Research Article
Volume 7:1, 2024

Journal of Pollution

ISSN: 2684-4958

Open Access

Effectiveness of Ambient Charges Under a Bertrand Duopoly

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Abstract

In this study, I examine the effectiveness of ambient charges a policy instrument aimed at reducing nonpoint source pollution originating from a duopolistic industry. Ganguli and Raju (2012) concluded in their study that ambient charges generate perverse effects under a Bertrand competition, implying that an increase in ambient charges by the government would increase total emissions. Accordingly, we argue that the effects of ambient charges become perverse depending on the degree of product differentiation between firms. In particular, ambient charges will not have perverse effects if an increase in the product price of one firm increases the market demand for the other firm's product by nearly twofold. Therefore, when considering the effects of ambient charges in a duopolistic market, they might be an effective policy instrument not only under Cournot competition, which has already been verified, but also under Bertrand competition.

Keywords: Duopoly • Emissions • Ambient charges • Bertrand competition • Product differentiation • Nonpoint source pollution

1. Introduction

Environmental problems discovered by the assessment of pollutant concentrations are known as ambient pollution problems (Phaneuf and Requate (2017)). One overriding characteristic of such problems is that the sources of pollution are nonpoint, such as the ambient air pollution caused by particulate matter released into the atmosphere by oil refineries. It is well known that ambient air pollution can pose significant health hazards. The World Health Organization (2016) estimates it to cause approximately 25% of lung cancer deaths, 8% of chronic obstructive pulmonary disease deaths, and about 15% of cases of ischemic heart disease and stroke. Therefore, it is important to implement effective environmental policy to effectively decrease ambient air pollution. Segerson (1988) suggested a scheme to reduce industrial nonpoint source pollution. According to her, if the amount of emissions from an industry goes beyond (below) a certain cut-off level, the government will uniformly impose a fine on (or grant a subsidy to) all of the firms in that particular industry. This scheme targets a difficult aspect of production that requires the government to measure each firm's emissions. Even if the amount of emissions varies among firms, the fine (subsidy) will be imposed (granted) at a constant rate depending on the extent to which the total emissions differ from the given baseline. Ganguli and Raju (2012) refer to this scheme as ambient charges. However, determining the effectiveness of ambient charges is still in the research phase; currently there is no example available on its implementation. On the one hand, Spraggon (2002) and Poe et al. (2004) were able to demonstrate its effectiveness in the field of experimental economics.

On the other hand, in the field of theoretical economics, oligopoly theory has been applied; e.g., Ganguli and Raju (2012) and Raju and Ganguli (2013) and Sato (2017) studied it under duopoly conditions, while Matsumoto studied it under an oligopoly. However, only Ganguli and Raju (2012) studied ambient charges under a Bertrand competition model. The others studied them in the context of a Cournot competition. In their study, Ganguli and Raju (2012) concluded that ambient charges have perverse effects on the environment under Bertrand competition. This feature indicates that if the government increases ambient charges for reducing emissions in an industry, contrary to the firms' intentions, that industry's emissions will increase. In this study, I show that such perverse effects depend on the degree of product differentiation; that is, even with product differentiation, if the degree is within a certain range (nearly twofold), as suggested by experimental economics, then the ambient charges will be an effective instrument of environmental policy against ambient pollution. The remainder of the paper is organized as follows. Section 2 establishes the model and Section 3 finds Bertrand equilibrium. Finally, Section 4 presents the conclusion.

2. The Bertrand competition model

This section describes a Bertrand competition. Two firms are competing under a Bertrand competition. Each firm i (i.e., $i=1, 2$) produces a differentiated substitute good and sets the product's price. The market demand function for product i is defined as follows:

$$q_i = a - p_i + b p_j,\ i, j = 1, 2;\ j \neq i \tag{1}$$

Where q_i represents the market quantity demanded for product i. The parameter b which is always greater than zero $(b > 0)$ represents the effect of product i on the market quantity demanded, Q_i, when the rival firm j ($j=1, 2; j \neq i$) increases the price of its product, p_j. The cost function of firm i is defined as follows:

$$Ci = c_i q_i \tag{2}$$

Where $c_i > 0$ represents the marginal cost (a constant) of firm i. When firm i produces q_i amount of goods, then $e_i q_i$ amount of pollutants are emitted. Here $e_i > 0$ represents the extent of pollution abatement by firm i, and the greater (smaller) its value, the greater (lesser) the amount of emissions. Since the two firms' e_i is likely not equal, the amount of emissions differ, even if their outputs are equal. Arguably, if firms have different pollution-abatement technologies installed, they will have different levels of emissions. Another reason for the difference could be that, for example, in an industry with a strong involvement of the state (e.g., China's coal and oil industries), the extent of collusion with government officials differs among firms. The total amount of pollutants E emitted by both firms is defined as follows:

$$E = e_1 q_1 + e_2 q_2 \tag{3}$$

The government does not measure firm-specific emissions, but it can measure E. The government sets an environmental standard $\bar{E}$ and depending on the measured deviation of $\bar{E}$ from the standard, the government will either impose a fine or grant a subsidy. That is, if the total amount of emissions exceeds the environmental standard (i.e., if $E–\bar{E}$) the government will impose

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Received: 02 January 2024, Manuscript No. pollution-24-124825; **Editor assigned:** 04 January, 2024, PreQC No. P-124825; **Reviewed:** 18 January 2024, QC No. Q-124825; **Revised:** 24 January 2024, Manuscript No. R-124825; **Published**: 30 January, 2024, DOI: 10.37421/2684-4958.2024.07.320

a fine, $m\ (E–\bar{E})$ on either of the firms, and if the total emissions are below the environmental standard (i.e., $(E–\bar{E})$, the government will grant a subsidy, m to either of the firms.

3. The Bertrand equilibrium

Let us consider a model in which the government announces $\bar{E}$ and m, and then the two firms simultaneously set a product price. Here, it is assumed that e_i (i=1, 2) does not change. The profit function of firm i is defined as follows:

$$\pi_i = p_i q_i - C_i - (E - \bar{E}) \quad (4)$$

By substituting equation (4) into equations (1), (2), and (3), and by finding the best response function of firm *i*, we obtain:

$$BRi = [a + c_i + bp_j + m\,(ei-)]/_2 \quad i, j=1, 2;\ j \neq i \quad (5)$$

Using equation (5), we obtain the Bertrand equilibrium price as follows:

$$p_i^* = [2(a + c_i) + b(a + c_j) - m\,(b^2 e_i - 2e_i + be_j)]/(4 - b^2) \quad (6)$$

Substituting p_i in equation (1) with this price and finding the Bertrand equilibrium quantity, we obtain:

$$q_i^* = [k_i - m\,(b^3 ej - 3bej + 2e_i)\,]/,(4 - b^2), \quad i, j=1, 2;\ j \neq i \quad (7)$$

where $k_i = 2(a-c_i) + b(a+c_j) + b^2 c_i$. Furthermore, we assume that $a > c_i$. If we find the total amount of emissions, E, under a Bertrand equilibrium, by substituting q_i in equation (3) with q^*_i from equation (7), we obtain the following function of the policy instrument, m:

$$E(m) = [e_1 k_1 + e_2 k_2 - 2m(e_1 e_2 b^3 - 3be_1 e_2 + e_1^2 + e_2^2)]/(4 - b^2) \quad (8)$$

By differentiating equation (8), we obtain:

$$E(m) = -2[e_1 e_2 b(b^2 - 3) + e_1^2 + e_2^2)/(2 - b)(2 + b) \quad (9)$$

From equation (9), $b < \sqrt{3}$ or $b > 2$, *because* $E'(m) > 0$, the effects of the ambient charges become perverse, as shown by Ganguli & Raju (2012). That is, if the government increases *m,* the total amount of emissions will increase. However, this condition only occurs when $b \in (\sqrt{3}, 2)$ and $E'(m) < 0$. If this happens, the effects of ambient charges will no longer be perverse. Therefore, the effects of ambient charges under a Bertrand duopoly are not always perverse. Because the effects of ambient charges are non-linear in terms of degree of product differentiation, the effects of ambient charges become perverse depending on the degree of product differentiation between firms.

Conclusion

In this paper, by utilising the theory of oligopoly, I examined the effectiveness of ambient charges as a policy instrument for controlling nonpoint source pollution that originates from a duopolistic industry. The results show that the extent of the effects depends on the degree of product differentiation. That is to say, in a duopoly, when an increase in one firm's price leads to a nearly twofold increase in the market quantity demanded for the other firm's product, then the ambient charges are an effective instrument of environmental policy. If the government commits to ambient charges as an environmental policy within a duopolistic industry, while product differentiation gradually advances under a Bertrand competition among firms, initially that environmental policy has perverse effects; however the policy then becomes effective rather suddenly after which the effects become perverse once again. In this case, ambient charges are only temporarily effective under a Bertrand duopoly. Certainly, if the degree of product differentiation is primarily invariant at the level indicated above, the effectiveness of ambient charges as a policy will be sustained. Sato has already shown that ambient charges do not always have perverse effects in a Cournot duopoly. Although ambient charges are not as robust under a Bertrand duopoly as they are under a Cournot duopoly, the effectiveness of the policy cannot be denied.

Acknowledgments

This work was supported by JSPS KAKENHI Grant-in-Aid for Scientific Research(C) under Grant number 18K01617.

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How to cite this article: Sato, Hideki. "Effectiveness of Ambient Charges Under a Bertrand Duopoly." *Pollution* 07 (2024): 320.