EFFECTS OF ENVIRONMENTAL REGULATIONS ON POLLUTION REDUCTION AND FIRM LOCATION

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Abstract

Urban pollution continues to be a crucial issue in cities across the globe, especially in developing countries. Examining the effect pollution tax has on a firm's decision to locate closer/further to the urban centre will be worthy from an environmental preservation perspective. This paper analyses the relationship between pollution tax and the firm's location when considering the firm's efficiency of pollution abatement and its efficiency of production. The results find that a firm which has exhibited increasing returns to scale in pollution abatement performance in response to pollution tax increases its output level. It also shows that the firm's location depends on the efficiency of pollution abatement and production efficiency. The changes to pollution level at the urban centre due to pollution tax depends on the changes to the firm's output level, the firm's location choice, and the firm's pollution abatement performance.

Keywords: firm location; environmental regulations; pollution abatement, efficiency
JEL classification:

1. Introduction

Environmental problems in urban areas continue to be crucial issues in various regions across the globe. The United Nations (1996) reports that urban issues, including urban environmental problems, are becoming more immediate and are greatly affecting the wellbeing of the majority of the population. For instance, the World Bank (1997) reports that many Chinese cities have ambient concentrations of particulates and sulphur dioxide which are significantly higher than the guidelines of the World Health Organization. The 6.32 million residents of the urban area of Shanghai are exposed to particulate matter levels which are substantially higher than the normal population exposure level in western countries (Kan and Chen, 2004). Shijianzhuang has an annual energy growth rate of approximately 10 percent, mainly induced by industrial development (Peng et al., 2002). Concentration of plants and increase in transportation in urban areas are major factors of environmental and human health degradation. According to Wackernagel and Rees (1996), each area has the carrying capacity to cope with pollution. However, pollutions beyond the carrying capacity may cause huge and irreversible damage to both the environment and human health (Arrow et al., 1995). Given that urban areas are closer to the threshold of the carrying capacity than the countryside, polluting firms locating to urban areas could push the pollution level beyond the threshold and lead to critical environmental damage and affect human health to urban dwellers (Doull, 1996; Millimet and Slottje, 2003; US National Research Council, 2002）. Taking these issues into consideration, it will be meaningful to examine the relationship between environmental policy and a firm's location decision to the urban area.

This paper will analyse how pollution tax influences a firm's location decision and how this is linked with urban pollution by using spatial economic theory. Spatial economic theory studies which examine the firm's choice to locate to the urban centre (output market site) or to the input site are well documented (e.g. Tan, 2001; Tan and Hsu, 2000; Park and Mathur, 1990; Park and Mathur, 1988). Concerning environmental regulations, though not common in spatial economic theory, there are several theoretical studies which focus on the role environmental regulations play. For example, Motta and Thisse (1994) consider a two-country, two firm economic model. When the environmental policy of a firm's home country and the market size of the firm's country change, they analyse whether a firm stays in its home country; or the firm produces in two countries; or the firm produces only outside the home country. In Markusen's (1997) study, he considers environmental policy to be endogenous and that there are strategic interactions between governments. Hoel (1997) using a partial equilibrium model, examines situations where regions provide incentives to attract industries through relatively lax environmental regulations resulting with firms suffering from disutility due to the abnormally high pollution effecting firms to choose elsewhere. Fredriksson et al. (2003) examine the impact environmental regulations have on plant location, controlling for bureaucratic corruption[1]

With regard to studies on the impact of environmental regulations on a firm's location using spatial economic theory, Hwang and Mai (2004) examine the impact pollution tax has on the firm's output, on the location and on the pollution level in the central business district. Tan (2005) analyses the effect pollution tax has on firms' location and on urban pollution concentration, under stochastic emissions using *n*-input sites model. However, these studies do not take into account the role pollution abatement has on firms' location decision. Pollution abatement refers to the ability for a firm to reduce the pollution it emits. There are spatial economic theories which consider the role of pollution abatement. Isik (2005) analyses how various taxes including emissions tax affect firm's location decision under the uncertainty of production and the cost of abatement investment and Mathur (1976) investigates the effect pollution tax has on the implementation of pollution abatement using both a cost minimizing model and a profit maximizing model. Gokturk (1979) examines the impact changes to the pollution tax has on the location decision and the abatement decision of firms by assuming that output and pollution emissions are joint outputs of a material input. Like Mathur's (1976) study, Forster (1987) studies the sufficient condition for pushing the polluting firm away from the urban centre, however he explains that the condition depends upon the specification of the production and pollution emissions technology.

These spatial economic studies which consider the role of pollution abatement do not, however, examine the role pollution tax have on the 'efficiency' of pollution abatement. The 'efficiency' of pollution abatement in response to pollution tax means whether more than one unit of pollution reduction can be achieved by an additional one unit in pollution tax.[2] It is natural to suspect that the efficiency of pollution abatement in response to pollution tax would differ amongst firms, and so the reduction in pollution level would also differ. As the Porter hypothesis implies, if the firm's technological innovation is triggered through environmental regulations such as pollution tax, the firm can improve its competitiveness and increase its profit (Porter and van der Linde, 1995). Given that the efficiency of pollution abatement is through technological innovation, the firm will succeed in reducing the burden of pollution tax and in turn, will influence the firm's production and profit. Hence, it will be meaningful to take into consideration the efficiency of pollution abatement.

One of the contributions of this paper is that in order to observe the efficiency of pollution abatement, it analyses the effect pollution tax has on the firm's location, focusing on three measures of pollution abatement efficiency - i) increasing returns to scale (IRS); ii) decreasing returns to scale (DRS); and iii) constant returns to scale (CRS). Analysing the effect pollution tax has on pollution abatement in this way is a first in not only spatial economic theories, but to the best of our knowledge, has not been used before. Furthermore, in past studies which observe the effect environmental regulations have on pollution

[1] There are many empirical studies which examine the influence of environmental regulations on a firm's location decision where the firm will move to the region with less stringent environmental regulations and then the region will suffer from pollution problems (pollution haven hypothesis). Some studies which support the pollution haven hypothesis are: Rowland and Feiock (1991), Birdsall and Wheeler (1993), Mani and Wheeler (1998) and Keller and Levinson (2002) and Cole and Elliott (2005). While the following studies do not support the pollution haven hypothesis: Kirkpatrick and Shimamoto (2008), Levinson (1996) and List and Co (2000). A review of the key issues are provided by Dean (1992), Nordstrom and Vaugham (1999) and Zarsky (1999).

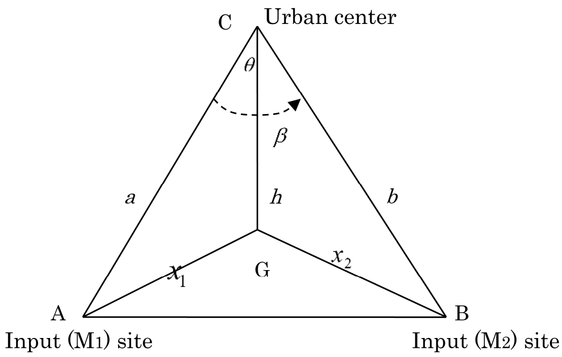
[2] The role of the efficiency of pollution abatement has been highlighted in other studies though they do not explicitly state that it is led by pollution tax. For instance, in studies on the Environmental Kuzunets Curve, it is explained both theoretically and empirically concerning the importance of the role pollution abatement play in achieving an inverted-U shape where pollution per capita begin to fall after a certain point of income per capita is reached (e.g. Andreoni and Levinson, 2001).

abatement, it was found that none had applied in their analysis the firm's production function ('efficiency' of production) which is used in spatial economic theory. In reality, firms will perform production activities in various forms and have varying degrees of productivity and so it will be necessary to consider the efficiency of the production. Hence this paper will not only examine how pollution tax influences the firm's output, location and the pollution level of the urban centre, it will also attempt to take into consideration the efficiency of production. The paper is based on the model introduced by Hwang and Mai (2004). As explained earlier, the model by Hwang and Mai (2004) does not include the efficiency of pollution abatement, which is applied to this model to investigate the decision making process of a firm's location influenced by pollution tax. The results find that a firm which has exhibited increasing returns to scale in pollution abatement efficiency in response to pollution tax increases its output level. It also shows that a firm's location depends on its efficiency of pollution abatement and production. Finally it demonstrates that the changes to pollution level in the urban centre caused by pollution tax are determined by the changes to the firm's output level, the location where the firm chooses, and the firm's pollution abatement efficiency.

The remainder of this paper is organized as follows. Section 2 applies a basic Weberian locational triangle framework to analyse the impact pollution tax policy has on a firm's output and location. Section 3 examines the impact pollution tax policy has on the pollution level of an urban centre. The main conclusions of the paper are provided in Section 4.

2. The Model

Figure 1. Locational Triangle



The model used in this paper is a partial equilibrium framework and a Weberian triangle space based on a monopolist, following the studies by Hwang and Mai (2004). The firm employs two transportable inputs $M1$ and $M2$, which are located at A and B, respectively, when producing output q. As represented in Figure 1, the output is sold at the urban centre (output market) C. The optimal location chosen by the firm is G. The distance between G from A and G from B are represented by $x1$ and $x2$, respectively; the distance between G and C is h; the angle between CG and CA is θ; the angle between CA and CB is β; and the lengths of CA and CB are represented by a and b, respectively.

In order to simplify the analysis, through the minimization of the total cost subject to a given output level, the total cost function is first derived as follows:

$$Min(\overline{w}_1 + r_1 x_1)M_1 + (\overline{w}_2 + r_2 x_2)M_2 \tag{1}$$

$s.t.\ q = f(M1, M2),$

where f specifies the production function of the firm. $\overline{w}_1$ and $\overline{w}_2$ are base prices of $M1$ and $M2$ at A and B, respectively. These are assumed to be constant. The constant transport rates of $M1$ and $M2$ are $r1$ and $r2$, respectively. $x1$ and $x2$ are defined by the law of cosines. That is

$$x_1 = \sqrt{a^2 + h^2 - 2ah\cos\theta},\quad x_2 = \sqrt{b^2 + h^2 - 2bh\cos(\beta - \theta)}.$$

It assumes the production function to be homothetic for simplicity. Shephard (1970) explained that if and only if the cost function is separable into input prices and output level, can the production function be homothetic. Therefore, the cost function as shown in Equation (1) can be represented as the product of input price function $c(w1,w2)$ and the input level be determined by the output level $H(q)$:

$$T(q) = c(w1,w2)H(q) = c(\theta, h)H(q), \tag{2}$$

where $w1 = \overline{w}_1 + r1x1$ and $w2 = \overline{w}_2 + r2x2$ represent the delivered prices for $M1$ and $M2$, respectively; c represents a function of $w1$ and $w2$, which are shown as a function of θ and h. θ and h are variables employed in a firm's location decision-making process. Using Equation (2), the relationship between the average and marginal costs can be derived as:

$$\frac{H}{q} > (=,<) H_q \quad , \tag{3}$$

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

It next assumes that the inverse demand function is differentiable at any point and that the increase of output leads to a decrease of price (i.e. $P = P(q)$, $Pq < 0$). Governments gain revenue by imposing pollution tax on pollution emitted. The following specifies the pollution tax revenue function $R(q)$:

$$R(q) = eA(e)y(q), \tag{4}$$

where e denotes the pollution tax rate[3] and $y(q)$ represents the amount of pollution which is dependent on the amount of output produced. Like Hwang and Mai (2004), this paper assumes that the output linearly leads to the increase of the emissions (i.e., $yq > 0$ and $yqq = 0$). Under this assumption, it is possible to derive that $Rq = eAyq > 0$ and $Rqq = 0$. $A(e)$ is the reduction rate of pollution ($0<A(e)<1$), i.e. the pollution abatement responding to the pollution tax rate (pollution abatement efficiency function). It assumes that the firm's pollution abatement improves due to pollution tax (i.e. $Ae < 0$). It also assumes that the pollution abatement efficiency function is everywhere twice differentiable. Further to these assumptions, the firm will need to:

$$\underset{q,\,\theta,\,h}{Max}\ \pi = [P(q) - th]q - c(\theta, h)H(q) - R(q), \tag{5}$$

where t denotes the constant transport rate of shipping one unit of the output to the urban centre. Deriving the first-order conditions for profit maximization with respect to q, θ, and h and then, in order to examine the effect a change in the pollution tax has on the production and location decisions, it performed a total differentiation on these first-order conditions with respect to q, θ, h, and e. Using the comparative static matrix obtained through this total differentiation procedure, it is possible to calculate the comparative static effects of a stricter pollution tax as follows:

$$\frac{dq}{de} = \frac{R_{qe} D_{\theta h}}{D} \quad , \tag{6}$$

$$\frac{dh}{de} = \frac{-\pi_{\theta\theta} c_h R_{qe}}{D}\left(\frac{H}{q} - H_q\right) \quad , \tag{7}$$

$$\frac{d\theta}{de} = \frac{\pi_{\theta h} c_h R_{qe}}{D}\left(\frac{H}{q} - H_q\right) \quad , \tag{8}$$

[3] As in the study by Hwang and Mai (2004), the pollution tax e is treated as an exogenous variable, not conditional on the location of the plant.

where D is the relevant bordered Hessian determinant. Note that the second-order conditions require $D < 0$, $D\theta h = \pi_{\theta\theta}\pi_{hh} - \pi_{\theta h}^2 > 0$, and $\pi_{\theta\theta} < 0$; and that $c_h < 0$. It takes into consideration the importance that the effect of a change in pollution tax has on production in understanding the economic factors effecting the optimal firm location and the measurement of pollution emission, by first observing the following.

$$R_{qe} = y_q(A + eA_e). \tag{9}$$

It follows immediately from Equation (6) and (9) that:

$$R_{qe} < 0 \quad \text{if} \quad \left|\frac{A}{e}\right| < |A_e| \quad \text{hence,} \quad \frac{dq}{de} > 0, \tag{10a}$$

$$R_{qe} = 0 \quad \text{if} \quad \left|\frac{A}{e}\right| = |A_e| \quad \text{hence,} \quad \frac{dq}{de} = 0, \tag{10b}$$

$$R_{qe} > 0 \quad \text{if} \quad \left|\frac{A}{e}\right| > |A_e| \quad \text{hence,} \quad \frac{dq}{de} < 0, \tag{10c}$$

where $\left|\frac{A}{e}\right| < (=,>) |A_e|$ indicates that pollution abatement efficiency function is IRS (CRS, DRS). As explained in Section 1, IRS (CRS, DRS) in pollution abatement efficiency function means that more than one (one, less than one) unit of pollution reduction can be achieved by an additional one unit increase in pollution tax. Therefore, the following proposition can be derived:

Proposition 1.
A firm where pollution abatement exhibits IRS is able to increase its change in output level even if the pollution tax rate is increased. On the other hand, a firm with DRS pollution abatement will decrease its change in output level if the pollution tax rate is increased. For a firm where pollution abatement exhibits CRS, a change to the output level is invariant with respect to a change in the pollution tax rate.

Proposition 1 will be explained in more detail. Pollution abatement is IRS when a one unit increase in pollution tax results in a more than one unit decrease in the level of pollution. This suggests 'efficiency' of pollution reduction, since there is a less than one unit burden of payment per unit increase in pollution tax. Hence, the firm can increase its output. On the other hand, when pollution abatement is DRS and a one unit increase in pollution tax results in less than one unit of pollution abatement, there is an increase in the burden of payment of more than one unit, reducing the firm's output. This suggests 'inefficiency' of pollution reduction. If the pollution abatement is CRS, the changes to the pollution tax rate are equivalent to the changes to the pollution abatement. This indicates no changes to the additional payment of pollution tax, so the additional output level of the firm does not change.

Next it will observe the effect on locational choice. The impact of pollution tax rate on firm location from Equation (3), (7) and (10a)-(10c) are summarized in Table 1.

Table 1: The impact of pollution tax rate on firm location

	$\frac{H}{q} > H_q$ (*IRS*)	$\frac{H}{q} = H_q$ (*CRS*)	$\frac{H}{q} < H_q$ (*DRS*)
$\left\lvert\frac{A}{e}\right\rvert < \lvert A_e\rvert$ (*IRS*)	$\frac{dh}{de} < 0$	0	$\frac{dh}{de} > 0$
$\left\lvert\frac{A}{e}\right\rvert = \lvert A_e\rvert$ (*CRS*)	0	0	0
$\left\lvert\frac{A}{e}\right\rvert > \lvert A_e\rvert$ (*DRS*)	$\frac{dh}{de} > 0$	0	$\frac{dh}{de} < 0$

From Table 1, it can derive the following proposition:

Proposition 2.

In response to an increase in pollution tax, the firm which will locate closer to the urban centre 1) will exhibit IRS in pollution abatement and IRS in production function; or 2) will exhibit DRS in pollution abatement and DRS in production function. On the other hand, the firm which will locate further from the urban centre 1) will exhibit IRS in pollution abatement and DRS in production function; or 2) DRS in pollution abatement and IRS in production function. The firm which will not locate closer to either the urban centre or the input sites 1) will exhibit CRS in pollution abatement; or 2) IRS or DRS in pollution abatement and CRS in production function.

Here it will explain Proposition 2 in more detail. At first, it will describe the firm which exhibit DRS in pollution abatement in response to the changes in pollution tax. As described in Proposition 1, the firm which exhibit DRS in pollution abatement responded to the increase in pollution tax rate by a decrease in the output level. For a firm which exhibit CRS in production function, a unit decrease in the output level will mean a unit decrease in the input level, suggesting that the output-input ratio is the same as that of before the change in the output level. Hence the firm will remain in the same location. For a firm which exhibits an IRS in production function, the input level will decrease by less than one unit with the decrease of one unit of the output level. Therefore, the decrease to the transportation cost of the input is smaller than the decrease in the transportation cost of the output, suggesting that the firm with production function under IRS will locate further from the urban centre. As for the firm which exhibit DRS in production function, the input level will decrease by more than one with a one unit decrease in the output level. Hence, the decrease to the transportation cost of the output is smaller than the decrease in the transportation cost of the input, indicating that the firm with production function under DRS will move closer to the urban centre.

Next, it will examine the firm which exhibits IRS in pollution abatement in response to the changes in the pollution tax rate. As described in Proposition 1, the output level of this firm increased responding to the change in the pollution tax rate. For the firm which exhibit CRS in production function, a one unit increase of input is led by one unit increase of the output, suggesting that the output-input ratio remain the same as before the changes to the output level. Accordingly, the firm remains in the same location. As for the firm which exhibit IRS in production function, the input level increases by less than one unit when the output increases by one unit. Hence, the increase to the transportation cost of the output is greater than the increase to the transportation cost of the input before the changes to the output level, indicating that the firm with the production function under IRS will move closer to the urban centre. Concerning the firm which exhibit DRS in production function, the input increases by more than one unit when the output increases by one unit. Hence, the increase to the transportation cost of the input is greater than the increase in transportation cost of the output before the increase to the output level, suggesting that the firm will move further from the urban centre.

As described in Proposition 1, the firm which exhibit CRS in pollution abatement has no changes to the output level with changes to the pollution tax rate. Hence, the input level does not change under any form of pollution abatement responding to changes in the pollution tax rate, meaning that the firm will remain in the same place.[4]

3. The Impact of Pollution Tax Policy on the Pollution Level in Urban Centres

Next, to examine the total pollution at C (i.e., urban centre), in Figure 1 it sets the following function. The pollution is generated by the firm located at G. The pollution level at C is generally lower than that at G and is dependent on the distance between G and C. If the total pollution level at G is set to Z^G, then the pollution level at C can be set as Z^C, which is defined by:

$$Z^C = k(h)Z^G, \tag{11}$$

k represents the rate of decreasing pollution level which is effected by the distance between C and G. where $k_h < 0$ and $k_{hh} > 0$, indicating that as the distance between the urban centre and the firm increases, the pollution level at C declines at a decreasing rate. Since the pollution generated by the firm is *A(e)y(q)*, then the pollution level at the urban centre can be represented as:

$$Z^C = k(h)A(e)y(q). \tag{12}$$

It can then derive the effect of an increase of *e* (i.e. a higher pollution tax) on Z^C as follows:

$$\frac{dZ^C}{de} = k_h h_e Ay + kA_e y + kAy_q q_e. \tag{13}$$

Equation (13) indicates that the effect of a higher pollution tax can be divided into three effects: the location effect (*LE*), the pollution abatement effect (*AE*) and the output effect (*QE*). The first term of the right-hand side of Equation (13) indicates the location effect, which is ambiguous since it relies on the sign of *he*, which is as shown in Equation (7), is dependent on the characteristic of the production function and the pollution abatement efficiency function. The second term shows the pollution abatement effect, which shows a negative sign as described in Section 2. The third term represents the output effect, which is ambiguous again, since it is dependent on the characteristics of the pollution abatement with respect to pollution tax rates. It will be possible to rewrite equation (13) as;

$$\frac{dZ^C}{de} = \alpha(A + eA_e)(\frac{H}{q} - H_q) + kA_e y + \beta(A + eA_e), \tag{14}$$

where

$$\alpha = -k_h Ay \frac{\pi_{\theta\theta} c_h}{D} y_q, \quad \beta = kA \frac{D_{\theta h}}{D} y_q^2.$$

[4] A change in the pollution tax signifies not only a change in the firm's distance to the urban center *h*, but also its locational triangle *θ*. The sign of $\frac{d\theta}{de}$, as shown in equation (8), cannot be determined as it is dependent on $\pi_{\theta h}$ as well as the characteristic of the production function, and pollution abatement efficiency function. The sign of $\pi_{\theta h}$ has not been pursued since there is no way to predict it in advance.

Following from Equation (14), the following proposition can be derived:

Proposition 3.

The effect pollution tax has on the pollution level at the urban centre depends on the total effect of the output effect, the location effect and the pollution abatement effect, which are, in turn, dependent on the efficiency of production and the efficiency of pollution abatement. These relationships are represented in Table 2 below:

Table 2: The impact of pollution tax rate on pollution level

	$\frac{H}{q} > H_q$ (*IRS*)	$\frac{H}{q} = H_q$ (*CRS*)	$\frac{H}{q} < H_q$ (*DRS*)
$\left\lvert \frac{A}{e} \right\rvert < \lvert A_e \rvert$ (*IRS*)	$AE^- \gtreqless LE^+ + QE^+ \rightarrow \frac{dZ^C}{de} \lesseqgtr 0$	$AE^- \gtreqless QE^+ \rightarrow \frac{dZ^C}{de} \lesseqgtr 0$	$AE^- + LE^- \gtreqless QE^+ \rightarrow \frac{dZ^C}{de} \lesseqgtr 0$
$\left\lvert \frac{A}{e} \right\rvert = \lvert A_e \rvert$ (*CRS*)	$AE^- \rightarrow \frac{dZ^C}{de} < 0$	$AE^- \rightarrow \frac{dZ^C}{de} < 0$	$AE^- \rightarrow \frac{dZ^C}{de} < 0$
$\left\lvert \frac{A}{e} \right\rvert > \lvert A_e \rvert$ (*DRS*)	$AE^- + LE^- + QE^- \rightarrow \frac{dZ^C}{de} < 0$	$AE^- + QE^- \rightarrow \frac{dZ^C}{de} < 0$	$AE^- + QE^- \gtreqless LE^+ \rightarrow \frac{dZ^C}{de} \lesseqgtr 0$

Note: AE^- represents pollution abatement effect; LE^+ (LE^-) refers to a positive (negative) location effect which represents a more adjacent (less adjacent) location to the urban centre; and QE^+ (QE^-)refers to a positive (negative) output effect which represents an increase (decrease) in output.

Proposition 3 will be explained in more detail.

Case 1) Pollution abatement is IRS and production function is IRS (Table 2 - first row and first column):

As described in Proposition 1, for a firm which exhibits IRS in pollution abatement, the output increases by more than one unit when the pollution tax rate increases by one unit. Furthermore, with production function exhibiting IRS, Proposition 2 explains that the increase in input is less than the increase to the output when responding to the change in the pollution tax rate. Hence, the firm will decide to choose the location closer to the urban centre. These results suggest that based on the increase in output and the production conducted close to the urban centre, this would cause an increase in pollution in the urban centre. However, there is the pollution abatement at work. Therefore, the pollution level at the urban centre will depend on the total effect of the positive output effect which reflects the increase of the output level; the positive location effect which represents locating closer to the urban centre; and the pollution abatement effect.

Case 2) Pollution abatement is IRS and production function is CRS (Table 2 - first row and second column):

As described in Proposition 1, for a firm which exhibits IRS in pollution abatement, the output increases by more than one unit when the pollution tax rate increases by one unit. Furthermore, with production function exhibiting CRS, Proposition 1 explains that the increase unit in input is equivalent to the increase unit in output when responding to the change in the pollution tax rate. Hence, the firm will not locate any closer to the urban centre or the input sites, suggesting that the location effect is zero. Therefore, the pollution level at the urban centre will depend on the total effect of the positive output effect which reflects the increase of the output level and the pollution abatement effect.

Case 3) Pollution abatement is IRS and production function is DRS (Table 2 - first row and third column):

As described in Proposition 1, for a firm which exhibits IRS in pollution abatement, the output increases by more than one unit when the pollution tax rate increases by one unit. Furthermore, with production function exhibiting DRS, Proposition 2 explains that the increase in input is greater than the increase to the output when responding to the change in the pollution tax rate. Hence, the firm will decide to choose the location further from the urban centre. These results suggest that there was an increase in output; the production was conducted away from the urban centre; and pollution abatement was at work. Therefore, the pollution level at the urban centre will depend on the total effect of the positive output effect; the negative location effect; and the pollution abatement effect.

Case 4) Pollution abatement is CRS and production function is IRS (Table 2 – second row and first column):

As described in Proposition 1, the firm's output level does not change with changes to the pollution tax rate. Hence, the firm will not locate either closer or further from the urban centre, meaning that the output effect and location effect are zero. The pollution level of the urban centre will only decrease with the effect of the pollution abatement.

Case 5) Pollution abatement is CRS and production function is CRS (Table 2 – second row and second column):

The same as Case 4.

Case 6) Pollution abatement is CRS and production function is DRS (Table 2 – second row and third column):

The same as Case 4.

Case 7) Pollution abatement is DRS and production function is IRS (Table 2 – third row and first column):

As described in Proposition 1, for a firm which exhibits DRS in pollution abatement, the output decreases by more than one unit when the pollution tax rate increases by one unit. Furthermore, with production function exhibiting IRS, Proposition 2 explains that the decrease in input is less than one unit when output decreases by one unit responding to the change in the pollution tax rate. Hence, the firm will decide to choose the location further from the urban centre. This means that there was a negative output effect which reflects the decrease in output and a negative location effect which represents location further away from the urban centre. Furthermore, the pollution abatement effect is at work. Therefore, the pollution level at the urban centre will decrease.

Case 8) Pollution abatement is DRS and production function is CRS (Table 2 – third row and second column):

As described in Proposition 1, for a firm which exhibits DRS in pollution abatement, the output decreases by more than one unit when the pollution tax rate increases by one unit. Furthermore, with production function exhibiting CRS, Proposition 2 explains that the change to the input is equivalent to the change to the output when responding to the change in the pollution tax rate. Hence, the firm will not decide to locate either closer to or further away from the urban centre, suggesting that the location effect is zero. Therefore, the pollution level at the urban centre will decrease due to the negative output effect which reflects the decrease in the output level and the pollution abatement effect.

Case 9) Pollution abatement is DRS and production function is DRS (Table 2 – third row and third column):

As described in Proposition 1, for a firm which exhibits DRS in pollution abatement, the output decreases by more than one unit when the pollution tax rate increases by one unit.

Furthermore, with production function exhibiting DRS, Proposition 2 explains that the decrease in input is greater than one unit when output decreases by one unit responding to the change in the pollution tax rate. Hence, the firm will decide to choose the location closer to the urban centre. This means that there was a negative output effect which reflects the decrease in output and a positive location effect which represents location closer to the urban centre. Furthermore, the pollution abatement effect is at work. Therefore, the pollution level at the urban centre will depend on the total effect of these three effects.

4. Conclusion

Urban pollution continues to be a crucial issue in cities across the globe, especially in developing countries. Hence, it will be meaningful to examine how pollution tax influences a firm's decision to locate to an urban centre and the different effects it will have on different firm's pollution abatement. The different pollution abatement responses to pollution tax will have an impact on the firms' production and location. If this is examined with the firm's efficiency of production, it will help provide insight to another dimension of a firm's behaviour. This analysis concerning the relationship between pollution tax and the firm's location as well as the relationship with the firm's output and pollution level at the urban centre has produced some interesting results. First of all, it was found that a firm which exhibit IRS in pollution abatement performance in response to pollution tax, that is, a firm with efficient pollution abatement, is able to increase its output level. Therefore, both policy-makers and firms should recognize that the pollution tax does not necessary damage the firm's production activity.

Second, in the firm's location decision, not only was it found that the efficiency of production effected the decision which is consistent with other studies, but it was found that the efficiency of pollution abatement also influencing the decision making process. This suggests to policy-makers that when trying to attract firms to locate to certain areas, it is necessary to understand the influence these effects have on the location decision when considering the optimal pollution tax policy. For instance, the relocating of a polluting firm affected by the pollution tax policy will have a negative impact on the environment of the area. Suppose that the carrying capacity of an urban centre is low or the urban centre is close to the threshold of its carrying capacity, a polluting firm locating to this urban centre can cause irreversible damage to the environment. Therefore, it will be necessary to avoid the polluting firm relocating to the urban centre. To achieve this goal, as indicated in Cases 4,5,6,7, 8 of Proposition 3, pollution tax will be effective with a firm in the region that has exhibited either CRS in pollution abatement; or DRS in pollution abatement and IRS or CRS in production function.

However, as in Case 3 of Proposition 3, if in the region there is a firm which has IRS in pollution abatement in response to pollution tax and DRS in production function, even with the pollution abatement at work and the firm choosing to locate away from the urban centre in response to the changes in the pollution tax, there is the risk that the firm will cause pollution and harm the environment. Hence, concerning the firm's location decision, policy-makers and stakeholders such as the community and NGOs will require assessing the firm's production and pollution abatement ability and conducting various environmental assessment such as environmental impact assessment or strategic environmental assessment.

References

Andreoni, J., Levinson, A., "The simple analytics of the environmental Kuznets curve", Journal of Public Economics, 80, 2001, pp.269-286.

Arrow, K., Bolin, B., Costanza, R., Dasgupta,, P. Folke, C., Holling, C. S., Jansson, B-O., Levin, S., Mäler, K-G., Perrings, C., Pimentel, D., "Economic growth, carrying capacity, and the environment", Science, 268 (28), 1995, pp.520-521.

Birdsall, N, Wheeler, D., "Trade policy and industrial pollution in Latin America: where are the pollution havens?", Journal of Environment and Development, 2 (1), 1993, pp.137-149.

Cole, M. A., Elliott, R. J. R., "FDI and the capital intensity of 'dirty' sectors: A missing piece of the pollution haven puzzle", Review of Development Economics, 9 (4), 2005, pp.530-548.

Dean, J., "Trade and environment: a survey of the literature", Policy Research Working paper World Development Report No. 966, Washington DC, World Bank,1992.

Doull, J., "Specificity and dosimetry of toxicologic responses", Regulatory Toxicology and Pharmacology, 24, , 1996, pp.55-57.

Fredriksson, P. G., List, J. A., Millimet, D. L., "Bureaucratic corruption, environmental policy and inbound US FDI: theory and evidence", Journal of Public Economics, 87, 2003, pp.1407-1430.

Gokturk S. S., "A theory of pollution control, location choice, and abatement decisions", Journal of Regional Science, 19 (4), 1979, pp.461-467

Hwang, H., Mai, C-C., "The Effect of pollution taxes on urban areas with an endogenous plant location", Environmental and Resource Economics, 29, 2004, pp.57-65.

Isik, M., "Environmental regulation and the optimal location of the risk-averse firm under uncertainty", Environment and Development Economics, 10, 2005, pp.435-452.

Kan, H., Chen, B., "Particulate air pollution in urban areas of Shanghai, China: health-based economic assessment", Science of the Total Environment, 322, 2004, pp.71-79.

Keller, W., Levinson, W., "Pollution abatement costs and FDI inflows to flows to U.S. states", Review of Economics and Statistics, 84, 2002, pp.691-703.

Kirkpatrick, C., Shimamoto, K., "The effect of environmental regulation on the locational choice of Japanese foreign direct investment", Applied Economics, 40(11), 2008, pp.1399-1409.

Levinson, A., "Environmental regulations and manufacturers' location choices: evidence from the census of manufactures", Journal of Public Economics, 62, 1996, pp.5-29.

List, J. A., Co, C. Y., "The effect of environmental regulation on foreign direct investment", Journal of Environmental Economics and Management, 40, 2000, pp.1-40.

Mani, M., Wheeler, D., "In search of pollution havens? dirty industry in the world economy, 1960-1995", Journal of Environment and Development, 7, 1998, pp.215-247.

Markusen J. R., "Costly pollution abatement, competitiveness and plant location decisions", Resource and Energy Economics, 4, 1997, pp.299 – 320.

Mathur, V. K., "Spatial economic theory of pollution control", Journal of Environmental Economics and Management, 3, 1976, pp.16–28.

Millimet, D. L., Slottje, D., "Industrial and environmental specialization", Applied Economics Letters, 10, 2003, pp.123-128.

Motta, M, Thisse, J. F., "Does environmental dumping lead to delocation?", European Economic Review, 38 (3-4), 1994, pp.563-76.

Nordstrom, H., Vaughan, S., Trade and Environment, Special Studies, No 4, Geneva, WTO, 1999.

Peng, C., Wu, G. L., Johnson, T., Shah, J., Guttikunda, S., "Urban air quality and health in China", Urban Studies, 39 (12), 2002, pp.2283-2299.

Park, K., Mathur, V. K., "Production-technology uncertainty and the optimal location of the firm", Journal of Regional Science, 28, 1988, pp.51-64.

Park, K., Mathur, V. K., "Location theory under uncertainty and the optimal location of the firm", Journal of Urban Economics, 27, 1990, pp.362-380.

Porter, M. E., van der Linde, C., "Towards a new conception of the environment competitiveness relationship", Journal of Economics Perspective, 9(4), 1995, pp.97-118.

Rowland, C. K., Feiock, R., "Environmental regulation and economic development: the movement of chemical production among states", in Dubnick, M. J. and Gitelson, A. R. (eds.), Public Policy and Economic Institutions, Greenwick, Conn, JAI press: 1991, pp.205-218.

Shephard, R. W., Cost and Profit Function. Princeton, New Jersey, Princeton University Press, 1970.

Tan, L-T., "Transport rate uncertainty and the optimal location of the firm: some new conclusions", Journal of Regional Science, 41, 2001, pp.301-315.

Tan, L-T. and S-K. Hsu, "Production location under technology uncertainty", Environment and Planning A, 32, 2000, pp.445-454.

Tan, L-T., "Spatial economic theory of pollution control under stochastic emissions", IEAS Working Papers, No.05-A009, 2005.

United Nations, World Urbanization Prospects: The 1996 Revision Database, New York, United Nations Population Division, 1996.

US National Research Council, Abrupt Climate Change: Inevitable Surprises, Washington DC, The National Academy of Sciences, 2002.

Wackernagel, M. and W. Rees, Our Ecological Footprint: Reducing Human Impact on the Earth. Gabriola Island, BC: New Society Publishers, 1996.

World Bank, Clear Water, Blue Skies: China's Environment in the New Century, Washington DC, World Bank, 1997.

Zarsky, L., "Havens, halos and spaghetti: untangling and the evidence about foreign direct investment", in Foreign Direct Investment and the Environment, Paris, OECD, 1999, pp.47-74.