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Abstract

This paper considers 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 compares the result of this study with that obtained from private Cournot duopoly competition. The paper demonstrates that our result is about the same as that of private Cournot duopoly competition.

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

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1. Introduction

The 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 leads 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 can lead 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

[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,

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.

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

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).

both firms a subsidy of m times the difference between $\overline{E}$ and $e_0 q_0 + e_1 q_1$, whereas if $e_0 q_0 + e_1 q_1 > \overline{E}$, then the firms will be penalized by $m\left[\left(e_0 q_0 + e_1 q_1\right) - \overline{E}\right]$. Firm 1 seeks to maximize (1).

Social welfare is given by

$$\begin{aligned} W(q_0, q_1) &= CS(q_0, q_1) + \pi_0(q_0, q_1) + \pi_1(q_0, q_1) + 2m\left(e_0 q_0 + e_1 q_1 - \overline{E}\right) \\ &= CS(q_0, q_1) + p_0(q_0, q_1) - c_0 q_0 + p_1(q_0, q_1) - c_1 q_1, \end{aligned} \tag{2}$$

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

Firm 0's objective function is given by

$$\begin{aligned} U_0(q_0, q_1) &= \lambda W(q_0, q_1) + (1-\lambda)\pi_0(q_0, q_1) \\ &= \lambda \left\{ \frac{1}{2}\left(q_0 + q_1\right)^2 + \left[a - \left(q_0 + q_1\right)\right] q_0 - c_0 q_0 + \left[a - \left(q_0 + q_1\right)\right] q_1 - c_1 q_1 \right\} \\ &\quad + \left(1-\lambda\right)\left\{\left[a - \left(q_0 + q_1\right)\right] q_0 - c_0 q_0 - m\left(e_0 q_0 + e_1 q_1 - \overline{E}\right)\right\}, \end{aligned} \tag{3}$$

where λ denotes the level of privatization. If $\lambda = 0$, firm 0 is purely private, 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 outputs:

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

Furthermore, the industrial emission quantity can be calculated as:

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

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:

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

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:

$$\frac{2\left(5\cdot 2 - 5^2 - 2^2\right) + 2\cdot 0.5\cdot 5^2 - 0.5\cdot 5\cdot 2 + 0.5\cdot 2^2}{3 - 2\cdot 0.5} = -8 < 0.$$

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

$$\frac{2\left(2\cdot 1 - 2^2 - 1^2\right) + 2\cdot 0.9\cdot 2^2 - 0.9\cdot 2\cdot 1 + 0.9\cdot 1^2}{3 - 2\cdot 0.9} = 0.25 > 0.$$

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

Notice 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 can always lead to less pollution.

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