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**Abstract**

This study explores the global welfare effects of international environmental agreements (IEAs) that coordinate emission policies between exporter countries. We show that, when export markets are imperfectly competitive, IEAs might cause a global welfare loss even if non-signatories benefit from lower emission levels. This result is due to a loss of consumer surplus in importer countries. From a global welfare perspective, the desirability of IEAs depends on the size of the domestic market for the export good and the harmfulness of emissions.

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JEL: Q56, F18

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# 1 Introduction

In the last decades, governments all over the world have signed a large number of international environmental agreements (IEAs). There are more than 270 IEAs in force today according to UNEP [14]; more than 120 of them were signed after 1990.

Economic research on IEAs has largely focussed on issues of stability and compliance.[1] In contrast, the global welfare effects of IEAs have not received much attention.

An IEA that implements jointly optimal environmental policies necessarily improves the total welfare of signatories. If such an agreement leads to less pollution, one is tempted to believe that, if any, the welfare effects on non-signatories are positive, and the world as a whole is better off with than without the IEA.

In this study we explore the global welfare effects of IEAs between governments that have strategic trade policy incentives, and come to a more nuanced conclusion.

Our analysis departs from the following simple setting: The production of an export good causes internationally mobile emissions. Governments of polluter countries can regulate emissions cooperatively or non-cooperatively. If firms compete on imperfectly competitive export markets, this changes the nature and effects of both cooperative and non-cooperative environmental policy setting as compared to perfect competition. From the literature on strategic environmental policy, it is well known that governments might use environmental policy as a proxy for strategic trade policy if the latter is not feasible. In such a situation, governments of exporting/polluting countries choose weak environmental regulation in order to shift rents from foreign firms to home firms. Signing an IEA on jointly optimal environmental policies eliminates this strategic conflict between exporting countries and thus unambiguously improves their welfare. However, the *global* welfare effects of such an IEA are less clear cut.

In this paper, we show that, even if non-signatories benefit from lower emission levels, an IEA might reduce global welfare as the associated loss of consumer surplus in importing countries might outweigh all welfare gains. In particular, we demonstrate that from a global perspective, the desirability of an IEA depends on the size of the signatory countries and the degree of harmfulness of

[1] See e.g. Carraro and Siniscalco [6] and Barrett [1].

emissions. Furthermore, we show that an IEA between exporter countries might implement environmental regulation that is either too lax or too strict as compared to the global optimum.

The remainder of this paper is structured as follows: Section 2 contains a literature review; in section 3 a simple model is developed; section 4 explains the main findings, and in section 5 the conclusions are presented.

## 2 Literature Review

The seminal contribution by Brander and Spencer [4] has laid the ground for a rich body of literature on trade policy under imperfect competition. Brander and Spencer [4] have shown that if export markets are imperfectly competitive, interventionist policies become attractive. The reason for this is the presence of rents that creates incentives for beggar-thy-neighbour trade policy [3]. Through strategic policy setting, governments can shift rents from a foreign firm to a home firm. If competition is à la Cournot, it is in the individual interest of exporting countries to subsidize, whereas they would do better as a group without subsidies.[2][3] Thus, governments find themselves in a Prisoner's Dilemma that leads to a Pareto-suboptimal outcome.

A notable extension of the original Brander and Spencer [4] model emerged parallel to advancing international trade liberalization beginning in the 1990s. With direct export subsidies becoming largely illegal under GATT/WTO rules, secondary trade policies have gained increasing attention. Several authors have extended the Brander and Spencer [4] framework to the case of polluting industries. Research in the area of strategic environmental policy has been spearheaded, among others, by Barrett [2], Rauscher [11] and Ulph [13]. One general conclusion emerging from these studies is that if the production costs of firms are positively related to the stringency of domestic environmental regulation, environmental policies will be laxer than first-best. However, Greaker [9] showed that the opposite is the case if emissions are an inferior input. Conrad [7] uses a reversed timing version of Brander and Spencer [4] in order to explain why firms engage in voluntary environmental agreements. Investigating this issue in a model where firms are footloose, Greaker [10] comes to the somewhat surprising result

[2] In fact, exporters' joint welfare-maximizing policy would be a negative export subsidy, i.e. an export tax [4].

[3] Eaton and Grossman [8] have shown that the opposite is true if firms compete in prices.

that the threat of plant relocation can lead to stricter environmental policy. Burguet and Sempere [5] analyze the effects of trade liberalization on environmental policies and welfare.

To our knowledge, Walz and Wellisch [15] are the only authors who include world welfare considerations in a model of strategic trade and environmental policy. In this sense, it is the paper most closely related to ours. However, our analysis differs in two fundamental ways from that of Walz and Wellisch [15]. First, while Walz and Wellisch [15] take pollution as being purely local, we consider globally mobile emissions. This adds an additional dimension to the model, as pollution constitutes a negative externality which has to be taken into account. Second, Walz and Wellisch [15] study a move towards free trade, *i.e.* direct export subsidies are allowed, and the welfare implications of a ban on such subsidies are analyzed. We start our analysis at a point where export subsidies are already banned, which we believe comes closer to today's reality. We then take the case of international environmental cooperation, and analyze its global welfare effects. In this sense, our study takes a new approach and arrives at results absent so far in the literature on strategic environmental policy.

## 3 The model

For our analysis, we develop a version of the Brander and Spencer [4] 2-stage game, where, in the first stage, governments of polluter countries set environmental policies, and, in the second stage, firms play Cournot-Nash. We then make a welfare comparison between international environmental cooperation and non-cooperation by considering two different ways of policy setting in the first stage.

The model consists of three countries A, B and C (rest of the world). In countries A and B there is one firm each, producing a normal homogeneous good. In our basic setup we assume that the total production is exported to country C, and thereafter extend the model to include domestic consumption. The two firms compete in quantities.

Production is accompanied by emission of a global pollutant for which governments set a standard.

In the first subgame, governments A and B simultaneously set emission standards.[4] In the second subgame, firms simultaneously decide on output levels, taking emission standards as given. We solve

[4] As there is only one firm per country, taxes and standards are equivalent. Hence, all results obtained in our analysis also hold for the case of emission taxes.

the model by backwards induction, considering the second stage of the game first.

### 3.1 Firms' behavior

We will assume that the two firms are symmetric and neither has means to influence its government's decision on the emission standard, so that each firm faces the following profit maximization problem:

$$\max_{x_i} \Pi_i = R_i(x_i, x_j) - C_i(x_i, e_i) \tag{1}$$

with the subscript denoting the country ($i = A, B$; $i \neq j$), x being output, Π being profit, R being revenue, C being costs and e being the emission standard. We assume that costs depend on the quantity of output produced and on the emission standard in the following manner:

$$\frac{\partial C_i}{\partial x_i} > 0, \frac{\partial C_i}{\partial e_i} < 0, \frac{\partial^2 C_i}{\partial x_i^2} > 0, \frac{\partial^2 C_i}{\partial e_i^2} > 0 \text{ and } \frac{\partial^2 C_i}{\partial x_i \partial e_i} < 0 \tag{2}$$

A first-order condition for a profit maximum obtains from taking the partial derivative of (1) with respect to $x_i$:

$$\frac{\partial \Pi_i}{\partial x_i} = \frac{\partial R_i}{\partial x_i} - \frac{\partial C_i}{\partial x_i} = 0 \tag{3}$$

We assume that the second-order condition and the Routh-Hurwitz stability conditions are satisfied so that the Cournot-Nash equilibrium is unique and stable.[5] Furthermore, the firms' output choices are strategic substitutes:

$$\frac{\partial^2 \Pi_i}{\partial x_i^2} < 0 \tag{4}$$

$$\left|\frac{\partial^2 \Pi_i}{\partial x_i^2}\right| > \left|\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j}\right| \tag{5}$$

$$\frac{\partial^2 \Pi_i}{\partial x_i \partial x_j} < 0 \tag{6}$$

**Lemma 1.** *Equilibrium output of firm i increases (decreases) in the emission standard of country i (j).*

[5] See Tirole [12] chapter 5.7.

*Proof.* See Appendix A.1. □

As the two firms are symmetric and the equilibrium is unique, the firms' output choices will be symmetric functions of the emission standards in both countries.

### 3.2 Strategic government behavior

In the first stage of the game, the emission standard of country i is determined by government i that maximizes welfare, given the Cournot-Nash game of the firms and the strategic choice of $e_j$ by government j.

Welfare consists of firm profits, consumer surplus from domestic consumption and environmental damage from emissions.

We normalize the size of the world market for the good to 1. A fraction $\frac{\phi}{2}$ of the demand originates in each exporter country and a fraction $1 - \phi$ in the rest of the world. The world market for the traded good is fully integrated, so that there is only one price. Global net consumer surplus is an increasing function of total consumption:[6]

$CS(X) \equiv \int_0^X P(X)dX - P(X)X$, with $CS'(X) > 0$ and $X = x_i + x_j$.

Furthermore, we assume that emissions cause environmental damage in each country. This damage is measured by a convex function of global emissions:

$\gamma D(E)$, with $\gamma D'(E) > 0$ , $\gamma D''(E) > 0$ where $E = e_i + e_j$ and $\gamma \geq 0$.

The parameter $\gamma$ is a measure of the harmfulness of emissions.

Government i hence solves the following maximization problem:

$$\max_{e_i} W_i = \Pi_i(x_i, x_j, e_i) + \frac{\phi}{2} CS(X) - \gamma D(E) \tag{7}$$

Differentiating (7) with respect to $e_i$ and substituting in (1) and (3) yields the following first-order condition for a welfare maximum:

$$\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\phi}{2} CS'(X)\frac{dX}{de_i} \tag{8}$$

[6]We assume the existence of a well-behaved demand function X(P) that is continuous and strictly decreasing wherever X(P)>0; P(X) is the implied inverse demand function.

where $\frac{dX}{de_i} = \frac{dx_i}{de_i} + \frac{dx_j}{de_i} > 0$.

Equations (8) are the usual conditions equating marginal damage and marginal benefit for both exporter countries.

Again we assume that the second-order conditions and the Routh-Hurwitz conditions are satisfied.

Considering the firms' behavior in the second stage and the government behavior in the first stage, equilibrium emission standards and output levels can be calculated. As country A and country B are identical, a unique symmetric Nash-equilibrium[7] obtains:

$$e_i^N = e_j^N = e^N \tag{9}$$

$$x_i^N = x_j^N = x^N \tag{10}$$

From the point of view of exporter countries, these emission standards are not jointly optimal.

**Lemma 2.** *In the Nash-equilibrium, a decrease in the emission standards leads to an increase in exporters' joint welfare.*

*Proof.* See Appendix A.2. □

This result is analogous to the result obtained by Brander and Spencer [4] on export subsidies and highlights the Prisoner's Dilemma faced by exporter countries. The choice of exporter countries that is individually rational leads to a jointly suboptimal outcome. Brander and Spencer [4] do not analyze the cooperative case correctly pointing out that countries could not credibly commit to cooperation. However, in repeated Prisoner's Dilemmas, cooperation can be sustained as equilibrium. While our model is not explicitly dynamic, one could imagine that governments face the decision whether or not to honor an IEA every period, rather than once and for all (which corresponds to the one-shot Prisoner's Dilemma), and thus cooperation is a relevant and important case to be considered.

### 3.3 Government cooperation

Let us now take the case of an IEA. If the governments cooperate in setting emission standards, they solve the following joint optimization problem in the first stage of the game:

[7] Throughout the paper we denote Nash-equilibrium values of variables with superscript N.

$$\max_{e_i, e_j} W_{i+j} = \Pi_i(x_i, x_j, e_i) + \Pi_j(x_i, x_j, e_j) + \phi CS(X) - 2\gamma D(E) \tag{11}$$

The first-order conditions yield:

$$2\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + \phi CS'(X)\frac{dX}{de_i} \tag{12}$$

Equations (12) differ from (8) in three ways reflecting that the governments now take into account the effects the emission standard in one exporter country has on environmental damage, revenues and net consumer surplus in the other exporter country. These additional terms reduce emission standards under a cooperative IEA[8] as the following proposition shows.

**Proposition 1.** *In the cooperative case, emission standards and output levels are strictly lower than in the Nash-equilibrium.*

*Proof.* See Appendix A.3. □ □

The rationale behind Proposition 1 is explained by the absence of rent-*shifting* and the presence of rent-*extracting* under an IEA. If governments cooperate, they individually have no longer any incentives to increase the home firm's market share at the foreign firm's expense by subsidizing exports through lax environmental regulation. Moreover, governments jointly have incentives to tax exports by setting strict emission standards in order to extract rents from the rest of the world. However, by doing so they also hurt the consumers within the exporter countries, which in turn attenuates the rent-extracting incentives.

# 4 World welfare

What are the effects of international environmental cooperation on global welfare? Let us define global welfare as the sum of welfare in the three countries:

$$W_G = 2W_E + W_I \tag{13}$$

[8]Throughout the paper we denote values of variables under a cooperative IEA with superscript C.

with $W_E$ being welfare of an exporting country in equilibrium and $W_I$ being welfare of the importing country corresponding to:

$$W_I = (1 - \phi)CS(X) - \gamma D(E) \tag{14}$$

Clearly, the net welfare effect of an IEA between exporting countries on the rest of the world is *a priori* ambiguous.

On the one hand, consumer surplus in the cooperative setting is lower than the Nash-level ('supply effect'). On the other hand, less production also causes fewer emissions and thus, less environmental damage ('pollution effect'). In general, either effect could dominate.

If the supply effect is outweighed by the pollution effect, the net global welfare effect of an IEA is positive. However, if the opposite is true, one has to weigh the welfare loss in the rest of the world against the welfare gains of exporters in order to determine the sign of the net global effect. This sign depends crucially on the amount of domestic consumption and the harmfulness of emissions.

In order to illustrate this point, let us consider the effect of each factor separately.

### 4.1 No domestic consumption: $\phi = 0$

This case corresponds to the "third market" model frequently studied in the literature on strategic trade policy.

The more harmful the emissions, the higher weighs the pollution effect against the supply effect. This can be seen most clearly by looking at equations (7) and (11). It is apparent that the weight of environmental damage relative to firm profits in the government's welfare maximization problem is determined by $\gamma$. We can establish that the global welfare effect of an IEA is negative (positive) if $\gamma$ lies below (above) a certain threshold:

**Proposition 2.** *There exists a value* $\gamma_0^* \in ]0, \gamma_c^C]$ *for which*

$\gamma < \gamma_0^* \Leftrightarrow \Delta W_G < 0$ *and*

$\gamma > \gamma_0^* \Leftrightarrow \Delta W_G > 0$

*with* $\Delta W_G \equiv W_G^C - W_G^N$

*Proof.* See Appendix A.4. □

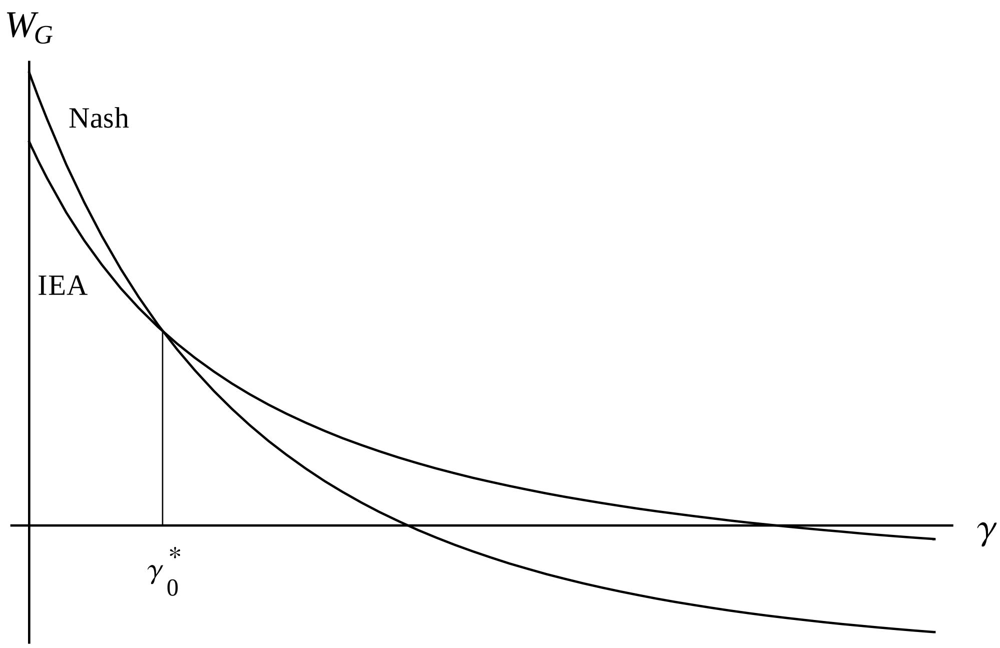


Figure 1: The critical damage parameter $\gamma_0^*$

Proposition 2 contains the main insight of the analysis and is illustrated in Figure 1. The governments of the exporting countries have two policy objectives. First, there is the environmental policy goal, namely minimizing damage from emissions. Second, there is the trade policy goal, namely securing maximal rents.

If exporting countries act strategically, governments seek to increase the home country's market share by implicitly subsidizing exports through lax environmental regulation. This beggar-thy-neighbour policy favors the rest of the world in terms of consumer surplus as output is higher than in the cooperative case. However, higher production also leads to higher emissions which harm the rest of the world.

If exporting countries cooperate, the strategic conflict between the governments is broken and exporters can implement their jointly optimal environmental regulation, which will lead to lower output. The rest of the world thus loses in terms of consumer surplus, but benefits from lower emissions.

If $\gamma$ is relatively low, the trade policy goal outweighs the environmental policy goal in the exporters' welfare function. As the objectives of the exporters and the rest of the world are congruent concerning environmental policy but diametrically opposed concerning trade policy, the rest of the world prefers that no IEA is signed. This is due to the fact that when exporter countries act strategically, their ability to pursue the trade policy objective (extracting rents) is lower than in the cooperative case.

If $\gamma$ is relatively high, emissions are relatively harmful so that the rest of the world prefers that an IEA is signed. If exporter countries act cooperatively, they will extract more rents from the rest of the world, but lower emission levels more than outweigh this negative welfare effect.

From a world welfare point of view, an IEA is only preferred if $\gamma$ lies above some critical value, *i.e.* that emissions are "harmful enough" so that the global environmental effect dominates the loss in total surplus.

### 4.2 The case with domestic consumption: $\phi \in ]0, 1]$

If the exported good is also consumed domestically, there is a welfare cost attached to contracting production under an IEA. This welfare cost increases in the size of domestic market.

By similar reasoning as in the above section we can show that:

**Proposition 3.** *For every* $\gamma < \gamma_0^*$, *there exists a* $\phi^* \in\ ]0, 1]$ *for which*

$\phi < \phi^* \Leftrightarrow \Delta W_G < 0$ *and*

$\phi > \phi^* \Leftrightarrow \Delta W_G > 0.$

*with* $\Delta W_G \equiv W_G^C - W_G^N$

*Proof.* See Appendix A.5. □

**Corollary 1.** *If* $\gamma$ *lies above* $\gamma_0^*$, *the sign of the global welfare effect of an IEA is positive and independent of* $\phi$*:*

$$\gamma > \gamma_0^* \Leftrightarrow \Delta W_G > 0\ \forall\ \phi \in [0, 1]$$

*Proof.* See Appendix A.5. □

Proposition 3 shows that the global welfare effect of an IEA between polluter countries is positively related to the size of the domestic market (see Figure 2). This result is quite intuitive. The

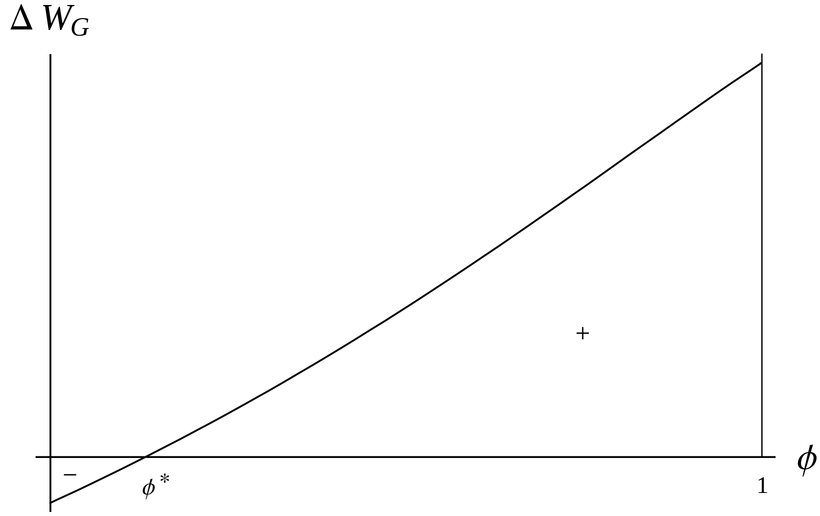


Figure 2: The critical population fraction $\phi^*$

higher the fraction of the global consumer surplus included in the decision of the governments, the higher are the benefits to be reaped by cooperation.

Figure 3 below finally shows the interdependence of the critical values of the harmfulness of emissions and the size of the domestic market. The grey area corresponds to combinations of $\gamma$ and $\phi$ that imply a negative global welfare effect of an IEA between exporter countries. As can be seen, the higher $\phi$, the lower is the critical $\gamma$ (and *vice versa*).

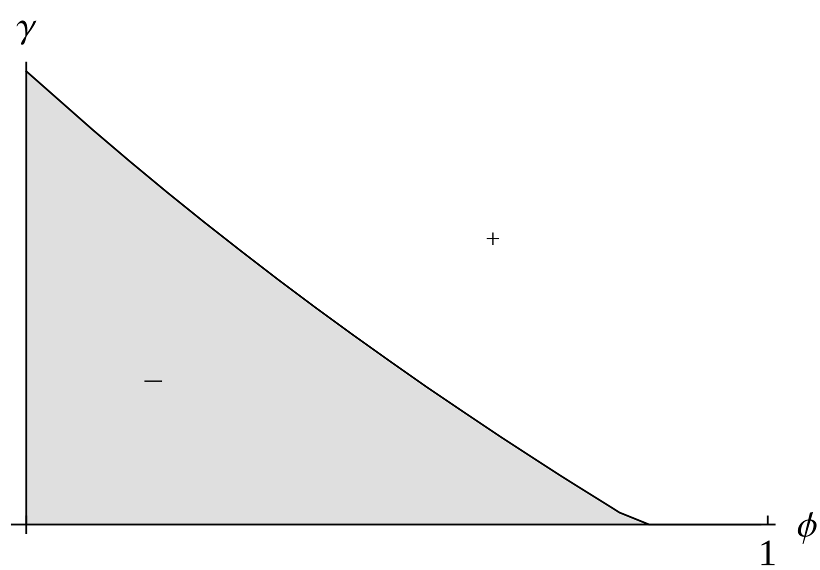


Figure 3: The sign of the global welfare effect of an IEA depends on $\gamma$ and $\phi$

### 4.3 The global optimum

Let us finally describe the globally optimal IEA. If the polluter countries take the welfare of the rest of the world into account when formulating an IEA, that is, if there is full global cooperation, the welfare optimization problem becomes:

$$\max_{e_i, e_j} W_G = \Pi_i(x_i, x_j, e_i) + \Pi_j(x_i, x_j, e_j) + CS(X) - 3\gamma D(E) \tag{15}$$

The first order conditions yield:

$$3\gamma D'(E) = \frac{\partial R_i}{\partial x_j}\frac{dx_j}{de_i} - \frac{\partial C_i}{\partial e_i} + \frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + CS'(X)\frac{dX}{de_i} \tag{16}$$

which corresponds to the equalization of marginal (global) environmental damage with net marginal (global) benefits from production and consumption of the good at the optimal emission level.

We denote the resulting global emission level with $E^*$ and note the following:

**Proposition 4.** *An IEA between polluter countries can lead to emission levels below or above the global optimum:*

$$E^* \lesseqgtr E^C$$

*Proof.* See Appendix A.6. □

This result shows that, perhaps against conventional wisdom, an IEA that does not internalize environmental damage in non-signatory countries does not necessarily lead to an emission level that is too high from a global perspective. The reason for this is that we are in a second best world with more than one distortion. The presence of market distortion due to imperfect competition can lead to a situation where the rest of the world is better off if the polluter countries set less stringent environmental regulations, even if this aggravates the pollution externality.

## 5 Concluding remarks

In this paper we have shown that IEAs in imperfectly competitive market environments carry various implications for the welfare of signatories and the rest of the world. Alongside the obvious positive welfare effect of the internalization of an environmental externality, negative welfare effects accrue due to a loss of consumer surplus. While signatories of IEAs are always better off with than without such an agreement, non-signatories might suffer a net loss in welfare even if they benefit from reduced global emission levels. This welfare loss potentially outweighs all positive welfare effects stemming from the IEA, so that the world as a whole is worse off if polluter countries cooperate in setting emission policies. We find that the global welfare effect of an IEA depends on the harmfulness of emissions and on the size of the domestic market for the export good.

To keep the analysis as clear as possible, in line with most of the literature on strategic trade and environmental policy, we consider a symmetric setting. This is clearly a simplification, but this allows us to abstract from effects due to idiosyncratic differences of governments and firms, and concentrate fully on the effects of strategic incentives on the nature of IEAs between exporter countries, which is the main focus of this paper. Incorporating North-South type differences in preferences for consumption or environmental quality would be an interesting extension that is left for further research.

Brander and Spencer [4] have explained the source and mechanism of strategic incentives that induce governments to subsidize exports when there is Cournot competition on the export market. Barrett [2] has shown that these strategic incentives translate into distorted environmental policies when direct trade policies are infeasible and environmental policy is used as a proxy. We find that exporters might profit from their strategic advantage vis-à-vis the rest of the world by signing an IEA that serves as a tool not only for internalizing external effects, but also for extracting rents. Such an IEA is *de facto* also a trade policy contract as it implicitly provides for export taxation by putting in place strict environmental regulation.

Apart from their theoretical contribution, the results of this study inform the policy debate surrounding IEAs and the world trade system. We show that IEAs can cause distortions of international trade flows that lead to a welfare loss for the world as a whole. Furthermore, we establish that regional environmental agreements, today part of numerous regional trade agreements, can secure rents for signatories at the expense of non-signatories. This makes enlargement of such agreements difficult, as existing members could lose by further accession and thus prefer to keep the agreement exclusive. Therefore, our results suggest that regional environmental agreements are rather stumbling blocks than building blocks for the solution of global environmental challenges.

There are a large number of IEAs and their number is steadily increasing, and advancing global trade liberalization makes environmental policy a more and more attractive vehicle for the exertion of market power and the exploitation of strategic advantages. This paper is an analytical attempt to understand the global welfare effects of IEAs by studying their interplay with international trade in an imperfectly competitive market environment. However, we believe that further theoretical and empirical research is needed to fully comprehend the implications of the ongoing proliferation of IEAs for the world trade system and global climate policy.

# A Proofs

## A.1 Proof of Lemma 1

It follows directly from the total differential of equations (3) and rearranging that:

$$\frac{dx_i}{de_i} = \frac{\frac{\partial^2 C_i}{\partial x_i \partial e_i}[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}]}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{17}$$

By assumptions (2), (4) and (5), both nominator and denominator are positive so that $\frac{dx_i}{de_i} > 0$.

An analogous calculation yields:

$$\frac{dx_i}{de_j} = -\frac{\frac{\partial^2 C_j}{\partial x_j \partial e_j}\frac{\partial^2 R_i}{\partial x_i \partial x_j}}{[\frac{\partial^2 R_i}{\partial x_i^2} - \frac{\partial^2 C_i}{\partial x_i^2}][\frac{\partial^2 R_j}{\partial x_j^2} - \frac{\partial^2 C_j}{\partial x_j^2}] - \frac{\partial^2 R_j}{\partial x_j \partial x_i}\frac{\partial^2 R_i}{\partial x_i \partial x_j}} \tag{18}$$

Both terms of the nominator are negative by assumptions (2) and (6), respectively, while it follows from (5) that the denominator is positive. Hence, $\frac{dx_i}{de_j} < 0$. □

## A.2 Proof of Lemma 2

In the Nash-equilibrium, a unilateral change in the emission standard of country i has the following effect on exporters' joint welfare ($W_{i+j}$):

$$\frac{\partial W_{i+j}(e_i, e_j)}{\partial e_i} = \frac{\partial W_i(e_i, e_j)}{\partial e_i} + \frac{\partial W_j(e_i, e_j)}{\partial e_i}. \tag{19}$$

The first term of the RHS of (19) equals zero by the first-order condition of government i. The second term equals:

$$\frac{\partial R_j}{\partial x_i}\frac{dx_i}{de_i} + \frac{\phi}{2}CS'(X)\frac{dX}{de_i} - \gamma D'(E) \tag{20}$$

The first term of (20) is negative by Lemma 1. The second term is smaller than the third term by (8). Hence it follows that $\frac{\partial W_{i+j}(e_i,e_j)}{\partial e_i} < 0 \quad \square$

## A.3 Proof of Proposition 1

The proof follows straightforwardly from Lemma 2. At the Nash-equilibrium level, lowering the emission standard in either country increases the exporter's joint welfare. Therefore, the joint welfare maximizing emission standard must lie below the Nash-level. It follows that $e^C < e^N$. As the firms' equilibrium output levels are strictly increasing in the emission level by Lemma 1, $e^C < e^N \iff x^C < x^N$. $\square$

## A.4 Proof of Proposition 2

**Claim 1:** If emissions cause no damage, the global welfare effect of an IEA is strictly negative:

$$\lim_{\gamma \to 0} \Delta W_G < 0$$

with $\Delta W_G \equiv W_G^C - W_G^N$

**Proof.** Consider once again equations (7) and (11), which characterize the government's problem in the Nash and the cooperative case, respectively. If $\phi = 0$ and $\gamma = 0$, the last terms disappear, which means that the government's objective becomes identical to the firm's problem of profit maximization, and global welfare equals total surplus. It follows that, in the Nash case, the outcome is a Cournot-duopoly, whereas in the cooperative case, the resulting equilibrium is a collusive duopoly, *i.e.* a two firm monopoly. Hence, the world as a whole suffers a deadweight welfare loss if an IEA is signed. $\square$

Let us next define $\gamma_c^N$ as the value at which global welfare in the Nash-equilibrium becomes zero.

**Claim 2:** $W_G^N(\gamma_c^N) < W_G^C(\gamma_c^N)$.

**Proof.** By construction, at $\gamma_c^N$, total surplus equals global environmental damage in the Nash-equilibrium, which means that the emission level lies above the global optimum. Hence, a decrease in emissions leads to an increase in global welfare. As emissions under an IEA are lower than in the Nash-case, the result follows. $\square$

Proposition 2 now follows from Claim 1 through 2 and the intermediate value theorem. $\square$

## A.5 Proof of Proposition 3 and Corollary 1

**Claim 1:** If there is no consumption in the rest of the world (*i.e.* no trade), the global welfare effect of an IEA is always positive:

$$\lim_{\phi \to 1} \Delta W_G > 0$$

with $\Delta W_G \equiv W_G^C - W_G^N$

**Proof.** It follows by inspection of (14) and by Proposition 1 that if $\phi = 1$, the rest of the world suffers no loss in consumer surplus but benefits from lower emissions under an IEA. Therefore, the world as a whole is better off if polluter countries cooperate. $\square$

By definition, for any $\gamma < \gamma_0^*$, $\Delta W_G$ is negative at $\phi = 0$; and for any $\gamma > \gamma_0^*$, $\Delta W_G$ is positive at $\phi = 0$.

Hence, the results follow from Claim 1 and the intermediate value theorem. $\square$

## A.6 Proof of Proposition 4

At $\gamma = 0$ (and $\phi \in [0, 1[$), $E^*$ clearly lies above $E^C$ as there is no environmental damage and the world as a whole suffers a pure deadweight loss from too little production in the cooperative case. As $\gamma$ increases, both $E^*$ and $E^C$ decrease, but the former at a higher rate than the latter as, under full cooperation, global environmental damage rather than environmental damage only in exporter countries is taken into account. Therefore, above a certain value of $\gamma$, $E^* < E^C$. $\square$

## References


1. Barrett, S., 1994a. Self-enforcing international environmental agreements. Oxford Economic Papers 45, 878-894.

2. Barrett, S., 1994b. Strategic environmental policy and international trade. Journal of Public Economics 54, 325-338.

3. Brander, J.A., 1986. Rationales for strategic trade and industrial policy. In: Krugman, P.R. (Ed.), Strategic Trade Policy and the New International Economics. The MIT Press, Cambridge, Massachusetts and London, England, 23-46.

4. Brander, J.A., Spencer, B.J., 1985. Export subsidies and international market share rivalry. Journal of International Economics 18, 83-100.

5. Burguet, R., Jaume, S., 2003. Trade liberalization, environmental policy, and welfare. Journal of Environmental Economics and Management 46, 25-37.

6. Carraro, C., Siniscalco, D., 1992. Strategies for the international protection of the environment. Journal of Public Economics 52, 309-328.

7. Conrad, K., 2001. Voluntary environmental agreements vs. emission taxes in strategic trade models. Environmental and Resource Economics 19, 361-381.

8. Eaton, J., Grossman, G.M., 1986. Optimal trade and industrial policy under oligopoly. Quarterly Journal of Economics 101(2), 383-406.

9. Greaker, M., 2003a. Strategic environmental policy; eco-dumping or a green strategy? Journal of Environmental Economics and Management 45, 692-707.

10. Greaker, M., 2003b. Strategic environmental policy when governments are threatened by relocation. Resource and Energy Economics 25, 141-154.

11. Rauscher, M., 1994. On ecological dumping. Oxford Economic Papers 46, 822-840.

12. Tirole, J., 1988. The theory of industrial organization. The MIT Press, Cambridge, Massachusetts and London, England.

13. Ulph, A., 1996. Environmental policy and international trade when governments and producers act strategically. Journal of Environmental Economics and Management 30, 265-281.

14. UNEP, 2005. Register of International Treaties and Other Agreements in the Field of the Environment, Nairobi, Kenya.

15. Walz, U., Wellisch, D., 1997. Is free trade in the interest of exporting countries when there is ecological dumping? Journal of Public Economics 66, 275-291.