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ENVIRONMENTAL POLLUTION AND THE EFFECTS OF AMBIENT CHARGES IN MIXED DUOPOLY MARKETS WITH DIVERSE FIRM OBJECTIVES

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Abstract: This paper uses three mixed Cournot duopoly games and examines the effects of ambient charges as a policy measure for reducing non-point source pollution. In the first game, the regulator of the government first announces the ambient charge, and after that a profit-maximizing firm and a partially cooperating firm simultaneously and independently choose their own output levels. The partially cooperating firm aims to maximize the sum of its own profit and a certain proportion of the profit of the rival. It is demonstrated that an increase in the ambient charge can lead to less pollution. In the second game, the regulator first announces the ambient charge, and after that a profit-maximizing firm and a socially concerned firm compete with each other. The socially concerned firm seeks to maximize the sum of its own profit plus a share of consumer surplus. It is also shown that an increase in the ambient charge leads to less pollution. In the third game, the regulator first announces the ambient charge, and after that a partially cooperating firm and a socially concerned firm compete with each other. It is shown that the result of this game is the same as those of the first and second games.

Keywords: Ambient charge, Cournot duopoly games, partially cooperating firm, environmental pollution, socially concerned firm

1. INTRODUCTION

The seminal paper by Segerson (1988) examined a general incentive scheme for controlling non-point pollution in the context of both a single suspected polluter and multiple suspected polluters, and showed that ambient charges were an effective environmental policy instrument for reducing non-point source pollution. Since Segerson (1988), the effects of ambient charges as a policy measure for reducing non-point source pollution have been

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investigated by many researchers (for example, see Poe *et al.*, 2004; Suter *et al.*, 2008; Xepapadeas, 2011; Ganguli and Raju, 2012; Sato, 2017; Ohnishi, 2021). The experimental analysis by Poe *et al.* (2004) investigates the performance of ambient-based policy when polluting firms cooperate with each other, and shows the effectiveness of ambient-based charges as a policy measure. The theoretical analysis by Ganguli and Raju (2012) investigates the effect of an increase in ambient charges as an environmental policy for reducing non-point source pollution in two Bertrand duopoly games. In the first game, the government announces the ambient charge, and after that two profit-maximizing firms simultaneously and independently set their own prices. The pollution abatement technologies are assumed to be fixed. In the second game, the government first announces the ambient charge. Secondly, two profit-maximizing firms simultaneously and independently choose their pollution abatement technologies. Thirdly, they simultaneously and independently set their prices. Ganguli and Raju demonstrate that in each game an increase in the ambient charge leads to more total pollution. On the other hand, Sato (2017) investigates the effect of an increase in ambient charges as a policy measure for reducing non-point source pollution in profit-maximizing Cournot duopoly competition, and shows that the result stands in contrast with that of profit-maximizing Bertrand duopoly competition. In addition, Ohnishi (2021) examines a quantity-setting mixed triopoly model comprising a profit-maximizing firm, a partially cooperating firm and a socially concerned firm to reassess the environmental effect of an increase in ambient charges. The partially cooperating firm aims to maximize the sum of its own profit and certain proportions of the profits of the other firms (for example, see Cyert and DeGroot, 1973; Bischi *et al.*, 2010; Cracau, 2015), while the socially concerned firm seeks to maximize the sum of its own profit plus a share of consumer surplus (for example, see Goering, 2007; Lambertini and Tampieri, 2012; Cracau, 2015; Kopel, 2015). Ohnishi shows that the result is the same as that obtained from profit-maximizing Cournot duopoly competition.

In this paper, we use three mixed Cournot duopoly games and examine the effects of ambient charges as a policy measure for reducing non-point source pollution. In the first game, the regulator first announces the ambient charge, and next a profit-maximizing firm and a partially cooperating firm simultaneously and independently choose their own output levels. In the second game, the regulator first announces the ambient charge, and next a profit-maximizing firm competes with a socially concerned firm. In the third game, the regulator first announces the ambient charge, and next a partially cooperating firm and a socially concerned firm compete with each other.

We find that the results derived in this paper are the same as that of profit-maximizing Cournot duopoly competition obtained by Sato (2017).

2. MIXED DUOPOLY WITH PROFIT-MAXIMIZING AND PARTIALLY COOPERATING FIRMS

We consider two firms: a profit-maximizing firm (firm P) and a partially cooperating firm (firm C). Throughout this paper, we consider neither entry nor exit. In the remainder of this paper, subscripts P and C represent firm P and firm C, respectively. The production quantity of firm i (i = P, C) is represented as q_i. The inverse demand function is linear: $P = a - (q_P + q_C)$, where P represents the market price and a is a constant. The level of total pollution generated by both firms is given by $E = e_P q_P + e_C q_C$, where $e \in (0, \infty)$ denotes the pollution abatement technology.

Firm i's profit is given by

$$\pi_i = \left(a - q_P - q_C\right) q_i - c_i q_i - m\left(e_P q_P + e_C q_C - \overline{E}\right), \tag{1}$$

where $C \in (0, \infty)$ represents the marginal cost of production and $\overline{E}$ is the environmental standard. If $e_P q_P + e_C q_C < \overline{E}$, then the firms receive a uniform subsidy given by $m\,[\overline{E} - (e_P q_P + e_C q_C)]$, whereas if $e_P q_P + e_C q_C > \overline{E}$, then the firms will be levied by $m\,[(e_P q_P + e_C q_C) - \overline{E}]$. Firm P aims to maximize (1).

Firm C's objective function is given by

$$V_C = \pi_C + \beta \pi_P, \tag{2}$$

where $\beta \in [0, 1]$ denotes the level of cooperation.

From (1), we derive firm P's best response function:

$$q_P^{PC}(q_C) = \frac{a - c_P - me_P - q_C}{2}. \tag{3}$$

In addition, we derive firm C's best response function from (2):

$$q_C^{PC}(q_P) = \frac{a - c_C - (1+\beta)me_C - (1+\beta)q_P}{2}. \tag{4}$$

Solving these best response functions simultaneously, we can obtain the Cournot equilibrium quantities:

$$q_P^{PC*} = \frac{a - 2c_P + c_C - 2me_P + (1+\beta)me_C}{3-\beta},$$
$$q_C^{PC*} = \frac{(1-\beta)a + (1+\beta)c_P - 2c_C + (1+\beta)me_P - 2(1+\beta)me_C}{3-\beta}.$$

The total pollution at the equilibrium can be calculated as $e_P q_P^{PC*} + e_C q_C^{PC*}$. This is a function of the policy parameter m. Hence, we denote $e_P q_P^{PC*} + e_C q_C^{PC*}$. as a function $E^{PC}(m)$ and consider the effect of a change in the ambient charge on total pollution:

$$E^{PC\prime}(m) = \frac{2\left(e_P e_C - e_P^2 - e_C^2\right) + 2\beta\left(e_P e_C - e_C^2\right)}{3-\beta}. \tag{5}$$

Now we can present the following proposition.

Proposition 1: In the quantity-setting mixed duopoly model with firm P and firm C, $E^{PC\prime}(m) < 0$.

Proof: Equation (5) is rewritten as follows:

$$E^{PC\prime}(m) = \frac{2e_P e_C - e_P^2 - e_C^2 + 2\beta e_P e_C - e_P^2 - e_C^2 - 2\beta e_C^2}{3-\beta}. \tag{6}$$

Since $\beta \in [0,1]$, the denominator of (6) is positive. Therefore, we prove that $2e_P e_C - e_P^2 - e_C^2 \le 0$. This inequality can be expanded as follows: $-e_P^2 + 2e_P e_C - e_C^2 \le 0 \leftrightarrow -\left(e_P^2 - 2e_P e_C + e_C^2\right) \le 0 \leftrightarrow -(e_P - e_C)^2 \le 0$. It is also evident that $2\beta e_P e_C - e_P^2 - e_C^2 \le 0$. Since $-2\beta e_C^2 < 0$, Proposition 1 is proved. Q.E.D.

3. MIXED DUOPOLY WITH PROFIT-MAXIMIZING AND SOCIALLY CONCERNED FIRMS

There are two firms: a profit-maximizing firm (firm P) and a socially concerned firm (firm S). In the remainder of this paper, subscript S represents firm S. The production quantity of firm j (j = P, S) is represented as q_j. The inverse demand function is $P = a - (q_P + q_S)$. The level of total pollution generated by both firms is $E = e_P q_P + e_S q_S$.

Firm j's profit is given by

$$\pi_j = \left(a - q_P - q_S\right)q_j - c_j q_j - m\left(e_P q_P + e_S q_S - \bar{E}\right), \tag{7}$$

Firm S's objective function is given by

$$W_S = \pi_S + \theta CS, \tag{8}$$

where $CS = \frac{1}{2}(q_P + q_S)^2$ represents consumer surplus and $\theta \in [0,1]$ is the level of social concern.

From (7) and (8), we derive firm P's and firm S's best response functions:

$$q_P^{PS}(q_S) = \frac{a - c_P - me_P - q_S}{2}, \tag{9}$$

$$q_S^{PS}(q_P) = \frac{a - c_S - me_S - (1-\theta)q_P}{2-\theta}. \tag{10}$$

We obtain the Cournot equilibrium quantities:

$$q_P^{PS*} = \frac{(1-\theta)a - (2-\theta)c_P + c_S - (2-\theta)me_P + me_S}{3-\theta},$$
$$q_S^{PS*} = \frac{(1+\theta)a + (1-\theta)c_P - 2c_S + (1-\theta)me_P - 2me_S}{3-\theta}.$$

We denote $e_P q_P^{PS*} + e_S q_S^{PS*}$ as a function $E^{PS}(m)$ and differentiate $E^{PS}(m)$ by m:

$$E^{PS\prime}(m) = \frac{2\left(e_P e_S - e_P^2 - e_S^2\right) + \theta e_P\left(e_P - e_S\right)}{3-\theta}. \tag{11}$$

We can now state the following proposition.

Proposition 2: In the quantity-setting mixed duopoly model with firm P and firm S, $E^{PS\prime}(m) < 0$.

Proof: Equation (11) is rewritten as follows:

$$E^{PS\prime}(m) = \frac{-\theta e_P e_S - e_P^2(2-\theta) + 2e_P e_S - e_P^2 - e_S^2}{3-\theta}. \tag{12}$$

Since $\theta \in [0,1]$, the denominator of (12) is positive, whereas both $-\theta e_P e_S$ and $-e_P^2(2-\theta)$ are negative.

Finally, we prove that $2e_P e_S - e_P^2 - e_S^2 \le 0$. This inequality can be expanded as follows: $-e_P^2 + 2e_P e_S - e_S^2 \le 0 \leftrightarrow -\left(e_P^2 - 2e_P e_S + e_S^2\right) \le 0 \leftrightarrow -\left(e_P - e_S\right)^2 \le 0$. Thus, Proposition 2 is proved. Q.E.D.

4. MIXED DUOPOLY WITH PARTIALLY COOPERATING AND SOCIALLY CONCERNED FIRMS

There are two firms: a partially cooperating firm (firm C) and a socially concerned firm (firm S). The production quantity of firm k (k = C, S) is represented as q_k. The inverse demand function is $P = a - (q_C + q_S)$. The total amount of pollution generated by both firms is $E = e_C q_C + e_S q_S$.

Firm k's profit is given by

$$\pi_k = (a - q_C - q_S)q_k - c_k q_k - m(e_C q_C + e_S q_S - \bar{E}), \quad (13)$$

Firm C's objective function is given by

$$V_C = \pi_C + \beta\pi_S. \quad (14)$$

Firm S's objective function is given by

$$W_S = \pi_S + \theta CS. \quad (15)$$

From (14) and (15), we derive firm C's and firm S's best response functions:

$$q_C^{CS}(q_S) = \frac{a - c_C - (1+\beta)me_C - (1+\beta)q_S}{2}, \quad (16)$$

$$q_S^{CS}(q_C) = \frac{a - c_S - me_S - (1-\theta)q_C}{2-\theta}. \quad (17)$$

We obtain the Cournot equilibrium quantities:

$$q_C^{CS*} = \frac{(1-\beta-\theta)a - (2-\theta)c_C + (1+\beta)c_S - (2+2\beta-\theta-\beta\theta)me_C + (1+\beta)me_S}{3-\beta-\theta+\beta\theta},$$

$$q_S^{CS*} = \frac{(1+\theta)a + (1-\theta)c_C - 2c_S + (1+\beta-\theta-\beta\theta)me_C - 2me_S}{3-\beta-\theta+\beta\theta}.$$

We denote $e_C q_C^{CS*} + e_S q_S^{CS*}$ as a function $E^{CS}(m)$ and differentiate $E^{CS}(m)$ by m:

$$E^{CS\prime}(m) = \frac{2(e_C e_S - e_C^2 - e_S^2) + (\beta-\theta-\beta\theta)e_C e_S - (2\beta-\theta-\beta\theta)e_C^2}{3-\beta-\theta+\beta\theta}. \quad (18)$$

We state the following proposition.

Proposition 3: In the quantity-setting mixed duopoly model with firm C and firm S, $E^{CS\prime}(m) < 0$.

Proof: The proof is very similar to the proofs of Propositions 1 and 2, and therefore omitted.

5. CONCLUSION

We have examined the effects of ambient charges as a policy measure for reducing non-point source pollution in the context of three mixed Cournot duopoly games. We have demonstrated that our results are the same as that obtained from profit-maximizing Cournot duopoly competition.

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