Effective Ambient Charges in a Vertically Differentiated Duopoly*

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1. Introduction

This paper demonstrates the effectiveness of environmental policies that use ambient charges as a way to reduce pollutant emissions from a vertically differentiated market.[1)] Under a system of ambient charges, the regulator establishes a quantitative limit on the total pollution that can generated by the industry as a whole. If the actual pollution generated by the industry exceeds the permissible limit, each producer in the industry pays a fine. All producers pay the same fine even if the amount of pollution generated by each firm is different. Similarly, if total pollution generated by the entire industry falls short of the standard set by the regulator, a uniform subsidy is paid to each firm.

As suggested by Segerson (1988), ambient charges are an environmental policy instrument designed to link with observation of nonpoint source pollution. Since nonpoint source pollution such as water and air pollutions originates from several sources, it might be impossible to measure firm-specific emissions whereas possible to measure the total level of pollution. From the perspective of oligopoly theory, recent years have seen significant attempts to investigate the effectiveness of ambient charges as a policy measure for reducing industrial aggregate emissions. Raju and Ganguli (2013) examine the ambient charge effects in a Cournot duopoly and numerically show its effectiveness. Sato (2017) analytically exhibits that a higher ambient charge reduces the total emission in a Cournot duopoly market. On the other hand, Ganguli and Raju (2012) model a

＊ It is my great honor to dedicate this paper to Professor Matsumoto in commemoration of his achievements and all his kindness. The usual disclaimer applies.

1） Vertical product differentiation models have been proposed by Gabszewicz and Thisse (1979) and Shaked and Sutton (1982).

Bertrand duopoly and numerically show that an increase of ambient charge rate could increase the total concentration, which is called a "perverse" effect. Matsumoto and Szidarovszky (2020) analytically show that if the levels of the abatement technologies are fixed, the ambient charge is always effective in a Bertrand duopoly market.[2)]

In this paper we study the effect of such ambient charges on total pollutions in a vertically differentiated duopoly market. Such a setting is also closely related to the study of various environmental policies in the presence of *green consumers*, that is, consumers who differentiate between products on the basis of their environmental attribute. A strand of economic literature models the impact of green consumers on the market equilibrium adopting the framework of a vertically differentiated oligopoly (Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999; Moraga-González and Padrón-Fumero, 2002; Bansal and Gangopadhyay, 2003; Lombardini-Riipinen, 2005; Bansal, 2008). A central issue in the literature is the choice and design of regulatory instruments in the presence of environmentally aware consumers. To our knowledge, there are no studies of ambient charges in the framework of vertical product differentiation. This paper theoretically shows that a higher ambient charge reduces aggregate emissions in a vertically differentiated duopoly market.

In what follows, we introduce a basic model in Section 2 and discuss our main results in Section 3. Concluding remarks are given in Section 4.

2. The Model

We present a duopoly model of environmentally differentiated products. Suppose that there are two firms in the same industry, producing a physically homogeneous good. The production quantity of firm $i\,(i=1,2)$ is represents as q_i. Firms are assumed to have same constant marginal cost of production; without loss of generality, let us assume that this cost is equal to zero.

Firm i emits pollutions and it is assumed that one unit of production emits one unit of pollution. However, using an abatement technology e_i, the firm can reduce the actual amount of pollution to $e_i\,q_i$ by abating $(1-e_i)\,q_i$. The technology is subject to $0 \leq e_i \leq 1$ with a pollution-free technology if $e_i=0$ (i.e., no pollution) and a fully-discharged technology if $e_i=1$ (i.e., no abatement). The pollution abatement technologies are assumed to be fixed. Without loss of generality, we assume the following condition for the pollution abatement technology parameter of firm i.

Assumption 1. $e_1 > e_2$.

2) Ishikawa, *et al.* (2019) and Matsumoto *et al.* (2017) extend the duopoly framework to an n-firm framework with product differentiation.

To control the ambient concentration, the regulator imposes an ambient pollution standard $\bar{E}$ and a uniform ambient charge t on the total emission quantity, $e_1 q_1 + e_2 q_2$. If $e_1 q_1 + e_2 q_2 > \bar{E}$ (or $e_1 q_1 + e_2 q_2 \leq \bar{E}$), then the regulator will levy (award) both firms the same penalty (subsidy), amounting to t times the difference between the total emission quantity and the environmental standard. For the sake of analytical simplicity, we make the following assumption by changing the ambient tax rate,

Assumption 2. $0 < t < 1$.

On the demand side, there is unit mass of consumers interested in buying at most one unit of the good. Consumers are environmentally conscious, taking the firms' abatement efforts into account when they choose which product to buy. A generic green consumer selects a product to maximize the following utility function:

$$U = V - \theta e_i - p_i, \qquad (1)$$

where V is the (homogeneous) gross utility of consuming one unit of the product, p_i is its price, θ is the consumer's marginal valuation for the green features of the product. We assume that θ is uniformly distributed on the interval [0, 1] with density one. No consumption is assumed to given zero surplus. The following assumption is used throughout the analysis.

Assumption 3. *V is sufficiently small so that not all consumers acquire the good in equilibrium.*

This assumption, which is formalized below, implies that the market is not fully covered in equilibrium, i.e., some consumers do not acquire any good at the equilibrium prices.

3. Ambient Charge Effect

Given prices $p_1 < p_2$, there are two marginal consumers. One, with valuation $\tilde{\theta}$, who is indifferent between two sellers, and another, with valuation $\hat{\theta}$, who is indifferent between buying from the firm 2 and nothing. Straightforward algebra, using Equation (1), it is easy to see that: $\tilde{\theta} = (p_2 - p_2)/(e_1 - e_2)$ and $\hat{\theta} = (V - p_2)/e_2$. Using the distribution function of θ, the two firms' demands are expressed as

$$q_1(p_1, p_2) = \frac{p_2 - p_1}{e_1 - e_2}, \quad q_2(p_1, p_2) = \frac{V - p_2}{e_2} - \frac{p_2 - p_1}{e_1 - e_2}. \qquad (2)$$

Then, the profit function for firm i can be expressed as

$$\pi_i(p_1, p_2) = p_i q_i - t(e_1 q_1 + e_2 q_2 - \bar{E}), \quad i = 1, 2. \qquad (3)$$

The necessary and sufficient conditions for an interior solution require

$$\frac{\partial \pi_1}{\partial p_1}=\frac{-2p_1+p_2}{e_1-e_2}+t=0,$$

$$\frac{\partial \pi_2}{\partial p_2}=\frac{e_2p_1-2e_1p_2+(e_1-e_2)V}{e_2(e_1-e_2)}=0.$$

Given the pollution abatement technologies, equilibrium prices are

$$p_1^*=\frac{(e_1-e_2)(2e_1t+V)}{4e_1-e_2},\ p_2^*=\frac{(e_1-e_2)(e_2t+2V)}{4e_1-e_2}. \tag{4}$$

Note that, under Assumptions 1, 2 and $V > (2e_1-e_2)t$, $0 < p_1^* < p_2^*$, i.e., the good with higher unit emissions is offered at a lower price. Observe also that given the prices in (4), the inequality $0 < \tilde{\theta} < \hat{\theta} < 1$ holds. Assumption 3 amounts to assume that

$$(2e_1-e_2)t<V<\frac{(4e_1-e_2)e_2+(e_1-e_2)e_2t}{2e_1+e_2}, \tag{5}$$

which guarantees that the market is not fully served.[3)]

Inserting (4) in (2), the expressions for demand can be obtained as

$$q_1^*=\frac{V-(2e_1-e_2)t}{4e_1-e_2},\ q_2^*=\frac{e_1(e_2t+2V)}{e_2(4e_1-e_2)} \tag{6}$$

When e_1 and e_2 are given, the total pollution at the equilibrium is

$$E^*=e_1q_1^*+e_2q_2^*.$$

Now consider the effect of a charge in the ambient charge on total pollution:

$$\frac{\partial E^*}{\partial t}=-\frac{2e_1(e_1-e_2)}{4e_1-e_2}, \tag{7}$$

which is negative due to Assumption 1. Then the following proposition holds:

Proposition 1. *Under Assumptions 1 and 2, the ambient charge is effective in controlling the aggregate level of pollution,*

$$\frac{\partial E^*}{\partial t}<0.$$

Following from Proposition 1, an increase in the ambient charge unambiguously lowers the total pollution in an environmentally differentiated market with two firms.

We now turn attention to the individual level of emission value of firm i. Differentiating the optimal production of each firm gives,

$$\frac{\partial q_1^*}{\partial t}=-\frac{2e_1-e_2}{4e_1-e_2}<0,\ \frac{\partial q_2^*}{\partial t}=\frac{e_1}{4e_1-e_2}>0.$$

Proposition 2. *Although the total pollution is negatively related to a change in the ambient charge rate, the individual response could be perverse,*

3) If $t < e_2/e_1$, then condition (5) is satisfied. Hence, Assumption 2 is a sufficient condition for this structure to emerge.

$$\frac{\partial q_1^*}{\partial t} < 0 \quad and \quad \frac{\partial q_2^*}{\partial t} > 0.$$

Proposition 2 indicates that the firm with a more efficient abatement technology could take perverse reaction.

4. Concluding Remarks

The effect of the ambient charges on total pollution in a vertically differentiated duopoly was examined. We analytically demonstrated that the total emission falls in response to an increase in the rate of the ambient charge. It is also show that an increase of the ambient charge can have a diverse effect on the individual output: if an abatement technology of firm i is more efficient than that of firm j, then firm i increases its output and firm j decreases its output.

This paper has not touch on the issue of what choices firms make when it comes to environmental technology. Therefore, we hope to reconstruct a two-stage duopoly game, in which optimal abatement technologies are chosen first and then the optimal prices as well as the optimal productions are determined. This will be the subject of our continued research project.

References

Arora, S. and S. Gangopadhyay (1995), "Toward a theoretical model of voluntary overcompliance," *Journal of Economic Behavior and Organization*, 28, 289–309.

Bansal, S. (2008), "Choice and design of regulatory instruments in the presence of green consumers," *Resource and Energy Economics*, 30, 345–368.

Bansal, S. and S. Gangopadhyay (2003), "Tax/subsidy policies in the presence of environmental aware consumers," *Journal of Environmental Economics and Management*, 45, 333–355.

Cremer, H. and J. F. Thisse (1999), "On the taxation of polluting products in a differentiated industry," *European Economic Review*, 43, 575–594.

Gabszewicz, J. and J. Thisse (1979), "Price competition, quality and income disparities," *Journal of Economic Theory*, 20, 340–359.

Ganguli, S. and S. Raju (2012), "Perverse environmental effects of ambient charges in a Bertrand duopoly," *Journal of Environmental Economics and Policy*, 1, 289–296.

Ishikawa, T., A. Matsumoto and F. Szidarovszky (2019), "Regulation of non-point source pollution under n-firm Bertrand competition," *Environmental Economics and Policy Studies*, 21, 579–597.

Lombardini-Riipinen, C. (2005), "Optimal tax policy under environmental quality competition," *Environmental and Resource Economics*, 32, 317–336.

Matsumoto, A. and F. Szidarovszky (2020), "Effective ambient charges on non-point source pollution in a two-stage Bertrand duopoly," *Journal of Environmental Economics and Policy*, https://doi.org/10.1080/21606544.2020.1786465

Matsumoto, A., F. Szidarovszky and M. Yabuta (2017), "Environmental effects of ambient charge in

Cournot oligopoly," *Journal of Environmental Economics and Policy*, 7, 41–56.

Moraga-González, J. L. and N. Padrón-Fumero (2002), "Environmental policy in a green market," *Environmental and Resource Economics*, 22, 419–447.

Raju, S. and S. Ganguli (2013), "Strategic firm interaction, return to scale, environmental regulation and ambient charges in a Cournot duopoly," *Technology and Investment*, 4, 113–122.

Sato, H. (2017), "Pollution from Cournot duopoly industry and the effect of ambient charges," *Journal of Environmental Economics and Policy*, 6, 305–308.

Segerson, K. (1988), "Uncertainty and incentives for nonpoint pollution control," *Journal of Environmental Economics and Management*, 15, 87–98.

Shaked, A. and J. Sutton (1982), "Relaxing price competition through product differentiation," *Review of Economic Studies*, 49, 1–13.

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