Environmental Regulations, International Trade and Strategic Behavior

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Abstract

In this paper, the issue of strategic behavior in the presence of environmental regulations and international trade is investigated. In a two-country, one-good, two-producer model as in Ulph (1996), we analyze the Nash equilibrium of the game where governments may behave strategically in choosing their environmental policies, and producers may behave strategically in choosing their R&D investments. In the simultaneous-move game, there is a unique equilibrium and both governments and producers act strategically. In the sequential-move game, two equilibrium sets of actions are present; however, one of them welfare-dominates the other: first-moving government acts strategically, the follower government will not act strategically, and none of the producers will behave strategically. Some of our results are in contrast with the implications of earlier papers in this literature.

Keywords: Environmental regulation, international trade, strategic behaviour

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1. Introduction

In recent years, there has been a great interest on the interactions between trade and environment. In general, the attention is mostly directed to two polar opposites: the impact of environmental regulations on the international competitiveness of regulated firms, and the impact of trade liberalization on environmental quality. No consensus exists regarding neither the impact of freer trade on the environmental quality and nor the impact of environmental regulations on the international competitiveness. Both the theoretical and empirical studies present mixed evidence.

A quick scan of different patterns of interactions between trade and environment will give an idea for the widely differential approaches to the problem in the literature. An interesting area of interactions is related to the use of international trade as an enforcement tool in international environmental agreements (IEA). In the absence of a supranational authority, IEAs are subject to free-riding, and thus, their chance of being successful is very limited if a proper enforcement mechanism is not developed. Barrett (1999) considers the applicability of trade sanctions as an instrument to enforce international environmental agreements aiming to provide a global public good, such as reduction in different pollutants[2]. He shows that trade policies can be used to enforce international environmental agreements provided that (1) every country must be better off as a signatory than as non-signatory when sanctions are imposed against free riders, and (2) when free-riding occurs, signatories must be better-off by imposing sanctions than by continuing to trade with non-signatories.

Alpay (2000) takes up the question whether the suboptimality of the production of a public good in a closed economy extends to open economy case, more explicitly, whether global environmental protection is also subject to free-riding in a model where trade connections among countries are taken into consideration. It has been shown that countries are not always reluctant to contribute to global environmental protection. Even if there is no self-financed transfers between countries, when the terms of trade changes associated with environmental protection are taken into consideration, countries may choose to contribute to global protection instead of free riding on others' contribution. This non-cooperative contribution, contrary to the conventional results, exceeds that of the cooperative one. As a policy implication, the paper concludes that the assessment of government policies on global environmental protection in a partial equilibrium framework by ignoring the possible trade interactions, may very well be misleading.

[2] An earlier study by Blackhurst and Subramanian (1992) on multilateral cooperation on environmental issues, sets out the obstacles in the path to cooperation (free-riding being the main component). They state that trade policies generate incentives for countries to participate in multilateral efforts to deal with environmental problems.

On the other hand, the impact of environmental regulations on the international competitiveness of firms has attracted a lot of attention. Conventionally, it was argued that environmental regulations would lower the competitiveness of the firms being regulated as compared to those subject to lax environmental conditions (for example see Palmer, Oates and Portney 1995). This argument was assumed to be robust to the type of the environmental regulations. Recently, this view has been challenged by a revisionist school. As the pioneer of this school, Porter and van der Linde (1995) argue that properly crafted environmental regulations (i.e., incentive-based) not only bring social benefits with it (like increased environmental quality, decline in health risks associated with pollution, etc.), but also can increase competitiveness of the firms being regulated as higher environmental standards can trigger innovation that may offset the compliance costs. There have been at least 100 empirical studies on this debate, however, there is lack of evidence on either side.

In this paper, we will focus on another important dimension: strategic environmental policy making in the presence of international trade. Environmentalists worry that trade-related goals may generate some distortions in environmental policies; freer trade may lead to laxer environmental standards in order to generate competitive advantage over the trading partners. This kind of strategic behavior, known as “eco-dumping” or “race-to-the-bottom”, attracted the attention of researchers, and a number of studies analyzed this subject.

The studies on strategic behavior usually incorporate extended versions of the Brander and Spencer (1985) model. Brander and Spencer Cournot duopoly model is designed to analyze export subsidies only, and environmental components are added later by Conrad (1993), Kennedy (1994), Barrett (1994) and Ulph (1996). In Brander and Spencer (1985), the governments in each country maximize the domestic surplus, defined as the profit of the domestic firm net of the subsidy whereas in its extended versions of trade-environment studies, the domestic surplus is usually the profit of the domestic firm net of the environmental damage.

Kennedy (1994) tries to find the optimum pollution tax in open economies. He argues that imperfect competition in global markets creates inefficient distortion of pollution taxes. He investigates two opposite effects that interact with each other: one to gain competitive advantage over the trading partner, and the other to shift the pollution to the other country. It has been shown that in case of perfect transboundary pollution, the second effect vanishes. If the pollution is partially transboundary, this distorts the pollution taxes that would otherwise be globally efficient.

Barrett (1994) studies the impact of market type on the environmental-policy-making of governments. He shows that if the domestic industry is a monopoly, the foreign industry is imperfectly competitive, and industrial competition is Cournot, then the domestic government has an incentive to set weak environmental standards; weak standards mean that at the level of chosen emissions, the marginal cost of abatement is less than the marginal damage from pollution. Strategically-optimal emission standards are set weaker than the environmentally-optimal emission standards.

Ulph (1996) extends the previous studies on strategic behavior into a setting where not only governments but also producers may act strategically. In a two-country, two-producer and one good model, governments internalize environmental damages associated with the production by either setting standards or levying taxes. Governments may behave strategically by distorting their environmental policies in order to generate competitive advantage to their firms, which are competing in a third country market. Producers' strategic behavior is associated with their choice of R&D investment. Ulph (1996) shows that if producers act strategically, this always reduces the incentives for governments to relax their environmental policies, and that if governments act strategically, this always increases the producers to overinvest in R&D (i.e. act strategically). The paper also demonstrates that when both producers and governments act strategically, the use of pollution taxes is inferior to the use of emission standards (with respect to the distortion in environmental policies and R&D investment), and finally welfare is lower when both producers and governments act strategically than when only one agent acts strategically.

In this paper, we will present the explicit and extensive welfare analysis of the game among producers and governments in the context described in Ulph (1996). Our main goal is to determine the Nash equilibrium of the strategic game. This is very critical as the final outcome regarding environmental policies, R&D investment, emission and welfare levels depend on the equilibrium behavior. This game can be divided into two stages. In the first stage, governments maximize the domestic welfare associated with the production of the polluting good (equal to producer's surplus net of welfare cost of pollution) by choosing the level of emissions. Governments may behave efficiently or strategically, in which case they will try to induce competitive advantage to their firms by incorporating the impact of the chosen emission levels on the foreign producer's behavior. Similarly, producers may behave optimally or strategically in the context defined in Ulph (1996). Therefore, there will be 16 different set of behaviors, such as both governments are playing strategically and producers behaving non-strategically etc. In our paper we will try to determine the equilibrium behavior. This will be done for both the sequential and simultaneous move game. Such an analysis has not been reported before.

The paper is organised as follows: in the next section, we introduce the basic model. Section 3 will present the welfare analysis of all possible cases. In section 4, we investigate the Nash equilibrium of the game. Section 5 concludes.

2. Model

We will analyze the strategic behavior of governments and producers in the presence of environmental regulations and international trade by making use of the model developed by Ulph (1996). This model assumes a two-country set-up with one producer in each of them. The producers produce a homogeneous good, the production of which generates pollution. The producers are competing in a third-country market. The inverse demand function (or price in the third country) is given by p= A – x – y, where p is the price, x is the domestic production, y is the foreign production and A is a positive constant. Then the revenue function for the home country producer is given by R(x , y) = x (A – x – y). Countries are assumed to be symmetric, and the terms corresponding to foreign country can thus be imagined easily.

The production cost of x is C (x,ö) = ö $x^2/4$, where ö represents the technology parameter (or R&D parameter). The producer chooses this strategic variable ö, and the cost associated with this choice is given by $\frac{1}{j}$ (one can visualize this process as the choice of a technology level, ö, and the cost of R&D required to obtain that technology, $\frac{1}{j}$). In the absence of strategic behavior, the producer will minimize the total cost function $j\,\frac{x^2}{4}+\frac{1}{j}$ for any given level of output to get the efficient level of ö. Cost minimization results in ö = $\frac{2}{x}$. Substituting this into the cost function gives us the total cost:

$$\text{Total cost} = \frac{2}{x}\frac{x^2}{4}+\frac{1}{2/x}=\frac{x}{2}+\frac{x}{2}=x$$

This is called as the efficient cost function (Ulph 1996). The producer's strategic behavior is associated with the choice of ö. Any level other than the efficient level indicates a strategic behavior.

The production of good x generates pollution. Producers can reduce their emissions by choosing a level of costly abatement, a. The cost of abatement is equal to $\frac{a^2}{2}$. The reason producers need to spend some of their resources on costly abatement is that governments in each country set standards for the level of emissions generated. By choosing units suitably, the level of emissions that the producer generates will be equal to e = x – a (it is being assumed that one unit of output generates one unit of emission). The welfare cost associated with the emissions is assumed to be $\frac{de^2}{2}$, where d is a positive constant. Governments determine the optimal emission levels, e and ε (emissions in foreign country), by maximizing their welfare functions associated with the production of this good, defined as total revenue minus total cost of production including cost of abatement minus total cost of pollution damage. We assume that the environmental damage is only local. Producers maximize their profit function, which is equal to total revenue minus total cost of production minus total cost of abatement, using the emission level determined by the government.

There are three stages of the game. In the first stage, governments choose the emission levels, e and ε, domestic and foreign respectively. Then the producers take the emission levels as given, and choose their R&D level, φ and ψ, domestic and foreign respectively. At the final stage the producers choose their output levels using the emission level set by the governments, and the R&D levels set in the second stage. The governments and producers can act strategically. In the present context, the governments are assumed to act strategically if they consider the impact of their emission levels on the output of the foreign producer. The producers act strategically by considering the side effects of their investment in R&D on the rival's output. When neither the government nor the producer is acting strategically, the government chooses the emission level ignoring the impact of its emission level on the foreign producer's output level, and the producer uses its efficient R&D level, $\varphi=2/x$ and $\psi=2/y$, for domestic and foreign producers respectively.

Thus, four possible cases will be present pertaining to the behaviour of governments and producers in each country. These are (1) neither the government nor the producer is acting strategically, (2) only the government is acting strategically, (3) only the producer is acting strategically, and (4) both the government and the producer are acting strategically. These cases are valid for both countries. So, overall we can observe 16 different cases related to the behaviour of governments and producers in these two countries.

The objective function of the producers and governments can be expressed as follows:

$$\pi_D = (A - x - y)\,x - x - 0.5(x - e)^2$$

where π_D represents the domestic producer's profit; here production cost function is taken as the efficient cost function. The welfare level of the domestic country is given by

$$W_D(e) = (A - x - y)\,x - x - 0.5(x - e)^2 - 0.5de^2$$

Similarly for the foreign country:

$$\pi_F = (A - x - y)\,y - y - 0.5(y - \varepsilon)^2.$$

$$W_F(\varepsilon) = (A - x - y)\,y - y - 0.5(y - \varepsilon)^2 - 0.5d\varepsilon^2.$$

3. Welfare Analysis of Behaviours of Governments and Producers

Our main objective is to determine the Nash equilibrium of the strategic game between the countries. Nash equilibrium is identified by computing the welfare levels (for the governments' behavior) and the profit levels (for the producers' behavior). We will first study 4 symmetric cases related to the behaviour of governments and producers. By symmetry we mean that both governments and producers are acting similarly. More explicitly, these cases are: 1) neither the governments nor the producers are acting strategically in both countries (NS—NS), 2) only governments are acting strategically(GS—GS), 3) only producers are acting strategically (PS—PS), and 4) both governments and producers are acting strategically (Both—Both). Ulph (1996) analyzes only these four symmetric cases. The remaining 12 hybrid cases will also be examined in this paper.

3.1 Non-strategic Equilibrium (NS versus NS)

In the non-strategic equilibrium, neither the producers nor the governments are acting strategically; in other words they will choose their variables without paying attention to their impact on the foreign producer. We will identify the optimal output, emission and welfare levels by adopting a backward solution. In the second and third stage of the game the producers choose their R&D and output levels respectively. Under non-strategic behavior, the choice of optimal R&D will lead to the efficient total cost function C(x) = x, and C(y) = y for domestic and foreign producers, respectively. Producers will maximize their profits by choosing the output levels. In case of domestic producer:

$$\max_{x} \quad (A - x - y)x - x - 0.5(x - e)^2 \tag{1}$$

The producers take the emission level and the output of the rival as given. The first order condition for this maximization problem results in:

$$x = (A - 1 + e - y) / 3 \tag{2}$$

Given the symmetry, foreign producer will have the following first order condition:

$$y = (A - 1 + \varepsilon - x) / 3 \tag{3}$$

where ε is the emission level of the foreign country. Substituting (2) and (3) into each other we get:

$$x = (2A - 2 + 3e - \varepsilon) / 8 \tag{4a}$$

$$y = (2A - 2 + 3\varepsilon - e) / 8 \tag{4b}$$

In the first stage of the game, the government chooses domestic emission level, e, by maximizing the welfare function (foreign emission level, ε, and the output level, y, are treated as given):

$$\max_{e} W(e) = (A - x - y)x - x - 0.5(x - e)^2 - 0.5de^2 \tag{5}$$

The first order condition is:

$$\left(A - 1 - y + e - 3x\right)\frac{\partial x}{\partial e} + x - e - de = 0$$

From equation (2), (A – 1 – y + e – 3x) = 0, so the first order condition becomes:

$$x - e = de \tag{6a}$$
$$e = x / (1+d) \tag{6b}$$

Equation (6a) represents a familiar outcome: the equality of marginal abatement cost (left side) and marginal damage cost (right side).

Under the symmetry assumptions, e and ε will be equal, and we combine (4a) and (6b) to get the output and emission levels.

$$x = (A - 1)(1 + d) / (3 + 4d) \tag{7}$$
$$e = (A - 1) / (3 + 4d) \tag{8}$$

The output and the emission level of the foreign country will be the same due to symmetry assumption. The resulting welfare levels for both countries will be:

$W_D(e) = (A - x - y)x - x - 0.5(x - e)^2 - 0.5de^2$.
$W_D(e) = (A - 1)\, e\, (1 + d) - 2e^2(1 + d)^2 - 0.5d^2e^2 - 0.5de^2$

$$W_D = W_F = (A-1)(1+d)\frac{A-1}{3+4d} - 2\left(\frac{A-1}{3+4d}\right)^2(1+d)^2 - 0.5d^2\left(\frac{A-1}{3+4d}\right)^2 - 0.5d\left(\frac{A-1}{3+4d}\right)$$

where W_D and W_F are welfare levels for domestic and foreign country, respectively. Determination of the Nash equilibrium of the game requires the comparison of welfare levels across different cases. As seen above it is not possible to compare the complex welfare expressions; thus, we will compute numerical values by assigning alternative values for the unknown parameters as in Ulph (1996). The final outcome will be shown in Table 1 and Table 2 below.

3.2 Only Governments Act Strategically (GS versus GS)

The governments act strategically by considering that the output of the foreign producer depends on the emission level they choose, i.e. they take into consideration that both x and y depend on e (ε for the foreign country). The first order condition associated with the welfare maximization in (5) now becomes:

$$(A - 1 - y + e - 3x)\frac{\partial x}{\partial e} - x\frac{\partial y}{\partial e} + x - e - de = 0$$

The producers do not act strategically and behave as in the previous case. Using equation (2) in the above first order condition, we get:

$$e\,(1 + d) = x - x\frac{\partial y}{\partial e} \tag{9}$$

From equation (4b), we get $\frac{\partial y}{\partial e}$ =-1/8 . Substituting this value into (9) gives us:

$$e = \frac{9x}{8(1+d)} \tag{10}$$

When we compare this with the non-strategic equilibrium, we see a higher emission level. Due to symmetry, e = ε and x = y, and solving (10) together with (4a) gives us the output and emission levels for this case:

$$x = y = (A - 1)(1 + d) / (3 + 4d - 1 / 8) \quad (11)$$
$$e = \varepsilon = 9(A - 1) / [8(3 + 4d) - 1] \quad (12)$$

The welfare levels of the countries will be:

$$W_D(e) = (A - x - y)x - x - 0.5(x - e)^2 - 0.5de^2.$$
$$W_D(e) = \frac{8}{9}(A - 1)\, e\, (1 + d) - \frac{128}{81} e^2(1 + d)^2 - \frac{e^2}{162}(8d - 1)^2 - 0.5de^2$$
$$W_D = W_F = \frac{8}{9}(A-1)(1+d)\frac{9(A-1)}{8(3+4d)-1} - \frac{128}{81}(1+d)^2\left(\frac{9(A-1)}{8(3+4d)-1}\right)^2$$
$$-\frac{(8d-1)^2}{162}\left(\frac{9(A-1)}{8(3+4d)-1}\right)^2 - 0.5d\left(\frac{9(A-1)}{8(3+4d)-1}\right)^2$$

3.3 Only Producers Act Strategically (PS versus PS)

This time the producers choose their R&D level by maximizing their profits with respect to φ (ψ for foreign producer) in the second stage instead of choosing it through the minimization of total cost. Using a backwards solution approach, producers determine their output levels (x and y) as a function of their R&D levels (φ and ψ) in the third stage. For domestic producer:

$$\max_{x}\ (A - x - y)x - \varphi x^2 / 4 - 0.5(x - e)^2 \quad (13)$$

The second term is the total cost function assuming that the level of R&D, φ, has been determined in the second stage. The first order condition is:

$$x = 2\,(A - y + e) / (6 + \varphi) \quad (14a)$$

Due to symmetry, foreign output level, y, will be

$$y = 2\,(A - x + \varepsilon) / (6 + \psi) \quad (14b)$$

Solving these two reaction functions in (14a) and (14b) together, we get:

$$x = \lambda[(8 + 2\psi)A + 2(6 + \psi)e - 4\varepsilon] \quad (15a)$$

$$y = \lambda[(8 + 2\varphi)A + 2(6 + \varphi)\varepsilon - 4e] \quad (15b)$$

where $\lambda = 1 / (32 + 6\varphi + 6\psi + \varphi\psi)$. λ is always positive since φ and ψ are always positive.

At the second stage producers maximize their profit functions with respect to their R&D levels (φ and ψ). This is where the strategic behavior of producers becomes visible:

$$\max_{\varphi} \ (A - x - y)x - \varphi x^2 / 4 - 1 / \varphi - 0.5(x - e)^2 \qquad (16)$$

Equation (16) is slightly different from (13) in the inclusion of the R&D cost in the objective function; in the third stage of the game there is no need to include the R&D cost since R&D level will already be chosen.

The first order condition corresponding to (16) is:

$$[A - y + e + 0.5(6 + j\ )x]\frac{\partial x}{\partial j} - x\frac{\partial y}{\partial j} - \frac{x^2}{4} + \frac{1}{j^{\ 2}} = 0$$

From equation (14a), the first term in the above expression is equal to zero, and we get:

$$1 / \varphi^2 = x^2 / 4 + x\frac{\partial y}{\partial j} \qquad (17)$$

From equation (15b):

$$\frac{\partial y}{\partial j} = 2\lambda x$$

So, $$\frac{1}{j} = \frac{x}{2}(1 + 8l\ )^{1/2} \qquad (18)$$

Similarly for foreign producer:

$$\frac{1}{y} = \frac{y}{2}(1 + 8l\ )^{1/2} \qquad (19)$$

When we compare this with the efficient choice of R&D, that is 1/φ = x/2 (or 1/ψ = y/2), we see that producers increase the R&D expenditure (as λ is positive) under strategic behavior.

In the first stage of the game, governments determine efficient emission levels as they are not acting strategically. The welfare maximization problem of the domestic country is:

$$\operatorname*{Max}_{e} \ (A - x - y)x - \varphi x^2 / 4 - 1 / \varphi - 0.5(x - e)^2 - 0.5de^2 \qquad (20)$$

The government knows that x and φ depend on e, the emission level; x depends on e both directly ($\frac{\partial x}{\partial e}$), and indirectly (x depends on φ, φ depends on e, $\frac{\partial x}{\partial j}\frac{\partial j}{\partial e}$). It neglects the impact of e on the foreign producer's output y (non-strategic behavior). The first order condition is:

$$[(A - y + e) - 0.5x(6 + j\ )]\left(\frac{\partial x}{\partial e} + \frac{\partial x}{\partial j}\frac{\partial j}{\partial e}\right) + \left(-x\frac{\partial y}{\partial j} - \frac{x^2}{4} + \frac{1}{j^{\ 2}}\right)\frac{\partial j}{\partial e} + x - e - de = 0$$

Using the values of x and φ in (14a) and (18), this first order condition simplifies to:

$$e = x / (1 + d)$$

which is the same emission level set by the government in the non-strategic case.

Due to symmetry e = ε, we get:

$$x = 2A / (2d + \varphi') \quad (21)$$

$$e = x / (1 + d) \quad (22)$$

where φ' solves:

$$8 / [(4 + \varphi')(8 + \varphi')] = [\,4D^2 + 4D\varphi' - (A^2 - 1)\,\varphi'^2] / A^2\varphi'^2 \quad (23)$$

and D = (3 + 4d) / (1 + d). It is not possible to find an explicit analytic solution; but equations (21), (22) and (23) give us an implicit solution. The welfare of both of the countries is:

$$W_D = W_F = (A - x - y)x - \varphi x^2 / 2 - 1 / \varphi - 0.5(x - e)^2 - 0.5de^2.$$

$$W_D = W_F = A\,e\,(1 + d) - e^2(1 + d)^2\,(2 + \frac{j}{4}) - \frac{1}{j} - 0.5d^2e^2 - 0.5de^2$$

where e is determined from equations (21), (22) and (23) by using numerical solution procedures. The value of φ is obtained from equation (18).

3.4. Both Governments and Producers Act Strategically (Both versus Both)

The producers use the same reaction functions that were determined in the previous case, equations (14a)--(14b), and they use the same R&D levels in equation (18) and (19). In this case, governments also act strategically by considering the impact of emission levels (their choice variable) on x, y, φ, and ψ. This yields the first order condition (the maximization problem is same as the one in equation 20):

$$[(A - y + e) - 0.5x(6 + j)]\left(\frac{\partial x}{\partial e} + \frac{\partial x}{\partial j}\frac{\partial j}{\partial e} + \frac{\partial x}{\partial y}\frac{\partial y}{\partial e}\right) - x\frac{\partial y}{\partial e} + \left(-x\frac{\partial y}{\partial j} - \frac{x^2}{4} + \frac{1}{j^2}\right)\frac{\partial j}{\partial e}$$

$$-x\frac{\partial y}{\partial y}\frac{\partial y}{\partial e} + x - e - de = 0 \quad (24a)$$

By using equations (14a) and (18) we simplify the first order condition in equation (24a) to:

$$e(1 + d) = x\left(1 - \frac{\partial y}{\partial e} - \frac{\partial y}{\partial y}\frac{\partial y}{\partial e}\right) \quad (24b)$$

We see that the deviation from the non-strategic rule is in two terms: $\frac{\partial y}{\partial e}$, the strategic incentive to influence the output of the foreign producer directly, and $\frac{\partial y}{\partial y}\frac{\partial y}{\partial e}$, the strategic incentive to influence the output of the foreign country indirectly, (through the foreign producer's investment in R&D). It is not possible to find an analytic solution for this case; as in the previous case, we will use numerical solution procedures. Then the welfare levels can be determined.

Up to this point we studied only the symmetric behaviors, i.e. we assumed that governments and producers in both countries adopted the same type of action. If domestic agent (government or producer) behaved strategically then the foreign counterpart is also assumed to behave strategically. Now we will look at non-symmetric or hybrid cases. We will abbreviate non-strategic as NS, strategic action *only* by government as GS, strategic action *only* by producer as PS and strategic action by *both* governments and producers as Both. So, we need to study the following cases: NS versus GS, where both the domestic government and producer are acting non-strategically (NS), and only the foreign government is acting strategically (GS). NS versus PS, non-strategic behavior in the domestic country (NS), and only the foreign producer is acting strategically (PS). Similarly, other cases will be NS versus Both, GS versus PS, GS versus Both, PS versus Both. Then we have the opposite six cases: GS versus NS, PS versus NS, Both versus NS, PS versus GS, Both versus GS, and Both versus PS. Due to symmetric country assumption, the welfare levels corresponding to these last six cases can easily be obtained by changing the positions of domestic and foreign countries in the previous six cases.

3.5 Non-strategic versus Only Foreign Government is Acting Strategically, (NS versus GS)

In this case the domestic government, domestic and foreign producers are acting non-strategically, and only the foreign government is acting strategically. Since the producers are not acting strategically in each country they use the output level given in equations (4a) and (4b). The emission levels set by the governments in the domestic and foreign countries are:

$$e = \frac{x}{1+d} \quad , \qquad \varepsilon = \frac{9y}{8(1+d)} \quad \text{respectively.}$$

We substitute these values into equations (4a) and (4b) and get the following reaction functions:

$$x = \frac{16(A-1)(1+d) - 9y}{64(1+d) - 24} \quad , \qquad y = \frac{16(A-1)(1+d) - 8x}{16(1+d) - 27}$$

Substituting one into the other gives us:

$$x = \frac{2(A-1)(1+d)[64(1+d) - 36]}{(5+8d)[64(1+d) - 27] - 9} \tag{25}$$

$$y = \frac{2(A-1)(1+d)[64(1+d) - 35]}{(5+8d)[64(1+d) - 27] - 9} \tag{26}$$

$$e = \frac{2(A-1)[64(1+d) - 36]}{(5+8d)[64(1+d) - 27] - 9} \tag{27}$$

$$e = \frac{9}{4}\frac{2(A-1)[64(1+d) - 35]}{(5+8d)[64(1+d) - 27] - 9} \tag{28}$$

We can express the welfare levels as:

$W_D(e) = (A - x - y)x - x - 0.5(x - e)^2 - 0.5de^2$.

$W_D(e) = A\ e\ (1 + d) - e^2(1 + d)^2 - \frac{8}{9}(1 + d)^2\ e\ \varepsilon - (1 + d)e - 0.5d^2e^2 - 0.5de^2$

$W_F(\varepsilon) = (A - x - y)y - y - 0.5(y - \varepsilon)^2 - 0.5d\varepsilon^2.$

$W_F(\varepsilon) = \frac{8}{9}A\ \varepsilon\ (1 + d) - \frac{8}{9}e\varepsilon(1 + d)^2 - \frac{64}{81}(1 + d)^2\ \varepsilon^2 - \frac{8}{9}(1 + d)\ \varepsilon$ . .

$-\frac{e^2}{162}(8d - 1)^2 - 0.5d\varepsilon^2$

where the values for e and ε are given in equations (27) and (28).

3.6 Non-strategic versus Only Foreign Producer is Acting Strategically (NS versus PS)

Since the producer in the domestic country is not acting strategically, its output will be obtained from equation (2); but the foreign producer is acting strategically, and its output will be determined from equation (14b). In the second stage of the game in the foreign country, foreign producer maximizes the foreign analog of the objective function in equation 16 with respect to ψ, and obtains the following relationship from first order conditions (counterpart of equation 17):

$$\frac{1}{y^2} = \frac{y^2}{4} + y\frac{\partial x}{\partial y} \tag{29}$$

Since none of the governments acts strategically, emission levels will be equal to e=x/(1+d) and ε=y/(1+d) for domestic and foreign countries respectively. Because of equation (29), analytic solution is not possible, and we will get the welfare levels for each country by using numerical solution procedures.

3.7 Non-strategic versus Both Foreign Government and Producer are Acting Strategically (NS versus Both)

The producer in the first country maximizes the profit function in (1); foreign producer behaves as in the previous section. The only difference with the previous case is the strategic behavior of the foreign government, which results in the emission level, $e = \frac{y}{(1+d)}(1 - \frac{\partial x}{\partial e})$. It can be shown that $\frac{\partial x}{\partial e} = \frac{-2}{(16 + 3y)}$, and $e = \frac{y(9 + 1.5y)}{(16 + 3y)}$. Then the welfare levels can be obtained by using numerical solution procedures, and they will be reported in Table 1 below.

3.8 Only Domestic Government and Foreign Producer are Acting Strategically (GS versus PS)

The reaction function for the domestic producer is same as the one in equation (2), and the reaction function for the foreign producer is given by equation (14b). The strategic behavior of foreign producer requires that the R&D level satisfy $\frac{1}{y^2} = \frac{y^2}{4} + y\frac{\partial x}{\partial y}$ (which is the foreign counterpart of equation 17). The domestic government behaves strategically, and thus as in section 3.4, domestic emission levels, e, will be determined from equation (24b). Foreign government sets its emission at the efficient level $e = \frac{y}{1+d}$. Foreign producer will use the R&D level in equation (29). The reaction functions for the producers' output levels are given in equation (2) and (14b) for domestic and foreign producers, respectively.

3.9 Domestic Government and Both Foreign Government and Producer are Acting Strategically (GS versus Both)

The domestic producer chooses its output level as in equation (2), and the foreign producer as in equation (14b). The strategic behavior of foreign producer requires that the R&D level satisfy $\frac{1}{y^2} = \frac{y^2}{4} + y\frac{\partial x}{\partial y}$ (as in equation 17). Both governments behave strategically, and thus they consider the impact of emission levels on the output levels of the producers both directly and indirectly (through R&D parameter). Domestic emission levels, e, will be determined from equation (24b). Foreign government sets its emission level by using $e = \frac{y}{(1+d)}(1 - \frac{\partial x}{\partial e})$. It can be shown that $\frac{\partial x}{\partial e} = \frac{-2}{(16+3y)}$, and $e = \frac{y(18+3y)}{(16+3y)}$. Then the welfare levels can be determined numerically.

3.10 Domestic Producer, and Both Foreign Government and Producer are Acting Strategically (PS versus Both)

As in section 3.4 above, producers in both countries will use the reaction functions given in equations (14a) and (14b). The government in the first country will set the emission level efficiently, $e = \frac{x}{(1+d)}$. From section 3.3 producers' strategic behavior will lead to the following reaction functions in R&D levels:

$$\frac{1}{j^2} = \frac{x^2}{4}(1+8l) \tag{30}$$

$$\frac{1}{y^2} = \frac{y^2}{4}(1+8l) \tag{31}$$

The foreign government behaves strategically and maximizes:

$$(A - x - y)y - \psi y^2 / 4 - 1/\psi - 0.5(y - \varepsilon)^2 - 0.5d\varepsilon^2 \tag{32}$$

The first order condition associated with (32) will be:

$$[(A-x+e)-0.5y(6+y)]\left(\frac{\partial y}{\partial e}+\frac{\partial y}{\partial y}\frac{\partial y}{\partial e}\right)+\left(-y\frac{\partial x}{\partial y}-\frac{y^2}{4}+\frac{1}{y^2}\right)\frac{\partial y}{\partial e}+y-e-de=0$$

Using equations (14b) and (19), the above first order condition simplifies to:

$$e(1+d)=y\left[1-\frac{\partial x}{\partial e}-\frac{\partial x}{\partial j}\frac{\partial j}{\partial e}\right] \tag{33}$$

From equations (15a) and (15b), we get:

$$\frac{\partial x}{\partial e}=-4l\,,\qquad \frac{\partial x}{\partial j}=-lx(6+y),\qquad \frac{\partial j}{\partial e}=\frac{4lj}{x}$$

Using these, we rewrite (33) as:

$$e=\frac{y\left[1+4l+4l^2(6+y)j\right]}{1+d} \tag{34}$$

Substituting equations (30) and (34) into (15a) and (15b), we get:

$$x=\frac{f(1-g')-uf'}{(1-g)(1-g')-uv}\quad \text{and}\quad y=\frac{f'(1-g)-vf}{(1-g)(1-g')-uv}\quad \text{where}$$

$$f=(8+2y)Al\,,\quad g=\frac{2l(6+y)}{1+d},\quad u=\frac{4Kl}{1+d},$$

$$f'=(8+2j)Al\,,\quad g'=\frac{2l(6+j)K}{1+d},\quad v=\frac{4l}{1+d}$$

$$K=1+4l+4l^2(6+y)j\,.$$

From equations (18) and (31):

$$(\psi x^2+6x^2)\varphi^3+(6x^2\psi+40x^2)\varphi^2-(4\psi+24)\varphi-(24\psi+128)=0 \tag{35}$$

$$(\varphi y^2+6y^2)\psi^3+(6y^2\varphi+40y^2)\psi^2-(4\varphi+24)\psi-(24\varphi+128)=0 \tag{36}$$

It is not possible to solve these two equations analytically, and we obtain the welfare levels by using numerical solution procedures. Given the identical country assumption, the welfare levels corresponding to the remaining last six set of behaviors can be obtained by interchanging the positions of domestic and foreign countries. Now, we start to identify the Nash equilibrium.

4 Nash Equilibrium

In the previous section we have identified the welfare levels of both countries for all possible set of behaviors. Now, by using them we will determine the Nash equilibrium of the game played by the governments and producers. Firstly, governments choose their environmental policy, then producers choose their R&D and output levels. Given that producers are rivals in a third country market, environmental policy and R&D levels may not be set at their efficient levels to generate competitive advantage. Thus, an interesting issue is whether producers and governments will act strategically or efficiently.

Welfare levels computed in the previous section can not be compared analytically; thus we are forced to assume numerical values for the basic parameters, A and d. As in Ulph (1996), we let A=10 and d=1. We have also considered other possible values for A and d, and the results were qualitatively similar. The pay-off table constructed from the welfare expressions obtained in the previous section for the 16 possible cases is given in Table 1:

Table 1. Welfare Levels—Pay-off Table.

Domestic Country \ Foreign Country	NS		GS only		PS only		BOTH	
NS	8,505	8,505	8,532	8,593	8,149	8,297	7,968	8,337
GS only	8,593	8,532	8,252	8,252	8,177	8,103	8,017	8,143
PS only	8,297	8,149	8,103	8,177	8,423	8,423	8.014	8.231
BOTH	8,337	7,968	8,143	8,017	8.231	8.014	8.070	8.070

Producers' actions will be based on their profit levels, and Table 2 presents the profit levels for the domestic and foreign producers for each of the 16 cases:

Table 2. Producers' Profits.

Domestic Producer \ Foreign Producer	NS		GS only		PS only		BOTH	
NS	9,315	9,315	9,311	9,611	8,964	9,153	8,765	9,452
GS only	9,611	9,311	9,330	9,330	9,262	8,944	9,082	9,231
PS only	9,153	8,964	8,944	9,262	9,248	9,248	8.839	9.324
BOTH	9,452	8,765	9,231	9,082	9.324	8.839	9.136	9.136

We will consider both the simultaneous and sequential move games for the Nash equilibrium of the game between countries represented by the payoff tables in Table 1 and 2.

4.1 Simultaneous Move Game

In the simultaneous-move game, first governments then producers will move simultaneously. Note that the pay-off tables are different for governments (Table 1) and producers (Table 2). If a Nash equilibrium exists, then the corresponding set of actions for producers and governments must match; this means that the Nash equilibrium corresponding to the pay-off tables above must indicate the same actions. Thus, we will determine the Nash outcome for both pay-off tables separately, and check if there is a common set actions.

From Table 1, there is multiple equilibrium for governments' game: NS—GS, GS—NS, PS—PS, and Both—Both (first action belongs to domestic government and the second one to foreign government). From Table 2, we see that producers' game has also multiple equilibrium: GS—GS, and Both—Both (first action belongs to domestic producer and the second one to foreign producer). Note that GS means that producer is not acting strategically, and Both refers to the case that both producer and government are acting strategically as described in the previous section. Both-Both is the only action pair common, so it is the unique Nash equilibrium for the simultaneous move game. Leaving the discussion of this result to the conclusion, we now move to the sequential move game.

4.2 Sequential Move Game

There may be alternative definitions of sequential move game in our context (as there two different types of agents). Nevertheless, we will only consider the one in which one of the governments moves first, and then the other government acts after observing this action. Producers are assumed to move simultaneously. Sequential behavior in the setting of environmental policy is not a strong assumption as it has been observed in reality much often especially in the developed and developing country context.

We will assume that domestic government moves first. From Table 1, it is clearly seen that the highest return that the domestic government can secure comes from GS-only action, i.e. domestic (leader) country will prefer to act strategically. The foreign government, the follower, then will act efficiently (non-strategically—NS action). Under these actions by governments, the pay-off table for producers (Table 2) reduces to the following subgame pay-off table.

Table 3. Sequential move game. Producers' Profits.

		Foreign Producer			
		NS		PS only	
Domestic Producer	GS only	9,611	9,311	9,262	8,944
	Both	9,452	8,765	9.324	8.839

As seen clearly, there are two equilibriums: GS—NS and Both—PS. These indicate that either both producers behave strategically or none of them behaves strategically. Producers get higher profits if they do not act strategically, and choose their R&D levels efficiently. We can argue that Both—PS equilibrium is inferior to GS—NS equilibrium; thus in the sequential move game only the leader government will behave strategically, and all other players will behave efficiently.

4.3 Emissions

It is also interesting to compute the emission values for each of the 16 cases. The resulting emissions are given in Table 4 below.

Table 4. Emission Levels.

	NS		GS only		PS only		BOTH	
NS	1,28571	1,28571	1,26994	1,44421	1,27665	1.3083	1.2624	1.4931
GS only	1,44421	1,26994	1,47273	1,47273	1.4735	1.2969	1.4594	1.4755
PS only	1.3083	1,27665	1.2969	1.4735	1,29791	1,29791	1,28406	1,47817
BOTH	1.4931	1.2624	1.4755	1.4594	1,47817	1,28406	1,45995	1,45995

In the simultaneous-move game, the equilibrium emission levels (corresponding to Both—Both) will be much higher than the efficient levels (corresponding to NS—NS) due to strategic behavior of governments and producers. Note that, producers' strategic behavior partially offsets the increase in emission levels associated with strategic behavior of governments (see the emissions corresponding to GS—GS). As producers invest more into the R&D when they act strategically, higher R&D level reduces emission levels. In the sequential move game, the emission levels will be higher in the domestic country (corresponding to the equilibrium behavior GS—NS). GS-NS equilibrium is also superior to Both—PS equilibrium with respect to resulting emissions. It is clearly observed that strategic behavior of governments increase the level of emissions, which is the cost of providing competitive advantage to their producers. Finally, emission levels are lowest when one government behaves efficiently and the other one strategically.

5 Conclusions

Will international trade lead to relaxation of environmental policies? Will the incentives of governments for acting strategically in setting their environmental policies be higher if producers competing in international markets behave strategically? What will be the Nash equilibrium of the strategic game between governments and producers in the presence of international trade and environmental regulations? How does the equilibrium change when we move from a simultaneous-move game to a sequential-move game?

Our paper attempts to provide answers to these questions. In a standard model used in earlier studies, we analyze the behaviors of governments and producers related to environmental policy making and R&D investment, respectively. Governments may act strategically by recognizing that the output of the foreign producer depends on the emission level it sets, and thus, it may distort its environmental policy in order to generate competitive advantage to its producer. Producers may act strategically by choosing the level of investment in R&D by considering the associated impact of the level of R&D on the output of rival producer. Our main objective is to determine the Nash equilibrium of this game including governments and producers in the presence of environmental regulations, international trade and innovation. Surprisingly, this has not been reported before.

We show that there is a unique Nash equilibrium in the simultaneous-move game, and both producers and governments behave strategically. Both countries end up with a lower welfare and higher emission level than the case in which none behaves strategically. This is like a prisoner's-dilemma-type outcome. In the sequential-move game, two equilibria exist, but one dominates the other in terms of both the welfare and emission levels. In the equilibrium, first-moving (leader) government acts strategically, the follower government will not act strategically, and none of the producers will behave strategically. The first-moving country gets higher welfare than the other country, whose government is not acting strategically. Similarly, producer in the first-moving country gets higher profits than the producer of the follower country. Furthermore, as expected, emission level is higher in the first-moving country because of the strategic behavior.

Our explicit analysis of the welfare levels and profits not only reveals the equilibrium behaviors but also puts doubt on some of the earlier conclusions in this literature. For example, Ulph (1996) states that allowing governments to act strategically increases the incentive for producers' to act strategically. As seen in the pay-off tables we have presented, producers will prefer to behave non-strategically (i.e. efficiently) when governments act strategically. Producers will prefer to act strategically only if the other producer is acting strategically. Finally, the highest welfare levels correspond to the cases in which only one government acts strategically and the other one efficiently, but this set of behaviors can not be sustained.

In this paper, we have studied only the symmetric case, i.e., both countries were identical. In our future work, we will release this assumption, and extend our analysis to non-symmetric cases.

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