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Equilibrium Pollution Taxes in Open Economies with Imperfect Competition[1]

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This paper argues that imperfect competition in global markets creates a strategic interaction between governments that can lead to the inefficient distortion of pollution taxes. This distortion can be decomposed into a rent capture effect and a pollution-shifting effect. The rent capture effect lowers equilibrium taxes as each country attempts to gain a competitive advantage over its trading partner and thereby capture foreign rent through net exports. The pollution-shifting effect raises equilibrium taxes as each country attempts to transfer production and its associated pollution to the other country. This effect vanishes if pollution is perfectly transboundary because shifted pollution causes as much damage to the domestic environment as does domestic pollution. The net effect on symmetric equilibrium taxes is negative, except in the special case of perfect competition with no transboundary pollution. In this case the two effects are mutually offsetting and the Nash equilibrium is efficient. When pollution is at least partially transboundary there also arises the usual transboundary externality and this reinforces the negative net strategic effect, giving rise to equilibrium taxes that are lower than what is globally efficient.

I. INTRODUCTION

Much of the popular opposition to trade liberalization is based on fears about its consequences for the environment.[2] Of particular concern in recent debate has been the possible strategic distortion of environmental policies for trade-related goals.[3] Most of the attention has focused on the possibility that trade liberalization will lead to lower environmental standards. It is argued that freer trade will lead governments to relax their environmental standards in order to gain a competitive edge over their trading partners. However, it is also possible that strategic distortions will operate in the opposite direction. Countries may raise environmental standards as a protectionist measure or as a means of driving out unwanted polluting production.[4] In either case, these strategic distortions are likely to detract from the gains to freer trade.

[1]I am grateful to Chris Green, Michael Hoel, Kathy Segerson, and two anonymous referees for useful comments and suggestions. Any errors in the paper are of course my own responsibility.

[2]For example, much of the popular opposition to the North American Free Trade Agreement is based on this concern. Similar arguments were made against the U.S.–Canada free trade agreement.

[3]This is of course not the only link between trade and the environment. See Copeland and Taylor [4] for a good discussion of non-strategic links.

[4]Tighter environmental standards can serve as a protectionist measure if the cost of compliance is higher for foreign suppliers than for domestic suppliers. For example, proposed German legislation that requires automobile makers to take back their expired cars for recycling has been criticized as a protectionist measure because it clearly favors domestic suppliers (*The Economist* [24]). Recycled paper content requirements in newsprint in the United States have been similarly criticized (Garbutt and Laplante [7]).

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This paper examines a particular aspect of this problem. Its purpose is to examine the strategic incentives to distort pollution taxes in free-trading economies. The model employed has three key features that allow strategic effects to be isolated and assessed for their welfare implications. First, the model assumes imperfect competition among producers. A significant part of world manufacturing trade takes place in imperfectly competitive markets, in which large multinational corporations are the main players. It is therefore often inappropriate to assume a competitive framework. In my model trade occurs between countries because the multinational firms based in those countries find it profitable to sell in foreign markets. This oligopolistic framework also allows me to abstract from the traditional bases for trade (such as comparative advantage) and focus on strategic effects.[5]

Second, the tax choice game between competing countries is modeled explicitly. This permits an examination of strategic tax distortions *in equilibrium*. This is crucial for gaining an understanding of the welfare implications of the distortions. It is sufficient to examine the optimal behavior of a single country in isolation only if that country alone has strategic power. Such an approach is inappropriate for studying a world in which large multinational firms from different countries compete for global markets.

Third, the model allows for transboundary pollution. This is important because it turns out that the size of the strategic distortions and associated welfare losses depends crucially on the degree to which pollution is transboundary. In particular, any incentive to raise taxes in order to drive out polluting firms will be heavily diluted if a significant part of that pollution flows back across the border. The model uses a single parameter to capture the extent to which pollution is transboundary and this permits the examination of a continuum of cases, from purely local pollution to perfectly transboundary pollution.

A number of other papers have examined pollution taxes in open economies.[6] Of these, the closest to my paper are Krutilla [10] and Markusen *et al.* [15]. Krutilla [10] examines the optimal pollution tax for a single large trading country facing competitive buyers and suppliers in the world market. Among a number of results, he shows that when tariffs and subsidies are not available, the optimal tax on polluting production will be distorted away from the standard Pigouvian level (at which the tax rate equals marginal damage). This is due to a terms-of-trade effect associated with the tax. If the country is a net exporter then the tax will have a favorable effect on the terms of trade and so it will be set above the standard Pigouvian level. Conversely, the tax will have an adverse terms-of-trade effect for a net importer and so the tax will be set below the Pigouvian level. My paper differs from that of Krutilla [10] in three key respects. First, it models the strategic interaction between two large trading countries and examines the equilibrium of that game. Second, it assumes imperfect competition in production and allows the trade pattern to be determined endogenously. In contrast, Krutilla assumes perfect

[5]To the extent that the "new trade theory" is best suited to explaining trade between developed countries, my analysis in this paper is most applicable to trade between similar developed countries, such as the United States and Canada and the countries of Western Europe.

[6]See Markusen [12, 13], Baumol and Oates [3],, Merrifield [16], Krutilla [10], Markusen *et al.* [14, 15], and Copeland and Taylor [4]. There is also a literature (Pethig [21], Asako [1], Siebert *et al.* [23], McGuire [17] and Baumol and Oates [3]) on trade-related effects of exogenously set pollution policy.

competition and specifies exogenously the pattern of trade. Third, my model allows for transboundary pollution while Krutilla assumes that pollution is purely local.

Markusen *et al.* [15] explicitly model the strategic interaction between two regions and the possible distortion of their pollution taxes.[7] A polluting monopolist chooses its plant locations in response to the equilibrium tax rates.[8] There is no transboundary pollution. Increasing returns to scale mean that small changes in tax rates can precipitate large welfare shifts if the firm relocates its plants in response to those changes. This important feature of their model necessitates the use of case-by-case analysis and numerical solution methods. In contrast, I assume fixed locations and constant returns to scale and employ marginal analysis. This allows the strategic interaction between countries to be examined at a finer level of decomposition and permits the examination of a continuum of industry structures, including perfect competition as a limiting case. It does however mean that the potentially important implications of increasing returns to scale that are examined by Markusen *et al.* [15] are not captured by my model.

The rest of this paper is organized as follows. Section II presents the model. Section III derives the efficient taxes as the solution to a global planning problem. This serves as a benchmark against which to compare the Nash equilibrium. The Nash equilibrium is then examined in Section IV. Section V discusses the results and Section VI concludes. The Appendix contains one proof.

II. THE MODEL

There are two identical countries, each producing a polluting homogeneous good x. Production in each country occurs within a symmetric oligopolistic industry with n firms. The entry of new firms is prevented by some sunk cost already incurred by established firms. The $2n$ firms compete freely in the two markets. Marginal production cost is constant and equal to the chosen level of pollution abatement θ. Output by a representative firm in country i is denoted y_i. This output is divided between home country sales y_i^{H} and foreign country sales y_i^{F}. Total production by country i firms is denoted Y_i. Production in country i generates pollution $Z_i = (Y_i/\theta_i)$ in country i, and a fraction $\alpha \in [0, 1]$ of this pollution also affects the other country.[9] If $\alpha = 0$ then pollution is purely local. If $\alpha = 1$ then pollution is perfectly transboundary.[10] Pollution generates environmental damage in country i according to the function $e_i = e(Z_i + \alpha Z_{-i})$, where a "$-i$" subscript denotes the other country. Damage is increasing and convex in pollution. The inverse demand for x in each country is $p(X_i)$, where X_i is the amount sold in country i.[11] The notational distinction between X_i and Y_i is

[7] There is also a substantial literature on destructive competition between regions in the quest to attract productive capital. Cumberland [5] and Oates and Schwab [19] examine this issue in an environmental context but neither paper explicitly models the game between regions.

[8] In an earlier paper, Markusen *et al.* [14] examine a related duopoly model without strategic interaction between the regions.

[9] It should be noted that consideration is confined to production-related pollution. The analysis of consumption-related pollution would undoubtedly yield different results.

[10] Note that the degree to which pollution is transboundary is entirely independent of the extent of trade. It is determined only by chemical and geographical factors.

[11] Note that this inverse demand function implies the absence of income effects. Equivalently, my analysis is partial equilibrium.

needed to allow for imports and exports. Welfare in each country is measured as the sum of consumer surplus and profit, less environmental damage. A pollution tax is the only policy instrument available.

III. EFFICIENT POLLUTION TAXES

The efficient solution is presented as a benchmark against which the Nash equilibrium can be compared. The planning problem is to set the taxes on pollution to maximize global welfare, given the equilibrium behavior of firms. It should be noted that the efficient taxes I derive here are not first-best. There are two market failures in this environment, pollution and imperfect competition, and the first-best solution can be achieved only with the use of a pollution tax *and* a production subsidy to address the under-production associated with the imperfect competition. I have ruled out a production subsidy (on the grounds that it is politically untenable), which means that the pollution tax will generally have to be set below its first-best level. The pollution taxes derived are therefore second-best, but nonetheless efficient *given* the limited availability of instruments. Since the countries are identical and since environmental damage is convex in pollution, it is sufficient to solve for a uniform tax.[12] The first step toward solving this problem is to characterize the industry equilibrium when all firms face the same tax rate.

Industry Equilibrium

The problem for the representative firm based in country i is

$$\max_{y_i^{\mathrm{H}}, y_i^{\mathrm{F}}, \theta_i} \; p(X_i) y_i^{\mathrm{H}} + p(X_{-i}) y_i^{\mathrm{F}} - \theta_i y_i - \tau(y_i/\theta_i), \tag{1}$$

where τ is the tax rate on pollution. Demand conditions are identical in the two countries so in equilibrium each firm will sell half its output in each country. The equilibrium first-order conditions therefore reduce to

$$p + yp'/2 = (\theta + \tau/\theta) \tag{2}$$

$$\tau/\theta^2 = 1, \tag{3}$$

where the i subscript has been omitted because τ is independent of i, and where $p \equiv p(X)$ and $p' \equiv p'(X)$. The second-order conditions are satisfied if $3p' + yp'' < 0$. This condition is henceforth assumed. Defining $t = \tau^{1/2}$, these conditions can be rewritten as $\theta = t$ and

$$p + yp'/2 = 2t, \tag{4}$$

where $2t$ is the after-tax marginal cost faced by the firm. The Nash equilibrium

[12] If damage is strictly concave in pollution and $\alpha < 1$ then it is not necessarily efficient to set a uniform tax. The efficient solution may be to concentrate all production in one country. Note that income transfers would generally be needed to support this solution as a cooperative equilibrium.

can be found by multiplying (4) by $2n$ and setting $ny = X$ to obtain

$$2np + Xp' - 4nt = 0. \tag{5}$$

The stability of this equilibrium is guaranteed by the constancy of marginal cost and the second-order condition for (1). Note that (5) implies the standard result that equilibrium price exceeds after-tax marginal cost by a factor inversely proportional to the number of firms:

$$p = 2t - Xp'/2n. \tag{6}$$

Differentiating (5) with respect to X and t yields

$$dX/dt = 4n/[(2n+1)p' + Xp'']. \tag{7}$$

This derivative is negative by the second-order conditions for (1).

The Planning Problem

The tax on pollution is chosen to maximize the welfare of a representative country, given the equilibrium behavior of firms embodied in (7). Welfare is equal to consumer surplus, plus profits, plus tax revenue, less environmental damage,

$$\begin{aligned} W &= \left[\int_0^X p(\tilde{X})\,d\tilde{X} - pX\right] + [pX - 2tX] + \tau X/t - e((1+\alpha)X/t) \\ &= \int_0^X p(\tilde{X})\,d\tilde{X} - tX - e((1+\alpha)X/t), \end{aligned} \tag{8}$$

since tax revenue is $\tau X/t = tX$. The second-order condition for (1) and the convexity of $e(\cdot)$ are sufficient to ensure that W is concave in t.[13] The first-order condition to the planning problem is

$$[p - t](\partial X/\partial t) - X = (1+\alpha)e'[t(\partial X/\partial t) - X]/t^2, \tag{9}$$

where $e' \equiv \partial e/\partial Z$. The LHS is marginal abatement cost. The RHS is marginal global damage. Note that marginal abatement cost has two components: the first term reflects the welfare cost of the reduced output associated with the tax, and the second term reflects the increased marginal cost of production. In a perfectly competitive market in which price is equal to the tax-inclusive marginal cost, (9) would reduce to $t^2 = e'(1+\alpha)$ or $\tau = e'(1+\alpha)$. That is, the tax would be set equal to marginal damage. In the competitive case, equilibrium price is set equal to social marginal cost and so the welfare cost of reducing pollution through reduced output is just balanced with the welfare cost of doing so with more abatement. In contrast, in an imperfectly competitive equilibrium, price is distorted above social marginal cost, so there is a strictly positive welfare cost associated with a reduction

[13]Note that there are a continuum of efficient production allocations when $\alpha = 1$ since location does not matter for environmental damage when $\alpha = 1$. However, there is a unique efficient tax rate when $\alpha = 1$, precisely because production location does not matter.

in output. This means that the efficient tax is set below marginal damage.[14] It is instructive to use (6) to rewrite (9) as

$$(t - e'(1 + \alpha)t) = Xp'\varepsilon/(\varepsilon - 1)2n, \tag{10}$$

where $\varepsilon \equiv (\partial Y/\partial t)t/Y$ is the elasticity of equilibrium output with respect to t. The RHS of (10) is negative for finite n so the optimal t^2 is less than $e'(1 + \alpha)$.[15]

IV. NASH EQUILIBRIUM

The governments in both countries will choose their tax rates knowing that the choice of the domestic tax rate will affect the world price and therefore affect production both in the home country and in the foreign country. This is the source of the strategic interaction between the two countries. Each country will choose its tax rate, taking as given the other country's tax rate and the equilibrium behavior of firms. It is important to note that the pollution tax is the only instrument available. In particular, the absence of an export subsidy or import tariff means that the pollution tax is forced to take on both pollution abatement and trade-related roles. This underlies the strategic distortion of the pollution taxes. In examining the equilibrium tax rates, I begin by characterizing the industry equilibrium when tax rates can differ.

Industry Equilibrium

The problem for the representative firm based on country i is the same as the problem in (1) except that τ is replaced with τ_i. The equilibrium first-order conditions are given by $\theta_i = t_i$ and

$$p + y_i p'/2 = 2t_i. \tag{11}$$

Multiplying (11) by n and setting $ny_i = Y_i$ then yield the aggregate reaction function for firms based in country i:

$$2np + Y_i p' = 4nt_i. \tag{12}$$

An analogous reaction function can be derived for firms based in the other country. Solving for the equilibrium yields

$$2np + p'X = 2n(t_i + t_{-i}), \tag{13}$$

[14]This result is well known for the monopoly case (see Lee [11], Barnett [2], and Oates and Strassmann [20]). To my knowledge, the oligopoly case has not been examined before.

[15]It is straightforward to show that if the planner has two instruments available, the pollution tax and a subsidy s on output (that can be financed with lump-sum taxes), then it will set $t^2 = e'(1 + \alpha)$ and $s = -Xp'/2n$. That is, it will correct the product market distortion with a subsidy and use the pollution tax to fully correct for the pollution externality. The first-best outcome cannot be achieved with a single instrument.

where $X = (Y_i + Y_{-i})/2$ is the equilibrium consumption in each country. Rearranging expression (13) yields

$$p = (t_i + t_{-i}) - Xp'/2n. \tag{14}$$

The equilibrium price reflects the two tax rates and the total number of firms in the world market. The equilibrium market share of firms based in country i also depends on the relative tax rates. To see this, substitute (14) into (12) to obtain

$$Y_i = X + 2n(t_i - t_{-i})/p'. \tag{15}$$

It will be shown later that this relationship between market share and relative tax rates creates a strategic incentive for each country to undercut the other country's tax rate, but some more preliminaries are needed first. Differentiating (13) with respect to X and t_i yields the effect of a unilateral change in t_i on domestic consumption in both countries:

$$\partial X/\partial t_i = 2n/[(2n + 1)p' + Xp'']. \tag{16}$$

This derivative is negative by the second-order conditions for profit maximization. The unilateral change in t_i will also change the distribution of total production between the two countries. The stability of the equilibrium ensures that $\partial Y_i/\partial t_i < 0$ and $\partial Y_{-i}/\partial t_i > 0$.[16] Note also that $(\partial Y_i/\partial t_i) + (\partial Y_{-i}/\partial t_i) = 2(\partial X/\partial t_i)$ since $Y_i + Y_{-i} = 2X$. These properties of the industry equilibrium are illustrated for the linear demand case in Fig. 1. R_i is the aggregate reaction function for firms based in country i. R_{-i} is the analogous reaction function for the other country. An increase in t_i causes cost to rise for country i firms, and this leads to an inward shift in R_i. Equilibrium production in country i falls and equilibrium production in the other country rises but by less than the fall in country i production. Total production therefore falls and the equilibrium world price rises.

Nash Equilibrium Taxes

Now consider the game between national governments. Each country chooses its tax rate to maximize domestic welfare, given the equilibrium behavior of firms and given the tax rate of the other country. Domestic welfare in the open economy is given by domestic consumer surplus, plus profits to domestic firms (gross of tax

[16]See Dixit [6] for the general result on comparative statics with respect to marginal cost in a stable Cournot oligopoly. To obtain the results explicitly for this particular model, differentiate (15) with respect to t_i to yield

$$\partial Y_i/\partial t_i = 4n/p' - 2n(\partial X/\partial t_i)\left[1 + [(t_i - t_{-i}) + Xp'/2n]p''/(p')^2\right],$$

which is easily shown to be negative. Deriving an expression analogous to (15) for Y_{-i} and differentiating with respect to t_i yields

$$\partial Y_{-i}/\partial t_i = -2n(\partial X/\partial t_i)\left[1 + [(t_{-i} - t_i) + Xp'/2n]p''/(p')^2\right],$$

which is necessarily positive.

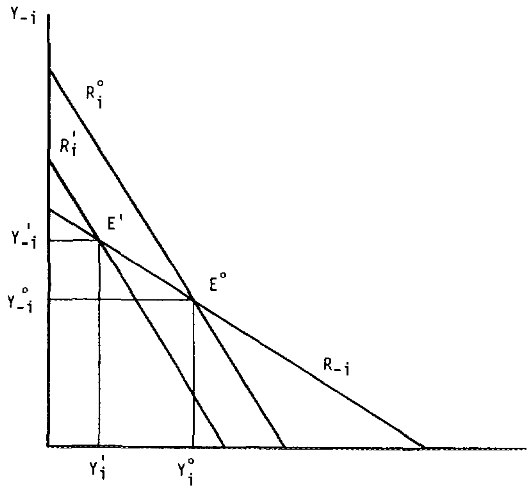

FIG. 1. The effect of a unilateral tax increase by country i.

payments), less domestic environmental damage:

$$W_i = \left[\int_0^X p(\tilde{X})\, d\tilde{X} - pX\right] + [pY_i - t_iY_i] - e(\alpha Y_{-i}/t_{-i} + Y_i/t_i). \quad (17)$$

It is instructive to rewrite this expression for welfare as

$$W_i = \left[\int_0^X p(\tilde{X})\, d\tilde{X} - t_iX\right] + [p - t_i][Y_i - X] - e(\alpha Y_{-i}/t_{-i} + Y_i/t_i). \quad (18)$$

This states that domestic welfare is equal to the sum of the social surplus on domestic consumption, plus the social surplus earned on net exports, less domestic environmental damage. Differentiating W_i with respect to t_i yields

$$\begin{aligned}\partial W_i/\partial t_i = {} & [p - t_i](\partial X/\partial t_i) - X \\ & + [p - t_i][(\partial Y_i/\partial t_i) - (\partial X/\partial t_i)] + [Y_i - X][p'(\partial X/\partial t_i) - 1] \\ & - \alpha e'(\partial Y_{-i}/\partial t_i)/t_{-i} - e'[t_i(\partial Y_i/\partial t_i) - Y_i]/t_i^2. \end{aligned} \quad (19)$$

Setting $\partial W_i/\partial t_i = 0$ with $t_i = t_{-i} = t$ and $Y_i = Y_{-i} = X$, yields the symmetric Nash equilibrium condition[17]

$$(t - e'/t) = Xp'\varepsilon_i/(\varepsilon_i - 1)2n + \alpha e'\varepsilon_{-i}/(\varepsilon_i - 1)t, \quad (20)$$

where $\varepsilon_i = (\partial Y_i/\partial t_i)t_i/Y_i$ and $\varepsilon_{-i} \equiv (\partial Y_{-i}/\partial t_i)t_i/Y_{-i}$. Comparing (20) with the efficiency condition in (10) clearly indicates that the Nash equilibrium will gener-

[17]Existence of equilibrium is assured only if t is bounded above zero. This restriction is needed for the competitive case with α close to one since in that case there is an incentive for each country to undercut any positive candidate equilibrium tax rate. This drives taxes toward $t = 0$ but this cannot be an equilibrium since it involves infinite pollution.

ally not be efficient. However, the direction of this inefficiency cannot be inferred directly from (10) and (20) since the elasticities in the two expressions are different. I use the following approach instead. I examine each country's unilateral incentive to deviate from the efficient taxes by evaluating the sign of $\partial W_i/\partial t_i$ at the efficient tax rates and the corresponding equilibrium production levels (a positive sign indicates an incentive to set a higher tax, and a negative sign indicates an incentive to set a lower tax). I then decompose the overall incentive into three separate effects. Let a "*" superscript henceforth denote values at the efficient solution. From (19),

$$\begin{aligned}\partial W_i/\partial t_i|_{t^*} = (p - t^*)(\partial Y_i/\partial t_i) - Y^* - \alpha e'(\partial Y_{-i}/\partial t_i)/t^* \\ - e'[t^*(\partial Y_i/\partial t_i) - Y^*]/(t^*)^2, \qquad (21)\end{aligned}$$

where $Y^* = Y_i^* = Y_{-i}^*$. To interpret this expression it is helpful to subtract $(\partial W/\partial t|_{t^*}) = 0$ from the RHS using (9) evaluated at t^*. Noting that $Y^* = X^*$, we then have

$$\begin{aligned}\partial W_i/\partial t_i|_{t^*} = (p - t^*)[(\partial Y_i/\partial t_i) - (\partial X/\partial t)|_{t^*}] \\ - e'[(\partial Y_i/\partial t_i) + \alpha(\partial Y_{-i}/\partial t_i) - (\partial X/\partial t)|_{t^*}]/t^* \\ + \alpha e'[t^*(\partial Y/\partial t)|_{t^*} - Y^*]/(t^*)^2, \qquad (22)\end{aligned}$$

where $[(\partial X/\partial t)|_{t^*}] = [(\partial Y^*/\partial t)|_{t^*}]$ is given by (7) evaluated at t^*.[18] Consider each of the RHS terms of (22) in turn. The third term represents the usual transboundary externality effect. It is clearly negative for $\alpha > 0$ and so tends to negatively distort the equilibrium tax rates from their efficient levels. Each country ignores the impact of the pollution created within its boundaries on the environment outside its boundaries, and tax rates therefore tend to be set lower than is globally efficient. If there is no transboundary pollution then $\alpha = 0$ and this term vanishes. It is important to stress that this source of inefficiency does not stem from the openness of the economies *per se*. The same transboundary pollution problem would persist in a noncooperative equilibrium between closed economies.

Next consider the first term in (22). This represents a *rent capture effect*. A unilateral change in a country's tax rate has a bigger effect on equilibrium domestic production than it does on equilibrium domestic consumption. The difference is reflected in a change in net exports. A unilateral reduction in the domestic tax rate therefore has the potential to raise net exports and so permit the capture of rent from foreigners. This rent can be viewed as comprising two parts. Recall that the value of net exports is

$$[p - t_i][Y_i - X] = [p - 2t_i][Y_i - X] + t_i[Y_i - X]. \qquad (23)$$

The first term in this expression represents the profits from net exports and the second term represents the tax revenue earned on net exports. Both contribute directly to domestic surplus. Note that the first term vanishes if the market is competitive because in that case price will be equal to the after-tax marginal cost.

[18]The two derivatives are necessarily equal at t^* because $X = Y, \forall t$, in the solution to the planning problem.

However, the tax revenue term does not vanish even with perfect competition. I will return to the competitive case later. Intuition suggests that the rent capture effect should be negative: each country will tend to undercut the other country's tax rate in an attempt to boost net exports. To see this, note from (7) and (15) that $(\partial X/\partial t) = 2(\partial X/\partial t_i)$ and recall that $2X = Y_i + Y_{-i}$. It follows that in (22), $[(\partial Y_i/\partial t_i) - (\partial X^*/\partial t)]|_{t^*} = -(\partial Y_{-i}/\partial t_i)|_{t^*}$. The rent capture effect can therefore be written as

$$RCE = -(p - t^*)(\partial Y_{-i}/\partial t_i)|_{t^*}. \tag{24}$$

This is clearly negative and so the rent capture effect tends to negatively distort the equilibrium tax rates from their efficient levels. Note that this distortion is a purely strategic effect arising directly from the openness of the economies. No rents are actually captured in equilibrium because both countries act symmetrically, but tax rates are distorted nonetheless. The distortions are therefore purely destructive.

This result lends some support to the argument that trade liberalization may lead countries to reduce their environmental standards in an attempt to gain a competitive edge over their trading partners. The pollution tax in this model raises marginal costs for the taxing country and so adversely affects the ability of its firms to compete for net exports. A competitive advantage (albeit one that evaporates in symmetric equilibrium) can be gained by reducing the tax.

At this point it is worth comparing the negative rent capture effect identified here with the terms-of-trade effect identified by Krutilla [10]. Krutilla (p. 132) shows that a large net-exporting country will set a production tax *above* the standard Pigouvian level. These apparently opposite results are in fact easily reconciled. The direction of trade in the Krutilla [10] model is determined exogenously by traditional factors such as comparative advantage. The taxing country's status as a net exporter (or net importer as the case may be) is not affected by marginal changes in the pollution tax. Moreover, the taxing country faces competitive buyers (or sellers). An exporting country therefore has an incentive to distort the pollution tax to act like an export tax and thereby extract monopoly rents from importing countries. In contrast, in my symmetric Cournot model, domestic firms tend to under-export in a free trade environment and there exists an incentive for the government to adopt a Stackelberg leader position by using an export subsidy. In the absence of such a subsidy, the pollution tax is negatively distorted to serve the same function.[19]

The rent capture effect is only the first of two such strategic effects. The second effect is captured by the second term in (22). It represents a *pollution-shifting effect* and it works in the opposite direction to the rent capture effect. A unilateral tax increase tends to shift production and its associated pollution to the other country. It is therefore possible to achieve a reduction in domestic pollution with a lower adverse impact on domestic consumption than would be possible in a closed economy. Of course the strategy is potentially effective only if pollution is not perfectly transboundary. If pollution is perfectly transboundary ($\alpha = 1$), then shifting production to the other country provides no relief for the domestic

[19] I am grateful to an anonymous referee for pointing out this interpretation of my result. It should also be noted that the result hinges on the assumption of Cournot conjectures and no entry or exit.

environment. In that case the pollution-shifting effect vanishes. For values of $\alpha < 1$ the pollution-shifting effect is strictly positive. To see this, rewrite the second term in (22) using the same transformations used to derive (24):

$$\mathrm{PSE} = e'(1-\alpha)\left[(\partial Y_{-i}/\partial t_i)|_{t^*}\right]/t^*. \tag{25}$$

It is clear from (25) that the pollution-shifting effect is positive when $\alpha < 1$ and so tends to positively distort the equilibrium tax rates away from their efficient levels. The effect is strongest when $\alpha = 0$ because none of the shifted pollution returns to damage the domestic environment. Like the rent capture effect, the pollution-shifting effect is a purely strategic effect that arises directly from the openness of the economies. It is also purely destructive. Pollution shifting yields no benefits in equilibrium because each country acts symmetrically but equilibrium taxes are nonetheless distorted in the attempt to shift pollution.

Markusen *et al.* [15] also identify a type of pollution-shifting effect in their model of endogenous plant locations. Among the equilibria they examine is one in which the two regions set their tax rates so high as to drive the polluting monopolist out of business, to the detriment of both regions. They refer to this as the NIMBY (not-in-my-backyard) equilibrium. Neither region wants the polluting plant in their backyard even though both regions could be better off (with compensating transfers) if the plant were established in one of the regions.[20]

The rent capture effect and the pollution-shifting effect operate in opposite directions, so the net strategic effect could potentially be either positive or negative. It turns out that the rent capture effect dominates the pollution-shifting effect except in one special limiting case. From (24) and (25) we have

$$\mathrm{RCE} + \mathrm{PSE} = -\left[(\partial Y_{-i}/\partial t_i)|_{t^*}\right]\left[(p - t^*) - e'(1-\alpha)/t^*\right]. \tag{26}$$

It is shown in the Appendix that this net effect is strictly negative except in the case of perfect competition with $\alpha = 0$. In that special case the second RHS term in (26) becomes $[t^* - e'/t^*]$ and this is zero by (10) when $\alpha = 0$ under perfect competition. Thus, there is no net strategic effect on taxes under perfect competition with $\alpha = 0$. The reason is clear. The two parts of the second term in (26) respectively represent the cost (foregone rent) and benefit (shifted pollution) of diverting production to the foreign country. Under perfect competition the foregone rent is simply the tax revenue t^*. When $\alpha = 0$ the private benefit from shifting pollution is equal to the domestic social benefit of reducing production, e'/t^*. This cost and this benefit are necessarily equal at the social optimum. Note that the usual transboundary externality also vanishes when $\alpha = 0$, so the Nash equilibrium is efficient in this special case. In all other cases the Nash equilibrium is inefficient and pollution taxes are too low. In particular, imperfect competition leads to a strictly negative net strategic effect even when $\alpha = 0$: the rent captured under imperfect competition exceeds the tax revenue and so must also exceed the benefits from shifting pollution. When $\alpha > 0$ the benefits of shifting pollution are even smaller and so the rent capture effect must continue to dominate. This net

[20] There is no transboundary pollution in their model but it is clear that if pollution is perfectly transboundary then the NIMBY equilibrium vanishes just as the pollution-shifting effect in my model vanishes when $\alpha = 1$.

TABLE I
The Direction of Distortions from Efficiency

	Imperfect competition			Perfect competition		
Effect	$\alpha = 0$	$0 < \alpha < 1$	$\alpha = 1$	$\alpha = 0$	$0 < \alpha < 1$	$\alpha = 1$
Rent capture	—	—	—	—	—	—
Pollution shifting	+	+	0	+	+	0
Net strategic	—	—	—	0	—	—
Transboundary pollution	0	—	—	0	—	—
Overall	—	—	—	0	—	—

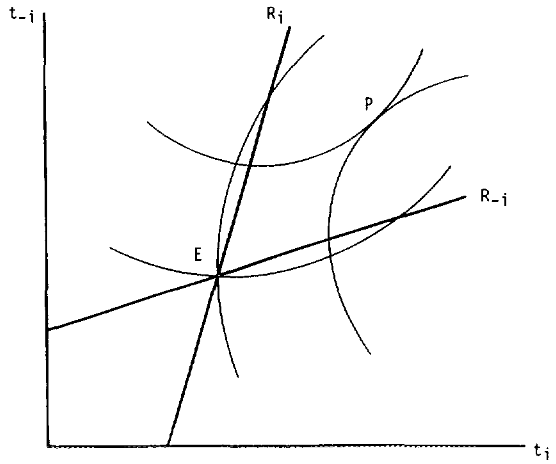

FIG. 2. The Nash equilibrium versus the efficient solution.

negative effect reinforces the usual transboundary externality in the $\alpha > 0$ case, giving rise to equilibrium taxes that are lower than is globally efficient.[21] These results are summarized in Table I.

The Nash equilibrium is illustrated in Fig. 2, where R_i and R_{-i} are the reaction functions for country i and the other country, respectively (represented as linear functions only for convenience). The symmetric Pareto-efficient taxes are determined by the tangency of the isowelfare contours at the point P. The Nash equilibrium occurs on the diagonal below P at point E where both countries have lower welfare. The Pareto-efficient point cannot be supported as a non-cooperative equilibrium because both countries have an incentive to defect from this point by reducing their taxes. At low values of α, R_i is relatively flat and R_{-i} is relatively steep so E is relatively close to P. This reflects the fact that the usual transboundary externality is weakest and the incentive to shift pollution is strongest when α is small. The divergence of E from P is greatest when $\alpha = 1$.

[21]The net strategic effect also tends to compound the environmental damage associated with the usual transboundary externality because the lower taxes lead to higher output.

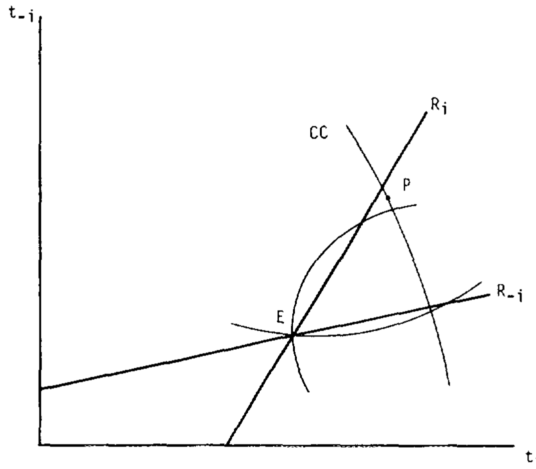

FIG. 3. The Nash equilibrium versus the efficient solution under asymmetry.

V. DISCUSSION

It is important to be clear about what the foregoing analysis does and does not show. It does indicate that there are strategic incentives to distort pollution taxes under free trade and that the benefits of free trade are unlikely to be fully realized in the absence of an accompanying agreement on environmental policy. There are clear mutual gains to such an agreement in my model. The strategic distortions are mutually destructive and both countries would be better-off by agreeing not to distort their policies. With complete information and perfect monitoring such an agreement may be reached and adhered to. In reality the outcome may be quite different.[22] Problems with monitoring and enforcability are likely to be further compounded by asymmetries between countries. Such asymmetries can mean that the first-best solution lies outside the core of the Nash equilibrium. In Fig. 2, the efficient point lies conveniently inside the core and can be reached without the need for compensating transfers. In contrast, an asymmetric case is illustrated in Fig. 3, where achieving optimality requires movement to a point P on the contract curve (CC) outside the core. A cooperative outcome is much less likely in such circumstances. This problem is of course well recognized with regard to trans-boundary externalities (Markusen [12], Hoel [8, 9]) but it is likely to be even more intractable with regard to purely strategic distortions of environmental policy.

The strategic distortion of policy under free trade is a problem that extends beyond environmental policy. I have merely focused on an environmental aspect of a more general issue. Imperfect competition in trade creates important strategic interactions between governments in almost all areas of policy. A free-trade agreement represents the coordination or harmonization of only a subset of those policies and there will generally arise strategic incentives to distort other policies (such as environmental policy) that have not been explicitly coordinated. It is possible that these distortions may seriously detract from the benefits of free trade.

[22] Witness the continuing absence of meaningful global agreements on greenhouse gases and biological diversity.

What this paper does *not* show is that a movement toward free or freer trade will lead to a lowering of environmental standards with a consequent reduction in welfare. I have compared the Nash equilibrium under free trade with a globally efficient cooperative outcome. I have not compared the Nash equilibria before and after trade liberalization. However, one can speculate that the strategic distortions associated with openness have the potential to be sufficiently destructive as to more than offset any benefits associated with trade liberalization.[23] An investigation of this issue is the subject of ongoing research.

VI. CONCLUSION

This paper has argued that imperfect competition in global markets creates strategic interaction between governments that can lead to the inefficient distortion of pollution taxes. This distortion can be decomposed into a rent capture effect and a pollution-shifting effect. The rent capture effect lowers equilibrium taxes as each country attempts to gain a competitive advantage over its trading partner and thereby capture foreign rent through net exports. The pollution-shifting effect raises equilibrium taxes as each country attempts to transfer production and its associated pollution to the other country. This effect vanishes if pollution is perfectly transboundary because shifted pollution causes as much damage to the domestic environment as does domestic pollution. The net effect on symmetric equilibrium taxes is negative, except in the special case of perfect competition with no transboundary pollution. In this case the two effects are mutually offsetting and the Nash equilibrium is efficient. When pollution is at least partially transboundary then there also arises the usual transboundary externality and this reinforces the negative net strategic effect, giving rise to equilibrium taxes that are lower than what is globally efficient.

APPENDIX

Proof of the negativity of the net strategic effect. Using (14) to substitute for p in (26) yields

$$\text{RCE} + \text{PSE} = \left[(\partial Y_{-i}/\partial t_i)|_{t^*}\right]\left[e'(1-\alpha)/t^* - (t^* - p'X^*/2n)\right].$$

Substituting from (10) and rearranging then yields

$$\text{RCE} + \text{PSE} = -\left[(\partial Y_{-i}/\partial t_i)|_{t^*}\right]\left[(t^* - e'(1+\alpha)/t^*)/\varepsilon + 2\alpha e'/t^*\right],$$

which is always negative for finite n or $\alpha > 0$.

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[23] In the context of the simple model used here, moving from a no-trade economy to a free-trade economy brings the benefits of increased competition; the net effect on welfare can be positive or negative. However, if n is large then welfare is unambiguously reduced.

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