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Centralized versus Decentralized Taxation of Mobile Polluting Firms[⋆]

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Résumé: Nous étudions un monde dans lequel une firme polluante mobile cherche à se localiser dans une de deux régions données. Les régions présentent des différences quant leur coût marginal des émissions polluantes et quant à leur coût de production. Il est démontré que dans un contexte d'information incomplète sur les coûts marginaux de pollution des régions, la concurrence fiscale peut mener à une localisation non-optimale de la firme. Il est également démontré que la centralisation de la taxation réduit la probabilité d'une localisation non-optimale.

Abstract: We consider a world in which a mobile polluting firm must locate in one of two regions. The regions differ in two dimensions: their marginal cost of pollution and the production cost of the firm. It is shown that under incomplete information on regional marginal costs of pollution, fiscal competition may lead to the sub-optimal location of the firm. We also show that under incomplete information, a sub-optimal location is less likely under centralized than under decentralized taxation.

Keywords: Fiscal Competition, Location, Pollution

JEL Classification: R38, H73, Q28

1. Introduction

Because firms take into account regional environmental policies when locating or relocating their production, these policies affect not only environmental quality, but also output and job levels. Government authorities therefore face a tradeoff between pollution and output. This tradeoff has been made more difficult to manage by the confluence of growing environmental concerns, persistent unemployment (in some areas), and high capital mobility. For example, the North American Free Trade Act has generated concerns that polluting firms may migrate to Mexico where environmental policies are less stringent than in Canada or in the United States. The potential response to capital mobility raises some concerns: some expect to see environmental norms driven down so as to retain firms (The Economist, October 7, 1995). Are those concerns well founded? From an empirical standpoint, some authors have indeed found that environmental regulation matters in the location decisions of some polluting firms (for instance see Gray (1995)).[1]

This empirical evidence is somehow not surprising as it has been shown by Oates *et al.* (1995) that firms' total costs are increasing in the stringency of environmental standards. Hence, with capital free to move, there is, *ceteris paribus*, an incentive for firms to go where environmental norms are lower. As a result, governments may consider lowering their standards to attract or keep a firm in their region. Trading off the higher welfare from more output and jobs with the lower welfare from more pollution, they compete to attract firms. What will result from this competition?

Markusen *et al.* (1995) consider this issue. They use a two-identical region, two-period model where governments compete in pollution taxes to attract a polluting firm which has increasing returns in production (the firm may locate in both regions to save on transportation costs). Most non-cooperative equilibria of the game are not Pareto optimal. Fiscal competition or decentralized taxation can be harmful in two ways. First, if the disutility from pollution is sufficiently low, the regions will compete by undercutting each others pollution tax down to non-optimal levels. Second, if the disutility from pollution is high enough, each region will not want the firm to operate on its territory. This will drive up pollution taxes until the firm decides not to produce at all, even if producing in one region with suitable compensation would produce greater welfare than no production at all. This is the NIMBY case (Not In My BackYard). Note however that since regions are identical in all respects, inefficiency comes from too much (or too little) pollution and not from a poor location choice. Using similar frameworks, Hoel (1997), Rauscher (1994) and Tanguay (1998) obtain similar

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[1] For an excellent survey on this subject, see Jaffe *et al.* (1993).

results concerning inefficiencies stemming from non-optimal pollution levels.

The current analysis differs from the above by considering asymmetric regions. The asymmetry of regions raises the possibility that inefficiencies may arise because of a bad location, and not solely from non-optimalities in production or pollution levels. That is, for given production and pollution levels, net social benefits are not maximized when the firm locates in the wrong region. In a complete information setting with asymmetric regions, Hoel (1997) confirms this possibility for a firm with increasing returns. However, Tanguay (1998) shows that under constant returns to scale, the firm will locate in the region which minimizes social costs (for a given production level). Note that this does not preclude the existence of excessive pollution or of the NIMBY case.

The present paper also introduces incomplete information. Papers that have done so in the past have analyzed fiscal competition in the language of auction theory.[2] Doyle and Wijnbergen (1984) and Bond and Samuelson (1986) both assume a firm that bargains sequentially with competing governments. As for Bond and Samuelson (1986), they introduce uncertainty by assuming that the firm does not know the regions' productivity when choosing its location. They focus on the possible role of tax holidays as a signal of a region's productivity. Black and Hoyt (1989) extend this analysis by considering simultaneous bidding for firms. In a similar framework, King *et al.* (1993) add the possibility that the firm relocates.

The current analysis differs by assuming that the firm pollutes (or more generally, that it creates some externalities) and that asymmetric information is precisely on the regions' marginal cost related to the externality. One of the goal is thus to assess the effects of incomplete information by concentrating on the location issue (abstracting from pollution level inefficiencies).[3] A two-region, two-period model is examined. In the first period, regions simultaneously choose their respective pollution tax. Given these taxes, the firm locates in the second period. Payoffs are then realized. This fiscal game can be seen as an auction in which bids (taxes) are made simultaneously. Incomplete information is introduced in the following way: each region knows its own pollution cost but not that of the other region. The distributions from which pollution costs are drawn are however common knowledge. This corresponds to the information structure

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[2] On auction theory, see McAfee and McMillan (1987).

[3] Some authors have used trade models that capture general equilibrium impacts to analyze the effects of countries' different pollution taxes on the pollution and production levels (For instance, see Copeland and Taylor (1994), (1995)). The present paper (and the literature reviewed in the introduction) does not use the same approach: it enriches the strategic aspects by looking at fiscal competition as an auction in which governments bid to obtain firms. This framework allows to focus on governments' strategies in relation to the available levels of information.

of a private-independent-values model in the auction literature. It is shown that the obtained equilibria are possibly Pareto-dominated by those obtained under complete information. That is, the region in which the firm locates in the optimum is not necessarily the one in which it locates under incomplete information.

Finally, we compare the outcome of the fiscal game with that which would obtain under centralized taxation, i.e. a situation in which a central authority determines the pollution tax rates for both regions. The comparison is performed for both the complete and the incomplete information cases. Centralized taxation can take two forms: differential or uniform. Under complete information and centralized taxation, an optimal location obtains if different tax rates can be applied to different regions, but this is not guaranteed if taxation has to be uniform. Under incomplete information, centralized taxation may lead to an inefficient location, but the probability that this will be the case is lower or equal to the equivalent probability under decentralized taxation.

The rest of the paper is organized as follows. Section 2 presents the problem facing the firm. Section 3 describes the regions' welfare functions. Section 4 presents the equilibria obtained under decentralized taxation (fiscal competition) under complete and incomplete information. In Section 5, we introduce the possibility of taxation by a central authority, and in section 6 we compare the solutions obtained under incomplete information for centralized and decentralized taxation. Finally, we conclude.

2. The Firm

The firm produces one unit of output or nothing.[4] If the firm produces, it generates one unit of pollution which affects only the country or region where the firm produces (*local pollution*).[5] Output price P is given on the world market (assumed to be competitive) and unit cost of production is c_i if the firm operates in region $i = a, b$. Moreover, facing pollution damages, there is a pollution tax t_i in each region.[6]

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[4] By avoiding output distortions, this production technology allows us to focus on location issues.

[5] We don't deny the importance of global pollution in environmental problems. We only consider local pollution to simplify the analysis and to focus on the incomplete information aspect. Moreover, a lot of pollution never crosses frontiers. For instance, this is the case of many firms that pollute the ground, the rivers or even the air depending on the nature of the pollutants.

[6] Note that since production is indivisible (0 or 1), pollution taxes serves only as a compensation mechanism and not as a mean to reduce pollution. Also, in that sense, t_i is equivalent to a production or pollution charge.

The firm maximizes its profits which are given by:

$$\pi_i(t_i) = (1-\tau)(P - c_i - t_i) \tag{1}$$

when it operates in region i, where τ is a profit tax which is constant across jurisdictions ($0 < \tau < 1$). Taking τ as exogenous in both regions seems a reasonable simplifying assumption for three main reasons. First, international trade rules generally preclude the use of different profit taxes for domestic and foreign firms. Thus, given profit tax rates are most likely not to vary in the light of entry by a new firm and it will be the same for all firms. Second, we can think that profit taxation is constant whether firms pollute or not. The specificity of polluting firms is then taken into account with pollution charges as is the case here with t_i.[7] Third, one can see τ as being the symmetric equilibrium of another fiscal game between regions. Since polluting firms represent only a small fraction of the total number of firms, the game in which the profit tax rate τ is determined, can be thought of as independently determined before the current analysis is done.[8]

To simplify the analysis, we make three assumptions. First, we rule out the possibility of the NIMBY case and impose positive profits in both regions. That is:

$$t_i < P - c_i, \quad i = a, b \tag{2}$$

Second, because of managerial and/or resource constraints, we suppose that the firm sets up only one plant even if it can make positive profits in both jurisdictions. Third, we suppose that the firm will locate in the region in which it earns the highest profit. In the case of equal profits we assume that the firm will operate in region a. Therefore, the firm locates in region a whenever $\pi_a(t_a) \geq \pi_b(t_b)$.

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[7] Because profit tax is the same for all firms (even if we focus on the entry of one firm only), profit taxation is not designed *de novo* for individual firms. On the other hand, because each region will choose a particular pollution tax for the studied firm, we consider that regions in fact tailor an "environmental package" involving a cost t_i for the firm. Given the disparities across regions and possible locations in a region, the implementation of standards and/or taxes may vary significantly across firms, thus giving rise to non-uniform standards and/or taxation. Hence, governments can in fact vary the applied environmental costs faced by firms by raising exception rules or by applying the environmental policy more or less to vary costs faced by firms (for example the number of inspections done can greatly vary costs for a given level of regulation or taxation). The reader can refer to the case study of the firm Magnola located in Asbestos (QC, Canada) for an example of an environmental regulation tailored for a given firm (Vachon, 1998). Also, on the real costs of environmental policies for firms when governments vary monitoring, we refer the reader to Dion *et al.* (1998).

[8] A constant profit tax rate across jurisdictions can be seen as the first step of this paper towards the possibility for both regions to choose both their pollution and profit taxes.

This simplifies to the following condition for location in region a:

$$t_a - t_b \leq c_b - c_a \tag{3}$$

Conversely, production will take place in region b whenever $t_a - t_b > c_b - c_a$.

3. Regional Welfare

Since the output price is assumed exogenous and not affected by the firm's location decision, regional demands do not vary with the new production brought by the firm. As a result, in our framework consumer surplus is not considered when the government(s) fix(es) the pollution tax(es). Also, we assume that the firm is owned by a third party so that profits do not enter directly in regional welfare. Thus, differences in regional well-being depend on: 1) profit tax revenues;[9] 2) pollution tax revenues; 3) social costs of pollution. One obtains for region i:

$$W_i = \tau {\pi_i}^{bt} + t_i - d_i \tag{4}$$

where d_i is the social cost of pollution, ${\pi_i}^{bt}$ are the profits before profit tax, and W_i is regional welfare.[10] Using eq.(1), we can rearrange eq.(4) to get:

$$W_i = \tau(P - c_i) + (1 - \tau)t_i - d_i \tag{5}$$

Note that we take d_i as being the marginal pollution cost. That is, in fiscal competition what really matters is how each region evaluates the additional cost of polluting emissions. We assume that each region knows its own d_i. Under complete information, the central government and regional governments know the marginal costs of pollution of both regions. That is, region a knows d_b and region b knows d_a. Incomplete information will depart from this in that each region knows its own marginal cost of pollution but only knows the probability distribution of the marginal cost of its rival. Also we assume that the information is more incomplete for the central authority: it will only know the probability distributions of the marginal pollution costs of both regions.

A Pareto optimal location is attained if the firm locates in the region where $P - c_i - d_i$ is highest (or conversely, where $c_i + d_i$ is the lowest). Taxes are only a means to redistribute welfare from the firm to the government.[11] What really

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[9] Incorporating a profit tax, τ, is a way to add another realistic reason for regions to want to attract the firm. Given the hypotheses of our framework, this inclusion is essential to derive non-trivial results.

[10] It is clear that d_i can be thought of as any cost other than pollution that can be brought by the firm. For example, the production can lead to industrial illnesses. In this sense, our framework can be used to study a broader range of problems.

[11] Note that there is no optimal pollution charge in this framework given that polluting emissions are fixed per unit of output and that the welfare and profit functions are linear.

matters in the location decision is the net total social benefits. Again, it will be instructive to see in which cases a Pareto optimal location can be attained.

4. Decentralized Taxation

This section compares the locational outcomes of fiscal competition both for the complete and the incomplete information cases. We will focus on centralized taxation in the next section.

4.1 Complete Information

To make it easier to compare the locational outcome under complete and incomplete information, we make the following simplifying assumptions. First, we suppose that the social cost of pollution is greater in region a than in region b: $d_a > d_b$. Second, we assume that region a has a lower cost of production than region b: $c_a < c_b$. Therefore, we can think of region a as being more developed than region b; a has a lower cost of production due to better infrastructure and/or higher labor productivity, but it has a higher marginal cost of pollution because it is more polluted than region b (and the marginal cost of pollution is increasing in the prevailing total pollution level). Finally, we limit our analysis to the non-subsidy case. A sufficient condition for this is (also recall that we always allow the firm to enter in only one of the regions):

$$d_i \geq \tau(P - c_i) \quad i = a, b \tag{6}$$

This last condition simply states that the marginal pollution cost should always be high enough relative to potential profit tax revenues, so that it will not pay to subsidize the firm with a negative pollution tax. Welfare being given by eq.(5), there exists a pollution tax, t_i^L, such that $W_i = 0$. For region i, this tax is given by:

$$t_i^L = \frac{d_i - \tau(P - c_i)}{1 - \tau} \tag{7}$$

Pollution tax t_i^L is the lowest possible tax that region i would be willing to charge; welfare is negative below this critical tax level.[12] At this tax level, the firm would get the following profits if it was to operate in i (using eqs. (1) and (7)):

$$\pi_i(t_i^L) = P - c_i - d_i \tag{8}$$

As we want to consider cases with possible entry, we assume $d_i < P - c_i$ (in line with eq.(2)).

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[12] We really should have $t_i = t_i^L + \varepsilon$ as the lowest possible tax corresponding to $W_i > 0$. But as ε gets very small, $t_i = t_i^L$ which corresponds to the limit case considered here.

In a complete information framework, it is easily shown that the outcome of tax competition between regions a and b depends directly on which region generates the highest profit level at its tax t_i^L (for more details on the characterization of equilibria under complete information in the present framework, see Appendix A). In a Nash equilibrium, the region in which the firm will eventually locate, say i, chooses its pollution tax $\bar{t_i}$ according to:

$$\pi_i(\bar{t_i}) = \pi_j(t_j^L), \quad i \neq j \tag{9}$$

where $\bar{t_i} \geq t_i^L$.[13] Solving for $\bar{t_i}$ gives:

$$\bar{t_i} = P - c_i - \frac{P - c_j - d_j}{1 - \tau} \tag{10}$$

From eq.(10), it is easily shown that a sufficient condition for the firm to locate in region a is that $c_a + d_a \leq c_b + d_b$ (reversed inequality for location in region b). *Thus, fiscal competition under complete information leads to the socially optimal location.*

4.2 Incomplete Information

4.2.1 Equilibrium

Incomplete information is introduced by assuming that each region i knows its own environmental damage cost d_i, but not that of its rival. We suppose that both regions know that there is a higher probability of observing $d_a > d_b$ than the reverse.[14] Indeed, it is common knowledge that for both regions, d_i is drawn independently from a uniform distribution over support $[\tau(P - c_i), \lambda(P - c_i)]$, with $\tau < \lambda \leq 1$ and $(P - c_a) > (P - c_b)$. It is also convenient to write the realized value of d_i as $\theta_i(P - c_i)$, with $\tau \leq \theta_i \leq 1$. Thus, θ_i is simply proportional (by a factor of $1/(P - c_i)$) to the realized value, or type of region i, d_i. Because we want to compare the incomplete information case with the complete information one, we will later examine situations in which the joint realization of d_a and d_b satisfies $d_a > d_b$ (i.e. $\theta_a(P - c_a) > \theta_b(P - c_b)$). Also, one has to note that the distribution supports are chosen so as to make entry profitable for the firm in either of the regions. This is in line with the complete information framework.[15]

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[13] Again, note this is not a pure Nash equilibrium, *stricto sensu*, as we really should have $\bar{t_i} | \pi_i(\bar{t_i}) = \pi_j(t_j^L) + \varepsilon$ with ε small.

[14] That is, the probability distribution of d_a first-order stochastically dominates that of d_b.

[15] Note that the firm does not know the exact d_i of a region i. However, the firm observes the chosen pollution taxes before it locates. Hence, incomplete information on d_i and d_j is not relevant for the firm.

Given the above characterization of d_a and d_b and the fact that governments fix their tax t_i simultaneously, the relevant equilibrium concept is that of Bayesian Nash equilibrium. An action for region i is a tax t_i chosen from the action space $\mathcal{T}_i = [t_i^L, P - c_i]$. Denote the type space for region i by $\mathcal{D}_i = [\tau(P - c_i), \lambda(P - c_i)]$. A strategy for region i is then a function $t_i : \mathcal{D}_i \rightarrow \mathcal{T}_i$, which assigns a tax rate t_i to each type d_i. Region i's payoff is $W_i = \tau(P - c_i) + (1 - \tau)t_i - d_i$ when it gets the firm (by allowing for the largest profits), and $W_i = 0$ when it does not obtain the firm. In a Bayesian Nash Equilibrium, region i's strategy $t_i(d_i)$ will be the best response to region j's strategy $t_j(d_j)$, and vice versa. We know that the firm will locate in region i if $c_i + t_i < c_j + t_j$. Under incomplete information, each region has to evaluate the probability that this will be the case. For region i, denote this probability by $\omega_i = \Pr(c_i + t_i < c_j + t_j)$. In our model, the strategy profile $(t_a(d_a), t_b(d_b))$ is a Bayesian Nash Equilibrium if for each d_i belonging to the type space $\mathcal{D}_i$, region i chooses t_i according to:

$$\max_{t_i} \quad \omega_i \ [\tau(P - c_i) - d_i + (1 - \tau)t_i] \tag{11}$$

To characterize the equilibrium, we assume that each government adopts a linear strategy.[16] Let a strategy for region i be given by:

$$t_i(d_i) = \alpha_i + \beta_i d_i, \quad i = a, b \tag{12}$$

Below, we solve for the parameters α_i and β_i in the Bayesian Nash equilibrium.

If both regions adopt a linear strategy as that given in eq.(12), the probabilities that the firm locates in region i is:

$$\omega_i = \frac{\beta_j \lambda(P - c_j) + \alpha_j + c_j - c_i - t_i}{\beta_j(\lambda - \tau)(P - c_j)} \tag{13}$$

Substituting eq.(13) in eq.(11), we obtain the following first-order condition on t_i:[17]

$$t_i = \frac{\beta_j \lambda(P - c_j) + \alpha_j + c_j}{2} + \frac{d_i + (2\tau - 1)c_i - \tau P}{2(1 - \tau)} \tag{14}$$

It is then possible to solve for α_i and β_i:

$$\alpha_i = \frac{2\lambda(P - c_j) + \lambda(P - c_i)}{6(1 - \tau)} + \frac{c_j - c_i}{3(1 - \tau)} - \frac{\tau(P - c_i)}{(1 - \tau)} \tag{15}$$

$$\beta_i = \frac{1}{2(1 - \tau)} \tag{16}$$

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[16] For the case of symmetric regions, it can be shown easily that the unique equilibrium is in linear strategies. However, for the current case with asymmetric regions, uniqueness is not guaranteed. But restricting the analysis to linear strategies is not a problem since the point made in this paper is that the equilibrium *can be* inefficient (non Pareto optimal), not that it is necessarily inefficient.

[17] Second-order conditions are satisfied.

Using $d_i = \theta_i(P - c_i)$, and slightly changing notation (with some abuse) so that types are now formulated in terms of θ_i rather than in terms of d_i (see above), we obtain the following equilibrium strategies:

$$t_i(\theta_i) = \frac{(3P - 2c_j - c_i)\lambda + 2(c_j - c_i) + (3\theta_i - 6\tau)(P - c_i)}{6(1 - \tau)} \tag{17}$$

We define the summary notation ρ_i as:

$$\lambda \leq \rho_i = \frac{(3P - 2c_j - c_i)\lambda + 2(c_j - c_i)}{3(P - c_i)} \leq 1 \tag{18}$$

It is then possible to re-write the equilibrium strategies as:[18]

$$t_i(\theta_i) = \frac{(\theta_i + \rho_i - 2\tau)(P - c_i)}{2(1 - \tau)} \tag{19}$$

To summarize, the profile of strategies $(t_a(\theta_a)), t_b(\theta_b))$, with $t_i(\theta_i)$ that satisfies eq.(19), is a Bayesian Nash equilibrium. We now turn to the analysis of the result of this equilibrium.

4.2.2 Location in Equilibrium

To determine where the firm will locate, we need to compare the profit levels in both regions, when taxes are set according to equilibrium strategies (recall that we restrict the analysis to cases in which profits are positive in both regions). Substituting $t_i(\theta_i)$ in the profit function of the firm when it operates in region i, we get:

$$\pi_i(\theta_i) = \frac{(P - c_i)(2 - \theta_i - \rho_i)}{2} \tag{20}$$

Profits in both regions are always positive for $\tau < \lambda \leq 1$ and $\tau \leq \theta_i < 1$. The rule of location, as in the complete information case, amounts to establishing the sign of $\pi_a(\theta_a) - \pi_b(\theta_b)$. Hence, we obtain location in a when $\pi_a(\theta_a) \geq \pi_b(\theta_b)$, and in b when $\pi_a(\theta_a) < \pi_b(\theta_b)$.

Two things should be noted. First, given that $W_i(\theta_i) + \pi_i(\theta_i) = P - c_i - d_i = (1 - \theta_i)(P - c_i)$ for $i = a, b$, it is clear that if $\theta_a = \theta_b = 1$, the NIMBY case will arise and there will be no entry. Second, when $\theta_a = 1 > \theta_b$, or when $\theta_a < 1 = \theta_b$, the firm locates in the good region, that is in the one with positive net social benefits (optimal location). But as we want to compare the outcome under complete and incomplete information for real entry problems, we now turn to cases in which welfare can be positive in both regions: $\theta_i < 1$ and $W_i(\theta_i) > 0$ for $i = a, b$.

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[18] Note that $t_i(\theta_i)$ given in eq.(19) could yield $W_i \leq 0$. In such cases, region i simply sets $t_i(\theta_i) = t_i^L$. We will focus on equilibria in which the actions played by the regions ensure them $W_i > 0$. In other words, we focus on realizations of types for which the regions play according to $t_i(\theta_i)$ given in eq.(19).

The decision rule consists in comparing $\pi_a(t_a(\theta_a))$ to $\pi_b(t_b(\theta_b))$. Using profits given by eq.(20) and rearranging, we get:

$$\pi_a(\theta_a) - \pi_b(\theta_b) = \frac{(2+\lambda)(c_b - c_a) + 3[\theta_b(P - c_b) - \theta_a(P - c_a)]}{6} \tag{21}$$

Re-arranging eq.(21), we obtain that location will take place in region a when:

$$c_a + \frac{3}{2+\lambda} d_a \leq c_b + \frac{3}{2+\lambda} d_b \tag{22}$$

Inspection of eq.(22) reveals that λ is key in generating sub-optimal locations. Indeed, with $\lambda < 1$, there will be cases in which $c_a + d_a \leq c_b + d_b$ (optimal location is in region a) but $c_a + 3/(2+\lambda)d_a > c_b + 3/(2+\lambda)d_b$ (location occurs in region b).

Clearly, as λ decreases, the likelihood of sub-optimal locations increases. To grasp the intuition for this state of affairs, consider the problem of setting the pollution tax from the perspective of region i. When λ is large, the upper bound of the support of d_j is also large and so, the likelihood of a large d_j being drawn is high. Given that region j plays a linear strategy with its tax increasing in its type, this means that for a given tax t_i, the likelihood that the firm will locate in region i is also high. Region i can therefore set its tax, putting proper weight on the cost of being polluted and less weight on strategic considerations. Because t_i is a good reflection of d_i, relatively few sub-optimal locations take place. However, when λ decreases, the upper bound of the support of d_j is reduced and so, the likelihood of a relatively large d_j is reduced. For a given tax t_i, the likelihood that the firm will locate in region i decreases. This leads region i to reduce its pollution tax as it puts more weight on the necessity to attract the firm and less on the cost of being polluted. Because t_i is not as good a reflection of d_i, more sub-optimal locations take place.

Also note that sub-optimal locations are less likely for larger production cost differentials, $c_b - c_a$. This is natural since when the production cost advantage of region a increases relatively to the marginal pollution cost differential $(d_a - d_b)$, it becomes more natural for the location to occur in a.

Figure 1 depicts, in the (da, db) space and for a given production cost differential, the realizations of pollution costs that lead to sub-optimal locations. It is easily seen that a decrease in λ or in $(c_b - c_a)$ reduces the likelihood of sub-optimal locations as it brings the two curves closer to each other.

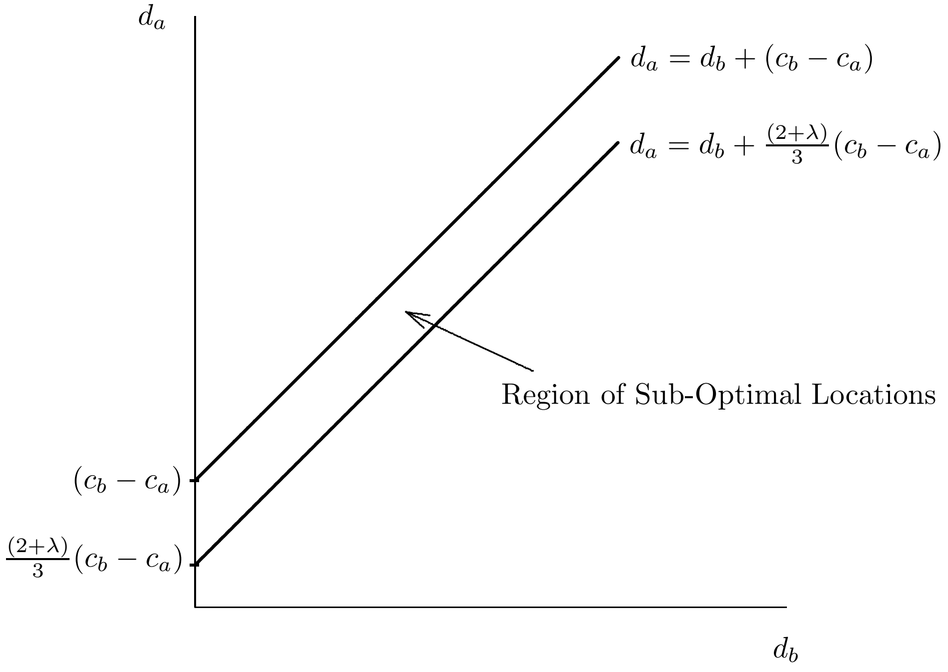

Figure 1: Sub-Optimal Locations

5. Centralized Taxation

In this section, we explore the implications of centrally chosen pollution taxes for both regions under complete and incomplete information. Recall that incomplete information refers to the central authority knowing only the regional probability distributions of marginal pollution costs. We investigate two cases. In the first one, we assume that the central government must apply the same tax to both regions. This could be because the constitution constrains taxation to be uniform. In the second one, we allow the government to tax the two regions at a different rate.

5.1 Complete Information

5.1.1 Uniform Taxation

If the central government applies the same pollution tax t in both jurisdictions, then the firm will always locate in region a because it has a lower production cost than b ($c_a < c_b$). Given this, and given that the government wants to extract the largest possible rent from the firm, the tax rate will be $t = P - c_a$. It should then be clear that this will not necessarily lead to an optimal location as $c_a < c_b$ does not necessarily mean that $c_a + d_a < c_b + d_b$. Hence, a globally sub-optimal location in region a can occur.

5.1.2 Non-Uniform Taxation

In this case, the central authority identifies the region that has the lowest total cost ($c_i + d_i$) and then ensures that the firm locates there. If location in region i is desired, it can be achieved by setting $t_i = P - c_i$ and by fixing a prohibitively high pollution tax rate t_j, $j \neq i$. This ensures optimal location with all the rent going to the government.

5.2 Incomplete Information

To simplify comparisons with decentralized taxation, we now assume that $c_b = c > c_a = 0$. Under this assumption, the central government only knows that d_a is uniformly distributed over support $[\tau P, \lambda P]$, and that d_b is uniformly distributed over support $[\tau(P - c), \lambda(P - c)]$.

5.2.1 Uniform Taxation

As in the complete information case, the firm will go where production costs are the lowest, again in region a. Knowing this, the central government will fix a tax rate $t = P$ and location will be in a, which will be optimal only by chance. To be more precise, it will be optimal if $d_a < d_b + c$. Given the probability distributions, it is possible to write the probability of a sub-optimal location under centralization as:[19]

$$\sigma_c = \Pr(d_a > d_b + c) = \frac{(\lambda - \tau)P + (\lambda + \tau)c - 2c}{2(\lambda - \tau)P} \leq \frac{1}{2} \tag{23}$$

One can note two things. First, σ_c is decreasing in the production cost differential c. For instance, if $c = 0$, then both regions have identical probability distributions of pollution costs and identical production costs so that σ_c is maximal and equal to 1/2. On the other hand, large discrepancies in production costs (i.e. c large) tend to reduce σ_c as it becomes more natural to locate in a. Second, σ_c increases when the supports of the distributions of d_a and d_b widen (i.e. when λ increases and/or τ decreases), which are intuitive: more uncertainty means that probability-based decisions are more likely to turn bad.

5.2.2 Non-Uniform Taxation

Under non-uniform taxation, the central government tries to attract the firm in the region with the lowest expected total cost ($c_i + d_i$). Because $\Pr(d_a > d_b + c) \leq 1/2$ (see eq.(23)), the government fixes a tax rate equal to $t_i = P$ and location is again in region a. So the probability of a sub-optimal location is again lower or equal to 1/2.

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[19] See Appendix B for calculations.

6. Comparing centralized and decentralized taxation under incomplete information

We have shown that incomplete information may yield a sub-optimal location under decentralized as well as under centralized taxation. Under centralized taxation, it was shown that location will always be in a and that the probability of this location being sub-optimal, σ_c, is less than or equal to $1/2$. It is instructive to assess if this probability is lower, equal or higher than the equivalent probability under decentralized taxation. It should be noted that under centralization, wrong locations are always cases in which the firm locates in a while it should have located in b. This is in contrast with the decentralized equilibrium in which the firm may locate in one or the other region, sub-optimality being possible in both cases.

The probability of sub-optimal location under decentralization is given by $\sigma_d = \Pr(\pi_b > \pi_a | d_a < c + d_b) + \Pr(\pi_b \leq \pi_a | d_a > c + d_b)$. After some manipulations, it is possible to obtain that $\sigma_d = \sigma_c + \Pr(\pi_a \leq \pi_b)\ [1 - 2\sigma_c]$. We denote by Δ the difference in the probabilities: $\Delta = \sigma_d - \sigma_c = \Pr(\pi_a \leq \pi_b)\ [1 - 2\sigma_c]$. Clearly, because $\sigma_c < 1/2$ and $\Pr(\pi_a \leq \pi_b) \geq 0$, $\sigma_d \geq \sigma_c$ always hold. Therefore the probability of a sub-optimal location under decentralized taxation is never less than that under centralized taxation. This can also be shown by examining Δ:[20]

$$\Delta = \frac{[3P(\lambda - \tau) + c(\lambda + 3\tau + 2)](2 - \lambda - \tau)c}{6(\lambda - \tau)^2 P^2} \geq 0 \tag{24}$$

It is therefore possible to conclude that the probability of a sub-optimal location under fiscal competition is larger or equal than that under centralized taxation.

7. Conclusion

This paper has shown that when two asymmetric regions compete in pollution taxes to attract a polluting firm, location will be optimal under complete information, but not necessarily under incomplete information. Decentralized taxation and incomplete information on regions' pollution costs may lead to a bias towards location in a region that does not maximize net total benefits. This paper has also shown that a central authority can play a role in diminishing the probability of inefficient outcomes.

Other conclusions can also be drawn from our analysis. First, it should be clear that real-life cases of sub-optimal locations are more likely under policies that reduce inter-provincial or inter-state productivity differentials. For instance, if those reductions occur in sectors subject to fiscal competition among states or

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[20] See Appendix C for the calculations of $\Pr(\pi_a \leq \pi_b)$.

provinces, then inefficiencies can result. This is similar to King *et al.* (1993) that showed "there was no efficiency basis for redistribution policies" in their model given that "subsidies distorted the equilibrium infrastructure choice from their efficient levels". Second, the diffusion of information on regions' characteristics can definitely help in reducing the uncertainty that leads to possibly inefficient outcomes. The diffusion of statistics related to regional productivity levels and/or regional pollution levels can help regions in assessing their true level of competitiveness and thus, in making "good" decisions concerning the package they offer to firms that consider location on their territory.

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Appendix

A. Complete Information: Location in Region *a*

Given that $W_j(t_j^L - \varepsilon) < 0$ for any ε, region i is going to insure it gets the firm by setting a tax $\bar{t_i}$ such that:

$$\pi(\bar{t_i}) > \pi(t_j^L) \ \geq 0, \quad i, j = a, b, \ i \neq j \tag{A1}$$

That is, region i will fix $\bar{t_i}$ so that region j cannot reduce t_j (without making its welfare negative). Note that $\bar{t_i}$ also has to satisfy $W_i(\bar{t_i}) \geq 0$. Given that regional welfare is increasing in pollution charge, region i wants $\bar{t_i}$ to be as high as possible. In the limit, $\bar{t_i}$ is given by:

$$\pi(\bar{t_i}) = \pi(t_j^L) > 0, \quad i, j = a, b, \ i \neq j \tag{A2}$$

We can then obtain $W_i(\bar{t_i})$ by substituting for $\bar{t_i}$ in the welfare function of region i to get:

$$W_i(\bar{t_i}) = (c_j + d_j) - (c_i + d_i), \quad i, j = a, b, \ i \neq j \tag{A3}$$

Welfare $W_i(\bar{t_i})$ will always be positive when location takes place in region i. This follows directly from the fact that the firms locates in region i if:

$$\pi(t_i^L) \geq \pi(t_j^L), \quad i, j = a, b, \ i \neq j \tag{A4}$$

This last condition is equivalent to $c_j + d_j \geq c_i + d_i$ so that $W_i(\bar{t_i}) \geq 0$. Also note that location under complete information is always optimal.

B. Computations of $\sigma_c = \Pr(d_a < d_b + c)$

For a given value of d_b, $\Pr(d_a < d_b + c) = [(c + d_b) - d_a^L]/[d_a^H - d_a^L]$ where d_i^L is the lowest possible marginal cost of pollution for region i and d_i^H is the highest. Using the definition of σ_c and integrating over d_b, we get:

$$1 - \sigma_c = \int_{(d_b^L + c)}^{(d_b^H + c)} \frac{(c + d_b) - d_a^L}{d_a^H - d_a^L} \ \frac{1}{d_b^H - d_b^L} \ dd_b \tag{B1}$$

After some computations and simplifications, we get:

$$1 - \sigma_c = \frac{d_b^L + d_b^H + 2c - 2d_a^L}{2(d_a^H - d_a^L)} \tag{B2}$$

Substituting for d_i^L and d_i^H, we obtain:

$$1 - \sigma_c = \frac{(\lambda + \tau)(P - c) + 2c - 2\tau P}{2(\lambda - \tau)P} \tag{B3}$$

Therefore:

$$\sigma_c = \frac{(\lambda - \tau)P + (\lambda + \tau)c - 2c}{2(\lambda - \tau)P} \tag{B4}$$

C. Calculations of $\varDelta$

We have that $\varDelta = \sigma_d - \sigma_c = \Pr(\pi_a \leq \pi_b)\ (1 - 2\sigma_c)$. We can compute π_a and π_b using the profits derived under decentralized taxation (eq.(20)). We then have:

$$\Pr(\pi_a - \pi_b \leq 0) = \Pr[P(2 - \theta_a - \rho_a) - (P - c)(2 - \theta_b - \rho_b) \leq 0] \qquad (C1)$$

Substituting for θ_is and ρ_is, we get:

$$\Pr(\pi_a - \pi_b \leq 0) = \Pr[3(d_b - d_a)P + 3(d_a - d_b)c + 2(P - c)(\lambda - 1)c \leq 0] \quad (C2)$$

which is equivalent to $1 - \Pr[d_a \leq d_b + (2(\lambda - 1)c/3)]$. Using the distributions of the d_is, we obtain:

$$\Pr(\pi_a - \pi_b \leq 0) = \frac{3\lambda(P + c) - 3\tau(P - c) - 2(\lambda - 1)c}{6(\lambda - \tau)P} \qquad (C3)$$

Finally we get:

$$\varDelta = \frac{[3P(\lambda - \tau) + (\lambda + 3\tau + 2)c](2 - \lambda - \tau)c}{6(\lambda - \tau)^2 P^2} \geq 0 \qquad (C4)$$