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ECONOMIC INCENTIVES FOR NONPOINT POLLUTION CONTROL: INSIGHTS FROM A MIXED BERTRAND DUOPOLY MODEL WITH PARTIAL PRIVATIZATION

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Abstract: This paper investigates how changes in ambient charges influence pollution levels within a mixed Bertrand duopoly model involving both a private firm and a partially privatized public firm. The focus is on reassessing the impact of increased ambient charges. The results suggest that the effect of ambient charges in this mixed Bertrand duopoly setting is about the same as that observed in mixed Cournot duopoly competition. This paper sheds light on the intricate relationship between environmental policies and market competition. By examining the mixed Bertrand duopoly market, the paper provides valuable insights into the dynamics of price competition and environmental impact. The findings contribute to the broader field of environmental economics and policy, emphasizing the importance of considering both private and public players in regulatory frameworks.

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

JEL classification: D21; L33; Q58

I. INTRODUCTION

Nonpoint source pollution, also referred to as diffuse pollution, occurs when water or air becomes contaminated from various dispersed sources rather than a single identifiable point. Unlike point source pollution, which stems from specific discharge points, nonpoint source pollution results from the cumulative impact of small amounts of contaminants across a large area. Nonpoint source water pollution affects bodies of water due to sources like polluted runoff from agricultural areas. Rainwater washes pesticides, fertilizers, and other pollutants from fields into rivers and streams. These pollutants may have originated from specific locations, but their widespread distribution classifies them as nonpoint pollution. The challenge lies in managing pollution arising from everyday activities across diverse sectors. In addition, nonpoint source air pollution impacts air quality. It includes emissions from sources such as smokestacks and vehicle tailpipes. While these pollutants may have specific origins, their long-range transport and contribution from multiple sources categorize them as nonpoint pollution.

Theoretical research on nonpoint source pollution remains a vibrant field, providing valuable insights into environmental economics, pollution control, and regulatory strategies to mitigate its impact on water and air quality. There are many theoretical research papers related to nonpoint source pollution (see, e.g., Ganguli and Raju, 2012; Jones and Corona, 2008; Levi and Nault, 2004; Matsumoto and Szidarovszky, 2021; Ohnishi, 2021b, 2022; Perera, 2022; Raju and Ganguli, 2013; Sato, 2017; Segerson, 1988; Wang, Wang and Zhao, 2009; Xepapadeas, 1992, 1995). For example, Sato (2017) considers a Cournot duopoly model in which there are two profit-maximizing private firms and shows that an increase in ambient charges can lead to less pollution. All these studies collectively contribute to our understanding of how economic decisions, market structures and regulatory mechanisms impact environmental outcomes. In the next section, we review some research papers related to ambient charges, environmental effects and firm interactions in various economic contexts.

This paper considers the 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; Heywood and Ye, 2010; 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 example, Matsumura (1998) investigates a mixed Cournot duopoly scenario where a private firm competes with a jointly owned privatized firm and shows that neither full privatization nor full nationalization emerges as the optimal solution; instead, partial privatization often proves to be a reasonable choice for governments.

The theoretical analysis by Ohnishi (2021a) considers 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 examined. The findings indicate that the effect of ambient charges in the mixed Cournot duopoly setting aligns closely with that observed in private Cournot duopoly competition.

Therefore, in the present paper, we examine 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 is organized as follows. In Section II, we review some theoretical papers related to nonpoint source pollution. Section III describes the model we use, and Section IV presents the results of this study. Section V explores the insights and implications arising from the results. Finally, the paper is concluded in Section VI.

II. LITERATURE REVIEW

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. This section briefly reviews some theoretical papers using ambient charges as a mechanism of nonpoint source pollution control.

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. 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. 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 under DRTS. Overall, pollution control mechanisms like ambient charges tend to be more effective under CRTS. 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' behaviour in managing nonpoint source pollution.

Perera (2022) focuses on the effectiveness of ambient charges as a policy measure for reducing nonpoint source pollution in a hybrid scheme. 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. 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. All these studies contribute valuable insights to environmental economics and policy.

III. 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 $e_0 q_0(p_0, p_1) + e_1 q_1(p_0, p_1) < \overline{E}$, the government regulator will provide both firms with a subsidy equal to m times the difference between $\bar{E}$ and $e_0 q_0(p_0, p_1) + e_1 q_1(p_0, p_1)$. @Conversely, if $e_0 q_0(p_0, p_1) + e_1 q_1(p_0, p_1) > \bar{E}$, the firms will face a penalty of $m\left[\left(e_0 q_0 + e_1 q_1\right) - \bar{E}\right]$. Firm 1 aims to maximize (1).

Consumer surplus is given by

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

Furthermore, social welfare is given by

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

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.

IV. RESULTS

From (1), we derive the best response function of firm 1:

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

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

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

Therefore, we obtain the Bertrand equilibrium prices:

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

Furthermore, we obtain the equilibrium quantities:

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

Equation (8) is a function of the policy parameter m. Hence, we denote $e_0 q_0^* + e_1 q_1^*$ as a function $E(m)$ and then differentiate $E(m)$ with respect to m.

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

We now present the following proposition.

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

Proof: Equation (9) is rewritten as follows:

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

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: $-e_0^2 + 2e_0e_1 - e_1^2 \le 0 \Leftrightarrow -\left(e_0^2 - 2e_0e_1 + e_1^2\right) \le 0 \Leftrightarrow -\left(e_0 - e_1\right)^2 \le 0$. 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 the market output. Therefore, from an environmental perspective, it can be argued that ambient charges effectively mitigate nonpoint source pollution from industrial activities.

V. DISCUSSIONS AND POLICY IMPLICATIONS

We delve into the intricate relationship between environmental regulation, pollution and partial privatization within the context of a mixed Bertrand duopoly model. The focus is on reassessing the impact of increased ambient charges. In this section, we explore the insights and implications arising from the research results.

We reevaluate the effect of increased ambient charges on pollution levels. Interestingly, the findings align with those of private Cournot duopoly competition obtained by Sato (2017). This suggests that the impact of ambient charges remains consistent across different ownership structures. Therefore, policymakers can leverage ambient charges as a tool for pollution reduction, regardless of whether firms are fully private or partially privatized.

We also find that the effect of ambient charges in this mixed Bertrand duopoly setting aligns closely with that observed in mixed Cournot duopoly competition. The findings suggest that the impact may not differ significantly between Bertrand and Cournot duopoly scenarios.

Policymakers must strike a balance between environmental objectives and market competition. While ambient charges can curb pollution, they should be implemented thoughtfully to avoid unintended consequences. A nuanced approach is necessary to achieve environmental goals without stifling market dynamics. Consideration of both private and public players is crucial.

Firms' pricing decisions significantly impact pollution levels. Policymakers should explore dynamic pricing mechanisms that incentivize cleaner technologies while maintaining competitiveness. Encouraging firms to adopt environmentally friendly practices through pricing incentives can lead to better outcomes.

Rather than relying solely on ambient charges, integrated policies that consider technology adoption, pricing and privatization dynamics can enhance pollution reduction efforts. Therefore, policymakers should adopt a comprehensive approach that addresses multiple facets of environmental management.

VI. CONCLUDING REMARKS

In this paper, we examine a mixed Bertrand duopoly model that includes both a private firm and a partially privatized public firm. Our focus is on reevaluating the impact of an increase in ambient charges. Our findings consistently indicate that higher ambient charges result in reduced pollution levels. We underscore the need for adaptive, evidence-based policies that account for market nuances, ownership structures and environmental goals. By fostering collaboration and considering diverse factors, policymakers can create a regulatory framework that promotes both economic growth and environmental well-being.

While our investigation centred 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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