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The Effects of Pollution Taxes on Urban Areas with an Endogenous Plant Location

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Abstract. This paper has integrated space into the effect of a direct pollution control on the pollution damage of heavily populated areas like CBD. This integration gives us some new insights into the effectiveness of a pollution tax as a pollution control device when the plant location of the firm is endogenized. It is shown that when the plant location is endogenous, as pollution taxes become higher, the firm moves its plant towards the CBD, causing higher pollution damage to the CBD residents, if the production function exhibits decreasing returns to scale.

Key words: endogenous plant location, pollution taxes

JEL classifications: R30, Q28

1. Introduction

In recent years, pollution control by governments by means of pollution taxation or pollution regulation has received a great deal of attention (For examples, see Hazilla and Kopp (1990), Xing and Kolstad (2002)). However, this literature is cast entirely in a locational vacuum, with the notable exceptions of Forsund (1972), Mathur (1976), Gokturk (1979), White and Wittman (1982), Oates and Schwab (1988), Hoel (1997) and Jeppesen et al. (2002). More specifically, Mathur (1976) has integrated space into the conventional theory of the firm in order to examine the effect of a pollution tax on waste disposal in heavily polluted areas as most urban areas are, and on different forms of abatement. It is shown that given a positive pollution tax, economies of scale may not necessarily lead to the concentration of economic activity at the market site, a result contrary to the one derived by Khalili et al. (1974). Gokturk (1979) has examined the effects of a change in the effluent charge on the locational choice and on abatement decisions of the firm. White and Wittman (1982) have broadened the analysis of pollution taxes by considering both their implications for efficient pollution abatement between fixed polluters and pollutees (short-run efficiency) and the incentives they set up for movement toward an efficient spatial location pattern (long-run efficiency). Oates and Schwab

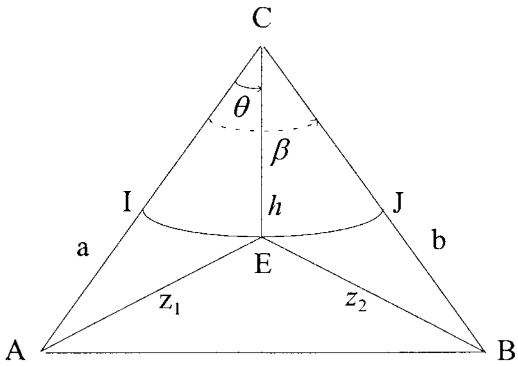

Figure 1. Locational triangle.

(1988) have set up a neoclassical framework to examine how local officials set two policy variables, a tax (or subsidy) rate on mobile capital and a standard local environmental quality, to induce more capital to enter the jurisdiction in order to raise wages. Hoel (1997) has assumed endogenous plant locations between two countries and found that the Nash equilibria of the game of the two countries on environmental policy are generally not Pareto optimal.

However, to the best of our knowledge, the effects of pollution regulation have not been fully explored in a spatial world. We shall prove that if plant location is endogenized, a *stricter* pollution policy (such as a higher pollution tax) may result in a *higher* pollution level at the CBD (i.e., Central Business District). This paper intends to set up a Weberian triangle model with endogenous plant location to explore this possibility.

The structure of this paper is as follows. In the next section, a simple Weberian locational triangle model is developed to examine the effects of a pollution tax on the firm's production and location decisions. In section 3, the pollution level at CBD is measured and its effect caused by a change in pollution tax is derived accordingly. Some concluding remarks are contained in the final section.

2. The Basic Model

The analysis in this paper is confined to a partial equilibrium setting and a Weberian triangle space.[1] A monopolist uses two transportable inputs M_1 and M_2 (which are located at A and B, respectively) in the production of the output q which is sold at market center C locating at the CBD as depicted in Figure 1. The firm chooses its optimum plant location, say E. Moreover, z_1 and z_2 are distances of E from A and B, respectively; h is the distance between E and C; θ is the angle between CE and CA; β is the angle between CA and CB; and a and b are lengths of CA and CB, respectively.

The production function of the firm can be specified as:

$$q = f(M_1, M_2) \tag{1}$$

To simplify our analysis, we first derive the total cost function by minimizing total cost subject to a given output level. That is

$$\begin{aligned} &Min \quad (\overline{w}_1 + r_1 z_1)M_1 + (\overline{w}_2 + r_2 z_2)M_2 \\ &s.t. \quad q = f(M_1, M_2) \end{aligned} \tag{2}$$

where $\overline{w}_1$ and $\overline{w}_2$ are the base prices of M_1 and M_2 at A and B, respectively, which are assumed to be constant; r_1 and r_2 are the constant transport rates of M_1 and M_2, respectively; and z_1 and z_2 may be defined by the law of cosines as follows:

$$\begin{aligned} z_1 &= \sqrt{a^2 + h^2 - 2ah\cos\theta} \\ z_2 &= \sqrt{b^2 + h^2 - 2bh\cos(\beta - \theta)} \end{aligned} \tag{3}$$

For simplicity, let us assume the production function to be homothetic. Shephard (1970) has shown that production function is homothetic if and only if the cost function is separable into input prices and output level. That is, the cost function as specified in Equation (2) can be written as the product of input price function $c(w_1, w_2)$ and output level $H(q)$:

$$T(q) = c(w_1, w_2)H(q) = c(\theta, h)H(q) \tag{4}$$

where $w_1 = \overline{w}_1 + r_1 z_1$ and $w_2 = \overline{w}_2 + r_2 z_2$ are delivered prices of M_1 and M_2, respectively; c is a function of w_1 and w_2, which are, in turn, a function of θ and h. Note that the firm's location decision involves two variables: θ and h.

Given Equation (4), the average and marginal costs are derivable as:

$$AC = \frac{T(q)}{q} = \frac{cH}{q} \tag{5}$$

$$MC = T_q = cH_q \tag{6}$$

From (5) and (6), we can further define the following relationship:

$$\frac{H}{q} > (=, <) H_q, \tag{7}$$

if the production function is increasing (constant, decreasing) returns to scale, i.e., IRS (CRS, DRS).

Next, the inverse demand function which is everywhere twice differentiable and negatively sloped is given by:

$$P = P(q),\ P_q < 0 \tag{8}$$

The pollution tax revenue function $G(q)$ is specified as follows:

$$G(q) = ey(q) \tag{9}$$

where e is the pollution tax rate and $y(q)$ is the amount of pollution generated by the production process which depends on the amount of output produced.[2] We assume throughout the paper that emission rises linearly with output (i.e., $y_q > 0$ and $y_{qq} = 0$).[3] Given this assumption, we can immediately derive that $G_q = ey_q > 0$, $G_{qq} = 0$, $G_{qe} = y_q > 0$ and $G_e > 0$. Moreover, an *increase* in e indicates that the government adopts a stricter pollution policy. As a result, the G function has the following properties: $G_q = ey_q > 0$, $G_{qe} = y_q > 0$ and $G_e > 0$.

Pursuant to these assumptions, the firm wishes to:

$$\underset{q,\theta,h}{Max}\, \pi = [P(q) - th]q - c(\theta, h)H(q) - G(q) \tag{10}$$

where t is the constant transport rate of shipping one unit of the output to the CBD. The first-order conditions for profit maximization are:

$$\pi_q = P_q q + (P - th) - cH_q - G_q = 0 \tag{11}$$

$$\pi_\theta = -c_\theta H = 0 \tag{12}$$

$$\pi_h = -tq - c_h H = 0 \tag{13}$$

Moreover, the second-order conditions are assumed to be satisfied. Hence, the possibility of a corner solution where the firm may locate at the vertex of the triangle or on an edge cannot occur as shown in the literature (e.g., see Miller and Jensen (1978) and Eswaran et al. (1981)).

To analyze the effect of a change in the pollution standard on the production and location decisions, we totally differentiate the system of Equations (11)–(13) with respect to q, θ, h, and e to obtain the following comparative static matrix:

$$\begin{bmatrix} \pi_{qq} & \pi_{q\theta} & \pi_{qh} \\ \pi_{\theta q} & \pi_{\theta\theta} & \pi_{\theta h} \\ \pi_{hq} & \pi_{h\theta} & \pi_{hh} \end{bmatrix} \begin{bmatrix} dq \\ d\theta \\ dh \end{bmatrix} = - \begin{bmatrix} \pi_{qe} \\ \pi_{\theta e} \\ \pi_{he} \end{bmatrix} de \tag{14}$$

where

$$\pi_{qq} = 2P_q + P_{qq}q - cH_{qq} < 0$$
$$\pi_{q\theta} = \pi_{\theta q} = -c_\theta H_q = 0$$
$$\pi_{qh} = \pi_{hq} = -t - c_h H_q = c_h(\frac{H}{q} - H_q)$$
$$\pi_{\theta\theta} = -c_{\theta\theta} H < 0$$
$$\pi_{\theta h} = \pi_{h\theta} = -c_{\theta h} H$$
$$\pi_{hh} = -c_{hh} H < 0$$
$$\pi_{qe} = -G_{qe} < 0$$
$$\pi_{\theta e} = 0$$
$$\pi_{he} = 0$$

Via Equation (14), we can evaluate the comparative static effects of a stricter pollution standard as follows:

$$\frac{dq}{de} = \frac{G_{qe} D_{\theta h}}{D} \tag{15}$$

$$\frac{dh}{de} = \frac{-\pi_{\theta\theta} c_h G_{qe}}{D} (\frac{H}{q} - H_q) \tag{16}$$

$$\frac{d\theta}{de} = \frac{\pi_{\theta h} c_h G_{qe}}{D} (\frac{H}{q} - H_q) \tag{17}$$

where D is the relevant Hessian determinant. Note that $D < 0$, $D_{\theta h} = \pi_{\theta\theta}\pi_{hh} - \pi_{\theta h}^2 > 0$, and $\pi_{\theta\theta} < 0$ by the second-order conditions; and $c_h < 0$, which can be seen from Equation (13).

Since the effect of a change in the pollution standard on production is important in understanding the economic forces controlling the optimal plant location and the measurement of pollution emission, we shall address this issue first. It follows immediately from Equation (15) that:

$$\frac{dq}{de} < 0 \tag{15$'$}$$

(15′) indicates that a higher pollution tax leads to a lower output level.

We now turn to the effect on locational choice. It follows from Equation (16) that:

$$\frac{dh}{de} \gtreqless 0 \qquad \textit{if} \qquad \frac{H}{q} \gtreqless H_q \tag{16$'$}$$

According to Equations (7) and (16′), we can derive:

Proposition 1

The plant location of the firm is invariant with respect to a change in the pollution tax policy if the production function is CRS. Nevertheless, the plant location moves closer to (farther away from) the CBD as a result of a higher pollution tax if the production function is DRS (IRS).

The logic behind this proposition is straightforward. A change in the output level induced by a pollution control policy will alter the firm's input–output ratio if the production function does not exhibit CRS. This change in the input-output ratio induces the firm to relocate in order to save the transportation costs of inputs and output. Under IRS, with less production under a higher pollution tax, more inputs are needed per unit of output so that closeness to inputs can raise profits. The opposite holds true under DRS.

According to the vast literature on environmental capital flight such as Markusen et al. (1995), Hoel (1997), Romstad et al. (2000) and Ulph (2000), firms respond to a tough environmental policy in one region by moving plants away from the region (and relocating to other regions). In a different setting with only one CBD, we have shown that a stricter pollution control would push the firm closer to the CBD if the production function is of DRS.[4]

A change in the pollution tax alters not only the firm's distance to CBD (i.e., h), but also its locational triangle θ. Note that a stricter environmental regulation (such as a higher pollution tax) tends to lower the output level. If h were given, in order to save transport cost, the firm tends to locate closer to the market of M_1 (i.e., a smaller θ) if the transport cost of M_1 becomes relatively cheap as compared to the one of M_2. If h is endogenous, the distances of plant location to the two input market sites (i.e., z_1 and z_2) become dependent of h as can be found in (3), and the sign of $\frac{d\theta}{de}$, as can been seen from equation (17), is indeterminate as it depends on not only the characteristic of the production function, but also the sign of $\pi_{\theta h}$. Since there is no *a priori* way to predict the sign of $\pi_{\theta h}$, we will not pursue it further.[5]

3. The Impact of a Pollution Standard Control on Pollution Level

Now, we can set a function to measure the total pollution at C (i.e., CBD) in Figure 1. Note that the pollution is emitted by the plant located at E. The pollution measured at C is in general lower than that at E and the difference depends on the distance between E and C. Let the total pollution measured at E be X, then the pollution measured at C, say X^*, is given by:

$$X^* = m(h)X \tag{18}$$

with $m_h < 0$ and $m_{hh} > 0$, implying that as the distance between the CBD and the plant goes up, the pollution measured at C not only declines but also declines at a decreasing rate.

Since the pollution emitted by the firm at the plant site is $y(q)$, the pollution measured at the CBD is:

$$X^* = m(h)y(q) \tag{19}$$

Then, the impact of a higher pollution tax (i.e., an increase of e) on X^* is derivable as follows:

$$\frac{dX^*}{de} = my_q q_e + m_h h_e y \gtreqless 0 \tag{20}$$

From (20), it is obvious that the effect of a higher pollution tax can be divided into two effects: the output effect and the location effect. The first term of the right-hand side of Equation (20) represents the output effect, which is negative, indicating that a higher pollution tax leads to a decline in X^*. The second term represents the location effect, which is ambiguous as it depends on the sign of h_e, in turn, relying on the characteristic of the production function as shown in Equation (16′). In particular, if the production function exhibits DRS, then the location effect is positive. In other words, an increase in e may lead to a higher level of pollution measured at C (i.e., $\frac{dX^*}{de} > 0$). This happens if the positive location effect outweighs the negative output effect. Thus, we have:

Proposition 2

If the production function is DRS, then a higher pollution tax may increase the pollution damage to the CBD residents.

Table I. A numerical example

e	1	2	3	4	5	6	7	8	9	10
θ	30°	30°	30°	30°	30°	30°	30°	30°	30°	30°
h	0.975	0.95	0.924	0.896	0.867	0.835	0.802	0.765	0.726	0.683
q	17.395	16.925	16.455	15.986	15.517	15.049	15.581	14.114	13.647	13.182
X^*	18.314	18.751	19.272	19.896	20.649	21.566	22.696	24.108	25.904	28.24

As the sign of (20) is ambiguous, a numerical example is provided to strengthen our argument in Proposition 2. Let us make the following assumptions to facilitate the numerical experiment. The demand function: $P = 50 - q$; the production function: $q = M_1^{0.4} M_2^{0.4}$; the base prices: $\overline{w}_1 = \overline{w}_2 = 0$; the transport rates: $t = 3, r_1 = r_2 = 1$; the amount of pollution generated from production: $y(q) = \alpha q$ with $\alpha > 0$; the pollution tax function $G(q) = ey(q) = \alpha eq$; the pollution's distance-decreasing function: $m(h) = h^{-2}$; the pollution measured at the CBD: $X^* = m(h)y(q) = \alpha q h^{-2}$ and the following parameter settings: $a = b = 3, \alpha = 1, \beta = 60°$. Under these assumptions, we can derive the results as shown in Table I. Table I indicates that an increase in e may lead to a higher level of pollution measured at CBD (i.e., X^*). For example, the value of X^* is equal to 18.314, at $e = 1$; it rises to 28.24 at $e = 10$. Clearly, Proposition 2 holds true.

4. Concluding Remarks

Most of the pollution control models are based on the theory of firms operating in a non-spatial economy. In this paper, we have integrated space into the effect of a direct pollution control on the pollution damage of heavily populated areas like CBD.[6] This integration gives us some new insights into the effectiveness of a pollution control device when the plant location of the firm is endogenized.

A tougher pollution control usually results in less pollution damage. This statement may not hold true in our spatial model. Our paper has shown that a stricter pollution policy such as a higher pollution tax may lead to higher pollution damage to the CBD residents when the plant location is endogenous and the production technology of the firm exhibits DRS. This is because when the production function exhibits DRS, the firm moves its plant *towards* the CBD as pollution regulation becomes stricter (such as a higher tax), making its pollution more accessible to the CBD residents. This result is also in contrast to the vast literature on environmental capital flight in which firms respond to a tough environmental policy in one region by moving plants *away from* the region.

Although the paper assumes the market to be of monopoly, the intuition derived in this paper is robust in other market structures, such as oligopoly or perfect competition.

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Notes

1. A survey on the analysis and application of the Weberian model can be found in Khalili et al. (1974) and Miller and Jensen (1978).
2. We are indebted to a referee for this suggestion.
3. All the results derived in the paper are still robust even if we relax the linear assumption.
4. We have treated the pollution tax e as an exogenous variable, not contingent on the location of the firm. Since pollution regulations may vary among states, the policy implications derived in the paper should not be applied to an inter-state case without modification.
5. It should be pointed out that if we assume θ to be constant, then the second row and second column of the comparative static matrix of Equation (14) drop out of the system. Therefore, the system consists of Equation (11) and (13) only. Proceeding as before, we can derive similar results as the ones treating both θ and h as decision variables. To save the space, we omit this part of the analysis in this paper. Readers who are interested in this issue are referred to Khalili et al. (1974) and Miller and Jensen (1978).
6. We did not compute the pollution damage in the paper. But we can think that the pollution damage is a monotonically increasing function of X^* (the pollution level measured at the CBD). Given this, a higher pollution level measured at the CBD implies a larger pollution damage.

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