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GAME MODELS OF ENVIRONMENTAL POLICY IN AN OPEN ECONOMY

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ABSTRACT

In this paper we study some aspects of the question of international environmental regulation from a game theoretic perspective. We address two broad questions. First, we examine the circumstances under which the pursuit of unilateral environmental policy by a country in a Stackelberg game, will make that country worse off. Second, we study the effects of environmental regulation by means of alternate price control instruments in a Stackelberg game where there is transboundary pollution.

We find that there are plausible theoretical circumstances in which the pursuit of unilateral environmental policy is not a good idea. Further, we show that in choosing between alternate pollution control instruments, national governments typically face a tradeoff between instruments which correct more distortions but are costly to implement and instruments which correct fewer distortions but are less costly to implement. In particular, we obtain a dominance result for a tariff policy; this result favors the use of tariffs from an informational standpoint alone.

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GAME MODELS OF ENVIRONMENTAL POLICY IN AN OPEN ECONOMY [1]

1. Introduction

In recent times, issues relating to the use and misuse of the environment have come to dominate debate in the public policy arena in most countries. International events such as the Earth Summit in Rio de Janeiro have only served to heighten public consciousness about the role of various nations in protecting the global environment. As a result, the myriad activities associated with the regulation of environmental externalities have come to attain greater significance than ever before.

In this paper, we study some aspects of the question of international environmental regulation from a game theoretic perspective. We address two broad questions. The first question concerns an examination of the conditions under which environmental policy, pursued unilaterally by a country in a Stackelberg game, will make that country worse off. Second, we study the effects of regulating environmental pollution via alternate means in a Stackelberg game when there is transboundary pollution.

The rest of the paper is organized as follows. In section 2, a detailed review is provided of the pertinent literature relating to the questions addressed in this paper. In section 3, the effects of unilateral environmental policy are discussed in a strategic context. In section 4, the analysis of section 3 is generalized to include the case of transboundary pollution. A natural question in such a context where one is concerned about the welfare effects of pollution control policy is the "choice of instrument" issue. The implications of controlling pollution in this setting are studied

[1] I thank Peter Berck and Larry Karp for their input; I alone am responsible for the output. This research has been supported by the USDA and the Giannini Foundation.

by means of alternate price instruments. The three price instruments which we consider are an import tariff (a trade policy instrument), a production tax (a domestic policy instrument) and a combination of the two instruments. Finally, in section 5, the salient findings are summarized.

2. International Pollution Regulation: A Synopsis of Findings

Previous researchers have studied questions related to ours. On the empirical front, in an early paper D'Arge and Kneese (1972) left the question of the effects of unilateral environmental controls open by demonstrating positive income effects for all countries being studied irrespective of whether environmental controls were instituted unilaterally or multilaterally. In another empirical study, Walter (1973, p. 68) came to the tentative conclusion that ". . . U.S. trade [would] be affected if the world's nations [adopted] different environmental standards and/or ways of implementing such standards." In a rather comprehensive empirical study of the effects of unilateral environmental controls in primarily the USA manufacturing sector, Leonard (1984) found little support for the industrial flight hypothesis. Similarly, Tobey (1990) has shown that the adoption of stringent environmental controls does not *per se* weaken a nation's comparative advantage in trade. On the other hand, Whalley (1991, p. 188) has argued that if ". . . indeed global policy responses to [environmental concerns such as] global warming are enacted, the consequences for . . . patterns of trade between regions, is likely to be severe." As this brief review of the empirical literature shows, a consensus on the empirical effects of environmental controls is yet to be achieved.

The theoretical literature is more uniform in its findings. Pethig (1976) and Asako (1979) have both shown that under certain conditions, when a nation's pollution intensive good is exported, increased trade can diminish that country's welfare. Siebert, Eichberger, Gronych, and Pethig (1980) have examined the relationship between environmental quality, environmental policy, and international trade in a two-country world in some detail. *Inter alia*, in a nonstrategic context, these authors have identified conditions for an increase in resource use in pollution abatement and a fall in national income in the pollution controlling country. In a somewhat different vein, McGuire (1982) has shown that in an open economy with factor mobility across countries, unilateral environmental regulation can drive the regulating country out of producing the regulated good.

Batabyal (1991) has studied the conditions under which environmental policy, pursued unilaterally by a large country will make that country worse off. Batabyal (1994) shows how a large developing country which is precluded from using its market power in trade can use its domestic tax structure optimally to attain environmental and trade policy objectives.

These two papers contain results regarding three variables of interest. First, it is shown that in a scenario with pollution, the terms of trade after taxation improve if and only if the marginal propensity to consume the polluting good in the taxing country exceeds the elasticity of supply of the same good. An implication of this result is that if the reverse condition holds, in a terms of trade sense, the taxing country can be *worse off.*

The second result concerns the post tax producer[2] price ratio in the taxing country. The expected result that the post tax producer price ratio in the taxing country should decline holds *only if* the taxing country's post tax terms of trade improve. If this last condition does not hold,

[2]Here, producer refers to the producer of the polluting good.

it is possible to obtain the perverse result in which the polluting good producers in the taxing country actually increase production owing to a rise in the price ratio faced by them!

The final result concerns the effect of the pollution tax on “environmentally adjusted” national income in the taxing country. The effect here is generally ambiguous. Collectively, the clear message of these findings is that plausible theoretical circumstances exist in which the unilateral conduct of environmental policy by a large country—in a nonstrategic context—can make that country worse off.

Felder and Rutherford (1993) have shown how unilateral actions taken by OECD countries can fail to reduce global CO_2 emissions to desirable levels because of free riding by nonparticipating nations. However, Hoel (1993) has argued that the harmonization of domestic carbon taxes in international climate agreements is not a good idea. He has suggested that an international carbon tax be used for the purpose of addressing problems such as global warming.

With regard to the question of pollution control (domestic and transboundary) in an imperfectly competitive economy, we note that general equilibrium or partial equilibrium models of trade with pollution are only beginning to be developed in a systematic fashion. In addition to the papers already cited, Markusen (1975a) has derived optimal taxes for pollution control when the incidence of pollution is international. His analysis, however, is conducted in a static competitive framework and hence does not address the important issues of imperfect competition, retaliation, and dynamics. In another paper, this time in an imperfectly competitive trade setting with an international externality, Markusen (1975b) has shown that the noncooperative Cournot outcome is not Pareto optimal. By comparing the noncooperative equilibrium and cooperative equilibrium, he has also shown that the cooperative imposition of national production taxes will not in general lead to a Pareto efficient outcome unless accompanied by transfer payments. Markusen, Morey, and Olewiler (1993) have studied the effects of environmental policy in a scenario with imperfect competition arising from increasing returns to scale. They show that pollution control policies can cause firms to close plants and/or shift production from one country to another. Hoel (1992) has analyzed a differential game model of global CO_2 emissions. He shows that although the Markov perfect equilibrium without taxes involves higher CO_2 emissions as compared to the open loop equilibrium without taxes, there exists a time path of CO_2 taxes which gives rise to the socially optimal rate of emissions in *both* the open loop and the Markov perfect equilibria.

In a paper that is rather similar to the present one in its motivation, Merrifield (1988) has studied the question of transboundary pollution control within the context of the USA-Canada acid deposition issue. Merrifield's analysis is static and conducted within a competitive framework. As a result, his analysis fails to take into account the strategic aspects of the USA-Canada acid deposition issue. Dockner and Long (1993) have studied the transboundary pollution control problem by formulating the problem as a differential game between two countries. They show that under certain circumstances cooperative pollution control policies can be supported *without* recourse to retaliation. However, they caution against excessive euphoria regarding this result because the number of assumptions needed to obtain this result is likely to diminish the practical relevance of the result. Rauscher (1991) has analyzed the relationship between international trade and environmental quality. He has shown that when environmental pollution is included in a trade model and a nation moves in the direction of free trade, the concomitant gains from trade are not necessarily positive anymore. Further, plausible circumstances exist in which a nation can actually improve its environmental quality by *lowering* its pollution emission tax. Conrad (1993) has constructed a model of international oligopoly and has shown how domestic welfare can be improved by governments. Such an improvement can be brought about by granting subsidies for pollution abatement efforts and/or for the use of polluting inputs.

Finally, the choice of alternate price instruments issue has been little studied. Very recently, a small number of researchers have begun to address this question theoretically and empirically. Ulph (1992) has shown that when international trade is modeled as a Stackelberg game and when both the producing countries have sufficiently small shares of world production, both countries do better when pollution is controlled by means of a standard by the follower. When trade is modeled as a Cournot game, once again the choice of standards by both countries dominates the choice of taxes. Conrad and Schroder (1991) have studied the resource costs of attaining a given level of environmental quality by means of emission standards, subsidies and emission taxes in an applied general equilibrium model. They have shown that the use of an emission tax involves the lowest resource cost, followed by subsidies and emission standards.

We now move onto the main analysis of this paper. In section 3 we examine the outcome of unilateral environmental policy in a Stackelberg game in which policy retaliation is allowed. In section 4, we generalize the game theoretic analysis of section 3 to the case where there is transboundary pollution.

3. The Imperfect Competition Model

3a. Preliminaries

There are two countries—A and B. In each country there is a government which chooses a tax to control pollution, a firm which produces a good for domestic and foreign consumption, and consumers who are affected by pollution differently and who buy on the domestic market from the A firm or the B firm. Further, there is a single good where production causes pollution in both countries. This good is denoted by q with the appropriate superscripts. The total quantity of the good in A is denoted by $Q^A = q^{AH} + q^{BX}$ where q^{AH} and q^{BX} denote the quantity produced by the A firm for home consumption and the quantity produced by the B firm for foreign consumption. We denote the pollution taxes by t^A and t^B, respectively. Note that the two countries are identical on the production side. The only difference between them arises from the fact that the constant marginal social disutilities of pollution in A and B are not necessarily equal.

In this paper we shall work with linear functional forms. However, even with the imposition of this additional structure, unambiguous results will, in general, not be forthcoming. Most of our results are in the form of inequalities. In certain cases, these inequalities can be easily understood, in other cases, the relevant inequalities are harder to interpret.

Recall that the A government levies a pollution tax on the production of the polluting good. We allow the B government to retaliate. Why does B retaliate? B retaliates due to two reasons. The first reason has to do with the fact that although there is pollution in B and B would like to control pollution, B is reluctant to undertake measures to do so unilaterally. A's actions give B a rationale for pollution prevention. Second, B retaliates because B fears that by allowing

A's actions to go unchallenged, B will be worse off owing to the perceived shift in the terms of trade in A's favor subsequent to the imposition of a pollution tax by A.[3] Note though that because the game being analyzed is a Stackelberg game, there is a clear asymmetry in the positions of A and B. A takes B's *reaction* as given whereas B takes A's *action* as given. Our goal is to characterize the optimal taxes and to explore the implications of such taxes in the equilibrium of a Stackelberg game.

3b. The Effects of a Pollution Tax

The total quantity of the good in A is $Q^A = q^{AH} + q^{BX}$ where q^{AH} is the quantity produced by the A firm for home consumption and q^{BX} is the quantity produced by the B firm for foreign consumption. Similarly, in B the total quantity on the market is $Q^B = q^{BH} + q^{AX}$. The inverse demand function in A is given by $P^A(Q^A) = a - Q^A$. The inverse demand function in B is $P^B(Q^B) = a - Q^B$. We can think of the intercept term "a" as the saturation level of demand in each country. That is, as the price approaches zero, the demand for the good approaches a.[4] The A and B firms have two kinds of costs; the cost of manufacturing the good and the cost associated with tax payment. The first cost for the A firm is given by $C^A(q^{AH}, q^{AX}) = c(q^{AH} + q^{AX})$ where c is the constant marginal cost. The second cost for the A firm is given by $t^A(q^{AH} + q^{AX})$. This second cost is what the government in A collects as tax revenues. The revenues are transferred to consumers in A in a lump sum manner so that the income distribution of consumers in A remains unaltered. Similarly, the B firm has two costs given by $C^B(q^{BH}, q^{BX}) = c(q^{BH} + q^{BX})$ and

[3]Batabyal (1991, 1994) has shown that in some circumstances, these concerns are legitimate.

[4]A more general specification for inverse demand would involve letting $P^A(Q^A) = a - b^A Q^A$, and $P^B(Q^B) = a - b^B Q^B$. For the purpose of analytical convenience, we have set $b^A = b^B = 1$.

$t^B(q^{BH} + q^{BX})$, respectively. The social welfare functions in A and B are given by $W^A(t^A, q^{AH}, q^{AX}) = (1/2)(Q^A)^2 + \pi^A(\bullet) + t^A(q^{AH} + q^{AX}) - v^A(q^{AH} + q^{AX})$ and $W^B(t^B, q^{BH}, q^{BX}) = (1/2)(Q^B)^2 + \pi^B(\bullet) + t^B(q^{BH} + q^{BX}) - v^B(q^{BH} + q^{BX})$, respectively, where $\pi^A(\bullet)$ and $\pi^B(\bullet)$ are the profit functions of each firm, and $v^A(\bullet)$ and $v^B(\bullet)$ are the national disutility from pollution functions. Thus, social welfare is the sum of consumer surplus,[5] firm profits, tax revenues, and the disutility from pollution, all measured in dollar terms.

The timing of the Stackelberg game is as follows. First, the governments in A and B choose t^A and t^B, respectively. Next, the A firm (the leader) chooses its quantities in the two markets taking as given the B firm's (the follower's) reaction. The B firm takes the A firm's action as given. Finally, the players receive their payoffs which are profits (π^A and π^B) for the two firms and social welfare (W^A and W^B) for the two governments. To find the Stackelberg equilibrium, we proceed in a manner analogous to the backwards induction method of solving extensive form games of the type being analyzed here (see Kreps, 1989, pp. 421-25).

Suppose that the two governments have chosen t^A and t^B. Then, if the 4-tuple (q_*^{AH}, q_*^{AX}, q_*^{BH}, q_*^{BX}) is a Nash equilibrium in the remaining game between the A firm and the B firm, it must be true that (q_*^{AH}, q_*^{AX}) solves

$$\max_{q^{AH} \in \Re_+, \, q^{AX} \in \Re_+} \pi^A(t^A, q^{AH}, q^{AX}, q_*^{BH}, q_*^{BX}) \tag{1a}$$

and that (q_*^{BH}, q_*^{BX}) solves

$$\max_{q^{BH} \in \Re_+, \, q^{BX} \in \Re_+} \pi^B(t^B, q^{BH}, q^{BX}, q_*^{AH}, q_*^{AX}) \; . \tag{1b}$$

[5] When the inverse demand function is $P^A(Q^A) = a - Q^A$, it is easily established that aggregate consumer surplus is given by $(1/2)(Q^A)^2$.

Now $\pi^A(\bullet)$ can be written as the sum of the A firm's profits on the two markets in which it sells its product. That is, $\pi^A = \pi^{AH} + \pi^{AX}$. Thus, we can write the A firm's original optimization problem as a pair of optimization problems.

Similarly, we note that $\pi^B = \pi^{BH} + \pi^{BX}$. Letting q_*^{BH} and q_*^{BX} be the solutions to the two B firm optimization problems, we can compute

$$q_*^{BH} = (1/2)(a - c - q_*^{AX} - t^B) \tag{2a}$$

and

$$q_*^{BX} = (1/2)(a - c - q_*^{AH} - t^B) \ . \tag{2b}$$

Using (2a) and (2b), we can compute the four best response functions. They are

$$q_*^{AH} = (1/2)(a - c + t^B - 2t^A) \ , \tag{3a}$$

$$q_*^{AX} = (1/2)(a - c + t^B - 2t^A) \ , \tag{3b}$$

$$q_*^{BH} = (1/4)(a - c + 2t^A - 3t^B) \ , \tag{3c}$$

$$q_*^{BX} = (1/4)(a - c + 2t^A - 3t^B) \ . \tag{3d}$$

Note that $q_*^{AH} = q_*^{AX}$ and that $q_*^{BH} = q_*^{BX}$. Having solved the second-stage game between the two firms, we can now solve the first-stage game between the two governments. The A government solves

$$\max_{t^A \in \Re_+} (1/2)(Q^A)^2 + \pi^A(\bullet) + t^A(q_*^{AH} + q_*^{AX}) - v^A(q_*^{AH} + q_*^{AX}) \tag{4a}$$

and the B government solves

$$\max_{t^B \in \Re_+} (1/2)(Q^B)^2 + \pi^B(\bullet) + t^B(q_*^{BH} + q_*^{BX}) - v^B(q_*^{BH} + q_*^{BX}) \tag{4b}$$

Solving (4a) and (4b) we get as our solutions

$$t_*^A = (1/14)(3c - 3a + t^B + 16v^A) \tag{5a}$$

and

$$t_*^B = (1/11)(7c - 7a - 6t^A + 24v^B) \ . \tag{5b}$$

Equations (5a) and (5b) give us the equilibrium taxes in the Stackelberg game. Note that $t_*^A \neq t_*^B$. The underlying strategic aspect of this Stackelberg game is captured by the interdependent equilibrium taxes of each government. In the sense of Bulow, Geanakoplos, and Klemperer (1985), each firm treats the output of its competing firm as a "strategic substitute." Using the tax expressions given by (5a) and (5b), the equilibrium outcome of this pollution tax game is given by

$$q_*^{AH} = q_*^{AX} = (1/154)(61a - 61c - 42t^A - 11t^B - 176v^A + 168v^B)$$

and

$$q_*^{BH} = q_*^{BX} = (1/308)(191a - 191c + 126t^A + 11t^B + 176v^A - 504v^B) \ .$$

We can now compare the posttax equilibrium with the status quo equilibrium, i.e., the equilibrium with no policy intervention. In A, consumer surplus with the tax ≤ consumer surplus without a tax iff $\{t^B + 2t^A\} \geq 0$. Similarly, the posttax profits of the A firm ≥ the pretax profits iff $\{a^2 + 4at^B - 8at^A - 6ct^B + 8ct^A - 8t^At^B + 4(t^B)^2 + 8(t^A)^2\} \geq 2c^2$. In B, consumer surplus with the tax ≤ consumer surplus without the tax as $\{2t^A + t^B\} \geq 0$. Profits for the B firm with the tax ≥ profits without the tax as $\{4at^A - 6at^B - 5ct^A + 8ct^B + 4(t^A)^2 - 12t^At^B + 9(t^B)^2\} \geq 0$. First, we note that the posttax consumer surplus in A and B almost certainly declines. The intuition for this result lies in recognizing that for the linear demand function that we have been using, consumer surplus is monotonically increasing in total market output; this output almost certainly declines with the imposition of the tax. Second, the effect of the tax on profits in A and B is ambiguous. The key variables here would appear to be the magnitude of t^A and t^B. Third, from (3a) to (3d), we see that the marginal impact on the A firm's output resulting from an increase in the A tax is less than the marginal impact on the B firm's output resulting from a similar increase in the B tax. This is what one would expect from the fact that the order of moves in the second stage of this game is sequential rather than simultaneous.

We conclude this section by noting that the unilateral pursuit of environmental policy is *not* necessarily a desirable goal for A. The *same* can be said of B (the following country) as well. Consumers will, most likely, lose with the conduct of unilateral environmental policy. Further, the post policy A and B firm profits may also be lower. We now analyze the case of transboundary pollution in a Stackelberg game.

4. The Imperfect Competition Model With Transboundary Pollution

4a. Preliminaries

In this section we analyze the efficacy of alternate pollution control instruments when there is transboundary pollution. The two governments in A and B are restricted to choosing between a domestic policy instrument (a production tax), a trade policy instrument (an import tariff), and a combination of these two instruments (the joint policy instrument). Since the underlying issues are now fairly involved, before studying the implications of the three policy regimes, we first discuss the issues intuitively.

The first issue concerns world welfare. When there are a number of distortions present in the world economy (these are discussed below) and national governments attempt to correct for these distortions by means of the instruments mentioned above in a *noncooperative* game, the ensuing equilibria are typically optimal in a myopic sense. That is, while individual country welfare is maximized by the respective governments, world welfare need not be. This stems from the noncooperative nature of the underlying game being played by the parties concerned. In some sense, the "correct" taxes and tariffs are those which arise from coordinated play by the respective governments. Practically, this involves coordination of environmental policy by *all* the players involved. This is something that is not only fairly well understood by economists but also something that one typically does not observe for a variety of well-known reasons.[6] It is worth noting that all of our subsequent results are myopic in the sense of this discussion.

In determining which policy instrument to adopt, the government of each country will attempt to weigh the effects of a particular policy on the three underlying distortions that are present in our two-country world. First, there is the pollution distortion. A production tax will reduce pollution by reducing the output of the good which causes pollution. However, this only reduces domestic pollution but does not do anything to reduce foreign pollution. An import tariff, on the other hand, reduces foreign pollution by making the posttariff purchase of the foreign good undesirable and by increasing the costs of foreign producers. However, since the amount of pollution that is reduced by means of a tariff is probably less than the amount of pollution reduced by means of a production tax, as far as the pollution distortion is concerned, an optimally calculated production tax is likely to be the superior policy instrument of the two considered so far.[7] The joint policy instrument would curb *both* domestic and foreign pollution. Therefore, as far as the pollution distortion *alone* is concerned, of the three instruments under consideration, *ex ante*, this instrument would appear to be the best means of pollution control.

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[6]See Batabyal (1993) for a discussion of this and related issues.

[7]Clearly, the actual answer depends on the elasticities of the relevant functions.

The second distortion concerns the domestic share of total output. In general, the monopolistic firm in each country will not sell the “correct” amount in the home market. In determining which policy instrument to adopt, the two governments would presumably like to increase the domestic market share of total good production and hence reduce imports. By discouraging the purchase of the foreign good, an import tariff would certainly increase the domestic market share of total output. A production tax on the other hand would not achieve this goal since a production tax would unambiguously curtail all domestic production. The joint policy instrument can be expected to result in total domestic output which is bounded below by the tax output and above by the tariff output. Thus, as far as this distortion is concerned, *ex ante*, a tariff would appear to be the best policy instrument.

The third distortion concerns monopoly rents. The second stage game in this model is a game between two monopolists earning *supra* normal economic rent. The government in each country would presumably like to capture some of this rent. By collecting some of the revenue which otherwise would have gone to the foreign monopolist, each government can capture some of this monopoly rent by means of an import tariff. An appropriately set production tax can also transfer some of the surplus collected by the home monopolistic firm to the government setting the tax. The joint policy instrument can also be expected to have the same qualitative impact as a tariff or a tax except that its quantitative impact will certainly be different. Thus, as far as this distortion is concerned, all three policy instruments can work in the right direction. We see that, in general, the properties of the three instruments are likely to be quite different. We now formally analyze the related questions of the effects of environmental policy and the choice of policy instrument issue in a Stackelberg game.

4b. The Control of Transboundary Pollution

We first study the import tariff case. In the Stackelberg tariff game, the second stage is characterized by sequential moves, first by the A firm (the leader) and then the B firm (the follower). The notation used here is the same as in section 3 except the tariffs levied by the two countries are now denoted by r^A and r^B, respectively. Writing B firm's profit-maximization problem as the sum of two separate profit-maximization problems and letting $q_*^{BH} \equiv \text{argmax}_{q^{BH}}\left\{q^{BH}\left(a - q^{BH} - q_*^{AX} - c\right)\right\}$ and $q_*^{BX} \equiv \text{argmax}_{q^{BX}}\left\{q^{BX}\left(a - q^{BX} - q_*^{AH} - c - r^A\right)\right\}$ we have

$$q_*^{BH} = (1/2)(a - c - q_*^{AX}) \tag{6a}$$

and

$$q_*^{BX} = (1/2)(a - c - q_*^{AH} - r^A)\ . \tag{6b}$$

Using (6a) and (6b), we can compute the four best response functions. They are

$$q_*^{AH} = (1/2)(a - c + r^A)\ , \tag{7a}$$

$$q_*^{AX} = (1/2)(a - c - 2r^B)\ , \tag{7b}$$

$$q_*^{BH} = (1/4)(a - c + 2r^B)\ , \tag{7c}$$

$$q_*^{BX} = (1/4)(a - c - 3r^A)\ . \tag{7d}$$

Equations (7a) through (7d) tell us the equilibrium quantities which will be produced by the A firm and the B firm in the home and in the export markets.

In the first stage of the two-stage game, the A and B governments solve

$$\max_{r^A \in \mathfrak{R}_+} (1/2)(Q^A)^2 + \pi^A(\bullet) + r^A q_*^{BX} - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX}) \tag{8a}$$

and

$$\max_{r^B \in \Re_+} (1/2)(Q^B)^2 + \pi^B(\bullet) + r^B q_*^{AX} - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX}), \qquad (8b)$$

respectively. The solutions to (8a) and (8b) are given by

$$r^A = (1/19)(5a - 5c - 8v^A + 12v^B) \qquad (9a)$$

and

$$r^B = (1/10)(a - c - 8v^A + 2v^B) . \qquad (9b)$$

The important aspect of the above solutions is that (9a) is independent of r^B and (9b) is independent of r^A. In other words, choosing tariffs given by (9a) and (9b) constitutes *dominant* strategies for the A and B governments. This is a rather strong finding; it tells us that *irrespective* of what one country is doing, it is always in the interest of the second country to set a tariff given by (9a) or (9b). This dominance result is due to: (a) the asymmetric incidence of tariffs in the relevant objective functions (compare (8a) with (11a) for instance), and (b) our use of linear functional forms. In more complicated models, this dominance result may or may not hold. Using (9a) and (9b), the four equilibrium quantities can be computed. The equilibrium outcome of this tariff game is given by

$$q_*^{AH} = (1/58)(29a - 29c - 16v^A + 24v^B),$$

$$q_*^{AX} = (1/10)(4a - 4c + 8v^A - 2v^B),$$

$$q_*^{BH} = (1/10)(3a - 3c - 4v^A + v^B),$$

$$q_*^{BX} = (1/19)(a - c + 6v^A - 9v^B),$$

(9a), and (9b).

We can now compare the posttariff outcome with the status quo outcome in the two countries. In country A, the status quo consumer surplus $\geq$ the post tariff consumer surplus as $0 \geq r^A$. The A firm's status quo profits $\geq$ its profits with the tariff as

$$\{a^2 + c^2\} \geq \{3ar^A - 2(r^A)^2 - 2ar^B + 2cr^B - 3cr^A - 6r^A r^B + 4(r^B)^2\} .$$

In country B, the status quo consumer surplus $\geq$ the post tariff consumer surplus as $0 \geq r^B$ and the status quo profits for the B firm $\geq$ its profits with the tariff as

$$0 \;\geq\; \{4ar^B - 4cr^B - 6ar^A + 6cr^A + 9(r^A)^2\} \;.$$

Recall that for the linear inverse demand function, consumer surplus is monotonically increasing in Q^A and Q^B, respectively. Thus, the posttariff consumer surplus in both nations declines as long as the two tariffs are positive. The effect of the tariff on firm profits is ambiguous.

Moving onto the Stackelberg tax game, the B firm's reaction functions are $q_*^{BH} = (1/2)(a - c - q_*^{AX} - t^B)$ and $q_*^{BX} = (1/2)(a - c - q_*^{AH} - t^B)$. Using these two expressions, the four equilibrium quantities are given by

$$q_*^{AH} \;=\; q_*^{AX} \;=\; (1/2)(a - c + t^B - 2t^A)\,, \tag{10a}$$

and

$$q_*^{BH} \;=\; q_*^{BX} \;=\; (1/4)(a - c + 2t^A - 3t^B)\;. \tag{10b}$$

The A government solves

$$\max_{t^A \in \Re_+} (1/2)(Q^A)^2 + \pi^A(\bullet) + t^A(q_*^{AH} - q_*^{AX}) - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX}) \tag{11a}$$

and the B government solves

$$\max_{t^B \in \Re_+} (1/2)(Q^B)^2 + \pi^B(\bullet) + t^B(q_*^{BH}\; q_*^{BX}) - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX})\;. \tag{11b}$$

Making the usual simplifications, simplifying the maximands, and differentiating (11a) and (11b) with respect to t^A and t^B, respectively, we get

$$t^A \;=\; (1/14)(3c - 3a + t^B + 16v^A - 8v^B) \tag{12a}$$

and

$$t^B \;=\; (1/11)(7c - 7a - 6t^A - 16v^A + 24v^B)\;. \tag{12b}$$

We see that, as contrasted to the tariff game, the choice of taxes in this game does *not* constitute a dominant strategy for either government. We shall have more to say about this when we discuss the merits of controlling pollution via the three instruments under consideration. For the moment, we note that the equilibrium outcome of this tax game is given by

$$q_*^{AH} = q_*^{AX} = (1/154)(61a - 61c - 42t^A - 288v^A - 11t^B + 256v^B),$$

$$q_*^{BH} = q_*^{BX} = (1/308)(191a - 191c + 11t^B + 512v^A - 592v^B + 126t^A),$$

(12a), and (12b).

Performing the usual comparative exercise, we see that the status quo consumer surplus in A $\geq$ the post tax consumer surplus iff $0 \geq \{t^B + 2t^A\}$ holds. The A firm's posttax profits $\geq$ the status quo profits iff

$$\{4ct^A - 4at^A + 20(t^A)^2 + (t^B)^2 + 2at^B - 2ct^B - 4t^At^B\} \geq 0 .$$

In country B, the status quo consumer surplus $\geq$ the posttax consumer surplus iff $0 \geq \{t^B + 2t^A\}$ holds and the B firm's posttax profits $\geq$ its status quo profits as

$$\{4at^A - 6at^B - 4ct^A + 6ct^B - 12t^At^B + 9(t^B)^2 + 4(t^A)^2\} \geq 0$$

holds.

We now analyze the equilibrium tariffs and taxes when the A and B governments use a combination of an import tariff and a production tax to control pollution. The four best response functions are

$$q_*^{AH} = (1/2)(a - c + r^A + t^B - 2t^A), \qquad (13a)$$

$$q_*^{AX} = (1/2)(a - c + t^B - 2r^B - 2t^A), \qquad (13b)$$

$$q_*^{BH} = (1/4)(a - c - 3t^B + 2r^B + 2t^A), \qquad (13c)$$

$$q_*^{BX} = (1/4)(a - c - 3r^A - 3t^B + 2t^A) . \qquad (13d)$$

The A government solves

$$\max_{r^A \in \Re_+, t^A \in \Re_+} (1/2)(Q^A)^2 + \pi^A(\bullet) + r^A q_*^{BX} + t^A(q_*^{AH} + q_*^{AX}) - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX}), \tag{14a}$$

and the B government solves

$$\max_{r^B \in \Re_+, t^B \in \Re_+} (1/2)(Q^B)^2 + \pi^B(\bullet) + r^B q_*^{AX} + t^B(q_*^{BH} + q_*^{BX}) - v^A(q_*^{AH} + q_*^{AX}) - v^B(q_*^{BH} + q_*^{BX}) . \tag{14b}$$

The solutions to (14a) and (14b) are

$$r^A = (1/19)(a - c - 7t^B + 26t^A - 8v^A + 12v^B), \tag{15a}$$

$$t^A = (1/16)(13a - 13c + 13r^A + t^B - 8r^B - 16v^A - 8v^B), \tag{15b}$$

$$r^B = (1/10)(3a - 3c + 3t^B + 14t^A + 8v^A + 4v^B), \tag{15c}$$

$$t^B = (1/11)(7c - 7a + 6r^B - 6t^A + 6r^A - 16v^A + 24v^B) . \tag{15d}$$

Using (15a) through (15d) we can determine the four equilibrium quantities. They are

$$q_*^{AH} = (1/3344)(2021c - 2021a - 825t^B + 1376t^A + 208v^A + 6376v^B + 2584r^B - 1805r^A),$$

$$q_*^{AX} = (1/880)(819c - 819a - 475t^A - 319t^B + 680r^B - 464v^A + 1048v^B - 1322t^A),$$

$$q_*^{BH} = (1/1760)(2259a - 2259c - 1160r^B + 1952t^A - 5r^A + 1744v^A - 2968v^B + 319t^B),$$

and

$$l_*^{BX} = (1/6688)(7317a - 7317c - 19r^A + 2057t^B - 4408r^B - 6064v^A - 15784v^B + 2736t^A)$$

This completes the determination of the equilibrium tariffs, taxes, and quantities.

We first compare the outcome of the tariff game with the outcome of the tax game for country A. Algebra reveals that consumer surplus with a tariff ≤ consumer surplus with a tax iff $r^A \geq \{t^B + 2t^A\}$ holds. The A firm profits in the tax game ≥ its profits in the tariff game if and only if

$$\{a^2 + c^2 - 8at^A + 8ct^A + 40(t^A)^2 + 2(t^B)^2 + 4at^B - 4ct^B - 8t^At^b\}$$

$$\geq \{3ar^A - 2(r^4)^2 - 2ar^B + 2cr^B - 3cr^A - 6r^Ar^B + 4(r^B)^2\}$$

holds. Similarly in country B, consumer surplus in the tariff game $\leq$ the consumer surplus in the tax game as $2r^B \geq \{2t^A + t^B\}$. The B firm's profits in the tax game $\geq$ the profits in the tariff game as

$$-12at^B - 8ct^A + 12ct^B - 24t^At^B + 18(t^B)^2 + 8(t^A)^2\} \geq \{4ar^B - 4cr^B - 6ar^A + 6cr^A + 9(r$$

Clearly, the conditions determining the effect of the tariff and the tax on firm profits are difficult to interpret intuitively. However, the results are understood by recalling that consumer surplus is monotonic in total output.

With regard to the efficacy of the joint policy instrument, we note that consumer surplus in A with the joint policy $\leq$ the status quo consumer surplus iff $\{r^A + t^B + 2t^A\} \geq 0$. Further, compared to the other two policies, the joint policy A consumer surplus $\leq$ the consumer surplus with the tariff only policy iff $\{r^A + t^B + 2t^A\}^{\text{Joint Policy}} \geq \{r^A\}^{\text{Tariff}}$ and $\leq$ the consumer surplus with the tax-only policy as $\{r^A + t^B + 2t^A\}^{\text{Joint Policy}} \geq \{t^B + 2t^A\}^{\text{Tax}}$. On the other hand, in country B the joint policy consumer surplus $\leq$ the status quo consumer surplus iff $\{t^B + 2r^B + 2t^A\} \geq 0$, and the joint policy consumer surplus $\leq$ the tariff only policy as $\{2r^B + t^B + 2t^A\}^{\text{Joint Policy}} \geq \{2r^B\}^{\text{Tariff}}$. Finally, the joint policy consumer surplus $\leq$ the tax only policy as $\{t^B + 2r^B + 2t^A\}^{\text{Joint Policy}} \geq \{2t^A + t^B\}^{\text{Tax}}$.

An initial examination of the above results suggests that the choice of instrument issue is hopelessly tangled. However, a few useful insights can still be gained. First, notice that the choice of tariffs given by (9a) and (9b) constitute dominant strategies for the two governments. Such is not the case as far as the equilibrium taxes or the equilibrium joint policy instruments are concerned. This biases the choice issue in favor of tariffs in the sense that pollution control can now be achieved by A, for instance, independent of what B does. Practically, this substantially reduces the informational requirements of pollution control. As long as a government knows the parameters of the various relevant functions in its *own* country, it can set an optimal tariff. There is no need to know or guess the second country's actions. With a production tax or with the joint policy instrument, the informational requirements are greater.

Second, when the instrument choice question is restricted to one between the tariff and the tax, we see that consumers in A are indifferent between the two means of pollution control when $r^A = t^B + 2t^A$. At this point of indifference, assuming that $t^B > 0$, the magnitude of the tariff in A exceeds the magnitude of the tax in A and the tax in B. We can expect the A firm to lobby the A government for a tariff against the B firm rather than be subjected to a tax. The B firm, on the other hand, would prefer a tax in A rather than have q^{BX} subjected to a tariff. The government in A will prefer the tariff to the production tax iff social welfare with the tariff exceeds social welfare with the tax. When $r^A < t^B + 2t^A$, consumers are worse off with a tariff than they are with a tax. Simple algebra tells us that the tariff which makes consumers worse off is bigger than the tariff which makes consumers indifferent between the tariff policy and the tax policy. Similarly, it is easily seen that the magnitude of the tax which makes consumers worse off is bigger than the magnitude of the tax which makes consumers indifferent between a tariff policy and a tax policy. Analogous results hold for country B as well.

Of the three instruments under consideration, the informational requirements of the joint policy instrument are the greatest. For instance, from (15a) through (15d), we see that in order to set r^B and t^B optimally, the B government must know both t^A and r^A and t^A, respectively. While the joint policy instrument is probably the most desirable in terms of correcting the different distortions alluded to in section 4a, its implementation, given its informational requirements, is likely to be very costly. This completes our discussion of the instrument choice question.

5. Conclusions

In this paper we have studied a number of important issues concerning optimal environmental regulation in an open economy from a game theoretic perspective. Before we summarize our principal findings, a few brief comments about the models used.

First, the models can be used to study the environmental policy formation process between trading entities such as the USA and EEC. In this case, assuming that the USA behaves as a Stackelberg leader, substitute USA for A and EEC for B. Alternatively, these models can be used to study why the policy response in large developing countries (LDCs), such as Brazil and India to environmental externalities is slow if not altogether nonexistent. In this case, one possibility would be to substitute LDC for A. With suitable alterations, other applications come to mind.

Second, the model can be made richer by making it truly dynamic and by explicitly incorporating uncertainty into the decision-making process. Alternatively, one may attempt to formulate a game with certain desired properties. This is a problem in mechanism design.

To recapitulate, after reviewing some of the previous research in this area, we explored the desirability of implementing environmental policy unilaterally in a strategic setting. In a Stackelberg game, we showed that there exist theoretical circumstances in which going it alone is *not* a good idea for the leading country. Further, the results are less than sanguine for the following country as well.

We then studied a Stackelberg game model of transboundary pollution. We considered in considerable detail, the important issue of prices versus prices, i.e., the merits of pollution control by means of an import tariff (a trade policy instrument), a production tax (a domestic policy instrument), and a joint policy instrument. Recognizing the impossibility of resolving the choice issue without considerable additional structure, we identified several conditions, in the form of inequalities, which determine whether consumers and producers are likely to gain or lose from the pursuit of a specific policy. A basic issue faced by the two governments concerned the tradeoff between policy efficacy on the one hand and the cost of policy implementation on the other. Indeed, as George Moore once said, “The difficulty in life is the choice.”

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