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Abstract

This paper examines a mixed Cournot duopoly model comprising a private firm and a partially privatized public firm to reassess the effect of an increase in ambient charges, and demonstrates that the result of this study is about the same as that obtained from private Cournot duopoly competition.

Keywords: ambient charge; Cournot duopoly; environmental regulation; partial privatization; pollution

JEL classification: C72; D21; L33; Q58

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1. Introduction

The analysis by Poe et al. (2004) examines results from experimental research that explores the performance of ambient-based approaches, and shows the effectiveness of ambient-based charges when nonpoint source polluting firms cooperate with each other. The theoretical analysis by Ganguli and Raju (2012) examines the effect of an increase in ambient charges as a policy measure for reducing industrial non-point source pollution in two Bertrand duopoly games. In the first game, the regulator first announces the ambient charge and then both firms simultaneously and independently choose their prices. The pollution abatement technologies are assumed to be fixed. In the second game, the regulator first announces the ambient charge. Second, both firms simultaneously and independently choose their pollution abatement technologies. Third, they simultaneously and independently set their prices. Ganguli and Raju demonstrate that in each game an increase in the ambient charge can lead to more pollution. In addition, Sato (2017) investigates the effect of an increase in ambient charges in the context of Cournot competition and demonstrates that an increase in the ambient charge leads to less pollution as opposed to Bertrand duopoly competition. These studies consider private duopoly game models.

In the present paper, we consider a mixed Cournot duopoly model comprising a private firm and a partially privatized public firm to reassess the effect of an increase in ambient

charges.[1] We compare the result of this study with that of private Cournot duopoly competition obtained by Sato (2017).

The remainder of this paper is organized as follows. In Section 2, the model is described. Section 3 presents the main result of this study. Finally, Section 4 concludes the paper.

2. The model

There is a market comprising a private firm (firm 1) and a partially privatized firm (firm 0) that is jointly owned by both the public and private sectors. Both firms produce perfectly substitutable goods. There is no possibility of entry or exit. The production quantity of firm $i(i=0,1)$ is represented as q_i. The market price is determined by the following inverse demand function: $p(q_0,q_1)=a-(q_0+q_1)$, where a represents a constant and $a>q_0+q_1$. The total amount of pollution generated by both firms is given by $E=e_0q_0+e_1q_1$, where $e_i\in(0,\infty)$ represents firm *i*'s pollution abatement technology.

[1] The seminal paper by Fershtman (1990) investigated a mixed Cournot duopoly model comprising a private firm and a partially privatized state-owned firm. Since then, the theoretical analysis of partial privatization of state-owned public firms has been conducted by many researchers (e.g., Matsumura, 1998; Chang, 2005; Chao and Yu, 2006; Lu and Poddar, 2007; Saha and Sensarma, 2008; Artz, Heywood and McGinty, 2009; Wang, Wang and Zhao, 2009; Ohnishi, 2010, 2016; Scrimitore, 2014; Chen, 2017; Fridman, 2018).

Firm i's profit is given by

$$\pi_i(q_0,q_1)=p(q_0,q_1)q_i-c_iq_i-m\left(e_0q_0+e_1q_1-\bar{E}\right), \tag{1}$$

where $c_i\in(0,\infty)$ denotes firm i's marginal cost of production and $\bar{E}$ is the environmental standard. If $e_0q_0+e_1q_1<\bar{E}$, then the regulator of the government will give both firms a subsidy of m times the difference between $\bar{E}$ and $e_0q_0+e_1q_1$, whereas if $e_0q_0+e_1q_1>\bar{E}$, then the firms will be penalized by $m\left[\left(e_0q_0+e_1q_1\right)-\bar{E}\right]$. Firm 1 seeks to maximize (1).

Social welfare is given by

$$\begin{aligned}W(q_0,q_1)&=CS(q_0,q_1)+\pi_0(q_0,q_1)+\pi_1(q_0,q_1)+2m\left(e_0q_0+e_1q_1-\bar{E}\right)\\&=CS(q_0,q_1)+p_0(q_0,q_1)q_0-c_0q_0+p_1(q_0,q_1)q_1-c_1q_1,\end{aligned} \tag{2}$$

where $CS(q_0,q_1)=\frac{1}{2}\left(q_0+q_1\right)^2$ represents consumer surplus.[2]

Firm 0's objective function is given by

$$\begin{aligned}U_0(q_0,q_1)&=\lambda W(q_0,q_1)+(1-\lambda)\pi_0(q_0,q_1)\\&=\lambda\left\{\frac{1}{2}\left(q_0+q_1\right)^2+\left[a-\left(q_0+q_1\right)\right]q_0-c_0q_0+\left[a-\left(q_0+q_1\right)\right]q_1-c_1q_1\right\}\\&\quad+(1-\lambda)\left\{\left[a-\left(q_0+q_1\right)\right]q_0-c_0q_0-m\left(e_0q_0+e_1q_1-\bar{E}\right)\right\},\end{aligned} \tag{3}$$

where λ represents the level of public ownership. If $\lambda=0$, firm 0 is purely private,

[2] In Wang, Wang and Lee (2009), social welfare is expressed by $W=CS+\pi_0+\pi_1+T-ED$, where T represents the tax revenues collected by the government and ED is the environmental damage. On the other hand, the model of this paper adopts ambient charges as a mechanism of pollution control, which have been widely discussed in many works (Segerson, 1988; Xepapadeas, 1991, 1992, 1995; Poe et al., 2004; Suter et al., 2008; Ganguli and Raju, 2012; Sato, 2017; Matsumoto and Szidarovszky, 2021).

while if $\lambda = 1$, it is purely public. We assume that $\lambda \in (0,1)$. That is, we consider the case of mixed duopoly competition in which firm 0 is neither purely private nor purely public.

3. Main result

In this section, we present the result of the model described in the previous section. From (1), we derive firm 1's best response function:

$$BR^1(q_0) = \frac{a - c_1 - me_1 - q_0}{2}. \tag{4}$$

In addition, we derive firm 0's best response function from (3):

$$BR^0(q_1) = \frac{a - c_0 - (1-\lambda)me_0 - q_1}{2-\lambda}. \tag{5}$$

Therefore, we obtain the Cournot equilibrium quantities:

$$\begin{aligned} q_0^* &= \frac{a - 2c_0 + c_1 - m\left[2e_0(1-\lambda) - e_1\right]}{3-2\lambda}, \\ q_1^* &= \frac{a(1-\lambda) + c_0 - c_1(2-\lambda) + m\left[e_0(1-\lambda) - e_1(2-\lambda)\right]}{3-2\lambda}. \end{aligned} \tag{6}$$

Furthermore, the industrial emission quantity can be calculated as:

$$e_0 q_0^* + e_1 q_1^* = \frac{a\left[e_0 + e_1(1-\lambda)\right] - 2c_0 e_0 + c_0 e_1 + c_1 e_0 - 2me_0^2(1-\lambda) - e_1(2-\lambda)\left[c_1 - m(e_0 - e_1)\right]}{3-2\lambda}. \tag{7}$$

This is a function of the policy parameter m. Therefore, we denote $e_0 q_0^* + e_1 q_1^*$ as a function $E(m)$ and differentiate $E(m)$ by m:

$$E'(m)=\frac{2\left(e_0e_1-e_0^2-e_1^2\right)+\lambda\left(2e_0^2-e_0e_1+e_1^2\right)}{3-2\lambda}. \tag{8}$$

The main result of this study is summarized in the following proposition.

Proposition 1: In the mixed Cournot duopoly model comprising firm 0 and firm 1, (i) $E'(m)$ is always negative if $e_0 \le e_1$, and (ii) $E'(m)$ is not always negative if $e_0 > e_1$.

Proof: (i) We first prove that if $e_0 = e_1$, then $E'(m) < 0$. Suppose that $e_0 = e_1 = e$. Then equation (8) is rewritten as follows:

$$E'(m)=\frac{2e^2\left(\lambda-1\right)}{3-2\lambda}. \tag{9}$$

This case follows since $\lambda \in (0,1)$.

Next, we prove that if $e_0 < e_1$, then $E'(m) < 0$. Since $e_0 < e_1$ and $\lambda \in (0,1)$, the following inequality holds.

$$2e_0e_1-2e_1^2-\lambda e_0e_1+\lambda e_1^2=e_1\left(2-\lambda\right)\left(e_0-e_1\right)<0$$

$$2\lambda e_0^2-2e_0^2=2e_0^2\left(\lambda-1\right)<0$$

Hence, Proposition 1 (i) is proved.

(ii) We show that if $e_0 > e_1$, then $E'(m)$ is not always negative. We provide the following two numerical examples. We first assume that $e_0 = 5$, $e_1 = 2$ and $\lambda = 0.5$. If these values are substituted into equation (8), then:

$$\frac{2\left(5\cdot 2-5^2-2^2\right)+2\cdot 0.5\cdot 5^2-0.5\cdot 5\cdot 2+0.5\cdot 2^2}{3-2\cdot 0.5}=-8.$$

Next, if $e_0=2$, $e_1=1$ and $\lambda=0.9$, then:

$$\frac{2\left(2\cdot 1-2^2-1^2\right)+2\cdot 0.9\cdot 2^2-0.9\cdot 2\cdot 1+0.9\cdot 1^2}{3-2\cdot 0.9}=0.25.$$

Thus, Proposition 1 (ii) is true. Q.E.D.

From this proposition, we see that the result of this study when $e_0\le e_1$ is consistent with that obtained from private Cournot duopoly competition.

4. Conclusion

We have examined a mixed Cournot duopoly model comprising a private firm and a partially privatized public firm to reassess the effect of an increase in ambient charges. We have demonstrated that, if the pollution abatement technology of the partially privatized public firm is equal to or less than that of the private firm, then an increase in the ambient charge always leads to less pollution.

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