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A BERTRAND MODEL OF TRADE AND ENVIRONMENTAL POLICY IN AN OPEN ECONOMY†

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Abstract: We analyze environmental policy in a two country world in which national governments and polluting firms behave strategically. Two general issues are examined. First, we specify the conditions under which the pursuit of one-sided environmental policy by a country in a Bertrand game, will immiserize that country. Second, we examine the effects of pollution control by means of alternate price control instruments in a Bertrand game in which national governments care about global pollution but polluting firms do not. We find that there are reasonable circumstances in which the conduct of one-sided environmental policy is immiserizing. Next, we show that when the two countries are similar, the joint policy instrument is the most desirable pollution control instrument. However, when the two countries are dissimilar, there is no clear answer as to which control instrument is the most desirable.

JEL Classification Number: F12, Q28
Key words: Bertrand game, environmental policy, international trade

1. INTRODUCTION

A number of recent world events have effectively enhanced public consciousness about the role of nations in protecting the world's environmental resources. As a result, national governments are now actively involved in a variety of environmental issues.

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One such issue that has dominated public debate concerns the nexus between international trade and the environment. In this paper, we conduct a game-theoretic analysis of environmental policy in a two country world. There are two specific questions that we examine. First, given that the incidence of pollution is domestic, under what conditions will one-sided or unilateral environmental policy, pursued by one country in a Bertrand game, make that country worse off? Second, once again in the context of a Bertrand game, suppose that both national governments are affected by international pollution, but polluting firms in the two nations are not. In this situation, what are the pros and cons of controlling pollution by means of alternate price control instruments? Our study of this second question will require us to focus on a phenomenon that Batabyal (1998) and Xu and Batabyal (2001) have called caring behavior by national governments.

The rest of this paper is arranged as follows. Section 2 contains a review of the literature. Section 3 sets up the game-theoretic model and discusses the effects of one-sided environmental policy when the incidence of pollution is domestic. Section 4 examines environmental policy when the two national governments care about international pollution. Here, specific attention is paid to the efficacy of pollution control with three different price control instruments. These are an import tariff (a trade policy instrument), a production tax (a domestic policy instrument), and a combination of these two instruments (the joint policy instrument). Section 5 concludes and offers suggestions for future research.

2. LITERATURE REVIEW

2.1. *One-sided environmental policy*

In early contributions, Pethig (1976) and Asako (1979) showed that under certain conditions, when a nation's pollution intensive good is exported, increased trade can decrease that nation's welfare. In a two country world, Siebert *et al.* (1980) analyzed the nexuses between environmental policy, environmental quality, and international trade. In a non-game setting, these researchers identified conditions in the pollution controlling nation that call for an increase in resource use in pollution abatement and a decline in national income. Analyzing related issues, McGuire (1982) showed that if there is factor mobility across nations, then in the presence of international trade, one-sided pollution control can result in the non-production of the polluting good in the controlling nation. Krutilla (1991) studied environmental control by a large country in an open economy. He showed that when a commodity is exported and the externality under consideration is a production externality, "even if some uncertainty exists about the ... calculation of the optimal tax policy, the environmental authority can take an incremental regulatory step (from a no-regulation baseline) and be confident that social welfare will improve" (Krutilla, 1991, p. 140).

Batabyal (1993, 1996) analyzed the conditions under which one-sided environmental policy will make a large country worse off. In a non-game setting, Batabyal (1993) showed that the post-policy terms of trade of a country may decline. In other words, it is possible for a country to immiserize itself with its *own* environmental policy. In a later paper, Batabyal (1996) examined the strategic effects of environmental policy in a Stackelberg game. Both these papers show that while it is likely that consumers will lose from the conduct of one-sided environmental policy, firm profits may decline as well. In sum, the salient message of these studies is that in both non-game and game settings, there are reasonable theoretical circumstances in which one-sided environmental policy by a large country will make that country worse off.

2.2. *The instrument choice question*

Very recently, a small literature has addressed the choice of instrument question. Ulph (1992) has shown that in a Cournot game with trade, standards dominate taxes. Conrad and Schroder (1991) have analyzed the resource costs of achieving a particular level of environmental quality with emission standards, emission taxes, and subsidies. They have shown that an emission tax results in the lowest resource cost, followed by subsidies, and then by emission standards. These findings have led Ulph (1996) to observe that the superiority of standards over taxes is not a general result. Batabyal (1996, 1998) has analyzed international pollution regulation in a game setting by means of a production tax, an import tariff, and an instrument that is part-production tax and part-tariff. In his Stackelberg and Cournot game models, the joint policy instrument is generally the best pollution control instrument; however, the informational requirements of this instrument are also the greatest.

In an international dispute, national governments generally care about the actions of other governments. For instance, as Behr (1994) and Simone (1994) have discussed, in agricultural trade disputes between Canada and the USA, the Canadian government is very interested in the actions being contemplated by its US counterpart, and vice versa. Although there appears to be a general awareness about the existence of this kind of caring behavior, this phenomenon has not been studied in any detail. Even less studied is the question of the effects of alternate pollution control instruments when national governments display caring behavior.

Recently, Batabyal (1996, 1998) and Xu and Batabyal (2001) have studied the instrument choice question in the presence of caring behavior. However, in the two Batabyal (1996, 1998) papers, polluting firms play Stackelberg and Cournot games respectively. In other words, these firms choose *quantities*. The paper that is most closely related to the present one is Xu and Batabyal (2001). In this paper, polluting firms play a *price leadership* game. There is a salient difference between our paper and the papers that we have just discussed. We analyze the instrument choice question in a game setting in which polluting firms are *Bertrand competitors*. A major objective of ours is to *compare* the results of this paper with those contained in Batabyal (1998) and in Xu and Batabyal (2001). As we shall see, this comparative exercise sheds valuable light on the effects that alternate game forms have on the conduct of one-sided environmental policy and on the open economy effects of pollution control by means of alternate price control instruments. To the best of our knowledge, this Bertrand analysis, and more specifically this comparative exercise, have *not* been undertaken previously in the literature.

Note that in contrast with quantity setting games, in a Bertrand game, the strategy spaces are *different*, the payoff functions are *different*, and the underlying Nash equilibria are *dissimilar* as well (Gibbons, 1992, p. 21). As such, an analysis of the Bertrand model will enable us to compare the policy implications of this model with those of other game-theoretic models. Moreover, in contrast with sequential move games, the Bertrand model is easier to analyze because it involves simultaneous moves by the various players. These are two basic reasons for wanting to study the Bertrand model.

Eaton and Grossman (1986) and Barrett (1994) have noted that if firms compete in prices rather than in quantities, the optimal strategic policy can be *reversed.* Consequently, having demonstrated a certain pattern of results regarding the pollution instrument choice question in quantity setting games (see Batabyal (1996, 1998)) and given the above finding, we would like to know whether the Batabyal (1996, 1998) results are *overturned* when the analysis is conducted in a Bertrand model. This is the final reason for focusing on the Bertrand model in this paper. We now proceed to the two main questions of this paper.

3. THE BERTRAND MODEL WITH DOMESTIC POLLUTION

3.1. Preliminaries

There are two countries A and B. In each country, a production tax is used by the government to control pollution. A monopolistic firm in each country jointly produces pollution and a good q for domestic and foreign consumption. Consumers in each country are detrimentally affected by pollution and they buy the good on the domestic market from either the A firm or the B firm. The total quantity of the good in A is $Q^A = q^{AH} + q^{BX}$, where q^{AH} and q^{BX} refer to the quantity produced by the A firm for the home market and the quantity produced by the B firm for the export market. The two pollution taxes are t^A and t^B respectively.

To keep the analysis of this paper manageable, it will be necessary to work with linear functional forms. However, even with the imposition of this structure, unambiguous results will not be forthcoming. In general, our results are in the form of inequalities of varying levels of complexity. To shed additional light on these inequalities, we shall frequently resort to numerical analyses.

Recall that the A government levies a tax on the production of the polluting good. We permit the B government to retaliate. Why does the government in B retaliate? This government retaliates due to two reasons. First, although there is pollution in B and the B government would like to control pollution, this government is reluctant to do so in a one-sided manner. The A government's actions give the B government a rationale for controlling pollution in its own nation. Second, the B government retaliates because it fears that by allowing the A government's actions to go unchallenged, B will be worse off due to the perceived shift in the terms of trade in $A's$ favor subsequent to the imposition of t^A by the A government. Is this a reasonable fear? The answer is yes. Indeed, Batabyal (1993) has shown that in some circumstances, it is possible for the post-pollution tax terms of trade to shift in $A's$ favor.

Let us now describe the optimal pollution taxes. We shall then discuss the implications of using such taxes. The algebra associated with the analysis in this paper is intricate. Specifically, complicated fractions—often with upwards of ten digits in both the numerator and the denominator—describe the coefficients of all the variables of interest. Consequently, as a rule, we shall describe the coefficients of the relevant variables with decimal expressions that are accurate to two decimal places. The only exception is when the use of this rule results in a coefficient being zero. In this case, we use longer decimal expressions to describe the relevant coefficient.

3.2. The pollution tax

Suppose that the *heterogeneous* representative consumers in A and B maximize quadratic and strictly concave utility functions. The specific form of these utility functions is taken from Singh and Vives (1984). We get $U^A = q^{AH} + q^{BX} - [2(q^{AH})^2 + q^{AH}q^{BX} + 2(q^{BX})^2]$ and $U^B = q^{BH} + q^{AX} - [(q^{BH})^2 + q^{BH}q^{AX} + (q^{AX})^2]$, where q^{AH} and q^{BX} are described in the first paragraph of Section 3.1 and q^{BH} and q^{AX} denote the quantities produced by the B firm for the home market and by the A firm for the export market, respectively. Note well that in both the A and the B markets, the two goods are *imperfect* substitutes. Maximization of the above utility functions gives rise to a linear demand structure in the two countries. We get $q^{AH} = 0.2 - 0.27p^{AH} + 0.07p^{BX}$, $q^{BX} = 0.2 - 0.27p^{BX} + 0.07p^{AH}$, $q^{BH} = 0.33 - 0.67p^{BH} + 0.33p^{AX}$, and $q^{AX} = 0.33 - 0.67p^{AX} + 0.33p^{BH}$.

The two kinds of costs faced by the A and the B firms are the cost of producing the good and the cost of tax payment. Denote the cost of production in A and B by $c(q^{AH} + q^{AX})$ and $c(q^{BH} + q^{BX})$, and let the cost of tax payment in A and B be $t^A(q^{AH} + q^{AX})$ and $t^B(q^{BH} + q^{BX})$ respectively. The marginal cost of production, c, is the same in both countries. The governments in the two countries collect the tax revenue; this revenue is then distributed to the representative consumers in the two countries in a lump sum manner. The social welfare functions in A and B are $W^A = [U^A - p^{AH}q^{AH} - p^{BX}q^{BX}] + \pi^A + [(t^A - v^A)(q^{AH} + q^{AX})]$ and $W^B = [U^B - p^{BH}q^{BH} - p^{AX}q^{AX}] + \pi^B + [(t^B - v^B)(q^{BH} + q^{BX})]$. In words, society's welfare in each nation is the sum of consumer surplus, firm profit, and tax revenue less the social disutility of pollution. Because consumers are heterogeneous, the constant marginal social disutilities of pollution (v^A, v^B) are not the same.

In the two stage game being analyzed here, events occur as follows. First, the two governments simultaneously choose taxes t^A and t^B. Second, the two firms observe these taxes and then they simultaneously choose their prices. The *ith* firm chooses (p^{iH}, p^{iX}) where $i = A, B$. Third, the players receive their payoffs which are profits (π^A, π^B) for the two firms and social welfare (W^A, W^B) for the two governments. As is customary (see Varian, 1992, pp. 291–300), to determine the equilibrium of this Bertrand game, we solve the game backwards.

3.3. The Bertrand equilibrium

Suppose that the two governments have chosen t^A and t^B. If the 4-tuple $(p_*^{AH}, p_*^{AX}, p_*^{BH}, p_*^{BX})$ constitutes a Nash equilibrium in the Bertrand game between the two polluting firms, then it must be true that (p_*^{AH}, p_*^{AX}) maximizes $\pi^A = \pi^{AH} + \pi^{AX}$ and that (p_*^{BH}, p_*^{BX}) maximizes $\pi^B = \pi^{BH} + \pi^{BX}$. Now let us focus on firm $A's$ optimization problems. In the domestic market, this firm chooses $p_*^{AH} = \arg\max_{\{p^{AH}\}} q^{AH}[p^{AH} - c - t^A]$, and in the export market, it chooses $p_*^{AX} = \arg\max_{\{p^{AX}\}} q^{AX}[p^{AX} - c - t^A]$. The solutions to these two problems are

$$p_*^{AH} = 0.38 + 0.5c + 0.13p^{BX} + 0.5t^A\,, \tag{1}$$

and

$$p_*^{AX} = 0.25 + 0.5c + 0.25p^{BH} + 0.5t^A\,. \tag{2}$$

In a similar fashion, we can obtain the optimal values of the B firm's choice variables. These are

$$p_*^{BH} = 0.25 + 0.5c + 0.25p^{AX} + 0.5t^B\,, \tag{3}$$

and

$$p_*^{BX} = 0.38 + 0.5c + 0.13p^{AH} + 0.5t^B\,. \tag{4}$$

Equations (1)–(4) gives us the reaction functions of the two firms. Solving equations (1) and (4) simultaneously and (2) and (3) simultaneously, we get

$$p_*^{AH} = 0.43 + 0.57c + 0.51t^A + 0.06t^B\,, \tag{5}$$

$$p_*^{BX} = 0.43 + 0.57c + 0.06t^A + 0.51t^B\,, \tag{6}$$

$$p_*^{BH} = 0.33 + 0.67c + 0.13t^A + 0.53t^B\,, \tag{7}$$

and

$$p_*^{AX} = 0.33 + 0.67c + 0.53t^A + 0.13t^B\,. \tag{8}$$

Equations (5)–(8) give us the equilibrium prices that will be charged by the two polluting firms in the two markets. Using equations (5)–(8) we can determine the optimal quantities. They are

$$q_*^{AH} = 0.11 - 0.11c - 0.13t^A + 0.02t^B\,, \tag{9}$$

$$q_*^{BX} = 0.11 - 0.11c + 0.02t^A - 0.13t^B\,, \tag{10}$$

$$q_*^{BH} = 0.22 - 0.22c + 0.09t^A - 0.31t^B\,, \tag{11}$$

and

$$q_*^{AX} = 0.22 - 0.22c - 0.31t^A + 0.09t^B\,. \tag{12}$$

We now solve the first stage game between the two governments. These two governments choose pollution taxes to maximize social welfare in their own countries. Formally, the A government solves

$$\max_{\{t^A\}} W^A = [U^A - p^{AH}q^{AH} - p^{BX}q^{BX}] + \pi^A + [(t^A - v^A)(q^{AH} + q^{AX})] \tag{13}$$

and the B government solves

$$\max_{\{t^B\}} W^B = [U^B - p^{BH}q^{BH} - p^{AX}q^{AX}] + \pi^B + (t^B - v^B)(q^{BH} + q^{BX})\,. \tag{14}$$

The solutions to problems (13) and (14) are

$$t_*^A = 0.13c - 0.13 + 1.1v^A + 0.02v^B \tag{15}$$

and

$$t_*^B = 0.42c - 0.42 + 0.001v^A + 1.4v^B\,. \tag{16}$$

Equations (15) and (16) give us the equilibrium pollution taxes in this Bertrand game. Note that because consumers in the two countries are heterogeneous and because the marginal social disutilities of pollution (v^A, v^B) are not the same, the two equilibrium taxes are not identical. Moreover, inspection of equations (15) and (16) tells us that the two optimal taxes are increasing in the marginal cost of production and in the own marginal social disutility of pollution. In symbols, $\partial t_*^i/\partial c > 0$, $i = A, B$, and $\partial t_*^j/dv^j > 0$, $j = A, B$. The strategic aspect of this Bertrand game is captured by the dependence of t_*^A on v^B and the dependence of t_*^B on v^A. Substituting the values of t_*^A and t_*^B from equations (15) and (16) into equations (5)–(8) gives us the equilibrium prices as a function of the three parameters of interest, i.e., c, v^A, and v^B. We get $p_*^{AH} = 0.34 + 0.66c + 0.56v^A + 0.1v^B$, $p_*^{BX} = 0.21 + 0.79c + 0.07v^A + 0.72v^B$, $p_*^{BH} = 0.09 + 0.91c + 0.15v^A + 0.76v^B$, and $p_*^{AX} = 0.21 + 0.79c + 0.59v^A + 0.2v^B$.

We can now compare the pollution tax equilibrium with the *status quo*, i.e., the equilibrium with no policy intervention by the two governments. We first focus on A. Here, the representative consumer's surplus (hereafter CS) with the tax is bigger than or equal to his CS without the tax if and only if (hereafter iff) $[0.05 - 0.09c + 0.05c^2 - 0.08v^A - 0.13v^B + 0.08cv^A + 0.13cv^B + 0.04(v^A)^2 + 0.0012v^Av^B + 0.07(v^B)^2] \geq 0$. The polluting firm's post-tax profit bigger than or equal to its pre-tax profit iff $[0.01 - 0.02c + 0.01c^2 - 0.37v^A + 0.1v^B + 0.37cv^A - 0.1cv^B + 0.26(v^A)^2 - 0.15v^Av^B + 0.02(v^B)^2] \geq 0$. Now let's consider B. Here, CS with the tax is greater than or equal to CS without the tax iff $[0.09 - 0.19c + 0.09c^2 + 0.18cv^A + 0.31cv^B - 0.18v^A - 0.31v^B + 0.09(v^A)^2 - 0.01v^Av^B + 0.16(v^B)^2] \geq 0$, and the firm's post-tax profit is greater than its pre-tax profit iff $[0.16 - 0.31c + 0.16c^2 - 0.12cv^A + 0.69cv^B + 0.12v^A - 0.69v^B + 0.02(v^A)^2 - 0.16v^Av^B + 0.42(v^B)^2] \geq 0$.

3.4. Discussion

The four inequalities in the previous paragraph tell us that the general effect of the two pollution taxes on CS and firm profit in the two countries is ambiguous. Together, these results tell us that it is theoretically *possible* for a country to immiserize itself with one-sided environmental policy with retaliation. For additional insight into the effects of one-sided environmental policy, consider the three cases described in Table 1.[1] In case 1, the marginal cost of production is low and the marginal social disutilities of pollution are close to each other. This is the case of similar countries. Here, we have a "win-win" situation because consumers and producers in *both* countries gain with the institution of

[1] Note that consumer heterogeneity in the two countries *is* important in the results that we have just been discussing. In particular, these results do *not* necessarily remain valid with homogeneous consumers. For instance, with regard to Table 1, the reader can check that when consumers are heterogeneous ($c = 2000$, $v^A = 10$, $v^B = 1000$), post-tax firm profits in A decline. In contrast, when consumers are homogeneous ($c = 2000$, $v^A = v^B = 10$), post-tax firm profits in A rise.

Table 1. The Effects of Alternate Parameter Values on Consumer Surplus (CS) and Firm Profit (FP) in A and B.

Country	Criterion of Interest	Outcome with Pollution Tax
Case 1: $(c, v^A, v^B) = (3, 5, 4)$		
A	CS FP	Higher with Tax Higher with Tax
B	CS FP	Higher with Tax Higher with Tax
Case 2: $(c, v^A, v^B) = (2000, 10, 1000)$		
A	CS FP	Higher with Tax Lower with Tax
B	CS FP	Higher with Tax Higher with Tax
Case 3: $(c, v^A, v^B) = (1000, 3000, 100)$		
A	CS FP	Higher with Tax Higher with Tax
B	CS FP	Higher with Tax Lower with Tax

one-sided environmental policy with retaliation. Things are different in case 2. Here, the marginal cost of production is high and consumers in B dislike pollution with a far greater intensity than do consumers in A. In this situation, consumers and the producer in B (the retaliating country) gain but the polluting firm in A loses. Consequently, in this case we can expect the producer in A to lobby *against* the conduct of one-sided environmental policy. In case 3, as compared to case 2, consumers in the two countries switch their positions. Now consumers in A dislike pollution to a far greater degree than do consumers in B, and the marginal cost of production is high. In this case, A "wins" and the producer in B loses. In contrast with case 2, we can now expect the producer in the retaliating country to lobby against the institution of environmental policy.

We can draw three specific lessons from this numerical exercise. First, it looks like the winners from one-sided environmental policy are consumers and the losers are firms. Second, case 1 suggests that a "win-win" situation is most likely when the marginal cost of producing the polluting good is low and when the two countries are similar in terms of their distaste for pollution. Third, cases 2 and 3 tell us that environmental policy is most likely to hurt the polluting firm in a country when that country's consumers, relative to the other country, care *less* about pollution.

What game should polluting firms play? This question can be analyzed with the aid of Table 2. This Table provides rankings for CS and firm profit in Bertrand, price leadership, and Cournot games with the indicated values for the three parameters. Inspecting these rankings, we see that in two out of the three cases, CS and firm profit in our two country world are highest when the polluting firms play a Cournot game.

Further, consumers and firms in the two countries fare poorly when the polluting firms play a Bertrand game. Put differently, consumer and producer welfare in both countries is *lower* when polluting firms set prices rather than quantities. From a policy perspective, this tells us that national governments need to be particularly vigilant about the regulation of polluting firms that control prices.

Let us now discuss the Table 2 results in the context of extant findings in Singh and Vives (1984). The reader should note that the pertinent findings in Singh and Vives (1984) are about a situation in which the two goods are substitutes; however, there is no governmental intervention of any kind. In this paper, the two goods are imperfect substitutes; moreover, we clearly do have governmental intervention. Consequently, we expect some but not total consistency between our results and the findings in Singh and Vives (1984). With this in mind, let us consider firms first. Singh and Vives (1984, p. 549) note that for "firms, if the goods are substitutes... Cournot profits are larger than Bertrand profits." In general, the Table 2 results are consistent with this finding. We see that in five out of six cases, firm profits are indeed higher in the Cournot game. Now consider consumers. Singh and Vives (1984) note that consumer surplus in general is higher in Bertrand than in Cournot competition. The Table 2 results are inconsistent with this finding because we are analyzing a two-stage and not a single-stage game

Table 2. Consumer Surplus (CS) and Firm Profit (FP) Rankings in Three Duopoly Games (1=highest and 3=lowest).[2]

Country	Criterion of interest	Rank in Bertrand game	Rank in price leadership game	Rank in Cournot game
Case 1: $(c, v^A, v^B) = (3, 5, 4)$				
A	CS	3	2	1
	FP	3	2	1
B	CS	3	2	1
	FP	3	2	1
Case 2: $(c, v^A, v^B) = (2000, 10, 1000)$				
A	CS	3	2	1
	FP	2	1	3
B	CS	3	2	1
	FP	3	2	1
Case 3: $(c, v^A, v^B) = (1000, 3000, 100)$				
A	CS	3	2	1
	FP	3	2	1
B	CS	3	2	1
	FP	2	3	1

[2] The inequalities used to compute the rankings in the price leadership and in the Cournot games are taken from Xu and Batabyal (2001, pp. 63–67) and Batabyal (1998, pp. 240–243, with $a = 1$) respectively.

and because governments do intervene in the relevant markets to set pollution taxes optimally.

4. THE BERTRAND MODEL WITH CARING GOVERNMENTS

4.1. Preliminaries

We not analyze the efficaciousness of alternate environmental policy instruments in a two country world in which both governments care about the pollution in each other's country. The governments in A and B may choose a domestic policy instrument (a production tax), a trade policy instrument (an import tariff), or a combination of these two policy instruments (the joint policy instrument) to regulate pollution. Before studying the effects of the three instruments formally, let us first discuss the pertinent issues intuitively.

Consider the world's welfare. When there are a number of distortions in the world economy and national governments address these distortions with the aforementioned instruments in a non-cooperative game, the resulting equilibrium is optimal in a narrow sense. This means that although individual country welfare is maximized by the respective governments, world welfare is not. Why not? This is because the correct taxes and tariffs are those that are set as a result of *coordinated* play by the two country governments. Although the desirability of such coordination is well understood by researchers, on account of a number of reasons—some of which are discussed in Batabyal (1996)—we do not observe the coordination of environmental policy. The reader should note that our subsequent results are "narrowly optimal" in the sense of the discussion in this paragraph.

In determining which policy instrument to use, the government in each country will consider the effects of a specific policy on the three distortions in our world economy. First, there is the pollution distortion. A production tax will lower pollution by reducing the output of the polluting good. However, this instrument will lower domestic pollution, but not foreign pollution. An import tariff will lower foreign pollution by making the post-tariff purchase of the foreign good unattractive and by increasing the costs of the foreign producer. This means that as far as the pollution distortion is concerned, while both these instruments will lower pollution, neither instrument will address the distortion in its totality. The joint policy instrument will lower both domestic *and* foreign pollution. As such, of the three instruments under consideration, the joint policy instrument would appear to be the appropriate pollution control instrument.

The second distortion concerns monopoly rents. The Bertrand game in this paper is a game between two monopolists earning excess economic rent. The governments in both A and B would presumably like to gain control over some of this rent. A production tax will transfer some of this monopolistic rent to the tax-setting government. An import tariff will also transfer some of this rent. However, the rent transfer will now take place from the monopolist in the other nation. The joint policy instrument will result in the largest transfer of rent to the government that uses this instrument. Consequently, as far as this distortion is concerned, all three instruments will, in principle, succeed in transferring this monopoly rent to the pertinent government.

The third distortion concerns the domestic share of total production. The monopolistic firm in each country will not produce the correct amount for the home market. Consequently, in ascertaining which policy instrument to use, the two governments would presumably like to increase the domestic share of total production and thereby reduce imports. By deterring the purchase of the foreign good, an import tariff will increase the home market share of the domestically produced good. In contrast, a production tax will not do this because its use will result in the reduction of domestic production. The joint policy instrument can be expected to result in total output that is bounded below by the tax output and above by the tariff output. Thus, with respect to this distortion, a *tariff* would appear to be the best policy instrument. We see that in general, the three instruments are likely to have very different effects on consumer and on producer welfare. Let us now address the related questions of the effects of international environmental policy and the choice of instrument issue in a setting in which polluting firms play a Bertrand game.

4.2. International environmental policy with alternate control instruments

Let r^A and r^B denote the tariffs used by the two countries. The rest of the notation used here is the same as in Section 3. We first address the general case. In this case, the two national governments use the joint policy instrument to control pollution. Recall that this instrument is part-tariff and part-production tax.

4.2.1. The joint policy instrument game

We know that $\pi^A = \pi^{AH} + \pi^{AX}$, and $\pi^B = \pi^{BH} + \pi^{BX}$. On solving these profit maximization problems, we get four reaction functions. They are

$$p_*^{AH} = 0.43 + 0.57c + 0.06r^A + 0.51t^A + 0.06t^B\,, \tag{17}$$

$$p_*^{BX} = 0.43 + 0.57c + 0.51r^A + 0.06t^A + 0.51t^B\,, \tag{18}$$

$$p_*^{BH} = 0.33 + 0.67c + 0.13r^B + 0.13t^A + 0.53t^B\,, \tag{19}$$

and

$$p_*^{AX} = 0.33 + 0.67c + 0.53r^B + 0.53t^A + 0.13t^B\,. \tag{20}$$

Equations (17)–(20) give us the optimal prices that will be charged by the two firms when their respective governments control their output by tariffs (r^A, r^B) and production taxes (t^A, t^B). These four equations can be used to solve for the optimal quantities. We get

$$q_*^{AH} = 0.11 - 0.11c + 0.02r^A - 0.13t^A + 0.02t^B\,, \tag{21}$$

$$q_*^{BX} = 0.11 - 0.11c - 0.13r^A + 0.02t^A - 0.13t^B\,, \tag{22}$$

$$q_*^{BH} = 0.22 - 0.22c + 0.09r^B + 0.09t^A - 0.31t^B\,, \tag{23}$$

and

$$q_*^{AX} = 0.22 - 0.22c - 0.31r^B - 0.31t^A + 0.09t^B\,. \tag{24}$$

Recall that the A and the B governments care about pollution in each other's country. This is accounted for by including $B's$ disutility from pollution in $A's$ objective, and vice versa. The A and the B governments solve

$$\max_{\{r^A,t^A\}} [U^A - p^{AH}q^{AH} - p^{BX}q^{BX}] + \pi^A + (t^A - v^A)(q_*^{AH} + q_*^{AX}) + (r^A - v^B)q_*^{BX} - v^B q_*^{BH}, \quad (25)$$

and

$$\max_{\{r^B,t^B\}} [U^B - p^{BH}q^{BH} - p^{AX}q^{AX}] + \pi^B + (t^B - v^B)(q_*^{BH} + q_*^{BX}) + (r^B - v^A)q_*^{AX} - v^A q_*^{AH}, \quad (26)$$

respectively. The solutions to problems (25) and (26) are

$$r_*^A = 0.43 - 0.43c + 0.09v^A + 0.17v^B, \quad (27)$$

$$r_*^B = 0.27 - 0.27c + 0.32v^A + 0.17v^B, \quad (28)$$

$$t_*^A = 0.12c - 0.12 + 1.1v^A - 0.24v^B, \quad (29)$$

and

$$t_*^B = 0.35c - 0.35 - 0.25v^A + 1.5v^B. \quad (30)$$

Equations (27)–(30) give us the equilibrium tariffs and taxes in the game in which the two governments care about pollution in each other's country and the joint policy instrument is used to regulate pollution. Substitution of equations (27)–(30) into equations (17)–(20) gives us the four optimal prices. These are

$$p_*^{AH} = 0.37 + 0.63c + 0.54v^A - 0.02v^B, \quad (31)$$

$$p_*^{BX} = 0.46 + 0.54c - 0.01v^A + 0.82v^B, \quad (32)$$

$$p_*^{BH} = 0.17 + 0.83c + 0.06v^A + 0.77v^B, \quad (33)$$

and

$$p_*^{AX} = 0.36 + 0.64c + 0.72v^A + 0.15v^B. \quad (34)$$

We now compare the joint policy outcome with the outcome with no government intervention of any kind. First, consider A. Here, CS with the joint policy instrument is bigger than or equal to the CS without any intervention iff $[0.004 - 0.01c + 0.004c^2 - 0.07v^A - 0.08v^B + 0.07cv^A + 0.08cv^B + 0.04(v^A)^2 - 0.04v^Av^B + 0.09(v^B)^2] \geq 0$. The polluting firm's profit with the joint policy instrument is greater than or equal to its *status quo* profit iff $[-0.02 + 0.06c - 0.02c^2 - 0.35v^A + 0.13v^B + 0.35cv^A - 0.13cv^B + 0.4(v^A)^2 - 0.28v^Av^B + 0.05(v^B)^2] \geq 0$. In B CS with the joint policy instrument is greater than or equal to the *status quo* CS iff $[0.04 - 0.08c + 0.04c^2 + 0.12cv^A + 0.29cv^B - 0.12v^A - 0.29v^B + 0.16(v^A)^2 - 0.09v^Av^B + 0.17(v^B)^2] \geq 0$, and the firm's post-policy profit is greater than or equal to its pre-intervention profit iff $[0.1 - 0.18c + 0.1c^2 - 0.24cv^A + 0.65cv^B + 0.24v^A - 0.65v^B + 0.07(v^A)^2 - 0.35v^Av^B + 0.5(v^B)^2] \geq 0$. It is clear that the CS and the firm profit comparisons are ambiguous. Because of this ambiguity, we now consider two special cases of this sub-section's general case. In the first case, an import tariff is the government's only policy instrument. In the second case, the government's sole policy instrument is a production tax.

4.2.2. The tariff game

The outcome of the tariff game can be determined by setting $t^A = t^B = 0$ in equations (25) and (26) and then resolving the two government problems. This yields

$$r_*^A = 0.33 - 0.33c - 0.09v^A + 0.67v^B \,, \tag{35}$$

and

$$r_*^B = 0.3 - 0.3c + 0.7v^A - 0.2v^B \,. \tag{36}$$

Now using the methodology of Section 4.2.1, we can compute inequalities for the change in consumer and producer welfare in the two countries. In A, CS with the tariff is greater than or equal to CS without the tariff iff $[-0.02+0.04c-0.02c^2+0.004v^A - 0.03v^B - 0.004cv^A + 0.03cv^B + 0.00025(v^A)^2 - 0.004v^Av^B + 0.02(v^B)^2] \geq 0$. The A polluting firm's post-tariff profit is greater than or equal to its profit without the tariff iff $[-0.04 + 0.09c - 0.04c^2 - 0.09v^A + 0.03v^B + 0.09cv^A - 0.03cv^B + 0.07(v^A)^2 - 0.04v^Av^B + 0.01(v^B)^2] \geq 0$. In B the post-tariff CS is bigger than or equal to the without tariff CS iff $[-0.04+0.08c-0.04c^2+0.07cv^A-0.02cv^B-0.07v^A+0.02v^B+0.04(v^A)^2 - 0.02v^Av^B + 0.003(v^B)^2] \geq 0$, and the B firm's post-tariff profit is bigger than its *status quo* profit iff $[-0.01 + 0.03c - 0.01c^2 - 0.05cv^A + 0.06cv^B + 0.05v^A - 0.06v^B + 0.01(v^A)^2 - 0.01v^Av^B + 0.03(v^B)^2] \geq 0$.

4.2.3. The tax game

As in the previous section, the equalibrium outcome of the pollution tax game can be determined by setting $r^A = r^B = 0$ in equations (25) and (26) and then resolving the two government maximization problems. We get

$$t_*^A = 0.13c - 0.13 + 1.1v^A - 0.24v^B \tag{37}$$

and

$$t_*^B = 0.42c - 0.42 - 0.34v^A + 1.4v^B \,. \tag{38}$$

Once again, using the methodology of Section 4.2.1, we can compute inequalities for the change in consumer and producer welfare in the two countries. Consider A first. CS with the tax is bigger than CS without the tax iff $[0.05 - 0.09c + 0.05c^2 - 0.05v^A - 0.11v^B + 0.05cv^A + 0.11cv^B + 0.04(v^A)^2 - 0.05v^Av^B + 0.07(v^B)^2] \geq 0$. The polluting firm's post-tax profit is greater than or equal to its pre-tax profit iff $[0.01 - 0.02c + 0.01c^2 - 0.39v^A + 0.19v^B + 0.39cv^A - 0.19cv^B + 0.29(v^A)^2 - 0.29v^Av^B + 0.07(v^B)^2] \geq 0$. In B CS with the tax is bigger than or equal to the pre-tax CS iff $[0.09 - 0.19c + 0.09c^2 + 0.11cv^A + 0.26cv^B - 0.11v^A - 0.26v^B + 0.1(v^A)^2 - 0.13v^Av^B + 0.16(v^B)^2] \geq 0$, and the polluting firm's post-tax profit exceeds or is equal to its pre-tax profit iff $[0.16-0.31c+0.16c^2-0.29cv^A+0.72cv^B+0.29v^A-0.72v^B+0.08(v^A)^2 - 0.37v^Av^B + 0.46(v^B)^2] \geq 0$.

4.3. A comparative analysis of the three policy instruments

Let us now compare the outcomes in the equilibria of the tariff game and the JPI game. In A CS with the joint policy instrument is bigger than or equal to CS with the tariff iff $[0.02-0.05c+0.02c^2-0.07v^A-0.05v^B+0.07cv^A+0.05cv^B+0.04(v^A)^2-0.03v^Av^B+0.08(v^B)^2]\geq 0$. Similarly, firm profit in A with the JPI is bigger than or equal to its profit with the tariff iff $[0.02-0.03c+0.02c^2-0.26v^A+0.1v^B+0.26cv^A-0.1cv^B+0.33(v^A)^2-0.24v^Av^B+0.04(v^B)^2]\geq 0$. In B the corresponding results are as follows. CS with the JPI is bigger than or equal to CS with the tariff iff $[0.08-0.16c+0.08c^2-0.05v^A-0.31v^B+0.05cv^A+0.31cv^B+0.12(v^A)^2-0.06v^Av^B+0.17(v^B)^2]\geq 0$. The firm's profit with the JPI is bigger than or equal to its profit with the tariff iff $[0.11-0.21c+0.11c^2+0.19v^A-0.59v^B-0.19cv^A+0.59cv^B+0.06(v^A)^2-0.34v^Av^B+0.47(v^B)^2]\geq 0$.

Comparing the outcomes in the JPI game with the tax game, we find that CS in A when the JPI is used is bigger than or equal to CS with the tax iff $[-0.04+0.08c-0.04c^2-0.02v^A+0.03v^B+0.02cv^A-0.03cv^B-0.004(v^A)^2+0.02v^Av^B+0.02(v^B)^2]\geq 0$, and the A firm's profit with the JPI is greater than or equal to its profit with the tax iff $[-0.03+0.08c-0.03c^2+0.04v^A-0.06v^B-0.04cv^A+0.06cv^B+0.11(v^A)^2+0.01v^Av^B-0.02(v^B)^2]\geq 0$. For B we have the following two results. CS with the JPI is bigger than or equal to CS with the tax iff $[-0.05+0.11c-0.05c^2-0.01v^A-0.03v^B+0.01cv^A+0.03cv^B+0.06(v^A)^2+0.05v^Av^B+0.01(v^B)^2]\geq 0$, and firm profit with the JPI is bigger than or equal to firm profit with the tax iff $[-0.06+0.13c-0.06c^2-0.05v^A+0.07v^B+0.05cv^A-0.07cv^B-0.01(v^A)^2+0.02v^Av^B+0.04(v^B)^2]\geq 0$.

Finally, let us compare the outcomes in the equilibria of the tariff and the tax games. In A CS with the tariff exceeds or is equal to CS with the tax iff $[-0.06+0.13c-0.06c^2+0.05v^A+0.08v^B-0.05cv^A-0.08cv^B-0.04(v^A)^2+0.05v^Av^B-0.05(v^B)^2]\geq 0$, and the firm's profit with the tariff is bigger than or equal to its profit with the tax iff $[-0.05+0.11c-0.05c^2+0.3v^A-0.16v^B-0.3cv^A+0.16cv^B-0.22(v^A)^2+0.25v^Av^B-0.07(v^B)^2]\geq 0$. For B the following results hold. CS with the tariff is bigger than or equal to CS with the tax iff $[-0.13+0.27c-0.13c^2+0.04v^A+0.28v^B-0.04cv^A-0.28cv^B-0.06(v^A)^2+0.11v^Av^B-0.16(v^B)^2]\geq 0$. The firm's profit with the tariff is bigger than or equal to its profit with the tax iff $[-0.07+0.34c-0.17c^2-0.24v^A+0.66v^B+0.24cv^A-0.66cv^B-0.07(v^A)^2+0.36v^Av^B-0.43(v^B)^2]\geq 0$.

A number of useful insights can be obtained by using the inequalities contained in the previous paragraphs to conduct numerical analyses. Table 3 presents the results of three case studies. The parameter values here are the same as in Tables 1 and 2. In case 1, the case of relatively similar nations, CS and firm profit in *both* nations are highest when the governments use the JPI to control pollution. Consequently, in both nations, consumers and producers will want the government to use the JPI to regulate pollution. This harmony in consumer and producer preferences breaks down progressively in cases 2 and 3.

In case 2, B consumers care a lot more about pollution than A consumers. Here, consumers in both nations will want their governments to use the tax to control pollution. In contrast, the A firm will want its government to use the tariff and the B firm will want its government to use the tax. In other words, there is a conflict between consumer and producer interests in A and an alignment of such interests in B. In case 3, the case

Table 3. The Effects of the Three Policy Instruments on Consumer Surplus (CS) and Firm Profit (FP) in A and B.

Country	Criterion of Interest	Tariff versus Tax	JPI versus Tariff	JPI versus Tax
Case 1: $(c, v^A, v^B) = (3, 5, 4)$				
A	CS	Higher with Tax	Higher with JPI	Higher with JPI
	FP	Higher with Tax	Higher with JPI	Higher with JPI
B	CS	Higher with Tax	Higher with JPI	Higher with JPI
	FP	Higher with Tax	Higher with JPI	Higher with JPI
Case 2: $(c, v^A, v^B) = (2000, 10, 1000)$				
A	CS	Higher with Tax	Higher with JPI	Higher with Tax
	FP	Higher with Tariff	Higher with Tariff	Higher with Tax
B	CS	Higher with Tax	Higher with JPI	Higher with Tax
	FP	Higher with Tax	Higher with JPI	Higher with Tax
Case 3: $(c, v^A, v^B) = (1000, 3000, 100)$				
A	CS	Higher with Tax	Higher with JPI	Higher with Tax
	FP	Higher with Tax	Higher with JPI	Higher with JPI
B	CS	Higher with Tax	Higher with JPI	Higher with JPI
	FP	Higher with Tax	Higher with JPI	Higher with Tax

in which A consumers care a lot more about pollution than B consumers, there is conflict between consumers and producers in *both* countries. In A consumers will prefer pollution regulation with the tax and the producer will want its government to use the JPI. In B, whereas consumers will want their government to regulate pollution with the JPI, the polluting firm will prefer the use of the tax. Intuitively, we would expect little or no conflict between consumers and producers when the two countries are *similar*. This intuition *is* supported by case 1 in Tables 1 and 3. In Table 1 there is no conflict between consumer and producers because all groups gain from the conduct of environmental policy. Similarly, in Table 3, both consumers and producers agree that it is most desirable for their governments to conduct environmental policy with the JPI.

As in Section 3, we now ask: What game should polluting firms play? To answer this, consider Table 4. This Table provides a ranking of CS and firm profit in the three cases that we have been focusing on thus far. Note that Table 4 strengthens the findings of Table 2. In particular, independent of the instrument used to control pollution and like in Table 2, consumer and producer welfare are generally highest when firms play *Cournot* games, i.e., when they choose quantities rather than prices.

To see this clearly, let us analyze the contents of Table 4 carefully. Consider consumers first. In cases 1 and 2, independent of the instrument used to control pollution, CS in both countries is highest when firms play Cournot games. Even in case 3 where CS is not always highest in Cournot games, in four out of the six instances, consumers gain most when firms play Cournot games. Turning to firms we see that the case for playing Cournot games is less strong now but still stronger than the case for playing

Table 4. Consumer Surplus (CS) anf Firm Profit (FP) Rankings in Three Duopoly Games When Governments Use Alternate Pollution Control Instruments (1=highest and 3=lowest).[3]

Case	Policy	Country	Criterion of Interest	Rank in Bertrand game	Rank in price leadership game	Rank in Cournot game
1: $(c, v^A, v^B) = (3, 5, 4)$	Tariff	A	CS, FP	3, 1	2, 2	1, 3
		B	CS, FP	2, 2	3, 3	1, 1
	Tax	A	CS, FP	3, 3	2, 2	1, 1
		B	CS, FP	3, 2	2, 1	1,1
	JPI	A	CS, FP	3, 2	2, 1	1, 3
		B	CS, FP	2, 2	3, 1	1, 3
2: $(c, v^A, v^B) = (2000, 10, 1000)$	Tariff	A	CS, FP	2, 2	2, 3	1, 1
		B	CS, FP	3, 2	2, 3	1, 1
	Tax	A	CS, FP	3, 3	2, 1	1, 2
		B	CS, FP	3, 2	2, 3	1, 1
	JPI	A	CS, FP	3, 2	2, 3	1, 1
		B	CS, FP	2, 1	2, 1	1, 3
3: $(c, v^A, v^B) = (1000, 3000, 100)$	Tariff	A	CS, FP	1, 1	2, 2	3, 3
		B	CS, FP	2, 2	3, 1	1, 3
	Tax	A	CS, FP	3, 3	2, 2	1, 1
		B	CS, FP	3, 2	2, 3	1, 1
	JPI	A	CS, FP	3, 2	2, 1	1, 3
		B	CS, FP	1, 2	2, 3	3, 1

price setting games. Specifically, in three of six instances in cases 1 and 3 and in four of six instances in case 2, firm profits are *highest* in Cournot games.

Once again, we can compare and contrast the Table 4 results with the findings in Singh and Vives (1984). As noted in Section 3.4, the reader should realize that the germane findings in Singh and Vives (1984) refer to a situation in which the two goods are substitutes but there is no governmental intervention of any kind. In this paper, the two goods are imperfect substitutes; however, we clearly do have governmental intervention. As such, we expect some but not total congruity between our results and the findings in Singh and Vives (1984). With this in mind, consider firms first. Singh and Vives (1984, p. 549) note that for "firms, if the goods are substitutes... Cournot profits are larger than Bertrand profits." The Table 4 results are broadly consistent—although not to the same degree as the Table 2 results—with this previous finding. Specifically,

[3] The inequalities used to compute the rankings in the price leadership and the Cournot games are taken from Xu and Batabyal (2001, pp. 71–75) and Batabyal (1998, pp. 240–243, with $a = 1$) respectively.

in eleven out of eighteen instances, firm profits are higher with Cournot competition. Finally, because we are analyzing a two-stage and not a single-stage game and because governments do intervene in the relevant markets to set pollution taxes optimally, we see that relative to Cournot competition and unlike the findings in Singh and Vives (1984), consumer surplus is higher in Cournot and not in Bertrand competition.

5. CONCLUSIONS

In this paper we analyzed two prominent issues about the conduct of strategic environmental policy in an open economy. We first examined the effects of one-sided environmental policy in a two-stage game model in which polluting firms are Bertrand competitors. With numerical analyses, we showed that when governments interact strategically, there *are* theoretical circumstances in which the conduct of one-sided environmental policy can immiserize a nation. This finding is a likely explanation as to why national governments are unwilling to conduct one-sided environmental policy even when the incidence of pollution is domestic.

Next, we studied the effects of pollution regulation with alternate price control instruments in a two country world in which national governments care about pollution in each other's countries and in which there are distortions in addition to pollution. We showed that although it is not possible to resolve the instrument choice issue unambiguously, one can derive inequalities that tell us whether consumers and producers gain or lose from the pursuit of a particular environmental policy. This paper's analysis shows that there are a number of circumstances in which consumer and producer welfare are highest when polluting firms choose *quantities*—play Cournot games—rather than prices. From a regulatory standpoint, this suggests that it would be worthwhile for governments to *prevent* polluting firms with market power from engaging in price competition.

The analysis of this paper can be generalized in a number of ways. In what follows, we suggest two possible generalizations. First, it would be useful to study the instrument choice question in settings in which national governments regulate pollution with price and/or quantity controls. Second, because international environmental disputes generally occur and are settled over time,[4] it would be useful to study the issues of this paper in an intertemporal setting. This will involve the use of a differential game setting or a repeated game framework. Formal analyses of trade and the environment that incorporate these aspects of the problem into the analysis will provide richer and practically more meaningful accounts of the pros and cons of conducting strategic environmental policy in an international setting.

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[4] For more on this see the papers in Batabyal (2000).

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