Returns to Scale and Environmental Regulation in Duopoly

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October 2001

[¤]The author is grateful to Prof. Michael Hanemann and Prof. P.K. Pattanaik for helful comments. The author is solely responsible for any errors in the paper.

ABSTRACT

I study the e®ects of an ambient charge on the total pollution generated in a duopolistic industry. Two models are studied in a game-theoretic framework under alternative assumptions about returns to scale. Simulation techniques have been used to examine the outcome of the charge. In both the models it has been shown that for certain values of the demand and cost parameters of the models the ambient charge increases total pollution from the industry. The \perverse" results in the models are due to the strategic interaction between the ¯rms under di®erent technologies.

Key words: Ambient charge, duopoly, returns to scale, environmental regulation, simulation.

JEL Classi¯cation: C-7, D-43, Q28

1 INTRODUCTION

The purpose of this paper is to study the e®ects of an ambient charge on the amount of total pollution generated by a duopolistic industry under alternative assumptions regarding production technology. Since ambient charges are not as commonly seen in the literature on environmental pollution as other regulatory instruments such as quantitative standards, taxes and permits, a brief description of the ambient charges may be helpful. Under a system of ambient charges, the regulator sets a quantitative standard on the total pollution that can be generated by the industry as a whole. If actual total pollution generated from the industry exceeds the permissible limit, then each producer in the industry has to pay a ¯ne. All producers pay the same ¯ne even if the amounts of pollution generated by each of them is di®erent. Similarly, if the total pollution generated by the entire industry falls short of the standard set by the regulator, then a uniform subsidy is paid to each producer.

In this paper I study the e®ect of such a system of ¯nes/subsidies (known as ambient charges) on the total pollution generated by a duopolistic industry on the basis of the di®erence between the benchmark for total pollution set by the regulator and the total pollution actually arising from the industry.

Quantitative standards, taxes and permits are some of the regulatory instruments that, unlike ambient charges, have been widely discussed in the literature (Baumol and Oates (1971), Baumol (1972),Weitzman (1974), Harford (1978), Requate (1993, 1993), Kim et al (1993), Stimming (1999)). However, these instruments can be used e±ciently only when the regulator can identify the amounts of pollution generated by individual ¯rms (also known as the \point source" cases). In real life the regulator ¯nds it di±cult to monitor the amount of pollution originating from the individual ¯rms.[1] In that case it becomes very di±cult to use instruments such as quantitative standards, emission taxes and permits. Given this, several authors over the past decade or so (Segerson (1988), Xepapadeas (1991, 1992, 1995)) have considered ambient charges as a possible solution. As I have explained earlier, implementation of ambient charges requires information about the total pollution originating in an industry as a whole rather than requiring information about pollution caused by individual ¯rms. Given the recent intellectual notion of ambient charges, it is not surprising that so far ambient charges have not been implemented in real life. Despite

[1]Added to this ambiguity is also the problem of natural phenomena such as wind, rainfall etc. which a®ect the ambient concentration of pollution.

this, given the severe information constraints usually faced by the regulators, it seems that ambient charges that need much less information for its implementation deserves to be studied in detail.

Authors in the past have studied the e®ects of ambient charges in a competitive market (Segerson (1988), Xepapadeas (1991, 1992, 1995)). The main purpose of my paper is to extend the analyses to the case of imperfect competition which is more commonly seen in real life. More speci¯cally, I study the e®ects of the ambient charge in a duopolistic market.

The basic framework of the paper is as follows. I consider duopolistic ¯rms in a given region. In the presence of imperfect information, the regulator is uncertain about the amount of pollution from each of these two sources.[2] The regulator sets an ambient standard for the pollutant such that if it is exceeded, producers will be penalized. On the other hand, if the total pollution is below the standard, producers receive a subsidy. The ¯ne as well as the subsidy is the same for both producers.

I consider two di®erent games between the regulator and the ¯rms and focus on the strategic interaction between the duopolists in response to an ambient charge imposed by the regulator. Each of the two models considers the strategic interaction between the duopolists under the alternative assumptions about the ¯rms' production technologies, namely constant, decreasing and increasing returns to scale. An important conclusion of the paper is that, in each of the two models, the strategic interaction between the ¯rms can lead to a \perverse" e®ect of ambient charges on total pollution for certain types of technologies. That is, for some types of technologies, an increase in the ambient charge may lead to a greater pollution in the industry. Simulation techniques are used to show this. In the above models, apart from the strategic interaction under duopoly, technology plays a very signi¯cant role in deciding the response of each ¯rm to the ambient charge.

Segerson (1988) introduced ambient charge to induce optimal abatement for one or more polluters in a perfectly competitive setup. I consider a purely positive analysis with no optimal abatement.

Xepapadeas (1992) develops a dynamic incentive scheme in a perfectly competitive framework introduced by Segerson (1988) in a static case. I consider an ambient charge in an imperfect market both in the short run and long run and prove that this instrument may

[2] Introducing uncertatinty due to natural phenomena such as wind, rainfall etc. does not bring about any substantial changes in the results in the models here. Hence I rule out uncertainty and assume that the total pollution generated by the ¯rms is equal to the ambient concentration of the pollution. \Total pollution" and \ambient concentration" will be used synonymously in the paper.

increase aggregate pollution under alternative assumptions about production technologies.

Xepapadeas (1995) considers combinations of ambient charges and Pigouvian taxes under stochastic ambient concentration of a pollutant in a perfectly competitive non-point source pollution (NPSP) framework with risk-averting firms where part of the emissions are observable.

The next section discusses the basic framework of the models. Section 3 discusses Model 1 and its various cases and presents the results. Section 4 discusses Model 2 along with its various cases and presents the results. The concluding remarks are presented in section 5.

2 Basic Framework

I examine a Cournot duopolistic market for good Q supplied by two firms indexed by $i = 1, 2$. Each firm i produces output q_i. Market inverse demand is given by $P = a - bQ$ where $Q = \sum_{i=1}^{2} q_i$ is the total output. Market inverse demand P is positive for $Q < \frac{a}{b}$.

Pollution is determined by output in the models as a fixed proportion of the total industry output.[3]

Ambient Charge Structure: Let $\alpha = \sum_{i=1}^{2} \beta_i q_i$ represent the total pollution generated from output Q, given the fixed emission coefficients, β_1 and β_2. The regulator does not know how much of the released pollution is transported to a river or to the atmosphere. He can at best measure the concentration of the pollutant in the water body or atmosphere. The regulator cannot identify which producer pollutes the most, or the least but can measure the ambient concentration which is identical to total pollution generated by both firms in the models.

The ambient charge is implemented by comparing the observed total pollution to a specific ambient standard. The ambient standard is set by the regulator and is the cut-off beyond which the total pollution is perceived to increase the risk to an unacceptable level. This fine has to be paid by both firms in case the total pollution exceeds the ambient standard of the pollutant set by the regulator. Again, if the total pollution is less than the ambient standard, then both firms receive subsidy. The ambient charge is $t(\alpha - \bar{\alpha}) > 0$, where $\bar{\alpha}$ is the specific ambient standard such that if the total pollution exceeds this cut-off, $\alpha > \bar{\alpha}$, the

[3] I assume that output and the polluting input are related by a fixed coefficient technology and there is no substitutability between polluting and non-polluting inputs. This makes the distinction between output and input based pollution trivial.

producers will be penalized by the amount of the charge per unit times the deviation of the total pollution from the ambient standard. If the level is less than or equal to the cut -o®, ® < $\bar{®}$; the producers may receive a subsidy where t(® ¡ $\bar{®}$) < 0: The subsidy is again equal to the charge per unit times the deviation of the total pollution from the ambient standard. Each producer pays/receives the same charge/subsidy or \t" per unit of the deviation of the concentration from the standard[4].

My study examines the e®ects of the ambient charge on total pollution in a duopoly market under various technologies (returns to scale) of the ¯rms.

3 Model 1.

The ¯rst model considers the case where the ¯rms choose their outputs when the charge is announced and the pollution technologies are given. Here pollution is determined by output. A proportion of the output namely $¯_i$ is emitted as pollution. I show that, under increasing returns to scale, an ambient charge may have the \perverse" e®ect of increasing total pollution for certain values of demand and cost parameters of the model using speci¯c cost function[5]. I prove that this possibility does not arise here under constant or decreasing returns to scale.

In this model the regulator announces the charge; pollution technology ($¯_1$; $¯_2$) is given to both the ¯rms and they choose outputs simultaneously. This is of importance in the short run when the ¯rms can only vary output (the variable factor of production) and not pollution technology (the ¯xed factor of production). In each of the three cases described below, the aim is to examine the e®ects of the ambient charge on total pollution. The generalized cost function is used when the expression $\frac{@®^¤}{@t}$ is unambiguous. The speci¯c cost function is used whenever the expression $\frac{@®^¤}{@t}$ is proved to be ambiguous when using a generalized cost function.

3.1 Case 1. (CONSTANT RETURNS TO SCALE)

Let the cost function for ¯rm i be written as $C_i = C_i\,(q_i; ¯_i)$ where i = 1; 2

which satis¯es the following properties,

[4] The formulation of the ambient charge in the paper follows directly from Segerson (1988) without the ¯xed penalty imposed whenever the ambient standard is exceeded.

[5] These results may arise in perfect competition only if the stability conditions are not satis¯ed.

$\frac{\partial C_i}{\partial q_i} > 0; \frac{\partial^2 C_i}{\partial q_i^2} = 0$: Marginal Cost is positive but there is no change in marginal cost due to a change in output. This represents the constant returns to scale industry case.

Let the profit equation for each firm be

$\pi_i = [a - b(q_i + q_j)]q_i - C_i(q_i; \beta_i) - t(\alpha - \bar{\alpha}); i, j = 1, 2; i \neq j$

From the first order conditions of profit maximization,

$$a - 2bq_i - bq_j - \frac{\partial C_i}{\partial q_i} - t\beta_i = 0; i, j = 1, 2; i \neq j \quad (1)$$

and the reaction functions are

$$q_i = \frac{\left(a - bq_j - \frac{\partial C_i}{\partial q_i} - t\beta_i\right)}{2b}; i, j = 1, 2; i \neq j \quad (2)$$

After calculations,

$$q_i^* = \frac{\left[a + c_j' - 2C_i' + t(\beta_j - 2\beta_i)\right]}{3b}; i, j = 1, 2; i \neq j \quad (3)$$

Consider the effect on total industry pollution due to the charge.

$$\frac{\partial \alpha^*}{\partial t} = \frac{\partial(\beta_1 q_1^* + \beta_2 q_2^*)}{\partial t} = \beta_1 \frac{\partial q_1^*}{\partial t} + \beta_2 \frac{\partial q_2^*}{\partial t} = \frac{\left[2E\phi'(\beta_1\beta_2 - \beta_1^2 - \beta_2^2)\right]}{3b}$$

Assume $\beta_i = \theta\beta_j$; $i, j = 1, 2; i \neq j$ for simplicity where θ is real. Here θ is introduced to show the relation between the pollution technologies of the two firms.

It can be shown that $\frac{\partial \alpha^*}{\partial t} < 0$ for all values of the parameters in the model.

Thus the effect of an ambient charge is to reduce total pollution under constant returns to scale in a Cournot duopoly game.

3.2 Case 2. (DECREASING RETURNS TO SCALE)

Let the cost function of firm i be written as $C_i(q_i; \beta_i)$ where $i = 1, 2$

which satisfies the following properties,

$\frac{\partial C_i}{\partial q_i} > 0; \frac{\partial^2 C_i}{\partial q_i^2} > 0; i = 1, 2$: Marginal cost is positive and increasing at an increasing rate with an increase in output of each firm. Hence this cost function represents decreasing returns to scale technology.

Proceeding in the same way as before, we have the same result $\frac{\partial \alpha^*}{\partial t} < 0$.

That is, effect of an ambient charge is to reduce total pollution under decreasing returns to scale in a Cournot duopoly game.

3.3 Case 3. (INCREASING RETURNS TO SCALE)

Using a generalized cost function does not allow me to prove any unambiguous effect of the ambient charge on total pollution. However, it is possible to demonstrate using a specific cost function that the effect of the ambient charge on total pollution depends on the values of the demand and cost parameters of the model. I use simulation techniques to demonstrate these results.

Consider an industry with the following cost function

$$C_i = m_i + n_i q_i + c_i q_i^2;\ i = 1, 2 \tag{4}$$

where $m_i > 0; n_i > 0; c_i < 0$. Hence $C_{q_i} > 0$ provided $q_i > -\frac{n_i}{2c_i}$; $C_{q_i q_i} < 0$.[6]

The marginal cost with respect to output is positive and the marginal cost increases at a diminishing rate. These properties of the cost function represent increasing returns to scale case here.

Let the profit equation of each firm be written as the following

$\pi_i = [a - b(q_i + q_j)]q_i - (m_i + n_i q_i + c_i q_i^2) - t(\alpha - \overline{\alpha});\ i, j = 1, 2;\ i \neq j$

From the first order condition of profit maximization

$\frac{\partial \pi_i}{\partial q_i} = 0;\ i = 1, 2$

$$a - 2bq_i - bq_j - n_i - 2c_i q_i - \beta_i t = 0;\ i, j = 1, 2;\ i \neq j \tag{5}$$

which give the reaction functions

$$\frac{(a - bq_j - n_i - \beta_i t)}{2(b + c_i)} = q_i;\ i \neq j;\ i, j = 1, 2 \tag{6}$$

After calculations, the optimal outputs in terms of the parameters of the model are

[6] The second order conditions for profit maximization are satisfied for all the specific cost functions used in the paper.

$$q_1^* = \frac{[a(b + 2c_2) - 2(b + c_2)n_1 + bn_2 + t\{b\beta_2 - 2\beta_1(b + c_2)\}]}{4(b + c_1)(b + c_2) - b^2} \quad (7)$$

and

$$q_2^* = \frac{[a(b + 2c_1) - 2(b + c_1)n_2 + bn_1 + t\{b\beta_1 - 2\beta_2(b + c_1)\}]}{4(b + c_1)(b + c_2) - b^2} \quad (8)$$

Now, consider the effect on total pollution.

$$\frac{\partial \alpha^*}{\partial t} = \frac{-1}{[4(b + c_1)(b + c_2) - b^2]}[\beta_1\{2\beta_1(b + c_2) - \beta_2 b\} + \beta_2\{2\beta_2(b + c_1) - \beta_1 b\}] \quad (9)$$

Assume again, as before that $\beta_1 = \theta\beta_2$.

Now, it can be shown that $\frac{\partial \alpha^*}{\partial t} > 0$ for $\beta_1 = \theta\beta_2$ for different values of θ, c_1, c_2 and b.

Thus an increase in the ambient charge may increase total pollution for certain values of the cost and demand parameters of the model.

Table 1a shows for different combinations of θ, c_1, c_2 and $b = 1$ for which $\frac{\partial \alpha^*}{\partial t} > 0$. (Please see Appendix).

Table 1b shows various combinations of θ, c_1, c_2 and b (not equal to 1) for which $\frac{\partial \alpha^*}{\partial t} > 0$. (Please see Appendix).

It can be proved that the expected result i.e. $\frac{\partial \alpha^*}{\partial t} < 0$ hold when $|c_1| < 0.5$ and $|c_2| < 0.5$.

Thus I show that, depending on the values of the cost and demand parameters of the model, an increase in the ambient charge may increase or decrease total pollution. This can be of interest for environmental policy formation as in an imperfect market operating under increasing returns to scale the regulator may not be successful in decreasing total pollution by increasing the ambient charge arbitrarily.

However, when $\beta_1 = \beta_2 = k$, $c_1 = -0.5, c_2 = -0.5$, for $b = 1$, $\frac{\partial \alpha^*}{\partial t} > 0$ for $0 < k < 1$. Thus when the firms are identical in terms of pollution technology and production technology (increasing returns to scale), for a certain value of the parameters namely, $c_1 = -0.5, c_2 = -0.5$, for $b = 1$, the perverse result comes through once again.

The "perverse" result that ambient charge increases total pollution for certain values of the demand and cost parameters of the model is due to the strategic interaction of the firms and increasing returns to scale. This is clear from Table 1a and Table 1b where $\frac{\partial \alpha^*}{\partial t} > 0$ for $|c_1| \geq 0.5$ and $|c_2| \geq 0.5$.

Let $b = 1$, then for $|c_1| = 0.9; |c_2| = 0.8; [4(b + c_1)(b + c_2) - b^2] < 0.$ Then $\frac{\partial q_1^*}{\partial t} = \frac{\{b\beta_1 - 2\beta_2(b + c_1)\}}{4(b + c_1)(b + c_2) - b^2} > 0$ means that $\{b\beta_1 - 2\beta_2(b + c_1)\} < 0$ which means $\beta_1 > \beta_2$. Thus, it can be shown that for certain values of the demand and cost parameters of the model, output of the more polluting firm increases and the output of the less polluting firm decreases with an increase in the ambient charge. This provides an explanation as to why an increase in the ambient charge may increase total pollution for certain demand and cost parameters of the model. Given this, so long as the output of the less polluting firm does not fall "too much" as compared to the increase in the output of the more polluting firm, there arises the possibility of an increase in total pollution with an increase in the ambient charge. This is what seems to be happening in the "perverse" case discussed above.

4 Model 2

In the second model, firms choose technologies in the first period and the outputs in the following period after the charge is announced. Here I prove, using specific cost functions and simulation techniques, that in all cases, namely, constant, increasing and decreasing returns to scale technologies, total pollution may increase with the charge. Method of backward induction is applied to solve for the firms' outputs and the pollution technologies. Assuming that the firms have already made their choices about their technologies, the values of the optimal outputs are found in the last stage of the game from the profit maximization exercise. In the first stage of the game the optimal values of the pollution technologies are solved for in terms of ambient charge and demand and cost parameters of the model.

For all the three cases considered below, generalized cost functions produce ambiguous results on the total pollution due to the ambient charge. Hence to demonstrate this fact I use specific demand and cost functions for constant, decreasing and increasing returns to scale technologies. It is shown for all the three cases in Model 2 how the ambient charge brings about increases in the total pollution for various values of the demand and cost parameters of the model.

4.1 Case 1. (CONSTANT RETURNS TO SCALE)

Let the demand function be $p = 1 - q_1 - q_2$ for simplicity where $a = 1; b = 1.$

$$C_i = \theta_i q_i - \beta_i; i = 1; 2 \tag{10}$$

where $\theta_i > 0; \beta_i > 0$.

Hence $C_{q_i} > 0; C_{q_i q_i} = 0; C_{\beta_i} < 0$. The signs have the same meanings as illustrated before. This is a special case of the cost function used in Model 1, Case 3 as the cost function is assumed to be separable in output and pollution technology.

For simplicity of calculations, it is

$\pi_i = (1 - q_i - q_j) q_i - \theta_i q_i + \beta_i - t(\alpha - \overline{\alpha}); i; j = 1; 2; i \neq j$

By the method of backward induction, solving for the level of output assuming that the level of pollution technology is already chosen by the firms, the first order condition of profit maximization gives,

$\frac{\partial \pi_i}{\partial q_i} = 0; i = 1; 2$

which implies,

$$1 - 2q_i - q_j - m_i - t\beta_i = 0; i = 1; 2; i \neq j \tag{11}$$

and output reaction functions are

$$q_i = \frac{1 - q_j - \theta_i - t\beta_i}{2}; i; j = 1; 2; i \neq j. \tag{12}$$

After calculations, the optimal outputs are

$$q_1^* = \frac{[1 + \theta_2 - 2\theta_1 + t(\beta_2 - 2\beta_1)]}{3} \tag{13}$$

$$q_2^* = \frac{[1 + \theta_1 - 2\theta_2 + t(\beta_1 - 2\beta_2)]}{3} \tag{14}$$

Now consider the first stage of the game where the firms choose the optimal pollution technologies in terms of the charge, the demand and the cost parameters of the model.

Substituting the values of q_1^* and q_2^* in the profit function,

$\pi_i^* = \left(1 - q_i^* - q_j^*\right) q_i^* - \theta_i q_i^* + \beta_i - t(\alpha^* - \overline{\alpha}); i; j = 1; 2; i \neq j$

Solving for the pollution technologies, assuming that outputs have already been chosen, the first order condition for profit maximization

$\frac{\partial \pi_i}{\partial \beta_i} = 0; i = 1; 2$ give

$$\frac{4t}{9} - \frac{8t}{9} + \frac{4m_j t}{9} - \frac{8\beta_i t^2}{9} + \frac{7\beta_j t^2}{9} = 1; i, j = 1, 2; i \neq j$$

After calculations, the pollution technology reaction functions are

$$7\beta_j - 8\beta_i = \frac{9}{t^2} - \frac{4}{t} + \frac{8m_i}{t} - \frac{4m_j}{t}; i, j = 1, 2; i \neq j. \quad (15)$$

which give

$$\beta_j - \beta_i = \frac{4(m_i - m_j)}{5t}; i, j = 1, 2; i \neq j \quad (16)$$

Substituting back in Eqn.(36) ; I have

$$7\left[\frac{4(m_i - m_j)}{5t} + \beta_i\right] - 8\beta_i = \frac{9}{t^2} - \frac{4}{t} + \frac{8m_i}{t} - \frac{4m_j}{t}; i, j = 1, 2; i \neq j.$$

Solving, the optimal pollution technologies are

$$\beta_i^* = \left(\frac{1}{7 - 40t}\right)\left(\frac{45}{t} - 20 + 12m_i + 8m_j\right); i, j = 1, 2; i \neq j \quad (17)$$

Consider the effect on ambient concentration due to the ambient charge.

$$\frac{\partial \alpha^*}{\partial t} = \frac{3(7-40t)^2\left[\frac{3420}{t^2} + \frac{315(m_1+m_2)}{t^2} + 800 - 800t(m_1+m_2)\right]}{9(7-40t)^4}$$
$$+\frac{3(7-40t)^2[-16t(m_1^2+m_2^2)]}{9(7-40t)^4} + \frac{-240t(7-40t)\frac{-3420}{t}}{9(7-40t)^4}$$
$$+\frac{-240t(7-40t)\left[-736 - \frac{315(m_1+m_2)}{t} + 584(m_1+m_2) - 800t - 800t(m_1+m_2)\right]}{9(7-40t)^4}$$
$$-\frac{240t(7-40t)[-28(m_1^2+m_2^2) + m_1m_2(832t-224)]}{9(7-40t)^4}$$
$$-\frac{16t(m_1^2+m_2^2)240t}{9(7-40t)^4}$$

For various combinations of the parameters of the model, the perverse result comes through in the constant returns to scale case of this more complicated model where the firms are playing a two-stage game with the regulator after the ambient charge has been announced.

Table 2 shows $\frac{\partial \alpha^*}{\partial t} > 0$ for various combinations of m_1, m_2 and t. (Please see Appendix).

Here in case of constant returns to scale industry, total pollution increases with the charge for certain values of the parameters of the model. This, like before, will have the same important policy consequences.

$\frac{\partial q_1^*}{\partial t} = \frac{t(\beta_2 - 2\beta_1)}{3} > 0$ implies that $\beta_2 > 2\beta_1$. The output of the less polluting firm increases and the output of the more polluting firm decreases with an increase in the ambient charge in the last stage of the game. This, however, may explain why the ambient charge increases total pollution for certain parameter values of the model when the decrease in the output of the more polluting firm is less than the increase in the output of the less polluting firm. However, in the first stage of the game it can be shown that an increase in the ambient charge may increase both β_1 and β_2 which makes the "perverse " case stronger. The final outcome is a combination of the two stages of the game which contributes to the "perverse" result.

4.2 Case2. (DECREASING RETURNS TO SCALE)

Let the cost function be

$$C_i = q_i^2 - \beta_i; i = 1; 2: \tag{18}$$

where $C_q > 0; C_{qq} > 0$ and $C_{\beta_i} > 0$: Here the signs have the usual meanings as before. This cost function is also a special case of the specific cost function used in Model 1 Case 3 as here cost function is assumed to be separable in output and pollution technology.

Then the profit equation of each firm is

$\pi_i = (1 - q_i - q_j)q_i - q_i^2 + \beta_i - t(\alpha - \bar{\alpha}); i = 1; 2; i \neq j:$

As in Case 1 of Model 3 above, following the method of backward induction, outputs of the two firms have been solved for.

From the first order condition of profit maximization,

$$\frac{\partial \pi_i}{\partial q_i} = 0; i = 1; 2$$

which gives

$$1 - 2q_i - q_j - t\beta_i = 0; i = 1; 2; i \neq j \tag{19}$$

and the output reaction functions

$$q_i = \frac{(1 - q_j - t\beta_i)}{4}; i; j = 1; 2; i \neq j \tag{20}$$

Solving, the optimal outputs, in terms of the parameters and the pollution technology, are

$$q_i^* = \frac{[3 + (\beta_i - 4\beta_j)t]}{15};\ i, j = 1, 2;\ i \neq j: \tag{21}$$

Now, as before, in the first stage of the game, knowing what the optimal levels of the outputs are, the optimal values of the pollution technologies are being solved for by the two firms in terms of the parameters of the model and the ambient charge.

Substituting the values of q_i^* in

$\pi_i^* = \left(1 - q_i^* - q_j^*\right) q_i^* - q_i^{*2} + \beta_i - t(\alpha^* - \bar{\alpha});\ i = 1, 2;\ i \neq j:$

and from the first order condition of maximization,

$\frac{\partial \pi_i^*}{\partial \beta_i} = 0;\ i = 1, 2$

which gives

$$\frac{48t}{225} - \frac{128\beta_i t^2}{225} + \frac{22\beta_j t^2}{225} - 1 = 0;\ i, j = 1, 2;\ i \neq j: \tag{22}$$

Solving, the pollution technologies are identical. This is not surprising, given that the cost function is separable in both outputs and pollution technology for both the firms.

$$\beta_1 = \frac{48t - 225}{256t^2} = \beta_2 \tag{23}$$

In order to find the effect of the charge on the total pollution,

$$\frac{\partial \alpha^*}{\partial t} = \frac{1}{49150t^6} \left[\begin{array}{c} (65536t^3)\,(59904t + 32400t - 140400) \\ -\,(196608t^2)\,(29952t^2 - 108000t - 151875) \end{array} \right] \tag{24}$$

Table 3 shows different values of the charge (t) for which $\frac{\partial \alpha^*}{\partial t} > 0$: (Please see Appendix). Thus in the case of decreasing returns to scale technology, ambient charge increases total pollution for certain initial values of the ambient charge. This again implies that the regulator may increase the ambient charge arbitrarily and "perverse" results in terms of increased pollution can follow.

In the last stage of the game $\frac{\partial q_1^*}{\partial t} = \frac{\beta_1 - 4\beta_2}{15} > 0$ if $\beta_1 > 4\beta_2$ which means that the output of the more polluting firm increases and the output of the less polluting firm decreases with the charge. Again considering the first stage of the game for different values of the charge

I have $\frac{\partial \beta_1}{\partial t} > 0$ and $\frac{\partial \beta_2}{\partial t} > 0$. The combination of both the effects of the charge in the two stages of the game along with strategic interaction between the firms may contribute to the increase in total pollution due to the ambient charge.

4.3 Case3. (INCREASING RETURNS TO SCALE)

Using even the simplest of cost functions has proved to be very complicated and so I have used the following cost and demand functions with particular parameter values.

Let the market demand function be $p = a - \frac{1}{4}(q_1 + q_2)$.

and

$$C_i = q_i - \frac{1}{2}q_i^2 - \beta_i \tag{25}$$

and with the usual signs of the partial derivatives. Separability of the cost function in technology and output is assumed as before.

$\pi_i = \left[a q_i - \frac{1}{4}(q_i + q_j) q_i \right] - \left(q_i - \frac{1}{2}q_i^2 - \beta_i \right) - t(\alpha - \overline{\alpha}); i, j = 1, 2; i \neq j.$

Solving similarly as before, for the level of output assuming that the technology is already chosen by the firms,

$$\frac{\partial \pi_i}{\partial q_i} = 0; i = 1, 2$$

which gives

$$a + \frac{1}{2}q_i - \frac{1}{4}q_j - 1 = 0 : i, j = 1, 2 : i \neq j. \tag{26}$$

Solving,

$$q_1^* = \frac{4}{3}(t\beta_2 + 2t\beta_1 + 3 - 3a); \quad i, j = 1, 2 : i \neq j. \tag{27}$$

Now considering the second last stage of the game where the firms choose optimal pollution technology when outputs have already been chosen,

$\pi_i^* = \left[a - \frac{1}{4}(q_i^* + q_j^*) \right] - (q_i^* - \frac{1}{2}q_i^* - \beta_i) - t(\alpha^* - \overline{\alpha}) \quad i = 1, 2; i \neq j.$

From the profit maximization condition,

$$\frac{\partial \pi_i^*}{\partial \beta_i} = 0; i = 1, 2$$

which gives,

$$\frac{8at}{3} - 8t\beta_j - \frac{16}{3}t^2\beta_i - \frac{28}{3}t + \frac{28}{3}at - \frac{8}{3}t + 2t^2\beta_j - \frac{16}{3}t^2\beta_i - 4t - 4at = 0; i, j = 1, 2; i \neq j. \tag{28}$$

Again, as before in Case 2 of Model 2, the pollution technologies are identical.

$$\beta_1 = \beta_2 = \bar{\beta} \tag{29}$$

Solving,

$$q_i = 4\left(t\bar{\beta} + 1 - a\right);\ i = 1, 2 : i \neq j: \tag{30}$$

and the optimal outputs are

$$q_i^* = \frac{18 + 16at - 32t - 16a}{4 - 3t} \tag{31}$$

In order to find the effect of the charge on the total pollution,

$$\frac{\partial \alpha^*}{\partial t} = \frac{t(4-3t)^2\,[388a - 276 - 960at - 160a^2 + 320a^2t + 640at] - (54 + 388at - 276t - 480at^2 - 160a^2t + 160a^2t^2 + 320at^2 - 48a)(16 - 48t + 27t^2)}{t^2(4-3t)^4}$$

Table 4 shows the various combinations of ambient charge (t) and a which give $\frac{\partial \alpha^*}{\partial t} > 0$:

Thus an increase in the ambient charge may increase total pollution for certain initial values of the ambient charges and for certain parameter values of the model. This again, as before has important policy recommendations.

In the last stage of the game, $\frac{\partial q_1^*}{\partial t} = \frac{4(\beta_2 + 2\beta_1)}{3} > 0$ and $\frac{\partial q_2^*}{\partial t} = \frac{4(\beta_1 + 2\beta_2)}{3} > 0$: Thus the ambient charge will increase total pollution. In the second last stage of the game, $\frac{\partial \beta_1}{\partial t} > \frac{\partial \beta_2}{\partial t}$ if $\beta_1 > \beta_2$: Thus the pollution technology of the more polluting firm will increase more than the pollution technology of the less polluting firm. The combination of the results in stage one and stage two of the game may bring about the "perverse" result.

5 CONCLUSION

For various specifications of the cost functions and under different returns to scale assumptions an ambient charge can increase total pollution in a duopolistic market under alternative assumptions about returns to scale. Quantitative standards, tradable permits and emission taxes have been studied and implemented to control pollution from point sources of pollution. Ambient charges have been only studied so far for controlling pollution sources under perfect competition. The results in previous studies (Segerson (1998), Xepapadeas (1992, 1995)), depended on the assumptions of a perfectly competitive set-up under uncertainty.[7] The \perverse" results in the models in this paper are due to the strategic interaction between ¯rms operating under di®erent returns to scale. The results have important consequences for environmental policy formation. This paper is particularly important in so far as the standard instruments cannot e±ciently control total pollution due to lack of information about each source. In this paper I show that in a duopoly market ambient charge is not only ine®ective in controlling ambient concentration of the pollutant but in fact may result in \perverse"outcomes for certain parameter values of the models. Hence the ambient charges may not be the best solution for controlling total pollution in the presence of imperfect market conditions and potential strategic interaction between the ¯rms under alternative assumptions about returns to scale.

[7] One point of di®erence here is that uncertainty of weather is not considered. As mentioned before, introduction of uncertainty does not bring about any substantial changes in the results.

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