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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 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

Non-point (or diffuse) source pollution results from a variety of activities that occur over the land such as agriculture, forestry, mining and urban development rather than at a single specific source, and includes excess fertilizers, herbicides and insecticides from agricultural lands, residential areas, oil, grease and toxic chemicals from urban runoff, and so forth. Non-point source pollution is the leading remaining cause of water quality problems (United States Environmental Protection Agency, 2021). Zhang et al. (2019) examine the effect of non-point source control in the Binjiang watershed in Southern China from 2005 to 2014, and shows that ammonia nitrogen and total phosphorus can be reduced by 32% and 43%, respectively. Furthermore, McCarthy (2000) considers a non-point control program to manage non-point source which affects water quality and says, "Our children's future matters to all of us, and we have a responsibility to leave to them the same beautiful and viable environment that we enjoy today."

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 non-point 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.

As well known, a worldwide wave of privatization of public firms has been observed since the 1980s. However, most public firms are not fully privatized, and many firms can be observed with a mixture of private and public ownership. The seminal theoretical work 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). For example, Matsumura (1998) examine a mixed Cournot duopoly model in which a private firm competes with a privatized firm jointly owned by both public and private sectors, and shows that neither full privatization nor full nationalization is optimal, that is, partial privatization is a reasonable choice for the government.

Therefore, 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. To the best of the author’s knowledge, there is no work dealing with such an economic situation. 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. 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: $p(q_0, q_1) = a - b(q_0 + q_1)$, where $a, b \in (0, \infty)$ are constants and $a/b > q_0 + q_1$. The total amount of pollution generated by both firms is given by $E = e_0 q_0 + e_1 q_1$, where $e_i \in (0, \infty)$ represents firm *i*'s pollution abatement technology.

Firm *i*'s profit is given by

$$\pi_i(q_0, q_1) = p(q_0, q_1)q_i - c_i q_i - m\left(e_0 q_0 + e_1 q_1 - \bar{E}\right), \quad (1)$$

where $c_i \in (0, \infty)$ denotes firm *i*'s marginal cost of production and $\bar{E}$ is the environmental standard. If $e_0 q_0 + e_1 q_1 < \bar{E}$, then the regulator of the government will give both firms a subsidy of m times the difference between $\bar{E}$ and $e_0 q_0 + e_1 q_1$, whereas if $e_0 q_0 + e_1 q_1 > \bar{E}$, then the firms will be penalized by $m\left[\left(e_0 q_0 + e_1 q_1\right) - \bar{E}\right]$. 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.[1]

Firm 0's objective function is given by

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

where λ represents the level of public ownership. If $\lambda=0$, firm 0 is purely private, and it can be thought that the result is the same as that by Sato (2017). On the other hand, if $\lambda=1$, then firm 0 is purely public. Firm 0's objective function is (2) and is not affected by $2m\left(e_0q_0+e_1q_1-\bar{E}\right)$. Therefore, we assume that $\lambda\in(0,1)$. We consider the model 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:

[1] In Wang, Wang and Zhao (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).

$$BR^1(q_0) = \frac{a - c_1 - me_1 - bq_0}{2b}. \tag{4}$$

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

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

Therefore, we obtain the Cournot equilibrium quantities:

$$\begin{aligned} q_0^* &= \frac{a(b-\lambda-b\lambda) - 2bc_0 + c_1(b-\lambda+b\lambda) - m\left[2be_0(1-\lambda) - e_1(b-\lambda+b\lambda)\right]}{b(3b-\lambda-b\lambda)}, \\ q_1^* &= \frac{a(1-\lambda) + bc_0 - c_1(2b-\lambda) + m\left[be_0(1-\lambda) - e_1(2b-\lambda)\right]}{b(3b-\lambda-b\lambda)}. \end{aligned} \tag{6}$$

Furthermore, the industrial emission quantity can be calculated as:

$$e_0q_0^* + e_1q_1^* = \frac{\begin{array}{c} a\left[e_0(b+\lambda-b\lambda) + e_1(b-\lambda)\right] - bc_0(2e_0 - e_1) \\ +c_1\left[e_0(b-\lambda+b\lambda) + e_1(2b+\lambda)\right] - m\left[2be_0^2(1+\lambda) + e_1(2b-\lambda)(e_0 - e_1)\right] \end{array}}{b(3b-\lambda-b\lambda)}. \tag{7}$$

This is a function of the policy parameter m. Therefore, we denote $e_0q_0^* + e_1q_1^*$ as a function $E(m)$ and differentiate $E(m)$ by m:

$$E'(m) = \frac{2b\left(e_0e_1 - e_0^2 - e_1^2\right) + \lambda\left(2be_0^2 - e_0e_1 + e_1^2\right)}{b(3b-\lambda-b\lambda)}. \tag{8}$$

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 $\lambda < 2b$; (ii) otherwise, $E'(m)$ is not always negative.

Proof: (i) If $\lambda < 2b$, since $\lambda \in (0,1)$, the denominator of (8) is positive.

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

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

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

Next, we prove that if $e_0 < e_1$, then $E'(m) < 0$. Since $\lambda \in (0,1)$, $\lambda < 2b$ and $e_0 < e_1$, the following inequalities hold:

$$2be_0e_1 - 2be_1^2 - \lambda e_0e_1 + \lambda e_1^2 = e_1(2b - \lambda)(e_0 - e_1) < 0,$$

$$2b\lambda e_0^2 - 2be_0^2 = 2be_0^2(\lambda - 1) < 0.$$

Hence, Proposition 1 (i) is proved.

(ii) We provide the following three numerical examples. We first assume that $e_0 = 5$, $e_1 = 2$, $\lambda = 0.5$ and $b = 1$. If these values are substituted into (8), then:

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

Second, if $e_0 = 4$, $e_1 = 5$, $\lambda = 0.5$ and $b = 0.1$, then:

$$\frac{2\cdot 0.1(4\cdot 5 - 4^2 - 5^2) + 0.5(2\cdot 0.1\cdot 4^2 - 4\cdot 5 + 5^2)}{0.1(3\cdot 0.1 - 0.5 - 0.1\cdot 0.5)} = 40.$$

Third, if $e_0 = 8$, $e_1 = 4$, $\lambda = 0.9$ and $b = 1$, then:

$$\frac{2(8\cdot 4 - 8^2 - 4^2) + 0.9(2\cdot 8^2 - 8\cdot 4 + 4^2)}{(3 - 0.9 - 0.9)} = 7\frac{2}{3}.$$

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

From this proposition, we see that the result when $e_0 \leq e_1$ and $\lambda < 2b$ is consistent with that obtained from private Cournot duopoly competition. An increase in m decreases each firm's optimal output. From (4) and (5), we see that a decreases in firm *i*'s optimal output may increase firm *j*'s optimal output $(i, j = 0,1; i \neq j)$. However, when $e_0 \leq e_1$, an increase in m always decreases the market output. Therefore, it can be thought that $E'(m)$ is always negative. On the other hand, when $e_0 > e_1$, an increase in m does not always decrease the market output.

If $E'(m) < 0$, an increase in m decreases $e_0 q_0 + e_1 q_1$. This decreases the market output and consumer surplus since e_0 and e_1 are given exogenously. However, from an environmental standpoint, it can be said that ambient charges are effective for reducing industrial non-point source pollution.

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 there is a case in which an increase in the ambient charge always leads to less pollution.

In this paper, we have considered a simple mixed duopoly model. In the future, we will examine various extended models of this study.

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