the game is resolved through backward induction. Firms supply a homogeneous good to the market, and we assume that no new entry firms exist. The inverse demand function is described as $p=a-Q$ ($a>0$, $Q=\sum_{i=1}^{m} q_i$), where p is the market price of the good, q_i is the output of firm i and Q is industry output.[5] In our model, two types of technology $j=G,B$ exist, while B involves environmental damage, that is, it is Brown ($j=B$), and G is environmentally-friendly technology, that is, Green ($j=G$). Firms generate pollution in the course of production, and the scale is set as θ_j per unit-of-output. We assume that $\theta_B>\theta_G\geq 0$, and the firms' technologies are all θ_B at the start of the stage1. Firm i's pollution emission is described as $\theta_j q_i$ and we assume that $\theta_G=0$ without loss of generality. Therefore, total pollution by this industry is given as $E=\sum_{i=1}^{m}\theta_j q_i$ and social damage due to pollution is $D(E)$, ($D'>0, D''\geq 0$).[6] In this model, we assume a constant marginal cost of firms denoted as $c_j(>0)$ and firms' private production costs are described as $c_j q_i$. To alleviate the environmental burden,

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[5] This simple inverse demand function means that this article addresses the situation in which consumers do not value the environmental performance of firms. If consumers value their environmental performance, firms would have the incentive to decrease pollution voluntarily.

[6] We referred to the setting of Innes and Bial (2002).

the government imposes an environmental tax denoted as $t(>0)$ per unit of pollution emission.[7] Therefore, as $\theta_G = 0$, environmental tax on type G firms is 0. Let us assume that all firms have the opportunity to carry out green innovations. If a firm succeeds in carrying out green innovation, its environmental technology improves from θ_B to $\theta_G (=0)$. The probability of success of this innovation is r $(0 \le r \le 1)$ and the probability of failure is $1-r$. Generally, it is thought that firms' marginal cost would increase as a result of a reduction of their environmental burden. If firms' marginal costs reduce as a result of their environmental conservation activities, then the firm would address environmental issues voluntarily. We assume that the marginal cost of type G firms increase from c_B to c_G $(> c_B)$. There are two cases of the magnitude correlation of marginal cost, which are (i) $c_G \le c_B + t\theta_B$, (ii) $c_G > c_B + t\theta_B$. In addition, we assume that $a - \max\{c_G, c_B + t\theta_B\} > 0$ to guarantee the existence of positive demand.

2.1 Without environmental regulation

Let us first describe the case in which the government does not regulate environmental issues. In this case, if firms succeed in green innovation, their marginal cost will increase from c_B to c_G. In this case, firms do not have a positive incentive to carry out green innovations. Therefore, in the case of the Cournot model, the expected profit of firm i is given by

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[7] We assume that environmental tax t is set at level $t = D'(E)$.

$$E\pi_{ic}^{0*} = (\frac{s_B}{m+1})^2. \tag{1}$$

Where $s_B = a - c_B$. In the Bertrand case, the expected profit of firm i is

$$E\pi_{ib}^{0*} = \begin{cases} 0 & \textit{if } m \geq 2, \\ (\frac{s_B}{2})^2 & \textit{if } m = 1. \end{cases} \tag{2}$$

Therefore, in equilibrium, firms do not invest in environmental R&D (stage 1), and they get the expected profit expressed in equations (1) or (2) (stage 2).

2.2 Environmental regulation

2.2.1 Output market competition

Next, we consider the case in which a positive environmental tax t is imposed on type B firms by the government. First, we analyze the situation in which case (i) $c_G \leq c_B + t\theta_B$ holds. To address the behavior of firm i in stage 2, we consider the following. If all firms do not carry out green innovations in stage 1, only type B firms exist in the output market. The expected profit of firm i in the Cournot competition is

$$E\pi_{ic}^{1*} = (\frac{s_t}{m+1})^2, \tag{3}$$

where $s_t = a - c_t$ and $c_t = c_B + t\theta_B$. The expected profit of firm i in the Bertrand competition in this case is

$$E\pi_{ib}^{1*} = \begin{cases} 0 & \textit{if } m \geq 2, \\ (\frac{s_t}{2})^2 & \textit{if } m = 1. \end{cases} \tag{4}$$

The expected profit is positive in the Cournot competition and 0 in the Bertrand competition except for the case of a monopoly.

If firms carry out green innovation in stage 1, the resulting market will have rm

type G firms and $(1-r)m$ type B firms since firms are assumed to be symmetric. Therefore, the objective function of firm i in the Cournot competition model is given by

$$\max E\pi_{ic}^2 = \max\{rE\pi_{ic}^G + (1-r)E\pi_{ic}^B\}, \tag{5}$$

where $\begin{cases} E\pi_{ic}^G = \{a-(q_i^G+(rm-1)q^G+(1-r)mq^B)-c_G\}q_i^G, \\ E\pi_{ic}^B = \{a-(rmq^G+(q_i^B+((1-r)m-1)q^B)-c_t\}q_i^B. \end{cases}$

From equation (5), the equilibrium quantity in the Cournot model is given by

$$\begin{aligned} q_{ic}^{G*} &= \frac{s_G+(1-r)m(c_t-c_G)}{m+1}, \\ q_{ic}^{B*} &= \frac{s_t-rm(c_t-c_G)}{m+1}, \end{aligned} \tag{6}$$

where $s_G = a-c_G$, $s_t = a-c_t$. The expected profit of firm i in the Cournot Nash equilibrium model is

$$E\pi_{ic}^{2*} = rE\pi_{ic}^{G*} + (1-r)E\pi_{ic}^{B*}, \tag{7}$$

where
$$\begin{cases} E\pi_{ic}^{G*} = \{\dfrac{s_G+(1-r)m(c_t-c_G)}{m+1}\}^2, \\ E\pi_{ic}^{B*} = \{\dfrac{s_t-rm(c_t-c_G)}{m+1}\}^2. \end{cases} \tag{8}$$

Next, we consider the Bertrand case. In this case, if all firms challenged the innovations in stage 1, the expected profit of firm i is described as

$$\max E\pi_{ib}^2 = \max\{rE\pi_{ib}^G + (1-r)E\pi_{ib}^B\}. \tag{9}$$

In the Bertrand competition, if only one firm succeeds in carrying out innovations, the market is monopolized by that firm. If there are two or more firms that succeed in carrying out innovations, then they have the same minimum marginal cost, and hence, the firms earn 0 profits. Therefore, if there are two or more firms in the market, the expected equilibrium profit is described as

$$E\pi_{ib}^{2*} = r(1-r)^{m-1}(\frac{s_G}{2})^2. \tag{10}$$

If only firm i exists in stage 1, then the expected profit of firm i if it carries out innovation is given by

$$E\pi_{ib}^{2*} = r(\frac{s_G}{2})^2 + (1-r)(\frac{s_t}{2})^2. \tag{11}$$

In this case, firm i can continue to acquire monopoly profits even if firm i does not succeed in its innovation.

2.2.2 Green innovation decision-making process

Here, we analyze the decision-making process of firm i in stage 1. Firm i invests in green innovation if the expected profit of carrying out innovation is larger than not investing in the said process. First, we consider the Cournot case. According to equations (3), (7), and (8), the conditions under which innovations would be carried out are

$$\Delta\pi_i^C = r\{\frac{s_G + (1-r)m(c_t - c_G)}{m+1}\}^2 + (1-r)\{\frac{s_t - rm(c_t - c_G)}{m+1}\}^2 - (\frac{s_t}{m+1})^2 \geq K. \tag{12}$$

Here, we are considering case (i) where $c_t - c_G > 0$, so $\Delta\pi_i^C$ is greater than 0.[8] Therefore, the region in which equation (12) holds exists. If inequality (12) is not satisfied, then firms choose not to innovate in stage 1. Likewise, we analyze the Bertrand case. According to equations (4), (10), and (11), the conditions under which innovations would be carried out are

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[8] $\Delta\pi_i^C = \frac{1}{(m+1)^2}\{\underbrace{r(s_G{}^2 - s_t{}^2)}_{+} + \underbrace{2(c_t - c_G)r(1-r)m(s_G - s_t)}_{+} + \underbrace{r(1-r)(c_t - c_G)^2 m^2}_{+}\} \geq 0$

$$\Delta\pi_i^B = \begin{cases} r(1-r)^{m-1}(\frac{s_G}{2})^2 \geq K & \text{if } m \geq 2, \\ r\{(\frac{s_G}{2})^2 - (\frac{s_t}{2})^2\} \geq K & \text{if } m = 1. \end{cases} \tag{13}$$

According to equations (12) and (13), the following is obtained. In this case $s^G - s^B \geq 0$, which is derived from $c_t - c_G \geq 0$. Therefore, the left side of inequality in equations (12) and (13) is positive.

As a result, if equation (12) is satisfied, then the expected profit is $E\pi_{ic}^{2*} - K$ and if equation (13) is satisfied, then the expected profit is $E\pi_{ib}^{2*} - K$. However, from equations (12) and (13), if the probability of success is $r = 1$, that is, firms' R&D investment always succeeds, then firms that are competing in the Cournot market can have positive incentives for innovations. On the contrary, firms that are competing in the Bertrand market ($m \geq 2$) do not have positive incentives. In other words, in the Bertrand competition, innovation success has to be uncertain for firms to have positive incentives except for the case of monopoly. Consequently, we have the following proposition:

Proposition 1: *There are positive incentives for green innovations under both the Cournot and Bertrand competition if environmental regulation is imposed. On the contrary, if* $r = 1$ *and* $m \geq 2$*, no firms have positive incentives for green innovation in the case of the Bertrand competition.*

Next, we analyze the case in which (ii) $c_G > c_B + t\theta_B$. In this case, increased marginal costs due to green innovations are greater than the taxed marginal cost.

Therefore, no firms carry out green innovations. As a result, the expected profit of firm i is given by equation (3) in the Cournot competition and equation (4) in the Bertrand competition.

3. The effects of environmental tax, the probability of success, and the number of firms

In this section, we examine the effects of environmental tax, the probability of success, and the number of firms on green innovation incentives. First, we analyze the effect of an environmental tax on green innovation incentives. The relationship between $\Delta\pi_i^C$ and t is given by

$$\frac{\partial \Delta\pi_i^C}{\partial t} = \frac{2r\theta_B}{(m+1)^2}\{(1-r)m(m+2)(c_t - c_G) + s_t\} > 0. \tag{14}$$

Therefore, in the Cournot case, as environmental tax becomes increasingly stringent, firms are more likely to carry out innovation. On the contrary, in the Bertrand case, the relationship between equation (13) and t is given by

$$\frac{\partial \Delta\pi_i^B}{\partial t} = \begin{cases} 0 & \text{if } m \geq 2, \\ \dfrac{rs_t\theta_B}{2} > 0 & \text{if } m = 1. \end{cases} \tag{15}$$

Therefore, in the Bertrand competition, firms' innovation incentives are independent of the environmental tax level if $m \geq 2$. On the contrary, if $m = 1$, then innovation incentives increase due to more stringent environmental tax. This is because if firm i chooses not to innovate, then increasing environmental tax will increase its marginal cost and reduce expected profit. From the above analysis, we immediately obtain the following proposition:

Proposition 2: *Under the Cournot competition,* increasing *environmental tax leads to more innovation incentives. Under the Bertrand competition,* increasing *environmental tax leads to more innovation incentives only when* $m = 1$.

Next, we examine the effects of changing the probability of success, r, on green innovation incentives. In the case of the Cournot model, the relationship between $\Delta\pi_i^C$ and r is

$$\frac{\partial\Delta\pi_i^C}{\partial r} = -\frac{2m(c_t - c_G)}{m+1}(rq_{ic}^{G*} + (1-r)q_{ic}^{B*}) + E\pi_{ic}^{G*} - E\pi_{ic}^{B*}. \quad (16)$$

Equation (16) can be positive or negative. The conditions under which r can lead to equation (16) being positive are given by

$$0 \le r \le \min\{\frac{1}{2} + \frac{s_G + s_t}{2m(m+2)(c_t - c_G)}, 1\}. \quad (17)$$

In equation (17), $(s_G + s_t)/2m(m+2)(c_t - c_G)$ is positive as $c_t - c_G > 0$. Within the interval given by equation (17), if the probability of success, r, increases, the incentives that a firm i would carry out green innovation increases. The upper bound in this case exists within the following interval: $[0.5,1]$. Therefore, under the Cournot competition, a rise in the probability of success increases the incentives for innovations within the following interval: $[0, 0.5]$. According to equation (17), the upper bound of the interval where the incentives for innovations increase is decreasing, and consequently, it is approaching the lower bound (0.5), as the number of firms increases.

In the Bertrand model, the effect of changing the probability of success r on green innovation incentives is represented as

$$\frac{\partial\Delta\pi_i^B}{\partial r} = (\frac{s_G}{2})^2(1-r)^{m-2}(1-rm) \qquad \text{if } m \ge 2. \quad (18)$$

If $1-rm \geq 0$, then, equation (18) is greater than or equal to 0. We can rewrite $1-rm \geq 0$ as $r \leq 1/m$, therefore, maximum value of r is 0.5. According to equation (18), under the Bertrand competition model, if the probability of success rises, then the incentives for green innovations increase within the interval: $[0,1/m]$. In this case, there are more than two firms, then the upper bound in this interval is 0.5 or less. Therefore, under the Bertrand competition, if the probability of success is more than 0.5, then the incentives that a firm has to carry out innovations decrease. In addition, if the number of firms increases, then the incentives to carry out innovations decrease because $1/m$ is decreasing. Therefore, if $r > 0.5$, then, the incentive can increase in the case of the Cournot, but not in the case of the Bertrand.

Next, the case of $m=1$, the effect of changing the probability of success r on green innovation incentives is given by

$$\frac{\partial \Delta \pi_i^B}{\partial r} = (\frac{s_G}{2})^2 - (\frac{s_t}{2})^2 > 0 \qquad if\ m=1. \qquad (19)$$

The above results lead to the following proposition:

Proposition 3: *In the Cournot case, a rise in the probability of success leads to an increase in the incentives for green innovations within the interval* $[0, 0.5]$*. The upper bound of* $\partial \Delta \pi_i^C / \partial r \geq 0$ *exists within the interval* $[0.5,1]$*. On the contrary, in the Bertrand case, if the probability of success rises, the incentives for environmental innovations increase within the interval* $[0,1/m]$*,* $(m \geq 2)$ *and the upper bound of* $\partial \Delta \pi_i^B / \partial r \geq 0$ *is* 0.5 *or less than* 0.5*.*

Next, we analyze the effects of the changes in the number of firms. In the Cournot case, the effects of these changes are represented as

$$\frac{\partial \Delta \pi_i^C}{\partial m} = \frac{-2r(c_t - c_G)}{(m+1)^3}\{a - (rc_G + (1-r)c_t) + s_t\} < 0. \tag{20}$$

In the case of the Bertrand model, the effects of these changes are given by

$$\frac{\partial \Delta \pi_i^B}{\partial m} = r(1-r)^{m-1}\ln(1-r) < 0 \qquad \textit{if } m \geq 2. \tag{21}$$

Therefore, we immediately obtain the following proposition from equations (20) and (21).

Proposition 4: *An Increase in the number of firms reduces the incentives for green innovations in both the Cournot and Bertrand competition.*

4. Relevance to the Porter hypothesis

In this section, we discuss the relationship between our results and the Porter hypothesis. The Porter hypothesis suggests the possibility of compatibility between environmental protection and firms' competitive advantage through innovations under strict environmental regulations (Porter, 1991; Porter and van der Linde, 1995). Although the hypothesis raises numerous contentious issues, existing studies (e.g., Ambec and Barla, 2002; Greaker, 2006; Greaker and Rosendahl, 2008; André et al., 2009; Lambertini and Tampieri, 2012; Qiu et al. 2018.) elucidated the theoretical mechanisms underlying the success of the Porter hypothesis. Our study can be seen as one of them because our analysis can explain the situation in which this hypothesis holds. Jaffe and Palmer (1997) classified this hypothesis into three versions: "weak," "strong," and "narrow."[9] The weak version explains that environmental regulation stimulates innovation. Note that these innovation incentives will not occur unless environmental regulations are introduced. In our model, equations (12) and (13) illustrate the conditions of the weak version. Therefore, whether in the case of either the Cournot or Bertrand competition, there can be situations in which the weak version is supported. The strong version of this hypothesis calls for not only the generation of innovations but also increased profit. That is, the situation is such that the profits earned after environmental regulations are imposed are greater than the profits earned before such regulations are imposed. In our model, if $(7)-(1)\geq K$ holds, then the strong version is supported in the Cournot case. This condition is described as

$$r\{\frac{s_G+(1-r)m(c_t-c_G)}{m+1}\}^2+(1-r)\{\frac{s_t-rm(c_t-c_G)}{m+1}\}^2-(\frac{s_B}{m+1})^2\geq K. \qquad (22)$$

Therefore, firms can increase their expected profit by carrying out green innovations if R&D cost $K\,(>0)$ is less than or equal to the value on the left-hand-side LHS of (22). Whether strong version holds depends on parameters. The conditions for (22) to be satisfied are stricter than (12) because the third term of LHS of (22) is the profit before environmental regulation ($s_B > s_t$).[10]

Next, we analyze the situation in which the strong version is established in the case of the Bertrand case. If $(10)-(2)\geq K$ in the case of $m\geq 2$ and $(11)-(2)\geq K$ in the case of $m=1$, then the strong version is supported. Therefore, we obtain the following inequality:

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[9] The narrow version is the category that shows how environmental regulations should be structured to promote innovation.

[10] To satisfy (22), at least the following condition $t>\frac{\{1+(1-r)m\}(c_G-c_B)}{m\theta_B(1-r)},(>0)$ is required. This inequality is obtained from $\frac{s_G+(1-r)m(c_t-c_G)}{m+1}>\frac{s_B}{m+1}$. If $\frac{s_G+(1-r)m(c_t-c_G)}{m+1}\leq\frac{s_B}{m+1}$ is satisfied, the LHS of (22) is never positive. This means that in order for strong version of Porter hypothesis to be established, the environmental tax level must be higher than a certain positive level.

$$\begin{cases} K \le r(1-r)^{m-1}(\frac{s_G}{2})^2 & \text{if } m \ge 2, \\ K \le r\{(\frac{s_G}{2})^2 - (\frac{s_t}{2})^2\} & \text{if } m = 1. \end{cases} \quad (23)$$

The RHS of the two inequalities of equation (23) is positive. Therefore, we conclude that the strong version holds, and this condition is the same as in equation (13), that is, the conditions of the weak version hold.

Proposition 5: *If* $c_t - c_G > 0$ *in the Bertrand case, there is a region of the R&D costs that satisfy the Porter hypothesis, and the conditions for establishment are the same for both the weak version and the strong version.*

As a result, in the Cournot case, the conditions for the establishment of both the weak version and the strong version are different. Whereas, the conditions for the weak version of the Porter hypothesis are established are equal to those of the strong version in the Bertrand case. This is because the profits of firms that do not innovate change before and after environmental regulation in the Cournot competition but remains 0 in the Bertrand competition ($m \ge 2$).

In addition, in the Bertrand case, the situation in which the strong version of the Porter hypothesis holds in an ex-post market occurs only when one firm succeeds in green innovation. In other words, it is caused by changes in the market structure as a result of environmental regulation. In this case, the output market is monopolized by the firm, and the price is higher than its marginal cost. Therefore, the situation in which the hypothesis holds in an ex-post market is not a socially desirable one. If two or more firms succeed in carrying out innovations in the case of the Bertrand competition, the equilibrium price is equal to their marginal cost and their technologies are θ_G, that is, social damage is $D(\theta_G Q) = 0$. In this case, we have a socially efficient state.

5. Concluding remarks

This paper analyzes the incentives for green innovations under the Cournot and Bertrand competition models. Several conclusions were arrived at under both the Cournot and Bertrand competition in relation to environmental regulations. When environmental regulations are imposed, there is a positive incentive for green innovations under both the Cournot and Bertrand competition. Although increasing environmental tax leads to more innovation incentives in the case of the Cournot, under the Bertrand competition, environmental tax leads to more innovation incentives only when $m = 1$. A rise in the probability of success of innovation always leads to an increase in the incentives for innovations within the interval $[0, 0.5]$ in the case of the Cournot model. On the contrary, it increases within the interval $[0, 1/m]$ in the case of the Bertrand model. In addition, in the case of the Bertrand model, the incentives always decline within the interval $[0.5, 1]$. As the market becomes more competitive, the incentives to carry out innovations decline in both competition models. Both competition models have the possibility of establishing the Porter hypothesis. The conditions for the weak version of the Porter hypothesis are established are equal to those of the strong version in the case of the Bertrand model. On the contrary in the case of the Cournot model, they do not match.

This study ignores some complications that should be examined in future research.

Although this study treats environmental R&D costs as an exogenous variable, it should be analyzed by treating it as an endogenous variable. Finally, our analysis needs to be extended to other environmental policies besides environmental tax while also introducing social welfare.

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