Environmental Regulation and the Optimal Location of the Firm under Uncertainty

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Abstract

This paper examines the optimal location of a competitive firm in response to environmental costs imposed by the abatement investment and taxes when the cost of the environmental regulation varies spatially under uncertainty. It contributes to the literature by incorporating the spatial setting into a risk-averse firm's location decisions in the presence of environmental regulation uncertainty. An increase in the cost of the environmental regulation moves a risk-averse firm closer to the output market. An augmented input or emission tax causes the risk-averse firm to locate closer to the output market. Uncertainty about environmental regulations in the form of the abatement investment and taxes also leads a risk-averse firm to locate closer to the output market, while it does not affect a risk-neutral firm's location decisions. The results have implications for the design and implementations of environmental and other development-related policies.

Key Words: risk aversion, uncertainty, regulation, market-based policies.

JEL Classification: D81, R38, Q28.

1. Introduction

The location choice of firms has important implications for the future development of various industries in agriculture and manufacturing sectors. Knowing the possible trends in the firm location improves our ability to formulate public policies affecting the industry development as well as to effectively respond to the environmental problems of concentrations of firms on certain areas. Therefore, it is important to examine how various policies would impact firms' location decisions. Environmental regulations in the form of mandatory abatement investment and market-based policies such as input, output and emission taxes and uncertainty about their implementations may affect firms' location decisions. As government regulations are imposed to improve the environmental quality, there might be changes in productions of goods and spatial locations of firms.

Environmental regulation and the added costs generally associated with compliance are considerations often factored into the choice of business location (Bartik, 1988; Jeppesen et al., 2002). Although national environmental policies have raised the minimum level of environmental standards, important differences in state environmental policies remain. In the U.S. state regulations governing hazardous waste disposal, wetlands filling, air and water pollution, and wildlife protection vary considerably (Meyer, 1995)[1]. It has been hypothesized that geographic variation in environmental regulations and enforcement can induce a migration of industries across state or country boundaries to "pollution havens" where compliance costs associated with environmental regulations are lower. Analysis of how spatial variability of environmental regulation and enforcement can affect location decisions may provide some insight into the pollution haven phenomenon. It may also shed some light on effects of

[1] For example, the history of federal regulation of pollution has empowered individual states to set policies and therefore has allowed for the current variability in the state regulations of the livestock and hog sectors.

environmental regulation in the international arena. Proposals to harmonize environmental standards across international boundaries add to the urgency of the question because of concerns raised that trade liberalization could induce increased investment in countries with lower environmental standards. In fact, the possibility of individual firms relocating in response to environmental costs has been a concern for public policy. The possibility of the U.S. manufacturing plants relocating to Mexico was an important issue in the North American Free Trade Agreement debate. This paper analyzes the optimal location of the firm in response to environmental costs imposed by the costs of abatement investment and various tax policies when the cost of the environmental regulation varies across space spatially under uncertainty.

Existing spatial variability of environmental regulations would create opportunities for firms to locate places with relatively lax environmental regulations. Most firms make their production and location decisions under various sources of uncertainty. Production is often subject to uncertainty about weather or other factors that can not be controlled by firms. Firms are also faced with uncertainty about environmental regulations. Uncertainty about environmental regulations in the form of either abatement investment or taxes arises because seemingly random changes in government policies make economic decisions risky. Additionally, the environmental policies do not have to change to make the firm's production and location decisions uncertain. Merely the discussions in Congress, administration and the media of potential policy changes introduce some elements of risk into firm-planning[2]. In fact, in the case of technology adoption, it is shown that uncertainty about government policies has the potential to impact the investment decision of farmers (Isik, 2003). Thus, uncertainty about the imposition

[2] For example, the differences in the scope, degree, and timing of current and proposed emissions control regulations have made power generation company compliance planning problematic by adding substantial uncertainty about elimination of future fuel flexibility and orderly power plant retirement and replacement (EPRI, 2003).

of environmental regulations or liabilities makes the costs of the regulation uncertain, which may affect the optimal production and location decisions of firms.

The purpose of this paper is to examine the impacts of environmental regulations on a risk-averse firm's production and location decisions under uncertainty about technology (production) and environmental regulation. It develops a theoretical model of firm decision-making by extending a spatial location model to analyze the extent to which the introduction of environmental regulations affects a risk-averse firm's optimal location decisions under uncertainty. The paper also aims at providing a systematic analysis of a risk-averse firm's response to various market-based policies such as output, input and emission taxes when deciding its location and the implications of spatially varying environmental regulations for location decisions.

Much of the literature in environmental economics, public finance and international trade abstract from the location decisions of individual firms under uncertainty. A number of studies explore the implications of changes in the degree of risk aversion on a firm's production and location decisions in a non-spatial context (Sandmo, 1971; Batra and Ullah, 1974; Briys and Eeckhoudt, 1985; Isik, 2002) and in a spatial context (Alperovich and Katz, 1983; Hsu and Tan, 2001; Katz, 1984; Mai, 1984; Mathur, 1983; Park and Mathur, 1988; Park and Mathur, 1990). However, there has been little attention given to the implications of uncertainty and risk aversion on a firm's production and location decisions in the presence of environmental regulations. A few theoretical studies examined the impacts of the environmental regulation uncertainty on the location decisions of risk-neutral firms[3]. Xepapadeas (1999) analyzed risk-neutral firms' abatement investment and location responses to the environmental policy, which takes the form

[3] A few theoretical and empirical studies also examined the impacts of the environmental regulation on the location of risk-neutral firms under certainty (Bommer, 1999; Jeppesen et al., 2002; Markusen, 1997; Motta and Thisse, 1994). However, these studies did not focus on the impact of environmental regulation uncertainty.

of emission taxes or tradable emission permits and subsidies under uncertainty. Similarly, Verbeke and De Clercq (2002) analyzed the relocation of a risk-neutral monopolist under various assumptions with respect to the difference in environmental policy stringency between the home and foreign country. None of these studies, however, examined the impact of environmental policy uncertainty on a risk-averse firm's location decision.

This paper contributes to the literature by incorporating the spatial setting into a model of firm location and production to obtain comparative statics results with respect to the level of environmental regulation uncertainty. It also derives results regarding the spatial effects of environmental regulations on a risk-averse firm's location decisions and examines the implications of the comparative statics results for the design and implementation of environmental policies. The results show that uncertainty about environmental regulations in the form of the abatement investment, output taxes, input taxes, and emission taxes leads a risk-averse firm to locate closer to the output market, while it does not affect a risk-neutral firm's location decisions. Under uncertainty, an increase in input and/or emission taxes leads to a decrease in the distance between a risk-averse firm's location and the output market, while it does not impact a risk-neutral firm's location decision. The results have implications for the design and implementations of environmental policies for pollution control and public policies for regional development.

2. The Model

The Conceptual Framework

We consider a competitive firm employing two transportable inputs, x_1 and x_2 to produce output Y. The inputs are available at the input markets I_1 and I_2. The firm supplies output to a consumption center (output market). Let d_i be the distance between the site of the output market and the input markets and h be the distance between the output market and the firm's location (Figure 1). Using the law of cosines, the distance between the firm's plant location to the input markets can be expressed as: $s_1 = \sqrt{d_1^2 + h^2 - 2d_1 h \cos\theta_1}$ and $s_2 = \sqrt{d_2^2 + h^2 - 2d_2 h \cos|\theta_2 - \theta_1|}$, where θ_1 is the angle of d_1 and h, and θ_2 is the angle of d_1 and d_2. The shipment of inputs and output from the input and output markets is costly. It is assumed that shipment cost of output and inputs per unit distance is r_i, i=0,1,2 for output and two inputs, respectively.

We consider environmental regulations in the form of mandatory technology adoption. With the environmental regulation, firms are usually required to use less pollution generating technologies, which require capital investment in new technologies. We also consider the impacts of various market-based policies such as input, output and emission taxes on the firm's location decisions, which can be used to regulate the industry through influencing firm location decision and affecting optimal input use and output.

The firm is assumed to face two types of uncertainty in choosing the plant location; technology (production) and environmental policy uncertainty. The production technology is represented by the following stochastic production function, $Y = F(x_1, x_2, \varepsilon)$, where ε is a random variable representing the effects of variations in stochastic weather conditions, labor efficiency, etc. This function is assumed to be a twice continuously differentiable function with $F_{x_i} > 0$ and $F_{xx_i} < 0$, i=1,2 for all values of ε. It is assumed that the higher values of ε represent the more favorable state of nature, i.e., $F_{\varepsilon} > 0$. Input prices (w_1 and w_2) and output price (P) are assumed to be known with certainty[4]. Pollution (waste) generated, z_i, is represented as a function of input use x_i as: $z_i = z_i(x_i)$.

The firm makes decisions concerning the plant location and input combinations under uncertainty about the cost of the environmental regulation. Assume that the cost of abatement investment from the investment in a new technology depends on where the firm locates its operations and volume of the pollution generated ($K(h, \theta_1, z_1(x_1), z_2(x_2))$). The cost of the environmental regulation would vary spatially because of variations in stringency of environmental regulations. For example, the costs of the environmental regulation could vary across states or counties as in the case of air and water pollution, hazardous waste disposal and wildlife regulations in the U.S. Additionally, in many cities, zoning has been used to control the use of land and improve the environmental quality by identifying areas around cities that require relatively high cost of abatement investment compared to the other areas. Some cities in Sweden introduced environmental zones in order to improve the ambient air quality. We take into account the stringency of the environmental regulation across space by making the cost function depending on h and θ_1. Given that the extent of the environmental regulation could vary across space with h and θ_1, the cost of abatement investment could take the form of $K(h, \theta_1, z_1(x_1), z_2(x_2)) = \alpha C(h, \theta_1, z_1, z_2)$, where α is an uncertain parameter with mean $\overline{\alpha}$ and with the support $[0, \alpha^U]$. Uncertainty about the costs of imposition of environmental regulations or liabilities is represented by assuming that α is a stochastic shift variable in the cost function.

The non-stochastic part of the cost function $C(h, \theta_1, z_1, z_2)$ is an increasing function of the pollution generated, i.e., $C_z > 0$ and $C_{zz} > 0$. This form of abatement cost function assumes

[4] In this paper, we consider a competitive firm's location decisions. Strategic reasons for relocation may also be important for firms that operate in a monopoly or oligopoly environments where firms' output and input use would affect output and input prices.

that the cost of the environmental regulation could vary spatially with h and θ_1. The sign of C_h determines whether the stringency of the environmental regulation and therefore the cost of the regulation increases or decreases as the firm moves closer to the output market. If $C_h < 0$, the closer the firm is located to the output market the higher the extent of the environmental regulation is. The cost of the regulation could also be uniform across space but vary with the pollution generated, i.e., $K(h,\theta_1) = \alpha C(z_1, z_2)$ and $C_h = 0$. In this type of regulations, given the same level of pollution generated, firms have to meet the same standards regardless of their locations. We examine the implications of alternative forms of the abatement cost function for the optimal location of the firm.

The firm is assumed to have a von Neuman-Morgenstern utility function, *U(W)* defined on wealth *W* with $U_W > 0$ and $U_{WW} < 0$. The wealth is represented by sum of the initial wealth, W_0 and returns from production, π. The Arrow-Pratt measure of absolute risk aversion at the expected post-risk wealth ($\overline{W}$) is defined as $R_A = -\frac{U_{WW}(\overline{W})}{U_W(\overline{W})}$. Note that relative risk aversion is $R_R = R_A\overline{W}$ [5]. The firm's objective is to maximize the expected utility of the wealth to find the optimal input combinations and its location. The firm's profit is given by:

$$\pi = (P - r_o h)Y - \sum_{i=1}^{2}(w_i + r_i s_i)x_i - K(h, \theta_1, z_1(x_1), z_2(x_2)). \tag{1}$$

Firm Location Decision under Uncertainty

The firm maximizes the expected utility of the wealth to find the optimal plant location and input combinations as:

[5] There are good theoretical and empirical reasons to assume that absolute risk aversion is decreasing and relative risk aversion is increasing in wealth (i.e., $dR_A/dW < 0$ and $dR_R/dW > 0$) as argued by Arrow (1971). A number of empirical studies have also found the evidence supporting this assumption (Bar-Shira, Just, and Zilberman, 1997; Saha, Shumway, and Talpaz, 1994; Isik and Khanna, 2003).

$$\max_{x_1, x_2, h, \theta_1} \; EU(W_0 + \pi). \tag{2}$$

We use a three-stage algorithm to solve the firm's decision problem. The first stage of the optimization problem involves finding the optimum amount of x_i that maximizes the expected utility at a given location choice (h, θ). The first-order conditions for the first-stage maximization are:

$$\frac{\partial EU}{\partial x_i} = EU_W \left[(P - r_o h) F_i - (w_i + r_i s_i) - \alpha C_{z_i} \, \partial z_i / \partial x_i \right] = 0 . \quad i\text{=1,2} \tag{3}$$

The second-order conditions for the maximum are assumed to be met, that is, $\partial^2 EU / \partial x_i^2 < 0$ and $\partial^2 EU / \partial x_1^2 - \partial^2 EU / \partial x_2^2 - \left(\partial^2 EU / (\partial x_1 \partial x_2) \right)^2 > 0$. Under only production uncertainty, equation (3) can be re-written as:

$$E\left[(P - r_o h) F_i - (w_i + r_i s_i) - \overline{\alpha} C_{z_i} \, \partial z_i / \partial x_i \right] + Cov(U_W, F_i) / EU_W = 0 \quad i\text{=1,2} \tag{4}$$

where the covariance $Cov(U_W, F_i)$ is positive (negative) when $F_{i\varepsilon} > (<) 0$. Thereby, x_i is a risk-increasing (risk-decreasing) input when $F_{i\varepsilon} > (<) 0$ under technology (production) uncertainty.

Let $x_i^*(h, \theta_1)$ be the values of x_i satisfying equation (4) and let $Y^*(h, \theta)$ and $\pi^*(h, \theta)$ be the corresponding values. The second stage of the optimization problem is to find the location variable θ_1 that maximizes $EU(W_0 + \pi^*)$ for a given h. Note that the firm only needs to find the optimal location variable θ_1 because θ_2 is known with the two input markets. The first-order condition for an interior θ_1 is given by:

$$\frac{\partial EU(W_0 + \pi^*)}{\partial \theta_1} = EU_W \left(-\sum_{i=1}^{2} r_i s_{i\theta} x_i^* - \alpha C_\theta \right) = 0 . \tag{5}$$

Finally, the third stage of the optimization problem is to find an optimum h that maximizes $EU(W_0 + \pi^*(h, \theta_1^*(h)), h)$, where $\theta_1^*(h)$ denotes the value of θ_1 satisfying equation (5). By differentiating $EU\left(W_0 + \pi^*(h, \theta_1^*(h)), h\right)$ with respect to *h*, the first-order condition for an interior *h* is obtained as[6]:

$$\frac{\partial EU\left(W_0 + \pi^*\right)}{\partial h} = EU_W\left(\pi_h\right) = 0\,, \tag{6}$$

where $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^* - \alpha C_h\right)$.

Impacts of Environmental Regulation on Location Decisions under Uncertainty

We now examine the impacts of the environmental regulation on the firm's location decisions under production uncertainty assuming that there is no uncertainty about the environmental regulation.

Proposition 1: Under production uncertainty, an increase in the cost of the environmental regulation will move a risk-averse firm closer to the output market, if the regulation is uniform across space. However, imposition of the uniform cost of the environmental regulation does not affect a risk-neutral firm's location decisions.

Proof: Assume that there is no uncertainty about environmental regulation or uncertainty about implementation of the regulation and therefore $K(h, \theta_1) = \overline{\alpha} C(h, \theta_1, z_1, z_2)$. The first-order condition in (6) becomes $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^* - \overline{\alpha} C_h\right)$. The impact of a marginal increase in the cost of the environmental regulation through an increase in $\overline{\alpha}$ on the firm's choice of location is examined by totally differentiating the first-order condition in (6) to obtain:

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[6] The second-order condition ($EU_W \pi_{hh} + EU_{WW}\left(\pi_h\right)^2 < 0$) is assumed to be met. Given that $s_{hh} < 0$, it holds if $C_{hh} > 0$ and $\pi_{hh} < 0$ (i.e., $\pi_{hh} = -\sum_{i=1}^{2} r_i s_{ihh} x_i^* - \alpha C_{hh} < 0$). If $C_{hh} \leq 0$ and therefore $\pi_{hh} > 0$, then it is satisfied when $EU_W \pi_{hh} < -EU_{WW}\left(\pi_h\right)^2$.

$$\frac{\partial h}{\partial \overline{\alpha}} = -\frac{1}{H} E[U_{WW}(\pi_h \pi_{\overline{\alpha}}) + U_W \pi_{h\overline{\alpha}}] = \frac{1}{H} E[U_{WW}(\pi_h C) + U_W C_h] \quad (7)$$

where $H < 0$ is the second-order derivative of the third-stage maximization problem. As shown in Appendix, $EU_{WW}\pi_h > 0$, if absolute risk aversion is decreasing. Thus, an increase in the cost of the environmental regulation decreases the distance between the firm's location and the output market, if the cost of the regulation increases as the firm moves away from the output market (i.e., $C_h > 0$). On the other hand, if the cost of the regulation decreases with an increase in *h* (i.e., $C_h < 0$), then an augmented regulation cost could increase or decrease the distance between the firm's location and the output market. The sign of (7) is determined by $E[U_{WW}(\pi_h C) + U_W C_h]$. If $C_h < 0$, then (7) is positive given that $E[U_{WW}(\pi_h C) + U_W C_h] > 0$. We can write $EU_{WW}(\pi_h C) > -EU_W C_h \Leftrightarrow -EU_{WW}/U_W(\pi_h C) < C_h \Leftrightarrow ER_A \pi_h Ch < hC_h$. Let $e_h^C = C_h\, h/C$ and $e_h^\pi = E\pi_h\, h/\pi$ be the elasticity of *C* and π with respect to *h*, respectively. Note that $e_h^C < 0$ and we expect $e_h^\pi < 0$. The condition then can be written as: $ER_A \pi e_h^\pi < e_h^C$. If this condition is satisfied, then $\partial h/\partial \overline{\alpha} > 0$. Thus, if the regulation cost decreases with an increase in *h*, the firm's response to increased environmental costs could be either to locate closer to the output marker or to move away from the output market depending on the degree of risk aversion and elasticities of cost and profit with respect to *h*.

Assuming that the cost of the environmental regulation (i.e., stringency of the environmental regulation) is uniform across space (i.e., $K(h,\theta_1) = \overline{\alpha}\, C(z_1, z_2)$ and $C_h = 0$), the impact of the cost of the environmental regulation on the firm's location decisions is given by: $\frac{\partial h}{\partial \overline{\alpha}} = \frac{1}{H} E[U_{WW}(\pi_h C)]$. Thus, an increase in the cost of the environmental regulation will cause the firm to locate closer to the output market under uncertainty and risk aversion, if absolute risk aversion is decreasing.

An increase in the cost of the environmental regulation does not have any impact on the location decision of a risk-neutral firm that maximizes the expected profits, if the cost is uniform across space (i.e., $C_h = 0$). On the other hand, it increases (decreases) the distance between the output market and the firm's location, if the cost of the regulation increases (decreases) as the location of the firm gets closer to (moves away from) the output market (i.e., $C_h < (>) 0$).

Impacts of Environmental Regulation Uncertainty on Firm Location Decisions

We now analyze the impacts of an increase in uncertainty about the cost of the environmental regulation on the firm's location decisions under uncertainty about production and environmental regulations.

Proposition 2: An increase in uncertainty about environmental regulation (the cost of abatement investment) leads a risk-averse firm to locate closer to the output market, if the cost of regulation is uniform across space or the cost of the regulation increases as the firm moves away from the output market.

Proof: We consider the impact of a marginal increase in uncertainty about the cost of the abatement investment on the firm's location decision. The marginal increase in the environmental regulation uncertainty is defined by multiplicative mean-preserving spread of the probability distribution of α. Let $\alpha^* = \gamma(\alpha - \overline{\alpha}) + \overline{\alpha}$. An increase in γ represents a mean-preserving spread of the original distribution of α (Rothschild and Stiglitz, 1970). Totally differentiating the first-order condition in (6) leads to:

$$\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\left[U_{WW}\left(\pi_h \pi_\gamma\right) + U_W \pi_{h\gamma}\right] = -\frac{1}{H} E\left[U_{WW} \pi_h (\pi - E\pi) + U_W (\pi - E\pi) C_h / C\right] \tag{8}$$

where $\pi_\gamma = (\pi - E\pi)$ and $\pi_{h\gamma} = (\pi - E\pi)C_h / C$ given that Y^* is fixed at its optimum quantity. To determine the sign of equation (8), we follow an approach used by Diamond and Stiglitz (1974) and Sandmo (1971). As shown in Appendix, if absolute risk aversion is decreasing, then $EU_W(\pi - E\pi) < 0$ and $EU_{WW}\pi_h > 0$, and if relative risk aversion is increasing, then $EU_{WW}\pi\pi_h < 0$. Thus, equation (8) is negative if $C_h > 0$, indicating that an increase in uncertainty about the environmental regulation leads the firm to locate closer to the output market. When $C_h < 0$, equation (8) is positive if $E[R_A e_h^\pi \pi] < e_h^C$. In this case, the impact of regulation uncertainty depends on the degree of risk aversion and elasticities of cost and profit. On the other hand, if the cost of the regulation is uniform across space ($C_h = 0$), the risk-averse firm is likely to move closer to the output market.

There are two opposing effects of an increase in the uncertainty about environmental regulation on the firm's location decisions. First, increased uncertainty makes a risk-averse firm worse off. Because the variance of the profits changes directly with *h*, a risk-averse firm tends to locate closer to the output market in order to reduce its exposure to uncertainty. Second, a lower output decreases the risk to the more risk-averse firm, *ceteris paribus*. Thus, the more risk-averse firm may choose to produce in a more risky site by locating farther away from the output market. Under a decreasing absolute risk aversion and increasing relative risk aversion, the first effect dominates the second effect (Briys and Eeckhoudt, 1985), leading a risk-averse firm to locate closer to the output market under uncertainty than under certainty.

Under risk-neutrality, the firm maximizes the expected profits and therefore $\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\pi_{h\gamma}$, which is equal to zero regardless of whether the regulation is uniform or not. Thus, uncertainty about the environmental regulation does not have any impact on a risk-neutral firm's location decision. These results indicate how risk aversion changes the impacts of uncertainty on the firm's location decisions.

Proposition 3: Under uncertainty about production and environmental regulation, a more risk-averse firm will locate nearer to the output market.

Proof: Assuming that preferences of the firm can be represented by a utility function of the form $U(W_0, \pi; \eta)$, we examine the locational effect of risk aversion as in Diamond and Stiglitz (1974). The index η relates to the absolute risk aversion function as $\partial R_A / \partial \eta > 0$. Thus, an increase in η corresponds to an increase in absolute risk aversion. Totally differentiating the first-order condition in (6), we obtain:

$$\frac{\partial h}{\partial \eta} = -\frac{1}{H} E\left[U_{WW} \pi_h \left(\partial U / \partial \eta\right)\right]. \tag{9}$$

With $\partial U / \partial \eta < 0$, equation (9) is negative if absolute risk aversion is decreasing ($EU_{WW} \pi_h > 0$). This indicates that the more risk-averse the firm is the lower the distance between the output market and the optimal location of the firm. Under uncertainty about the imposition of environmental regulations or liabilities, the firm moves closer to the output market in order to reduce the variability of returns. As the degree of risk aversion rises, the variance of the profit and therefore the risk premium increases[7]. The risk-averse firm with nonincreasing absolute risk aversion is likely to seek to reduce the variability of return or to cut its exposure to uncertainty by locating closer to the output market.

Impacts of Output, Input and Emission Taxes on Location Decisions

We now examine the impacts of various market-based policies such as output, input, and emission taxes on a risk-averse firm's location decisions under production and environmental

[7] The risk premium is the amount that the firm is willing to pay for receiving the maximum expected profit, instead of bearing production and environmental regulation uncertainty.

policy uncertainty[8]. Market-based instruments such as taxes or subsidies are typically proposed as a means for implementing environmental policies. For example, taxes on observable factors such as input use have been proposed for achieving desirable reductions in runoff of fertilizers and have been used in the U.S. and Europe (Larson et al., 1996). Now, assume that the industry is regulated by imposing taxes on output, input, or emissions. The profit of the firm with a pre-determined output tax is given by $\pi = (P - r_o h)(1 - t_0)Y - \sum_{i=1}^{2}(w_i + r_i s_i)x_i$.

Proposition 4: Under production uncertainty, an augmented output tax could increase or decrease the distance between the output market and the firm's location. However, under risk-neutrality it increases the distance between the output market and the firm's location. An increase in the uncertainty about the output tax leads a risk-averse firm to locate closer to the output market.

Proof: With a pre-determined output tax, the firm's output (Y) in equation (1) will be replaced by $Y(1 - t_0)$. The first-order condition of the firm's location decision is similar to (6), with only difference being the definition of the wealth and $\pi_h = \left(-r_0 Y^*(1 - t_0) - \sum_{i=1}^{2} r_i s_{ih} x_i^*\right)$. We totally differentiate the first-order condition to obtain:

$$\frac{\partial h}{\partial t_0} = -\frac{1}{H} E\left[-U_{WW}\left(\pi_h (P - r_o h) Y^*\right) + U_W r_0 Y^*\right] \tag{10.a}$$

where $H < 0$. The sign of equation (10.a) is determined by the signs of the terms inside the brackets. If $E[R_A \pi_h (P - r_o h)] < r_0$, then equation (10.a) is negative, indicating that the distance between the output market and the firm's location decreases with an increased output tax. Note

[8] In this section, we only consider the impacts of market-based policies on the firm's location decisions. However, it is possible that some combinations of these policies along with the abatement investment could be implemented to address certain environmental problems.

that under risk-neutrality an increase in the output tax increases the distance between the output market and the firm's location.

We now consider the marginal impact of an increase in uncertainty about the output taxes on the firm's location decisions. Let $t_0^* = \gamma(t_0 - \bar{t}_0) + \bar{t}_0$, where γ represents a mean-preserving spread of the original distribution of t_0 (Rothschild and Stiglitz, 1970). Totally differentiating the first-order condition in (6) with the output tax results in:

$$\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\left[U_{WW}\pi_h(\pi - E\pi) + U_W\left(-r_0 Y + r_0 Y(\pi - E\pi)/((P - r_o h)Y)\right)\right]. \tag{10.b}$$

If absolute risk aversion is decreasing, then $EU_W(\pi - E\pi) < 0$ and $EU_{WW}\pi_h > 0$, and if relative risk aversion is increasing, then $EU_{WW}\pi\pi_h < 0$. Thus, equation (10.b) is negative with a decreasing absolute risk aversion and increasing relative risk aversion. This indicates that an increase in uncertainty about the output taxes leads the risk-averse firm to locate closer to the output market. A risk-averse firm moves closer to the output market in order to reduce its exposure to uncertainty. With a risk-neutral firm, equation (10.b) is equal to zero, indicating that uncertainty about environmental regulations does not affect the firm's location decisions.

Proposition 5: Under uncertainty, an increase in an input tax and/or an increase in uncertainty about its implementations decreases the distance between a risk-averse firm's location and the output market. Increased input tax does not have any impact on a risk-neutral firm's location decision.

Proof: Under an input tax policy, the firm's input cost (w_i) in equation (1) will be replaced by $w_i(1+t_x)$. With an input tax policy, the first-order condition of the firm's location decision problem is similar to (6), with only difference being the definition of the wealth and $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^* \right)$. Totally differentiating the first-order condition leads to:

$$\frac{\partial h}{\partial t_x} = \frac{1}{H} E\left[U_{WW} \pi_h \left(w_i x_i^*\right)\right]. \tag{11.a}$$

Equation (11.a) is negative if absolute risk aversion is decreasing, i.e., $EU_{WW}\pi_h > 0$. Hence, an increase in the input tax results in a decrease in the distance between the output market and the firm's location, making firms to concentrate around the output market which is more likely to be populated. Under risk-neutrality where the firm maximizes the expected profits, an increase in the input tax, however, does not have any impact on a risk-neutral firm's location decision.

We also analyze the marginal impact of an increase in uncertainty about the input taxes on the firm's location decisions by letting $t_x^* = \gamma\left(t_x - \bar{t}_x\right) + \bar{t}_x$, as in the case of examining the impacts of uncertainty about output taxes (Rothschild and Stiglitz, 1970). Totally differentiating (6) with the input tax leads to:

$$\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\left[U_{WW} \pi_h (\pi - E\pi)\right]. \tag{11.b}$$

Equation (11.b) is negative and it indicates that an increase in uncertainty about the input taxes leads the firm to locate closer to the output market, if absolute risk aversion is decreasing.

Proposition 6. An increase in an emission tax and/or an increase in uncertainty about its implementations lead to a decrease in the distance between a risk-averse firm's location and the output market under uncertainty. Under risk-neutrality, an increase in the emission tax does not impact the firm's location decision if the pollution generated is independent of the firm's location. Uncertainty about emission taxes does not impact a risk-neutral firm's location decision.

Proof: Given that $z_i = z_i(x_i)$, the profit of the firm under a pre-determined emission tax is given by $\pi = (P - r_o h)Y - \sum_{i=1}^{2}(w_i + r_i s_i)x_i - \sum_{i=1}^{2} t_{ei} z_i(x_i)$. The first-order condition with respect to h is similar to (6), with only difference being the definition of the wealth and $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^*\right)$. Totally differentiating the first-order condition with the emission tax leads to:

$$\frac{\partial h}{\partial t_{ei}} = \frac{1}{H} E\left[U_{WW} \pi_h z_i(x_i)\right]. \tag{12.a}$$

Equation (12.a) is negative if absolute risk aversion is decreasing, i.e., $EU_{WW}\pi_h > 0$. Hence, an increase in the emission tax results in a decrease in the distance between the output market and the firm's location, making firms to concentrate around the output market which is more likely to be populated. Note that an increase in the emission tax, however, does not have any impact on a risk-neutral firm's location decision.

Now suppose that the pollution generated is a function of x_i, h and θ_1 as: $z_i = z_i(h, \theta_1, x_i)$. In this case, the pollution generated varies across space, given the same level of input use. For example, this would be the case in agriculture where the runoff generated depends not only on the input use but also on the physical soil characteristics, weather conditions, and production technology available to the firm across space. With the assumption of $z_i(h, \theta_1, x_i)$ and risk-aversion, $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^* - z_{ih}\right)$ and $\frac{\partial h}{\partial t_{ei}} = \frac{1}{H} E\left[U_{WW} \pi_h z_i(x_i, \theta_1, x_i) + U_W z_{ih}\right]$. If absolute risk aversion is decreasing and $z_{ih} > 0$, then $\partial h / \partial t_{ei} < 0$. If $z_{ih} < 0$, then $\partial h / \partial t_{ei} > 0$, provided that $E\left[R_A \pi_h z_i\right] > z_{ih}$. On the other hand, under risk neutrality, $\partial h / \partial t_{ei} < (>) 0$, if

$z_{ih} > (<) 0$. Thus, increased emission tax does not impact a risk-neutral firm's location decision if the environmental regulation is uniform across space while it is likely to affect the location choice if the pollution function depends on *h*.

We also analyze the marginal impact of an increase in uncertainty about emission taxes on the firm's location decisions. Let $t_{ei}^{*} = \gamma(t_{ei} - \bar{t}_{ei}) + \bar{t}_{ei}$, as in the case of examining the impacts of uncertainty about output and input taxes analyzed above. Totally differentiating (6) with the emission tax and $z_i = z_i(h, \theta_1, x_i)$ leads to

$$\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\left[U_{WW}\pi_h(\pi - E\pi) + U_W(\pi - E\pi)z_{ih}\right]. \tag{12.b}$$

As shown above, under a nonincreasing absolute risk aversion and nondecreasing relative risk aversion, equation (12.b) is negative if $z_{ih} \geq 0$. This indicates that an augmented uncertainty about the environmental regulation leads the firm to locate closer to the output market. This occurs because a risk-averse firm seeks to reduce its exposure to uncertainty. If $z_{ih} < 0$, then the impact of uncertainty on the location decisions is ambiguous. If $z_i = z_i(x_i)$ (i.e., $z_{ih} = 0$), an increase in uncertainty about the emission taxes leads the risk-averse firm to locate closer to the output market. Under risk-neutrality, the firm maximizes the expected profits and therefore $\frac{\partial h}{\partial \gamma} = -\frac{1}{H} E\pi_{h\gamma}$, which is equal to zero regardless of whether z_{ih} is zero or not.

3. Conclusions and Policy Implications

This paper develops a theoretical model of firm decision-making to examine the impacts of environmental regulations on a competitive firm's production and location decisions under uncertainty about production and environmental regulation. It also provides a systematic analysis of a risk-averse firm's choice of plant location and its response to taxes such as input, output and emission when deciding its location under uncertainty. This paper makes contributions to the literature by obtaining comparative statics results with respect to the level of environmental regulation uncertainty and by deriving results regarding the spatial effects of environmental regulations on the firm location decisions.

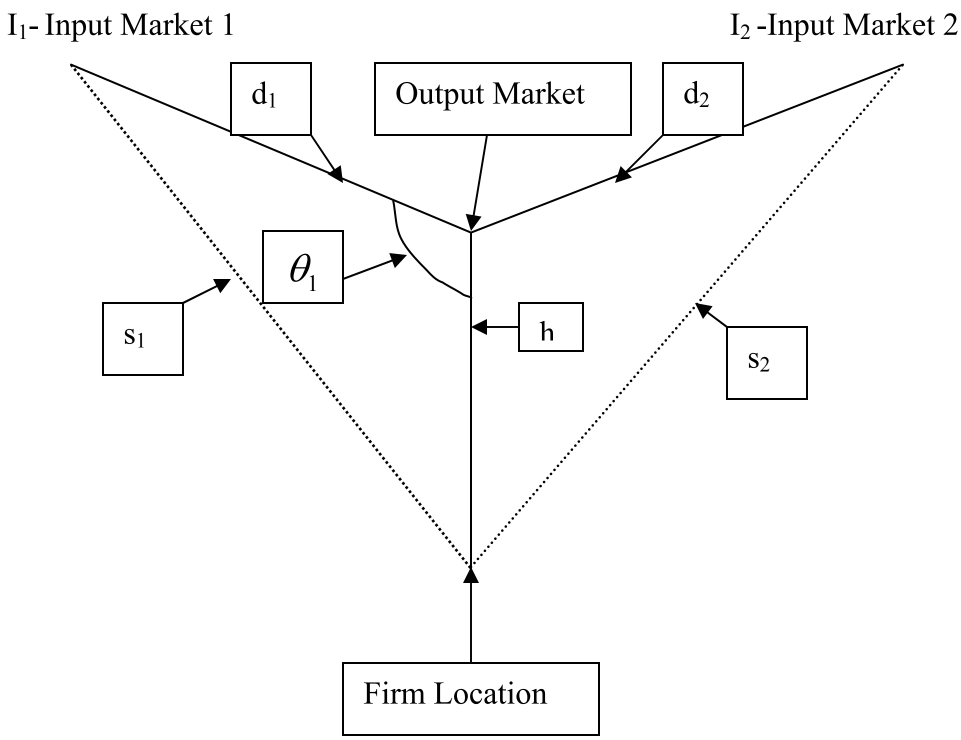
The comparative statics results show that an increase in the cost of the environmental regulation under production uncertainty moves a risk-averse firm closer to the output market if the regulation is uniform across space. An augmented cost of the environmental regulation does not impact a risk-neutral firm's location decision, if the cost of the regulation is uniform across space. Increased emission taxes or input taxes causes the risk-averse firm to locate closer to the output market. Uncertainty about environmental policies (cost of the abatement, output taxes, emission taxes, and input taxes) has the potential to affect the optimal location of the firm. In particular, it leads a risk-averse firm to move closer to the output market that is likely to be more populated. Thus, under uncertain policy environments, environmental policies may not be effective in encouraging firms not to locate nearer to the output markets or consumption centers.

The results have implications for the design and implementation of spatial environmental policies for pollution control. It has generally been seen that businesses prefer setting up their production facilities near big cities because this gives them proximity to the consumer market. There has been a large increase in industrial development around the major cities. Emissions from these industries are a concern to neighboring residents in many locations. Many cities have used zoning to improve the environmental quality. The results obtained in this paper illustrate the usefulness of spatial environmental policies that aims at encouraging firms not to locate nearer to the output markets and the importance of reducing uncertainty about environmental regulations in implementing these policies.

The possibility of individual firms relocating in response to environmental costs has been a major concern for public policy and regional developments. The results have implications for policies that seek to harmonize state environmental regulations. For example, major changes are being considered in federal water quality rules for the livestock and hog industry in the U.S. These changes would harmonize manure management standards across states. Additionally, the results provide insight for evaluating the influence of market-based policies such as output taxes, input taxes and emission taxes on regional development. Tax policies and risk-reducing policies have impacts on regional development and on the environment through affecting the firm location decisions.

Location decisions also have an international context, with concerns about companies shifting investment outside the U.S. and the European Union. For example, the European Union experience with its Nitrate Directive demonstrates that limiting producers' options with strict regulation of nitrate levels in an area with a limited land base has the potential to reduce the scale and to influence the location of animal production. Moreover, harmonization of environmental standards across international boundaries is a contentious topic in World Trade Organization discussions, because of possible effects on the location of businesses and geographic dispersion of the emissions. If uniform environmental regulations were to raise costs of production in some countries so high that they could no longer be competitive in export markets, producers in those countries would likely appeal for an exemption, and some countries might be willing to enhance their export competitiveness at the expense of the environment.

Figure 1. The Firm's Location to the Input and Output Markets



Appendix

Consider two utility functions, U and W. The utility function W represents greater risk aversion than U if there exists an increasing and strictly concave function k such that $W=k(U)$. The first-order condition for an interior h for the utility function W requires

$$E[k'(U)U'\pi_h] = 0. \quad \text{(A.1)}$$

Let $\hat{\alpha}$ be the value of α such that $\pi_h = \left(-r_0 Y^* - \sum_{i=1}^{2} r_i s_{ih} x_i^* - \hat{\alpha} C_h\right) = 0$. Based on the definition that $R_A = -U_{WW}/U_W$, a decreasing R_A implies

$$-U_{WW}/U_W > (<) R_A(W_0 + \hat{\pi}) \text{ as } \alpha > (<) \hat{\alpha} \quad \text{(A.2)}$$

For $\hat{\alpha} > \alpha$, because $\pi_h > 0$, the following occurs

$$U_{WW}(W_0 + \pi)\pi_h > -U_W(W_0 + \pi)R_A(W_0 + \hat{\pi})\pi_h. \quad \text{(A.3)}$$

The inequality in (A.3) also holds for $\hat{\alpha} < \alpha$ because $\pi_h < 0$. Therefore,

$$EU_{WW}(W_0 + \pi)\pi_h > -EU_W(W_0 + \pi)\pi_h R_A(W_0 + \hat{\pi}) = 0. \quad \text{(A.4)}$$

Equation (A.4) indicates that $EU_{WW}\pi > 0$. Similarly, based on the definition of relative risk aversion such that that $R_A = -(W_0 + \pi)U_{WW}/U_W$, an increasing R_R implies

$$-(W_0 + \pi)U_{WW}/U_W < (>) R_R(W_0 + \hat{\pi}) \text{ as } \alpha > (<) \hat{\alpha}. \quad \text{(A.5)}$$

Using the same approach as above leads to $EU_{WW}\pi\pi_h < 0$. Therefore, if absolute risk aversion is decreasing, then $EU_W(\pi - E\pi) < 0$ and $EU_{WW}\pi_h > 0$, and if relative risk aversion is increasing, then $EU_{WW}\pi\pi_h < 0$.

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