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NONCOOPERATIVE EQUILIBRIA IN REGIONAL ENVIRONMENTAL POLICIES WHEN PLANT LOCATIONS ARE ENDOGENOUS

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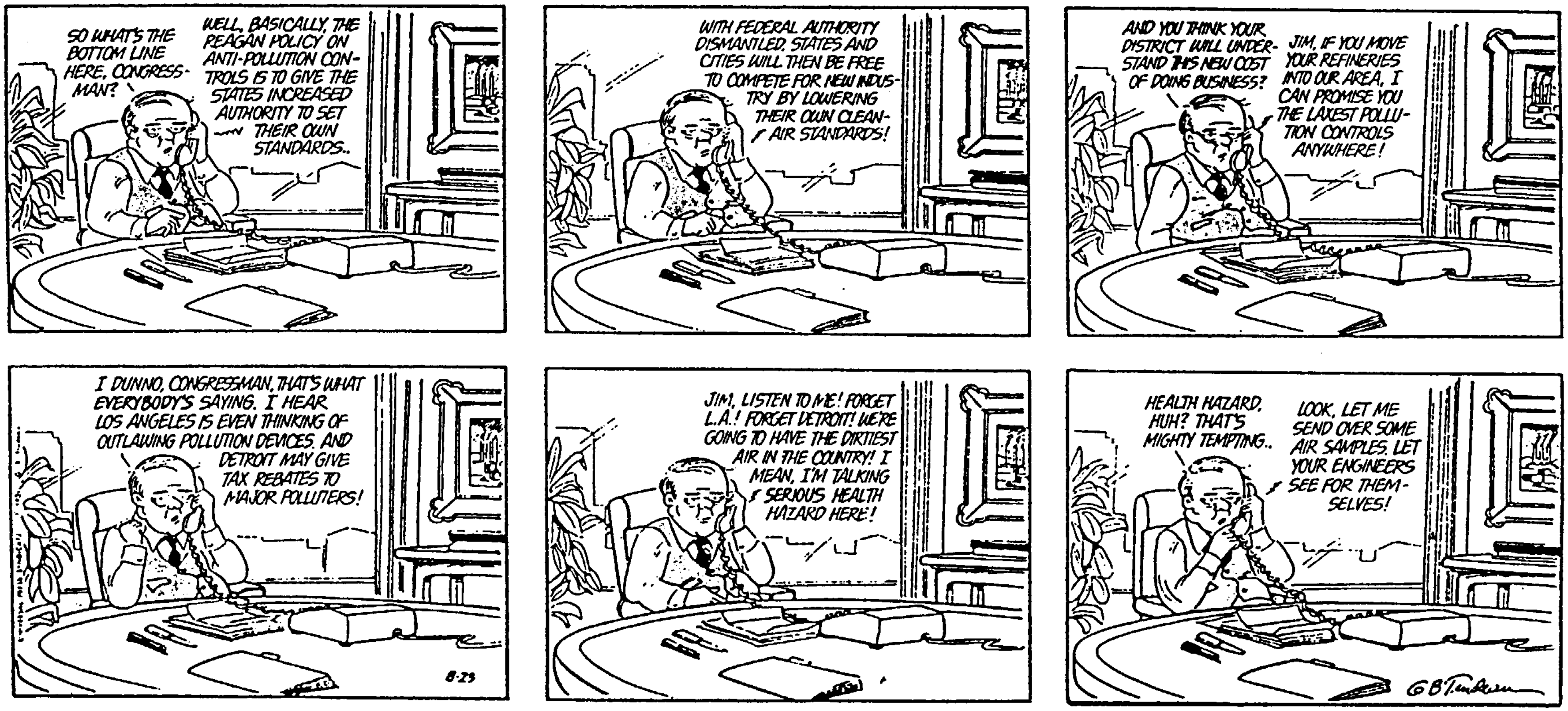
SO WHAT'S THE BOTTOM LINE HERE, CONGRESSMAN?
WELL, BASICALLY, THE REAGAN POLICY ON ANTI-POLLUTION CONTROLS IS TO GIVE THE STATES INCREASED AUTHORITY TO SET THEIR OWN STANDARDS..
WITH FEDERAL AUTHORITY DISMANTLED, STATES AND CITIES WILL THEN BE FREE TO COMPETE FOR NEW INDUSTRY BY LOWERING THEIR OWN CLEAN-AIR STANDARDS!
AND YOU THINK YOUR DISTRICT WILL UNDERSTAND THIS NEW COST OF DOING BUSINESS?
JIM, IF YOU MOVE YOUR REFINERIES INTO OUR AREA, I CAN PROMISE YOU THE LAXEST POLLUTION CONTROLS ANYWHERE!
I DUNNO, CONGRESSMAN, THAT'S WHAT EVERYBODY'S SAYING. I HEAR LOS ANGELES IS EVEN THINKING OF OUTLAWING POLLUTION DEVICES, AND DETROIT MAY GIVE TAX REBATES TO MAJOR POLLUTERS!
8-23
JIM, LISTEN TO ME! FORGET L.A.! FORGET DETROIT! WE'RE GOING TO HAVE THE DIRTIEST AIR IN THE COUNTRY! I MEAN, I'M TALKING SERIOUS HEALTH HAZARD HERE!
HEALTH HAZARD, HUH? THAT'S MIGHTY TEMPTING..
LOOK, LET ME SEND OVER SOME AIR SAMPLES. LET YOUR ENGINEERS SEE FOR THEMSELVES!
GBTrudeau

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ABSTRACT

A two-region model is presented in which an imperfectly competitive firm produces a good with increasing returns at the plant level, and in which shipping costs exist between the two markets. Production of the good causes local pollution, and regional governments can levy pollution taxes or impose environmental regulations. The firm decides, partly on the basis of these environmental policy variables, whether to maintain plants in both regions, serve both regions from a single plant or shut down. A non-cooperative equilibrium in regional environmental policies occurs when each region is choosing the environmental policy that maximizes its welfare given the environmental policy in the other region. Two types of harmful tax (regulatory) competitions are documented. If the disutility of pollution is high enough, each region will only want the polluting good produced in the other region and the two regions will likely compete by increasing their environmental taxes (standards) until the polluting firm is driven from the market. This is the case of *Not in my backyard*. Alternatively, if the disutility from pollution is not as great, each region will realize that their welfare could decrease if their environmental policy causes the firm to not operate in their region. In this case, the regions will usually compete by undercutting each others pollution tax rates (environmental standards).

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1. INTRODUCTION

There are at least two conceptually distinct types of environmental problems that can play a significant role in interregional and in international policy. One problem is transfrontier pollution such as acid rain, and global warming. Transfrontier pollution has attracted considerable attention, and a rapidly increasing amount of economic analysis.

A second and to some extent overlapping problem involves strictly *local pollution* externalities, but involves interregional and international considerations insofar as the location of production is endogenous. The issue of plant endogeneity has traditionally attracted the attention of regional politicians and their constituents, but has not gotten much attention from economists. As environmental issues have moved to the forefront of public debate, regional politicians ambivalently worry that imposing stricter environmental standards will drive industry from their region, while strongly believing that highly polluting plants, although sometimes necessary, should only be located in someone else's region. These issues are now receiving considerable attention from an international perspective. The Canadian - U.S. Free Trade Agreement, the debate on North American free trade, and the impending completion of the internal market for the European Economic Community in 1992 are forcing politicians to confront these issues. For example, some US, and Canadian groups, are worried that free trade will mean the movement of many of their plants to Mexico in order to take advantage of the cost savings afforded by lower environmental standards in Mexico. This raises the possibility of regions competing for plants by lowering environmental standards and ending up in a noncooperative equilibrium that is not Pareto Optimal.

Alternatively, if the disutility from pollution is sufficiently high, each region will want the polluting firm to produce only in the other region. In this case, the regions might bid up each others environmental standards until the firm is driven from business. This can happen even though both regions would be better off if the firm operates a plant in one of the regions, and the region without the plant compensates the region with the plant for the pollution they experience. This is the case of *NIMBY* (*Not in my back yard*). For example, no one wants a hazardous waste site in their region, but we are collectively better off with one, than without one.[2]

In a previous paper (Markusen, Morey, Olewiler (1992), henceforth MMO), we address the issue of plant endogeneity in a two-region model that involves two polluting firms choosing plant locations: location decisions that are influenced by the environmental policy of one region (the other region is passive). That model, which involves increasing returns to scale at the plant level, produces results that differ dramatically from those obtained from more traditional competitive models using Pigouvian marginal analysis. We show in MMO that regional welfare functions exhibit large discontinuities at critical levels of the environmental policy variables when plant location decisions are endogenous. Policy analysis must worry about market structure itself (the number and location of plants) in addition to concerning itself with marginal price and output decisions. The purpose of the present paper is to turn our attention to the governments themselves, and consider the fact that the governments of two regions can compete in terms of their environmental policies.

Our work builds on the literature on tax competition among governments. In the part of this literature most relevant to our work, capital and goods, but not individuals, are mobile across regions.[3] In most of the tax competition literature, taxes are used to generate the revenues to provide public goods. Jurisdictions desire to attract industry and the

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[2] Mitchell and Carson (1986) consider the locating of such facilities in a model that emphasizes aversion to risk taking. There is no interregional competition in their model.

[3] Along another vein, Tiebout (1956) generated a government competition literature where people are mobile and *vote with their feet*. In this literature, governments compete to provide a mix of public goods that maximizes households' utility. The resulting equilibria are efficient.

resulting competition typically results in lower tax rates and the underprovision of public goods.[4] See, for example, Arnott and Grieson (1981), Beck (1983), Wilson (1985, 1986), Mintz and Tulkens (1986), Wildasin (1988, 1989), and several papers in a special issue of *Regional Science and Urban Economics* edited by Wildasin and Wilson (1991). These papers all model the "rationale" which motivates destructive tax competitions. Mintz and Tulkens, in addition, explicitly consider the resulting non-cooperative equilibrium as the result of a game between the regions. Mintz and Tulkens use the Nash equilibrium concept with tax rates as the strategic variable. We do the same.

A substantial difference between the above work and ours is that we assume noncompetitive behavior and increasing returns to scale, whereas the above mentioned literature assumes pure competition. With competitive behavior, marginal analysis is perfectly appropriate. With increasing returns to scale, in addition to the marginal decisions over continuous variables. firms make discrete decisions such as whether to operate in a given region or whether to serve the region from a plant in another region.

There are a few papers that look specifically at environmental quality and government competition (Cumberland (1979, 1981), and Oates and Schwab(1986)). Both assume pure competition. Neither explicitly models the game between the governments. Cumberland considers environmental standards, rather than taxes, and argues that regions are likely to compete by relaxing standards to attract industry. He concludes that this competition will result in too low a level of environmental quality. He does not consider the NIMBY possibility. Oates and Schwab consider the joint determination of a tax rate on capital (to finance public goods), and the appropriate level of environmental quality. The n regions in their model do not compete directly in terms of either tax rates or environmental standards. Like the models cited above, the tax on capital is used to raise revenue and is distortionary. The nature of the *tax competition* in their model is a capital

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[4]Because the focus of these articles is on the provision of public goods, and not negative externalities, a Nimby case where tax rates are bid up cannot arise.

relocation externality; i.e. when capital is mobile, regions realize that as they level taxes to finance local public goods, capital will move to untaxed regions. The result is too few public goods and too low a level of environmental quality. Strategic behavior is not modelled.

Returning to this paper, we assume a single, imperfectly-competitive firm producing some product X with increasing returns to scale. The X firm may choose to build plants in both regions, a plant in only one of the regions, or not produce at all. The existence of shipping costs between regions is responsible for the fact that the firm may choose plants in both regions despite increasing returns to scale. Pollution is generated as a bi-product of the production of X, but this pollution does not cross regional borders. There is also a competitive Y industry in each region. The Y industry does not pollute. The issue addressed is thus trans-border competition in environmental policies, not transfrontier pollution.

Each government's decision criteria is to maximize their region's consumer surplus from the consumption of X, plus tax revenue, minus the region's disutility from pollution.[5] These regional goals conflict. The resulting competition between the two governments is modelled as a two-stage non-cooperative game. In the first stage of the game, the two governments simultaneously set the values of environmental policy variables. These are interpreted as pollution taxes throughout the analysis, but they could also be thought of as regulatory variables that impact on the firm's marginal cost (e.g., requiring cleaner fuel or other more expensive inputs). In the second stage, the firm chooses one of four configurations of plants: a plant in both regions, referred to as (1,1), a single plant in Region A, denoted (1,0), a single plant in Region B, denoted (0,1), or zero plants, denoted (0,0). The game is solved backwards in the usual fashion. The second stage is solved first in two

[5]For simplicity, we assume that the ownership of the firm is widely distributed throughout the "world" so that the firm's profits are not taken into consideration in regional welfare. Because our industry is non-competitive, the optimal pollution tax is not equal solely to the marginal disutility from pollution, but is more complex as will be shown later in the paper. Thus, there may be tax revenue in excess of total pollution disutility.

steps. We first solve for the firm's maximum profits given the levels of the pollution taxes and given a particular configuration of plants. We then solve for the firm's choice of plant locations given the tax levels. In the first-stage of the game, we solve for the two governments' non-cooperative equilibrium levels of pollution taxes using a Nash (best response) solution concept.

2. THE EFFECT OF TAXATION ON THE NUMBER AND LOCATION OF PLANTS

This section develops the model and solves for the equilibrium configuration of plants as a function of the two countries' tax rates. As noted earlier, the four possible equilibria are (1,1), (1,0), (0,1) and (0,0).

The two regions are assumed to be absolutely identical in all respects. The resulting symmetry aids us greatly in obtaining simple expressions for solutions. An individual consumer in each region has the utility function

(1) $$U = \alpha C_x - (\beta/2)C_x^2 - \gamma(X_d + X_e) + C_y$$

where C_x and C_y are per capita consumption levels of X and Y respectively. $X = (X_d + X_e)$ is the total domestic production of X. X_d denotes production sold domestically and X_e denotes production that is exported. Assume one unit of pollution is produced in a region for each unit of X produced in that region. γ is thus the marginal disutility of pollution to a consumer. Let N denote the total number of individuals in a region. Each individual views the total level of pollution in his or her region as exogenous, and in the absence of a pollution tax, or regulation, this externality will, ceteris paribus, lead to a market failure. Note that the system is also distorted by the market power of the X firm.

An individual is assumed to own L units of labor, and the production function for Y is simply $Y = L_y$ where L_y is the labor allocated to Y production out of the endowment of NL units of labor. Y or L is numeraire, and p_x denotes the price of X in terms of Y or L. There is no pollution associated with the production of Y. The X firm produces with a constant marginal cost m and with fixed costs as discussed below.

Let t denote the pollution tax levied on the production of X that is sold domestically, and let t_e denote the pollution tax that is levied on the production of X that is exported. The tax rate t_e can be thought of as the sum of the domestic pollution tax t plus a supplemental tax or subsidy, e, on export sales; i.e., $t_e = t + e$. Assume no other taxes. Allowing a region's pollution tax rates to differ as a function of where the good whose production caused the pollution is consumed gives each region greater flexibility, than would a single pollution tax, to jointly address the pollution and market power distortions in a world where plant locations are endogenous.

Assume tax revenues are redistributed equally among all individuals. An individual's budget constraint is thus given by

(2) $$L + tX_d/N + t_eX_e/N = p_xC_x + C_y$$

Maximizing (1) subject to (2) yields the very simple linear demand function

(3) $$p_x = \alpha - \beta C_x$$

Profits, before fixed costs, for the X producer from production for sale within a region ($C_x = X_d/N$) are given by

(4) $$(\alpha - \beta(X_d/N))X_d - mX_d - tX_d$$

Maximizing (4) with respect to X_d yields the firm's optimal supply.[6]

(5) $$X_d = N(\alpha - m - t)/(2\beta)$$

When the firm considers export sales, there is an equation similar to (4) but with t_e and an additional term for exporting costs: sX_e, where s is per-unit transportation cost. The supply function for exports (recall that populations are identical) is thus

(6) $$X_e = N(\alpha - m - s - t_e)/(2\beta)$$

Let $\pi(i,j)$ denote the profits of the firm in market structure (i,j). Let subscripts a and b denote Regions A and B respectively. Let G denote the plant-specific fixed cost and F the firm-specific fixed cost. Inserting (5) and (6) into the profit equations, the maximized values of profits under each market structure are given by

(7) $$\pi(1,1) = N[(\alpha - m - t_a)^2 + (\alpha - m - t_b)^2]/(4\beta) - 2G - F$$

(8) $$\pi(1,0) = N[(\alpha - m - t_a)^2 + (\alpha - m - s - t_{ae})^2]/(4\beta) - G - F$$

(9) $$\pi(0,1) = N[(\alpha - m - s - t_{be})^2 + (\alpha - m - t_b)^2]/(4\beta) - G - F$$

and $\pi(0,0) = 0$.

For a given set of tax rates, the firm will choose that configuration of plants that maximizes its profits. This configuration can be found by using equations (7) - (9) and $\pi(0,0)$ to determine maximum profits, at the given tax rates, for each of the four possible configurations. Said loosely, for given tax rates, the probability that the firm will choose the (1,1) configuration, rather than (1,0) or (0,1), is increasing in t_e and s (exports are less attractive as t_e and/or s increases); decreasing in t (production for local consumption

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[6]We assume throughout (and specify in the examples) that L is sufficiently large such that consumers are able to pay for the X produced at the implied price. Resources used for fixed costs may come from the "outside world".

becomes less attractive as t increases); and decreasing in G (a second plant becomes less attractive as G increases). The probability that the firm will choose to not operate, (0,0), is increasing in F,G,m,s,t and t_e. For example, (1,1) at $t = t_e = 0$ corresponds to a situation where plant-specific costs are low relative to the size of the market (N) and low relative to shipping costs (s) so that the X producer prefers to bear the fixed cost of an additional plant relative to the unit shipping cost. Horstmann and Markusen (1992) analyzes these determinants of market structure in more detail. Note that the firm's choice of plant locations does not directly depend on the disutility from pollution, γ.

The next step is to determine each region's choice of tax rates. Before determining the non-cooperative equilibrium tax rates that will result when plant locations are endogenous across regions, we derive, as a pedagogic device to help determine the actual equilibrium, each region's optimal tax rates under the artificial assumption that plant locations are exogenous. These tax rates are set ignoring the strategic nature of the competition between the regions, and, since they are set to equate the marginal benefits and costs of pollution reduction, can be interpreted as the Pigouvian tax rates. They are therefore the optimal *non-strategic Pigouvian* tax rates. For brevity, we will refer to them as the *non-strategic* tax rates and identify them with the superscript η; i.e. t^η and t_e^η.

3. REGIONAL SOCIAL WELFARE AND OPTIMAL TAXES FOR EXOGENOUS PLANT LOCATIONS: THE OPTIMAL NON-STRATEGIC TAX RATES

Substituting equations (2) and (3) into (1) and multiplying by N gives social welfare for the region.

$$(10) \qquad W = NU = N(\beta/2)C_x^2 + (t - \gamma N)X_d + (t_e - \gamma N)X_e + NL$$

If one plant is operating in each region, (1,1), $C_x = X_d/N$ and $X_e = 0$ (if we let X_m equal imports of X, $X_m = 0$ as well). Welfare of each region is thus

(11) $W(1,1) = (\beta/(2N))X_d^2 + (t - \gamma N)X_d + NL$

Under asymmetric plant configurations, (1,0) or (0,1), Region A's welfare equations are

(12) $W_a(1,0) = (\beta/(2N))X_d^2 + (t_a - \gamma N)X_d + (t_{ae} - \gamma N)X_e + NL$

(13) $W_a(0,1) = (\beta/(2N))X_m^2 + NL$

where X_m is equal to the exports of Region B.

Now consider the optimal taxes for a region *assuming* exogenous plant locations. Begin by considering the plant configuration (1,1). To obtain the non-strategic pollution tax for a (1,1) market structure differentiate (11) with respect to t and set the derivative equal to zero.

(14) $$\frac{dW(1,1)}{dt} = \left((\beta/N)X_d + t - \gamma N\right)\frac{dX_d}{dt} + X_d = 0 \qquad \frac{dX_d}{dt} = -\frac{N}{2\beta}$$

where the second equation is derived from (5). Substituting the second equation of (14) into the first and using (5), we get the non-strategic tax formula.

(15) $t^n = (\alpha - m)/3 + 2\gamma N/3$

Substituting (15) into (5), we get X^n and substituting X^n and t^n into (11), we get welfare under the (1,1) market structure, denoted W^n.

(16) $X^n = N(\alpha - m - \gamma N)/(3\beta)$

(17) $W^n(1,1) = N(\alpha - m - \gamma N)^2/(6\beta) + NL$

Next, consider the taxes that the government of Region A will set on pollution associated with production for domestic consumption and for export, given the exogenous configuration of plants (1,0). Assume that the firm is able to price discriminate between the regional markets (prices can be set independently in A and B). Referring to welfare in equation (12), we see that the derivative with respect to t is the same as (14), and so Region A will set $t = t^{\eta}$ as in the case of market structure (1,1). To determine t_e^{η}, differentiate (12) with respect to t_{ae} to obtain

$$(18) \quad \frac{dW_a(1,0)}{dt_{ae}} = (t_{ae} - \gamma N)\frac{dX_e}{dt_e} + X_e = 0 \qquad \frac{dX_e}{dt_{ae}} = -\frac{N}{2\beta}$$

where the second equation follows from (6). Substituting the second equation of (18) into the first and using (6), we get the non-strategic export tax formula

$$(19) \qquad t_e^{\eta} = (\alpha - m - s + \gamma N)/2 \quad where \quad (t_e^{\eta} - \gamma N) = (\alpha - m - s - \gamma N)/2$$

Therefore, each region will set $t = t^{\eta}$ and $t_e = t_e^{\eta}$ if they ignore the strategic interactions.

Substituting (19) into (6) we get the non-strategic export function

$$(20) \qquad X_e^{\eta} = N(\alpha - m - s - \gamma N)/(4\beta) \quad where \quad (t_e^{\eta} - \gamma N)X_e^{\eta} = N(\alpha - m - s - \gamma N)^2/(8\beta)$$

For the remainder of the paper, we will assume parameterizations of the model such that $(\alpha - m - s - \gamma N)$ is positive. Elaborating, $(\alpha - m - s - \gamma N) > 0$ implies that pollution is not so bad that the export tax is prohibitive; i.e., if $t_e = t_e^{\eta}$ at (1,0), the tax revenues from exports minus the disutility from pollution on those exports, $(t_e^{\eta} - \gamma N)X_e^{\eta}$, is positive.

To get social welfare for Region A with plant configuration (1,0) at tax rates (t^{η}, t_e^{η}), equation (12) indicates that we simply add the right-hand equation of (20) to (17).

$$(21) \qquad W_a^{\eta}(1,0) = N(\alpha - m - \gamma N)^2/(6\beta) + N(\alpha - m - s - \gamma N)^2/(8\beta) + NL > W^{\eta}(1,1)$$

Equation (21) and its right-hand inequality indicate that, if the firm chooses only a single plant at the non-strategic tax rates, the region that gets the plant is better off than if the firm chooses two-plants. When Region A gets the sole plant at (t^{η}, t_e^{η}), it realizes the same welfare benefit from domestic sales that it does in the (1,1) configuration, but, in addition, it captures the benefit of tax revenue in excess of the disutility of pollution on export sales.

If there is just one plant, the region which does not get the plant realizes the welfare level shown in equation (13), where $X_{bm} = X_{ae}$. Region B's welfare in (1,0) at (t^η, t_e^η) is

(22) $$W_b^\eta(1,0) = N(\alpha - m - s - \gamma N)^2/(32\beta) + NL < W^\eta(1,1) < W_a^\eta(1,0)$$

Thus *if* plant configuration (1,0) or (0,1) is chosen by the X producer at (t^η, t_e^η), the region that does not get the plant does worse than the region that does, and worse than in market structure (1,1). The country without the plant receives no tax revenue net of pollution disutility, and receives a lower consumer surplus from X due to the higher price caused by the transport cost.

4. NON-COOPERATIVE ENVIRONMENTAL POLICY EQUILIBRIA: THREE CASES

Depending on the values of the parameters, a number of different types of non-cooperative equilibria can occur.

CASE I: Too many plants, too much pollution

For Case I, initially assume the firm will choose one plant at $t^\eta = t_a = t_b$, $t_e^\eta = t_{ae} = t_{be}$. Said loosely, Case I assumes that pollution is not "too bad" and that plant specific cost (G) is large relative to the shipping cost s.

Let $\pi^\eta(1,0)$ denote the profits of the X producer when it locates its single plant in Region A, given A maintains its non-strategic tax rates. In terms of this notation, the initial assumption of Case I is that

(23) $$\pi^\eta(1,0) > \pi^\eta(1,1), \qquad \pi^\eta(1,0) > 0.$$

where $\pi^\eta(1,1)$ may be greater than or less than zero.

If both countries impose taxes of t^η and t_e^η, the firm will serve one region by exports.

Assume without loss of generality that the firm produces for both regions from a single plant in Region A. Region A earns the welfare level given in equation (21) and Region B earns the welfare level given in equation (22). Region A's welfare is significantly higher than Region B's. This situation cannot be a Nash equilibrium of our simple game. Region B can under-cut Region A's tax schedule by an arbitrarily small amount, and given these new rates, the X producer will switch to Region B. By continuity of the welfare expressions in t and t_e, Region B has improved its welfare by this small tax under-cutting. Thus (1,0) with tax schedule ($t^?$, $t_e^?$) cannot be an equilibrium.

> Proposition 1 If one is plant chosen at $t^?$, $t_e^?$, this situation can not be a Nash equilibrium because there is an incentive for the region without the plant to undercut.

The under-cutting process must continue over some finite interval. The under-cutting process may be terminated either by the governments, or by the firm switching to two plants. Referring to equations (12) and (13), the welfare of the region with the plant must decrease (as taxes deviate more from their non-strategic levels) and the welfare of the region without the plant must increase (its consumer surplus must increase as its import price falls with the fall in the other region's export tax) as the under-cutting continues.

Eventually we may have an equilibrium at a (t, t_e) combination with plant locations (1,0) or (0,1) if (12) equals (13), and if it continues to be the case that $\pi(1,0)$ or $\pi(0,1)$ exceeds $\pi(1,1)$. We will not develop this possibility in detail, but instead concentrate on the case when, as the under-cutting proceeds, we arrive at (t, t_e) values such that $\pi(1,0)$ or $\pi(0,1) < \pi(1,1)$ and the firm switches to one plant in each country.

Note that there is a discrete change in a region's incentive to under cut when taxes fall to the level that supports two plants. Above these tax rates, a region is engaged in under-cutting to move itself away from the situation of having no plant, importing at high cost and receiving no tax revenue. When the taxes fall to the critical levels necessary to support (1,1), each country has one plant and further under-cutting would be for the purpose of gaining the additional tax revenue from export sales, but at the expense of higher pollution levels.

We propose the following as a possible equilibrium. Undercutting occurs until each region's export tax reaches the level $t_e^e = \gamma N$, such that each region is indifferent to having production for export. Second, each region's domestic tax is cut until the X producer is just indifferent to maintaining two plants and switches to (1,1). This tax rate, which we will denote by t^e is found by setting equation (7) equal to (8), letting $t_e = \gamma N$ and solving.

$$(24) \qquad t^e \equiv (\alpha - m) - ((\alpha - m - s - \gamma N)^2 + 4\beta G/N)^{1/2}$$

Several things can be deduced at this proposed equilibrium. First, neither region has an incentive to lower its export tax further to induce the firm to shut its other plant because the added pollution will outweigh the tax revenue. Second, neither region has an incentive to raise its export tax since this has no effect (there are no exports in (1,1)). Third, neither region has an incentive to lower its domestic tax because this is already below t^η: if the firm chooses one plant at (t^η, t_e^η) and then the export taxes are lowered, it must be the case the domestic taxes are then lowered to induce the firm to maintain two plants. Fourth, profits of the X producer at clearly positive at the proposed equilibrium and the producer is willing to maintain two plants by definition of t^e.

Two additional conditions must be established to prove that there is a non-cooperative equilibrium at (t^e, t_e^e). At the proposed equilibrium, neither region must have an incentive to raise its domestic tax to drive the plant out. Let $W^e(1,1)$ be the welfare level a country enjoys when $t = t^e$, $t_e = t_e^e$. Let $W_a^e(0,1)$ be the welfare enjoyed by Region A if A then raised taxes to drive out the local plant, B's taxes constant. $W_b^e(1,0)$ is similarly defined. The necessary condition for the region with a plant not to want to shed its plant is that $W^{\epsilon}(1,1) > W^{\epsilon}_{a}(0,1) = W^{\epsilon}_{b}(1,0)$. A *sufficient* condition for this is that $t^{\epsilon} \geq \gamma N$.[7]

Sufficient conditions for a (1,1) equilibrium at $(t^{\epsilon}, t^{\epsilon}_{e})$ are thus summarized as follows where the superscript ϵ denotes the non-cooperative equilibrium tax rates.

> Proposition 2 If one is plant chosen at (t^{η}, t^{η}_{e}) and if $t^{\epsilon} \geq \gamma N$, market structure (1,1) is a non-cooperative equilibrium with tax rates $t^{\epsilon}_{a} = t^{\epsilon}_{b} = t^{\epsilon}$ (defined in (24)), $t^{\epsilon}_{ae} = t^{\epsilon}_{be} = \gamma N$.

It is easy to find parameterization of the model such that the conditions of proposition 2 hold, and thus (1,1) is an equilibrium market structure at $t = t^{\epsilon}$ (given by (24)), and $t_{e} = t^{\epsilon}_{e} = \gamma N$. Table 1 gives such a parameterization and associated results (indeed, $t^{\epsilon} < \gamma N$ in Table 1, emphasizing that $t^{\epsilon} \geq \gamma N$ is sufficient but not necessary).

Result 1 in Table 1 indicates that t^{η} and t^{η}_{e} significantly exceed t^{ϵ}. The direct profit calculation in Result 2 indicates that the firm will operate only one plant at (t^{η}, t^{η}_{e}). Result 3 indicates that the example satisfies the welfare condition of proposition 2, implying that at (1,1) with tax rates $(t^{\epsilon}, t^{\epsilon}_{e})$, neither region can do better by raising its taxes sufficiently to drive out the plant and import instead. Result 4 implies that neither country can do better by lowering its export tax to induce the firm to shut its other plant: the additional tax is outweighed by the disutility of additional pollution. Thus the two countries have no incentive to deviate from tax rates $(t^{\epsilon}, t^{\epsilon}_{e})$. Result 5 of Table 1 indicates that the firm also has no incentive to deviate from two plants. Thus (1,1) is a Nash equilibrium.

Table 1 then presents some welfare effects. Welfare for each region is presented under the arbitrary assumption that the one plant is in Region A, (1,0), rather than (0,1) at

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[7] If $t^{\epsilon} \geq \gamma N$, the country loses the non-negative excess of tax revenue over the disutility of pollution plus loses consumer surplus from the higher import price if it drives the plant out.

The last condition is more subtle. Each country must not have an incentive to induce the X producer to close its foreign plant through some combined policy of raising its domestic pollution tax above t^{ϵ} (where $t^{\epsilon} < t^{\eta}$), compensated for by a sufficient lowering of its export tax below t^{ϵ}_{e}. We can show that this last condition need not be specified as an additional assumption (i.e., it is implied by the other assumptions,proof available from the authors).

tax rates (t^7, t_e^7). Equivalent figures for the (0,1) market structure are found by simply reordering the two regions. Result 2 of Table 1 indicates that (1,0) is feasible at (t^7, t_e^7) from the firm's point of view: it earns more with one plant than with two plants or with zero plants. The welfare numbers at the bottom of Table 1 indicate that the combined welfare levels of the two regions is 4% higher with (1,0) than with (1,1) (the two identical utility functions are additive). But the higher aggregate welfare with (1,0) is very unevenly distributed. Region A gets both the tax revenue in excess of pollution disutility $((t^7 - \gamma N) > 0)$ and the consumer surplus gain from a lower price for X. Thus Region B has an incentive to under cut Region A's taxes. The result, for the parameterization of Table 1, is a Nash equilibrium (1,1) at (t^f, t_e^f) with Region A doing worse and Region B doing better than at (1,0).[8]

As a final point, we note that the two regions can jointly do even better than at a (1,0) market structure with taxes (t^7, t_e^7). The joint welfare of the two regions can be increased from this point if t_e is lowered. The level t_e^7 is too high to maximize joint welfare because it is calculated ignoring the fact that as t_e is increased in Region A it reduces consumers' surplus in Region B.[9] The export tax that maximizes joint welfare is $t_e^* = 3.0$ rather than $t_e^7 = 4.0$. The optimal domestic tax is t^7; i.e., $t^* = t^7$. The welfare and pollution levels for this Pareto efficient outcome are reported in the third column of welfare numbers in Table 1. These show the further increase in joint welfare over (t^7, t_e^7) (note that pollution rises since export volume is now higher, and the welfare of A is lowered). To maintain this position as a cooperative equilibrium, Region B will have to make a side-payment to Region A.

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[8]Note that there is no suggestion that this is a unique Nash equilibrium given the assumptions of proposition 2.

[9]This result is also found in some of the tax competition literature that we cited earlier.

TABLE 1

A Numerical Example of a Non-Cooperative Equilibrium with Plant Locations (1,1)

$$\text{at } t_a^{\epsilon} = t_b^{\epsilon} = t^{e} \equiv (\alpha - m) - ((\alpha - m - s - \gamma N)^2 + 4\beta G/N)^{1/2} < t^{\eta},$$

$$t_{ae}^{\epsilon} = t_{be}^{\epsilon} = \gamma N < t_e^{\eta}$$

Parameterization

$$N = s = \beta = \gamma = 1, \; m = 0, \; \alpha = 8, \; G = 3.4, \; F = 4, \; L = 16$$

These parameter values imply the following results:

(1) $t^{\epsilon} = 0.957 < t^{\eta} = 3.33, \quad t_e^{\epsilon} = 1 < t_e^{\eta} = 4.0$

(2) $\pi^{\eta}(1,1) = 0.104 < \pi^{\eta}(1,0) = \pi^{\eta}(0,1) = 0.302$

(3) $W^{\epsilon}(1,1) = 22.051 > W_a^{\epsilon}(0,1) = W_b^{\epsilon}(1,0) = 20.500$

(4) $(t_e^{\epsilon} - \gamma N) = 0$

(5) $\pi^{\epsilon}(1,1) = \pi^{\epsilon}(0,1) = \pi^{\epsilon}(1,0) = 14.008 > 0$

Welfare Implications

	At the Non-strategic tax rates	The Non-cooperative equilibrium	A Pareto Optimal Outcome
Market Structure and Taxes	(1,0) at (t^{η}, t_e^{η})	(1,1) at $(t^{\epsilon}, t_e^{\epsilon})$	(1,0) at (t^{*}, t_e^{*})[10]
Welfare of Region A	28.712	22.051	28.312
Welfare of Region B	17.125	22.051	18.000
Sum of A and B	45.837	44.102	46.312
X producer's profits	0.302	14.008	2.052
Total Pollution	3.835	7.044	4.335

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[10]Where $t^{*} = t^{\eta} = 3.33$ and $t_e^{*} = 3.0$.

Case II: Correct number of plant, too much pollution

In this section, we assume that the X producer will choose two plants at tax rates (t^{n}, t^{n}_{e}). We can switch from Case I to this case by either lowering the disutility of pollution (thus decreasing t^{n}), and/or by lowering the plant-specific fixed cost G. The fact that in Case II the firm chooses two plants at the non-strategic tax rates does not imply that (1,1) is an equilibrium at (t^{n}, t^{n}_{e}). One region may wish to under cut on its export tax to induce the firm to shut its foreign plant, if the resulting increase in tax revenue exceeds the added disutility of pollution. Note that in an initial configuration of (1,1), neither region has an incentive to cut its domestic tax below t^{n}, since that will have no effect on the firm's location decisions. Also note that by inequality (22), neither region has an incentive to raise its domestic tax to induce the firm to shut its local plant. Thus to determine whether there is a noncooperative (1,1) equilibrium at (t^{n}, t^{n}_{e}) we need only examine a region's incentives to cut its export tax below t^{n}_{e}.

To determine this, set $t_b = t^{n}$ and solve for the value of t_{ae} that makes the firm indifferent between (1,1) and (1,0); specifically, substitute t^{n} from equation (15) into (7) for t_b, and set (7) equal to (8). Rearranging one obtains

$$(25) \qquad (\alpha - m - s - t_{ae})^2 = (2/3(\alpha - m - \gamma N))^2 - 4\beta G/N$$

This is a rather awkward implicit function in t_{ae} so, to simplify, we will assume that G = 0. This assumption is consistent with the assumption that the firm will choose a (1,1) market structure at (t^{n}, t^{n}_{e}). Remember that lowering G makes this more likely.

Setting G equal to zero and taking square roots, (25) becomes

$$(26) \qquad t_{ae} = (\alpha - m)/3 + 2\gamma N/3 - s = t^{n} - s \quad ;$$

i.e. if t_{ae} is $\leq$ this amount, the firm will shut its plant in Region B. With zero plant-level fixed costs, Region A can induce the firm to shut its Region B plant by setting an export tax that is less than t^η by the amount of the transport cost. This raises two questions: first, should Region A do this; i.e., will Region A benefit by such a tax cut, and second, should Region A cut its export tax even further? We answer the second question first. Equation (19) gives Region A's optimal export tax *given* the market structure (1,0). If we subtract (26) from (19) we get

$$(27) \qquad t_e^\eta - t_{ae} = (\alpha - m - \gamma N)/6 + s/2 > 0 \qquad \text{if } X^\eta > 0$$

The non-strategic tax *given* (1,0) is greater than the *maximum* tax that can be set to induce the firm to choose (1,0), and so the latter is binding. If Region A cuts its export tax, it should cut it the minimum amount.

The question of whether or not Region A ought to cut its export tax from t_e^η is then easily resolved by noting from (11) and (12) that the question turns simply on the sign of $(t_{ae} - \gamma N)$; i.e., $W_a(1,0) \gtrless W_a(1,1) \leftrightarrow (t_{ae} - \gamma N) \gtrless 0$. Substituting (26) for t_{ae} in $(t_{ae} - \gamma N)$, we get the condition for Region A *not* cutting, and therefore the condition that (1,1) is an equilibrium at taxes equal t^η, t_e^η.

$$(28) \qquad (t_{ae} - \gamma N) = (\alpha - m - \gamma N)/3 - s < 0$$

Thus if at the t_{ae} that just induces the firm to shut its plant in Region B, the benefits to A from doing this are negative, there is no incentive to bid down t_e from t_e^η. Note that there is no benefit from a combined policy of lowering t_e and raising t because the latter is already optimal. We then have the following proposition.

> Proposition 3 If $G = 0$ and if two plants are chosen at (t^η, t_e^η), the configuration of plants (1,1) is an equilibrium with taxes (t^η, t_e^η) if, in addition, $(\alpha - m - \gamma N) - 3s < 0$.

Since the term $(\alpha - m - \gamma N)$ in proposition 3 has the same sign as X^η from (16), it is clear that proposition 3 will fail for a sufficiently low value of s and will be valid for a sufficiently large value of s. Intuitively, the higher s, the more that Region A must cut its export tax to induce the firm to shut its plant in Region B. But the more that A has to cut that tax, the less likely it is that the cut will benefit A. Also the larger is γ the more likely it is that proposition 3 will be valid.

Suppose now that $(\alpha - m - \gamma N) - 3s > 0$. Then at a market structure of (1,1) with taxes (t^η, t_e^η), each region has an incentive to deviate by lowering its export tax and thus this cannot be a Nash equilibrium. Suppose A begins the process by deviating to $t_{ae} = t^\eta - s$. The firm shuts its plant in B and supplies both regions from its plant in A. B initially enjoys the same level of consumer surplus because its price for X is the same. But B loses its tax revenue $(t^\eta - \gamma N)X^\eta$.

Region B should now cut its domestic tax by a small bit to regain a plant to supply for domestic consumption. The added consumers' surplus and tax revenues will more than offset the disutility from the resulting pollution. Region B should in turn cut its export tax to capture A's market, provided $(t_{be} - \gamma N)$ remains positive. The under-cutting continues in this manner, with each region in turn cutting its domestic tax and cutting its export tax to capture the foreign market. This process comes to an end when there is no incentive to capture the other region's market; i.e., when there is no longer an incentive to get the firm to shut its foreign plant. This occurs when the export tax is driven down to $t_e = \gamma N$. Given this export tax, a country sets its domestic tax as high as possible without loosing its domestic market.[11] Thus its domestic tax must be $t = t_e + s = \gamma N + s$.

> <u>Proposition 4</u> If $G = 0$, if two plants are chosen at (t^η, t_e^η), and if $(\alpha - m - \gamma N) - 3s > 0$, a non-cooperative equilibrium configuration of plants is (1,1) with both countries having domestic taxes of $t^\epsilon = \gamma N + s$, and export taxes of $t_e^\epsilon = \gamma N$.

Table 2 presents an equilibrium in which the configuration of plants is (1,1) at the nonstrategic tax rates, but in which tax competition drives the two regions' tax rates down

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[11] From (15) we can write $t^\eta = (\alpha - m - \gamma N)/3 + \gamma N$, and since we are dealing with the case where $(\alpha - m - \gamma N)/3 > s$, we have $t^\eta > \gamma N + s$. Thus each region should set its domestic tax at the maximum value, $(\gamma N + s)$, which does not drive the plant out.

below t^{η}, to the rates indicated in Proposition 4. The parameterization differs from that of Table 1 only in that G is lowered to zero. Result 1 of Table 2 indicates that the last condition of Proposition 4 is satisfied, so that each country has an incentive to deviate from (t^{η}, t_e^{η}) by lowering its export tax to induce the firm to shut its foreign plant. Result 2 states that the Nash equilibrium tax rates are $t^{f} = 2.0$ and $t_e^{f} = 1.0$. Result 3 verifies that the firm earns higher profits as a consequence of tax competition, while result 4 verifies that the two regions lose as a result of this competition. Result 5 notes that each region earns a surplus of tax revenue over the disutility of pollution on production for domestic consumption at the Nash equilibrium, and verifies that export taxes are set such that there is no equivalent surplus on (potential) exports, so that neither region has an incentive to under cut. Result 6 of Table 2 notes that the firm is indifferent at the equilibrium between one and two plants.

The welfare implications of noncooperative equilibrium are summarized relative to the (1,1) configuration of plants with tax rates t^{η}. This is done at the bottom of Table 2. Tax competition reduces the welfare of the two regions and significantly increases the profits of the firm. Total pollution is 28% higher at the Nash equilibrium than with non-strategic taxes. It should also be noted that the non-strategic tax rates are Pareto optimal in this case (they maximize the sum of Region A and Region B's welfare).[12] Note

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[12] This last point not withstanding, note in Tables 1 and 2 that the sum of welfare (which is defined exclusive of the X producer's profits) and profits is larger at the Nash equilibrium than at $t = t^{\eta}$. The reason is that, from a "world" point of view, the two regions are over taxing the firm by ignoring the contribution of its profits to welfare. If each region took profits into account, tax rates would be substantially lower and could possibly be negative. The equilibrium tax rates would still be driven down by the existence of tax competition. The incentive to gain tax revenue by inducing the firm to shut its foreign plant still exists. Furthermore, equilibrium tax rates may remain too high from the "world" point of view. For example, if each region held 50% equity in the firm, an action by Region A that reduces the profits of the firm by $1 only reduces the equity income of Region A by $0.50 (instead of $0.00 in our formulation) so the tendency to over tax persists. This result is analogous to those derived in the tax competition literature without trade. See, for example, Mintz and Tulkens (1986), Oates and Schwab (1988) and Wildasin (1988, 1989).

TABLE 2

A Numerical Example of a Non-cooperative Equilibrium with the Configuration of Plants (1,1) at $t^{\epsilon}_{a} = t^{\epsilon}_{b} = \gamma N + s \; < \; t^{\eta}, \;\; t^{\epsilon}_{ac} = t^{\epsilon}_{bc} = \gamma N$

Parameterization

$$N = s = \beta = \gamma = 1, \; m = 0, \; \alpha = 8, \; G = 0, \; F = 4, \; L = 16$$

These parameter values imply the following Results:

(1) $(\alpha - m - \gamma N) - 3s = 4 > 0$

(2) $t^{\eta} = 3.33 > t^{\epsilon} = 2.0, \;\; t^{\eta}_{c} = 4.0 > t^{\epsilon}_{c} = 1.0$

(3) $\pi^{\eta}(1,1) = 6.888 < \pi^{\epsilon}(1,1) = 14.0$

(4) $W^{\eta}(1,1) = 24.165 > W^{\epsilon}(1,1) = 23.5$

(5) $(t^{\epsilon} - \gamma N) = 1.0 > 0, \;\; (t^{\epsilon}_{c} - \gamma N) = 0$

(6) $\pi^{\epsilon}(1,1) = \pi^{\epsilon}(0,1) = \pi^{\epsilon}(1,0) = 14.0 > 0$

Welfare Implications

	At the Non-strategic tax rates[13]	The Non-cooperative equilibrium
Market Structure and Taxes	(1,1) at (t^{η}, t^{η}_{c})	(1,1) at $(t^{\epsilon}, t^{\epsilon}_{c})$
Welfare of Region A	24.165	23.500
Welfare of Region B	24.165	23.500
Sum of A and B	48.330	47.000
X producer's profits	6.888	14.000
Total Pollution	4.670	6.000

[13]Note that this is also a Pareto Optimal outcome; i.e. $t^{*} = t^{\eta}$ and $t^{*}_{c} = t^{\eta}_{c}$.

that, unlike in Case I, neither region has to make a side-payment to maintain this Pareto Optimal cooperative equilibrium, they just need to agree to each impose the non-strategic tax rates.

CASE III: Too few plants, too little pollution

Our third and final case focusses on the *NIMBY* possibility, in which neither region will accept a plant in a non-cooperative equilibrium but in which a cooperative equilibrium, with one plant, can achieve a higher level of joint welfare. In this situation pollution is sufficiently high, and plant-specific fixed costs are sufficiently high, that neither region wants a plant in their region, but pollution is not so bad that it is collectively best that X is not produced.

We construct a very simple example to illustrate the *NIMBY* possibility. Suppose that we raise the plant and firm specific costs sufficiently (relative to their levels in the two previous sections) such that (1) the firm chooses only one plant at zero taxes, and (2) the firm just breaks even at zero taxes.

Under these assumptions, there will only be a plant in one region, and this will only occur if taxes in that region are zero. Assume arbitrarily that the single plant is located in Region A. Welfare expressions for Regions A and B with taxes set to zero in Region A are

(29) $$W_a(1,0) = [\beta/(2N)]X_d^2 - \gamma N(X_d + X_e) + NL \qquad W_b(1,0) = [\beta/(2N)]X_e^2 + NL$$

As in the previous two Cases, the model can be parameterized in different ways to yield different outcomes. Perhaps the most interesting case occurs when Region A would rather have no X produced than have a plant, but yet in which the combined welfare of the two regions exceeds 2NL if there is one plant. $W_a(1,0) < NL$ at zero taxes if $(\beta/(2N))X_d^2 - \gamma N(X_d + X_e) < 0$. In which case, if the tax rates are zero and Region A has the one plant, Region A will impose a positive domestic tax and drive the plant to Region B. Since $W_b(0,1) < NL$ when Region B has zero taxes, Region B will respond by imposing a positive domestic tax and the firm will be driven out of business. Neither region has an incentive to deviate from these tax rates so the Nash equilibrium is (0,0) at positive domestic taxes (N.B., adding positive export taxes is also a Nash equilibrium).

<u>Proposition 5</u> If at $t = t_e = 0$ the firm chooses one plant and just breaks even, and if, in addition, $(\beta/(2N))X_d^2 - \gamma N(X_d + X_e) < 0$ at $t = t_e = 0$, then $(t^r, t_e^r) > 0$ is a non-cooperative equilibrium with no plants, (0,0).

Note that in this case, the non-cooperative equilibrium tax rates, (t^r, t_e^r), are also the nonstrategic tax rates; i.e., the firm would impose positive tax rates even if they ignored the strategic nature of the problem.

If, in addition to assuming that $(\beta/(2N))X_d^2 - \gamma N(X_d + X_e) < 0$ at $t = t_e = 0$, it is also the case that joint welfare of the two regions is greater than 2N when there is one plant then $t = t_e = 0$ are the tax rates that maximize this joint welfare; i.e., $t^* = t_e^* = 0$. However, zero tax rates can only maintained by a cooperative equilibrium in which the region without the plant subsidizes the region with the plant.

Table 3 presents an example in which the non-cooperative equilibrium is (0,0) but in which it is also true that the sum of the welfare levels in the two regions is higher if one of the regions will accept a plant at zero taxes. This Case is quite the opposite of Case I. As in Case I, a transfer payment is needed to achieve this outcome but the direction of the transfer is now opposite to that of Case I. Here it is the region *without* the plant that must pay the region with the plant to achieve the cooperative outcome. We also have the opposite results to Case 1 with respect to both the numbers of plants and the level of pollution. Here we have two few plants and too little pollution at the Nash equilibrium.

TABLE 3

A Numerical Example of an Non-Cooperative Equilibrium with No Plants, (0,0)

Parameterization

$N = s = \beta = 1, \;\; m = 0, \;\; \alpha = 8, \;\; \gamma = 1.33, \;\; G = 28.25, \;\; F = 10, \;\; L = 16$

These parameter values imply the following results:

(1) $X_d^c = 0, \;\; X_e^c = 0$ and , $\pi^c = 0$ at $t^c, t_e^c > 0$.

(2) $X = 4.0, \;\; X_e = 3.5$, at $t = t_e = 0$.

(3) $\pi(1,0) = \pi(0,1) = 0 > \pi(1,1) = -14.5$ at $t = t_e = 0$.

(4) $W_a(1,0) = -1.0, \;\; W_b(1,0) = 7.125$ at $t = t_e = 0$.

Welfare Implications

	Pareto-Optimum (zero taxes)	The Non-cooperative (and Non-strategic) equilibrium
Market Structure and Taxes	(1,0) at ($t = t_e = 0$)	(0,0) at ($t^c, t_e^c > 0$)
Welfare of Region A	14.000	16.000
Welfare of Region B	22.125	16.000
Sum of A and B	36.125	32.000
X producer's profits	0.000	0.000
Total Pollution	7.500	0.000

6 Summary and Conclusions

A two region model is developed where a firm can locate plants in one, both or neither region, and where production from the plant(s) causes local pollution. In this world, the two governments compete in terms of the environmental policies. The model differs significantly from the Pigouvian tradition of marginal analysis in competitive models by assuming production with increasing returns to scale and shipping costs between regions. The single firm chooses between the high fixed-cost option of having plants in both of two regions, versus the high variable cost option of serving both markets from a single plant. There are large jumps in a region's welfare at critical levels of policy variables where the firm switches the number and location of its plants. In addition to concerning itself with the traditional price and output decisions of the firm, policy must also address discrete-choice problems such as whether to (1) attract a plant to the region, (2) expel a plant due to its environmental externality, and (3) induce the firm to close its foreign plant and serve that foreign market by exports from its local plant. Policy makers must also be aware that they are involved in a non-cooperative game with the policy makers in the other region.

In this context, pollution taxes affect the firm's choice and therefore regional welfare in two ways. First, generally higher taxes in both regions are, from the firm's point of view, a contraction in effective demand. Thus the firm may shift away from the high fixed-cost option of two plants to the high-variable cost option of a single plant. Second, relatively lower taxes in one region may induce the firm to move its single plant to that region, and/or close its plant in the other region.

Our Case I focusses more on the first effect. In case I, when both regions impose their optimal non-strategic taxes (taxes that are optimal assuming that market structure remains fixed with plants in both regions), the firm chooses a single plant. We then show that the region that does not get the plant has an incentive to cut its taxes, and a tax competition results. A Nash equilibrium with taxes lower than their non-strategic values results, and that equilibrium may either have a single plant or plants in both countries. We presented a numerical example of the latter, in which tax competition results in too many plants and too much pollution.

Our Case II focusses more on the second effect of taxes. In this case when both regions impose their non-strategic taxes, the firm continues to choose two plants. But both regions may have an incentive to under-cut in order to induce the firm to close its foreign plant, if the added tax revenue from export sales exceeds the disutility of added pollution. We derive sufficient conditions for the non-strategic tax rates to be the non-cooperative equilibrium rates (i.e., conditions under which there is no incentive to undercut from the non-strategic rates). We also derive sufficient conditions for under-cutting to occur and then solve for the non-cooperative equilibrium tax rates. In the latter case, an equilibrium is reached with plants in both regions, but at tax levels lower than the non-strategic levels. The non-cooperative outcome in this case has the right number of plants, but too much pollution.

Our Case III focusses on the *NIMBY* possibility, in which the Nash equilibrium involves no production of X and no pollution. Yet the joint welfare of the two regions is higher if one of them will accept a plant, an outcome that can be supported by an appropriate transfer payment from the region without the plant. Case III is in a sense opposite to Case I in two respects: in the former, (1) there are too few plants and too little pollution at the Nash equilibrium instead of too many and too much, and (1) the transfer payment must be from the region without the plant to the region with the plant rather than the other way around as in Case 1.

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Appendix

The purpose of this appendix is to demonstrate the assertion made in Cases I and II of section 4 that a region cannot improve its welfare (at the proposed (1,1) equilibrium) by inducing the firm to shut its other plant by a combination of raising its domestic tax and lowering its export tax (we proved in the text that neither of these things individually are welfare improving). The effect of a small lowering of the export tax and an increase in the domestic tax in Region A that leaves the firm indifferent between (0,1) and (1,0) can be divided into the usual marginal effect plus the impact effect of a sudden discrete change in the level of exports (initially zero at the proposed equilibrium). In Cases I and II, $(t_e - \gamma N) = 0$ initially, so the impact effect is zero.

Consider then the marginal effect of raising t and lowering t_e. Intuitively, this does not seem to make sense since raising the domestic tax generates a loss of consumer surplus while the combined effects of the two tax changes may leave pollution and tax revenue roughly unchanged.

Note from (8) that profits for the firm with one plant in Region A, (1,0), can be written as

$$\text{(A1)} \qquad \pi = (\beta/N)X_d^2 + (\beta/N)X_e^2 - G - F$$

The minimum amount Region A can lower t_e for a given increase in t without the firm switching to (0,1) is given by setting the total differential of (A1) equal to zero.

$$\text{(A2)} \qquad 2(\beta/N)[X_d(dX_d/dt)dt + X_e(dX_e/dt_e)dt_e] = 0 \qquad dX_i/dt_i = -N/(2\beta)$$

Substituting the right-hand equation (i = d,e) into the left, this condition becomes

(A3) $dt_e = -(X_d/X_e)dt$

The effect of the proposed scheme on welfare is given by

$$\text{(A4)}\quad dW = \left[[(\beta/N)X_d + (t-\gamma N)]\frac{dX_d}{dt} + X_d\right]dt + \left[(t-\gamma N)\frac{dX_e}{dt_e} + X_e\right]dt_e$$

Now replace dt_e with (A3) and replace dX_i/dt_i with $-N/(2\beta)$. Finally, divide through by dt > 0. (A4) becomes

$$\text{(A5)}\quad dW_a/dt = -(X_d/2) - (t-\gamma N)[N/(2\beta)] + (t_e-\gamma N)[N/(2\beta)](X_d/X_e)$$

In cases I and II of section 4, $(t_e - \gamma N) = 0$ and $(t - \gamma N) > 0$ initially, so the whole expression in (A5) is negative. At the proposed (1,1) equilibrium in both cases, Region A cannot improve its welfare by a combined policy of raising its domestic tax and lowering its export tax in order to induce the X producer to shut its plant in Region B.