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Pollution, partial privatization and the effect of ambient charges: price competition

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Abstract

Nonpoint pollution arises from dispersed sources and lacks direct monitoring. Observing individual abatement levels or discharges is generally impractical. This paper addresses the economic incentives for controlling nonpoint pollution, which differs from point source pollution due to difficulties in monitoring individual polluting actions. The paper examines a mixed Bertrand duopoly model where there are two firms: a private firm and a partially privatized public firm that is jointly owned by the public and private sectors. The model of the paper uses ambient charges as a policy measure for reducing industrial nonpoint source pollution. This paper shows that ambient charges are an effective policy measure.

Keywords: Ambient charge; Nonpoint pollution: Partial privatization; Price competition

JEL classification: D21; L33; Q58

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I. Introduction

Nonpoint source pollution, also known as diffuse pollution, refers to contamination of water or air that does not originate from a single discrete source. Unlike point source pollution, which results from a single identifiable source, nonpoint source pollution arises from the cumulative effect of small amounts of contaminants gathered from a large area. Nonpoint source water pollution affects bodies of water due to sources such as polluted runoff from agricultural areas, which drains into rivers. Nonpoint source air pollution impacts air quality. Examples include emissions from smokestacks or vehicle tailpipes. Although these pollutants may have originated from specific points, their long-range transport and multiple sources classify them as nonpoint pollution. Controlling nonpoint source pollution is challenging because it arises from the everyday activities of many different people. In summary, nonpoint source pollution results from widespread activities and requires improved management across various sectors to mitigate its impact on both water and air quality.

Theoretical research on nonpoint source pollution remains active, contributing valuable insights to environmental economics, pollution control, and regulatory approaches to mitigate its impact on water and air quality Here are summaries of some theoretical papers related to nonpoint source pollution. Segerson (1988) proposes a general incentive scheme combining rewards for environmental quality above a given standard with penalties for substandard quality. This approach encourages firms and individuals to adopt preventive measures to reduce nonpoint pollution. Segerson contributes to understanding economic incentives for managing nonpoint pollution, considering uncertainty and heterogeneity among suspected polluters. Segerson's research emphasizes the importance of designing flexible and cost-effective mechanisms to tackle nonpoint pollution. Levi and Nault (2004) explore how policymakers can encourage firms to adopt cleaner production technologies to benefit the environment. The authors consider situations where firms need to make significant technological conversions to reduce environmental harm. Levi and Nault address the challenge of heterogeneity in firms' plant and equipment conditions, which cannot be directly observed by policymakers. By linking plant conditions to production costs, environmental damage, and conversion costs, Levi and Nault discuss when perfectly discriminating incentives for technology conversion are not feasible. They also highlight that firms with better plant conditions are more likely to adopt cleaner technologies, while those with poorer conditions may not. Ganguli and Raju (2012) investigate the impact of raising ambient charges as a policy measure to mitigate industrial nonpoint source pollution in two Bertrand duopoly games. In the first game, the regulator initially announces the ambient charge, after which both firms independently set their prices. The pollution abatement technologies remain fixed. In the second game, the regulator announces the ambient charge first. Then, both firms independently select their pollution abatement technologies. Finally, they simultaneously and independently determine their prices. Surprisingly, Ganguli and Raju discover that in both games, an increase in the ambient charge can actually result in greater pollution. Raju and Ganguli (2013) investigate the impact of environmental regulation and ambient charges on nonpoint source pollution in a Cournot duopoly. The authors consider both constant returns to scale (CRTS) and decreasing returns to scale (DRTS) scenarios. A higher ambient charge leads to increased pollution abatement (reducing pollution) and lower output. Pollution abatement and output reduction reinforce each other, resulting in an unambiguous decrease in nonpoint source pollution. A higher ambient charge decreases output, but its effect on abatement is ambiguous. The marginal effect of an ambient charge change is larger under CRTS than DRTS. Overall, pollution control mechanisms like ambient charges tend to be more effective under CRTS.

Sato (2017) investigates the effectiveness of ambient charges as a policy measure for reducing industrial nonpoint source pollution. The author focuses on a Cournot duopoly model and demonstrates that ambient charges are an effective policy measure for controlling nonpoint source pollution. Sato contributes to understanding how different economic mechanisms impact pollution reduction in imperfectly competitive markets. Matsumoto and Szidarovszky (2021) construct a two-stage Bertrand duopoly game, where optimal abatement technologies are chosen first, followed by determining optimal prices and productions. The ambient charge is always effective at the second stage. However, its effect could be ambiguous at the first stage. Matsumoto and Szidarovszky shed light on the conditions under which the ambient charge becomes effective and contribute to understanding how policy instruments like ambient charges can influence firms' behavior in managing nonpoint source pollution. Ohnishi (2022) investigates the impact of ambient charges as a policy measure for reducing nonpoint source pollution within a mixed Cournot duopoly setting. Three games are considered. In the first game, the regulator announces the ambient charge, and then a profit-maximizing firm and a partially cooperating firm independently choose their output levels. The partially cooperating firm aims to maximize its profit and a proportion of the rival's profit. In the second game, the regulator announces the ambient charge, and then a profit-maximizing firm competes with a socially concerned firm. The socially concerned firm seeks to maximize its profit plus a share of consumer surplus. In the third game, the regulator announces the ambient charge, and then a partially cooperating firm competes with a socially concerned firm. In all three games, an increase in the ambient charge leads to reduced pollution. The author highlights the effectiveness of ambient charges as an environmental policy instrument. Ohnishi (2021b) 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 impact of an increase in ambient charges. The author demonstrates that an increase in the ambient charge can reduce pollutant emissions. This finding holds even in a mixed triopoly scenario with diverse firm objectives. Perera (2022) focuses on the effectiveness of ambient charges as a policy measure for reducing nonpoint source pollution in a hybrid scheme and examines how ambient charges impact pollution reduction. The model considers an energy market with hybrid technology competing in an oligopoly setting. Each power plant uses a mix of fossil fuels and renewable energy sources to generate electricity. The electricity demand is not realized when the firm (leader) makes decisions. The competition between energy sources follows Nash-Cournot equilibria. Perera derives the Stackelberg-Nash-Cournot equilibrium under the assumption of affine demand function and quadratic cost functions for power plants. The analysis provides insights into using ambient charges as an environmental economic policy measure and allows for specific control technologies to maintain emissions standards in a hybrid scheme. Environmental authorities can set ambient charges and pollutant limits based on technological variations. Perera sheds light on the role of ambient charges in pollution abatement within a dynamic market context. These studies contribute valuable insights to environmental economics and policy.

This paper considers partial privatization introduced by Fershtman (1990). Over the past few decades, there has been a global trend of privatizing public companies. However, many public firms remain in a state of partial privatization, where they are jointly owned by both private and public entities. Fershtman's influential research in 1990 explored a mixed Cournot duopoly model, featuring a private firm competing alongside a partially privatized state-owned firm. Since then, numerous economists (including Artz, Heywood, and McGinty, 2009; Chang, 2005; Chao and Yu, 2006; Chen, 2017; Fridman, 2018; Heywood, Hu, and Ye, 2017; Lu and Poddar, 2007; Matsumura, 1998; Ohnishi, 2010, 2016; Saha and Sensarma, 2008; Scrimitore, 2014; Wang and Lee, 2010; Wang, Wang, and Zhao, 2009) have delved into the theoretical analysis of partial privatization. For instance, Matsumura (1998) investigated a mixed Cournot duopoly scenario where a private firm competes with a jointly owned privatized firm. Surprisingly, neither full privatization nor full nationalization emerges as the optimal solution; instead, partial privatization often proves to be a reasonable choice for governments.

Ohnishi (2021a) examines a mixed Cournot duopoly model involving a private firm and a partially privatized public firm to reassess the impact of an increase in ambient charges. The effect of an increase in ambient charges is analyzed. The findings indicate that the result aligns closely with that of private Cournot duopoly competition.

Therefore, in the present paper, we analyze the impact of raising ambient charges in a mixed Bertrand duopoly model that includes both a private firm and a partially privatized public firm.

The remainder of this paper proceeds as follows. In Section II, we describe the model. Section III presents the main result of this study. Finally, the paper is concluded in Section IV.

II. Model

We consider a market where there are two firms: a private firm (firm 1) and a partially privatized firm (firm 0) that is jointly owned by both the public and private sectors. Throughout this paper, subscripts 1 and 0 represent firm 1 and firm 0, respectively. Additionally, when i and j are used to represent firms in an expression, they should be understood to refer to firm 1 and firm 0 with $i \neq j$. There is no possibility of entry or exit. The demand function of firm i is represented by $q_i(p_i, p_j) = (1-\gamma - p_i + \gamma p_j)/(1-\gamma^2)$, where $p_i \in (0,\infty)$ denotes the price of firm i and $\gamma \in (0,1)$ is the degree of product substitutability. For simplicity, we assume $\gamma = 0.5$. The total amount of pollution generated by both firms is given by $E = e_0 q_0(p_0, p_1) + e_1 q_1(p_0, p_1)$, where $e_i \in (0,\infty)$ denotes firm *i*'s pollution abatement technology parameter.

Firm *i*'s profit is given by

$$\pi_i(p_i, p_j) = (p_i - c)\left[\frac{2(1-2p_i+p_j)}{3}\right] - m\left\{e_i\left[\frac{2(1-2p_i+p_j)}{3}\right] + e_j\left[\frac{2(1-2p_j+p_i)}{3}\right] - \overline{E}\right\}, \tag{1}$$

where $c \in (0,\infty)$ represents the marginal cost of production and $\overline{E}$ is the environmental standard. If $e_0q_0(p_0, p_1) + e_1q_1(p_0, p_1) < \overline{E}$, the government regulator will provide both firms with a subsidy equal to m times the difference between $\overline{E}$ and $e_0q_0(p_0, p_1) + e_1q_1(p_0, p_1)$. Conversely, if $e_0q_0(p_0, p_1) + e_1q_1(p_0, p_1) > \overline{E}$, the firms will face a penalty of $m\left[(e_0q_0 + e_1q_1) - \overline{E}\right]$. Firm 1 aims to maximize (1).

Consumer surplus is given by

$$CS(p_0, p_1) = \frac{2\left[p_0^2 + p_1^2 + 2(1-p_0-p_1) - (1-p_0)(1-p_1)\right]}{3}. \tag{2}$$

Furthermore, social welfare is given by

$$W(p_0, p_1) = CS(p_0, p_1) + \pi_0(p_0, p_1) + \pi_1(p_0, p_1) + 2m\left\{e_0\left[\frac{2(1-2p_0+p_1)}{3}\right] + e_1\left[\frac{2(1-2p_1+p_0)}{3}\right] - \overline{E}\right\}, \tag{3}$$

Firm 0's objective function is given by

$$U_0(q_0, q_1) = \lambda W(q_0, q_1) + (1-\lambda)\pi_0(q_0, q_1), \tag{4}$$

where λ determines the degree of public or private ownership. When $\lambda = 0$, firm 0 operates as a purely private entity. Conversely, when $\lambda = 1$, firm 0 functions as a purely public entity. We assume that $\lambda \in (0,1)$. Therefore, we consider the model of mixed duopoly competition in which firm 0 is neither purely private nor purely public.

III. Main result

This section presents the result of the model described in the previous section. From (1), we derive the best response function of firm 1:

$$BR^1(p_0) = \frac{1 + 2c - m(e_0 - 2e_1) + p_0}{4}. \tag{5}$$

Furthermore, we derive the best response function of firm 0 from (3):

$$BR^0(p_1) = \frac{1+2c-\lambda(1+c)+m(1-\lambda)(2e_0-e_1)+p_1}{4-2\lambda}. \quad (6)$$

Therefore, we obtain the Bertrand equilibrium prices:

$$p_0^* = \frac{5(1+2c)-4\lambda(1+c)+m\left[e_0(7-8\lambda)-2e_1(1-2\lambda)\right]}{15-8\lambda},$$
$$p_1^* = \frac{5(1+2c)-\lambda(3+5c)-m\left[2e_0-e_1(7-3\lambda)\right]}{15-8\lambda}. \quad (7)$$

Furthermore, we obtain the equilibrium quantities:

$$q_0^* = \frac{2\left\{(10-3\lambda)(1-c)-4m\left[4e_0(1-\lambda)+e_1(1-2\lambda)\right]\right\}}{3(15-8\lambda)},$$
$$q_1^* = \frac{2\left\{(10-6\lambda)(1-c)+m\left[e_0(11-16\lambda)-2e_1(8-5\lambda)\right]\right\}}{3(15-8\lambda)}. \quad (8)$$

Equation (8) is a function of the policy parameter m. Hence, we denote $e_0q_0^*+e_1q_1^*$ as a function $E(m)$ and then differentiate $E(m)$ with respect to m.

$$E'(m) = \frac{2\left(15e_0e_1-16e_0^2-16e_1^2-16\lambda e_0e_1+16\lambda e_0^2+10\lambda e_1^2\right)}{3(15-8\lambda)}. \quad (9)$$

We now present the main result of this study.

Proposition 1: In the mixed Bertrand duopoly model comprising firm 0 and firm 1, $E'(m) < 0$.

Proof: Equation (9) is rewritten as follows:

$$E'(m) = \frac{\begin{array}{c}15\left(2e_0e_1-e_0^2-e_1^2\right)-15\left(2\lambda e_0e_1-\lambda e_0^2-\lambda e_1^2\right)\\ -17e_0^2+17\lambda e_0^2-17e_1^2+5\lambda e_1^2-2\lambda e_0e_1\end{array}}{3(15-8\lambda)}. \quad (10)$$

Since $\lambda \in (0,1)$, the denominator of (10) is positive. We first prove that $2e_0e_1-e_0^2-e_1^2 \le 0$. This can be expanded as follows: $-e_0^2+2e_0e_1-e_1^2 \le 0 \Leftrightarrow -\left(e_0^2-2e_0e_1+e_1^2\right) \le 0 \Leftrightarrow -(e_0-e_1)^2 \le 0$. Hence, $15\left(2e_0e_1-e_0^2-e_1^2\right) \le 0$. Since $\lambda \in (0,1)$, $15\left(2e_0e_1-e_0^2-e_1^2\right)-15\left(2\lambda e_0e_1-\lambda e_0^2-\lambda e_1^2\right) \le 0$. In addition, $-17e_0^2+17\lambda e_0^2<0$,

$-17e_1^2 + 5\lambda e_1^2 < 0$, and $-2\lambda e_0 e_1 < 0$. Thus, this proposition is proved. Q.E.D.

Since $E'(m) < 0$, an increase in m leads to a decrease in $e_0 q_0 + e_1 q_1$. Consequently, this reduction affects both market output and consumer surplus, given that e_0 and e_1 are exogenously determined. Therefore, from an environmental perspective, it can be argued that ambient charges effectively mitigate nonpoint source pollution from industrial activities.

IV. Conclusion

We analyzed a mixed Bertrand duopoly model that includes both a private firm and a partially privatized public firm. Our focus was on reevaluating the impact of an increase in ambient charges. Our findings consistently indicate that higher ambient charges result in reduced pollution levels.

While our investigation centered on a one-shot duopoly game, it is essential to recognize that real-world scenarios involve long-term competition. Consequently, we intend to explore the equilibrium of a repeated mixed oligopoly model. In this extended framework, a partially privatized public firm competes with numerous private firms.

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