Regional Environmental Agreements under Incomplete Information and Political Pressure

This paper addresses the issue of environmental agreements under incomplete information at both the national and the international levels, taking into account the fact that firms might exercise political pressure on their country's government. Domestic firms may have private information about their cost functions (and might have the ability to influence the government), while countries generally have information unknown to other parties engaged in treaty negotiations. At the domestic level, governments can act as mechanism designers to implement some environmental regulation. However, efficiency cannot be achieved under incomplete information when a system of taxes is not sufficient to separate "cleaner" from "dirtier" firms. Neither can a mechanism be internally efficient when some degree of political pressure is present. But, in both cases, countries can improve over the no domestic policy situation. At the international level, such kinds of "solutions" are not possible due to the absence of a supranational authority to design the corresponding mechanism. Then, some sort of bargaining among countries has to take place. This paper shows that, even in case of incomplete information where the parties involved are not willing to reveal their characteristics, countries can sign environmental agreements which improve efficiency relative to status quo and are respected by everybody in equilibrium no matter what some countries beliefs are about the other countries' types. The nature of those agreements depends on the fundamentals of each country (consumers' preferences and firms' costs), on the pre-existent domestic regulation and the situation to design them (the degree of knowledge of national firms' costs and their political pressure), and also on the information on the possible types the other parties in the negotiations can be.

Este artículo analiza el tema de la firma de tratados ambientales internacionales tomando en cuenta la existencia de falta de información y presiones políticas. Las empresas nacionales tienen información acerca de sus funciones de costos (y eso les da poder para poder influenciar al gobierno), mientras que los países cuando van a negociar tratados ambientales poseen información acerca de las empresas y consumidores nacionales que los otros países no tienen. Al nivel doméstico los gobiernos pueden actuar como diseñadores de un mecanismo para implementar algún tipo de regulación ambiental (por ejemplo, impuestos sobre las emisiones). Sin embargo, la eficiencia interna no puede ser alcanzada bajo información incompleta cuando un sistema de impuestos no alcanza para "separar" las empresas "limpias" de las empresas "sucias". Tampoco puede la regulación ambiental ser eficiente a nivel nacional si existe algún nivel de presión política. Pero, en ambos casos, los países pueden mejorar sobre la situación de no hacer ninguna política ambiental doméstica. A nivel internacional, este tipo de soluciones no son posibles debido a la ausencia de una autoridad supranacional para diseñar el mecanismo correspondiente. Por lo tanto, se puede pensar que lo que sucede es algún tipo de negociación entre los países. Este artículo muestra que aún en los casos de información incompleta cuando las partes del tratado no están dispuestas a revelar sus características, los países pueden firmar acuerdos que mejoran la eficiencia con respecto al status quo y son respetadas por todos en equilibrio cualquiera sean las creencias que cada uno tenga acerca de qué tipo de país es el otro. La naturaleza de esos tratados depende de los "fundamentals" de cada país (las preferencias de los consumidores y los costos de las empresas), la regulación ambiental interna preexistente al tratado y las condiciones en que ésta fue diseñada (el grado de conocimiento de los costos de las empresas nacionales y la presión política que ejercen sobre el gobierno), y también de la información sobre los posibles tipos de los cuales pueden ser las otras partes en la negociación.

Q2, C7, y D8

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I. Introduction

International environmental agreements have become an important source of international debate in the last 25 years. The economic literature has captured this phenomenon in several papers on international environmental externalities. However, the usual framework depicts governments as representative agents who negotiate an international treaty. Little attention is given to the reciprocal influence between domestic and international environmental affairs. But the facts are that governments in each country face both their domestic constituents and their neighboring countries. In general, the dynamic of that relationship has been that countries adopt environmental policies more or less independently primarily to improve local pollution. Then, some countries engage in international negotiations to reduce emissions further, while considering the domestic implementation of those measures.

There is no generalized indication of strategic behavior when countries decide their domestic environmental policy. An example of that is the acid rain problem between the US and Canada. The former began to regulate pollutants that lead to acidification through the Clean Air Act (1970), while Canada committed itself to a reduction of 50% (from 1980 levels by 1994) in its emissions of those pollutants. However, only in 1991 both countries began to agree on some common rules to take into account the transnational externalities generated by acid rain. European nations also provide an illustration of how, when beginning to implement pollution's control, the primary focus is on the domestic level since several of them devised the installation of tall smokestacks as the way to disperse pollutants.

In addition, there is sufficient evidence to say that "implementation deficits" are common at both levels when designing environmental policies. The US standards for water pollution planned in 1972 (under the Clean Water Act) were not met by 1977, so the government moved the deadline to 1982 and then to 1987, and the provisions of the UK's Control of Pollution Act remained unimplemented for several years (Weale, 1992). In the same line, target emission reductions of some pollutants within the Rhine Action Program were not fully attained by the countries surrounding that river in the agreed time framework. In some cases, non-implementability at the domestic level causes agreements not to be signed[1]. In general, governments attempt to take provisions such that implementation problems are minimized.

Both domestic and international relationships are limited by information problems and political pressure. Lack of information on the amount of emissions (hidden actions) and on consumers, firms or countries valuations (hidden characteristics) create opportunities for strategic behavior. The impact of hidden actions is greater at the national than at the international level since while aggregate emissions (the key to international cooperation) are possible to derive, that is not sufficient for domestic regulation where the crucial point is to distinguish each type of firm's emissions. Aggregate emissions generated per country can be approximated by taking samples of the resource at each border and having some reliable information on how pollution is transported. Such kind of information is available for water pollution in some lakes (e.g., the Great Lakes), and for acid rain in Europe[2]. However, when there is only regulation at the national level, it is not enough to take a sample of the resource at the country's border because its state is affected by several types of firms and other countries' pollution. Each government (to know each type of firms' emissions) should monitor each type of firm explicitly. However, such monitoring is possible at a certain cost for "point sources" (e.g., industrial plants or automobiles) but not for "non-point sources" (e.g., agricultural runoffs). The existence of hidden actions in this context changes the departure situation for any international agreement, and might cause them not to be reached because countries cannot enforce their application at the national level.

On the other side, problems of hidden characteristics are present when discussing the issue of environmental externalities. There is unknown information at the two levels: governments do not know with certainty consumers' preferences for the environment and firms' abatement costs in their own country, while they also are uncertain about the other countries' characteristics. Under emissions' regulation, individual consumers cannot *directly* change how much pollution they suffer. But firms, which are allowed to pollute different amounts according to their characteristics, naturally attempt to alter the amounts they are allowed to pollute by misrepresenting their costs[3]. A similar problem appears among governments, which have incentives to act strategically in revealing their countries' characteristics in order to be "assigned" less strict regulations when signing an agreement to improve the border resource. Governments' misrepresentations might take the form of concealing the nature of consumers' preferences and firms' costs, the place of environmental issues in their agendas, or even their domestic groups' political pressure.

Government failure problems caused by political pressures are closely linked to those of characteristics' revelation. Consumers join forces to exert direct pressure on the government through ecological groups, while (to be more effective) they may exaggerate their taste for a clean environment. On the other hand, firms also attempt to influence the government through direct political pressure since environmental regulations clearly influence their costs. The extent of firms' misrepresentation varies if they know they can exert some pressure. In addition, since observers from interest groups are allowed at negotiations (and there is an increasing number who attend them), there may be an extra pressure exercised at the moment countries' governments seat in a negotiation table[4].

This research attempts to formalize the relationship between all three problems: real externalities, informational externalities and political pressure, in both the domestic and international scenarios. However, these relationships differ at each level because domestically there is a government which can act as a mechanism designer to implement some specific regulations, while at the international level there is no agency which can do so. Then, international agreements are analyzed as the result of negotiations among countries.

The range of potential (domestically implementable) environmental agreements is influenced by several factors. Consumers' preferences toward the environment and firms' abatement costs in each country constitute the basis of any negotiation. The set of possible agreements is different if some kind of domestic environmental policy is already in place in any of the countries (i.e., the possible outcomes are relatively "better" if there are some previous policies). The circumstances under which domestic regulations are conceived (and modified in case of an agreement) play a key role. Regulations are different (and so are their effects) if they are designed under political pressure, they also differ according to the information governments possess and their ability to allow different emission levels to cleaner than dirtier firms. Finally, the range of potential environmental agreements also depends on how the other parties in such treaties may be like (i.e., the association to a more "environment-oriented" country may be more beneficial).

The paper is organized in the following way. Part II contains a review of the literature on which this research is based. Part III presents a model with several situations, which help to disentangle the problems of information and political pressure in international environmental agreements. Part IV deals with a simple example to illustrate the model. Finally, Part V summarizes the main conclusions.

II. Review of the Literature

This paper has points of contact with two main bodies of literature: the political science "two-level games", and the pollution control/mechanism design literature. The former set of writings is oriented to show that domestic politics matter when countries negotiate international agreements (for a general reference, see Downs and Rocke, 1995).

International negotiations among countries constitute the level I and the relation between each government and their domestic agents is called level II. The seminal paper in this line is Putnam (1988), who compares international negotiations to a “two-table” game, and illustrates two aspects of countries’ lack of information: the existence of a domestic situation, which allows countries to claim that they only can grant a few concessions because of their internal difficulties; and the increase in the risk of defection, because governments who want an agreement may conceal the true domestic support that it will receive.

In the last few years, other authors in the political science literature developed more formal ways to deal with these games. Iida (1993) considers the effect of both domestic and international incomplete information on the bargaining power of countries and the possibility that negotiations break down. Three cases are analyzed: when there is complete information, when the foreign country does not know about the domestic situation but the national government does, and when neither the foreign nor the domestic countries have complete knowledge. Using a somewhat different approach, Mo (1994) explores the political bargaining process of countries, which make international agreements, when governments have their own interests conflicting with those of some domestic groups. Milner and Rosendorff (1996) deal with a two-level game in which domestic lobbies provide information about a trade agreement to Congress prior to its ratification, and therefore, have an impact on the outcome of the international negotiations.

The present paper is similar to the “two-level” games’ literature in the sense that it tries to capture the impact of both domestic political factors and domestic and international uncertainty on environmental policies. However, it is different in several respects. First, there is no reference to problems of “divided government” (e.g. EPA versus the Congress or the Executive). Second, the domestic political process is not explicitly modeled. Instead, political pressure is incorporated through a government objective function, which gives more weight to groups that exercise some form of direct political pressure[5]. The domestic level is modeled with types of consumers and firms and not as the decision of a “majority rule” which represents them. Third, level I is not a single “fixed” outcome, which has to be implemented at level II[6]. Here, there are different initial domestic conditions from which international negotiations may begin. The resulting potential environmental agreements (level I) are those which guarantee to all countries a higher welfare than the status quo, and can be implemented at the domestic level. Level II is more sophisticated here, not only because it is determined by consumers’ and firms’ characteristics, but also because it allows the possibility of a preexistent domestic environmental policy before any agreement. This last characteristic of the model establishes a connection with the mechanism design/optimal pollution control literature.

The design of a mechanism depends on how much information the designer has and also on the political pressure that he bears. In a world of complete information, it is irrelevant in terms of efficiency whether the government uses emission taxes or emission standards to regulate firms (Baumol and Oates, 1975). However, when information is not complete, different things may happen and these possibilities are discussed in the literature. There are basically two groups of papers in this line: in the first group (“one-round” communication), the regulator has some expectations about the objective functions of the agents and decides the mechanism according to them; and, in the second group (“two-round” communication), the government “asks firms to reveal their types” by establishing emissions standards and taxes which depend on how firms are like.

The first approach began with Weitzman (1974, 1978) who considers both the cost of controlling pollution by firms, and the consequent damages to the consumers, to be unknown to the regulator. Its main conclusion is that quantity-based instruments (e.g., emission standards) are better than a price-based instrument (e.g., emission taxes) when the expected marginal benefits for decreasing emissions have a steeper slope than the expected marginal abatement costs. Roberts and Spence (1976) propose a mixed system of price and quantity regulations to decrease the effects of incomplete information. Using such a scheme, the social losses of pollution are approximated in a way to make firms’ profit functions identical to the expected social welfare function and almost yields efficiency (Dasgupta, Hammond and Maskin, 1980).

When firms communicate information to the government, an efficient dominant strategy mechanism can be instrumented through the use of lump sum payments. Once that mechanism is established, firms emit the efficient amounts and report their type truthfully. An alternative proposed in Kwerel (1977) is a Bayesian mechanism that is implemented by a mix of effluent charges and licenses for which it also matters what other firms reveal. This paper makes use of the results of the pollution control/mechanism design literature when dealing with the interaction between governments and firms. Governments act domestically as mechanism designers, but there is no agency that can do the same at the international level[7]. Internationally, it must be some sort of bargaining which leads countries to environmental agreements.

III. The Model

A. General Framework

In this framework, there are J countries (indexed by j) sharing a resource which is on their common political border. Each country can be of N possible types, all of which are compatible with the same average pollution at the domestic level. Each country has a government, and is inhabited by different types of consumers (indexed by h) and firms (indexed by f). There is a continuum of consumers and a continuum of firms of each type, and there is a finite number of types. There is one common natural resource (a), one money commodity (m), and one non-money commodity (denoted by c or y according to whether it is consumed or produced) in each country.

Consumers like both of the goods and value the stock of the resource. More precisely, each type of consumer in each country has the following quasi-linear utility function: $U^j_{n,h} = v^j_{n,h}(c^j_{n,h}, a^j) + m^j_{n,h}$, and a budget constraint: $p^j_n \cdot c^j_{n,h} + m^j_{n,h} = 0$, where $c^j_{n,h}$ is the quantity of the non-money commodity consumed by consumers of type h, $m^j_{n,h}$ is the quantity of the money commodity consumed by these households, and p^j_n is the price of the non-money commodity (all in country j of type n).

On the other hand, each type of firm in each type of country chooses its level of production so as to maximize its profits (or producer surplus). It also generates some pollution which affects the quality of the natural resource. Then, its objective function can be written as: $\Pi^j_f(y^j_{n,f}, x^j_{n,f}) = p^j_n \cdot y^j_{n,f} - TC^j_f(y^j_{n,f}, x^j_{n,f})$, where $y^j_{n,f}$ is the quantity of the non-money commodity produced by firms of type f in country j of type n, and $x^j_{n,f}$ is the level of those firms' emissions. Then, cost functions depend on output, emissions and a parameter $\theta_f \in \Theta$, the set of possible types: $(\theta_1,...,\theta_F) \subset \Re^1$, which represents firms' private information about their costs, and is denoted by the subscripts in the profit and cost function (Π^j_f, TC^j_f). Different values of θ_f represent the different "types" the firms can be. The cost function is a decreasing function of θ_f, the higher values corresponds to a "dirtier" type of firm, whose abatement costs are then lower[8]. The potential types of firms are assumed to be the same in each type off country, what is different is the masses of each type within them (i.e., some countries have a greater proportion of cleaner firms than another country).

Each country has a government whose aim is to maximize the welfare of its own nation, defined as the sum of domestic consumers' and firms' surpluses: $g^j_n = \sum_h s^j_{h,n} \cdot \left[v^j_{h,n}(c^j_{h,n}, a^j) - p^j_n \cdot c^j_{h,n}\right] + \alpha^j \cdot \left(\sum_f r^j_{f,n} \cdot \left[p^j_n \cdot y^j_{f,n} - TC^j_f(y^j_{f,n}, x^j_{f,n})\right]\right)$, where $s^j_{h,n}$ is the mass of consumers of type h and $r^j_{f,n}$ is the mass of producers of type f (in country j of type n). The parameter α^j >0 indicates the relative strength of the pressure exercised by firms on the government. The closer alpha is to one, the lower is that pressure. Alpha is assumed to be the same for firms of different types, but different across countries. On one side, the assumption of equal pressure by every firm's type is important (and realist) because if cleaner firms lobbied clearly less than dirtier, doing so would be equivalent to reveal their type. On the other side, the fact that the pressure is different across countries is reflected in several cases. For example, for air pollution, the two largest emitters in Canada (the Ontario Hydro Electric Company and the International Nickel Company of Canada) have accepted the government control orders to reduce emissions, while in the US electric power and coal associations have been hostile to the idea of embarking in an acid-rain control program (Sjöstedt, 1993). In Europe, ecological groups' pressure has been higher in the Nordic countries than in the Southern ones after the environmental damage caused by acid rain became evident on forests and lakes.

Finally, the state of the resource depends on pollution by all types of firms in all countries: $a^j = Z^j(X^1,\dots,X^J)$, where $X^j = \sum_f r^j_{f,n} \cdot x^j_{f,n}$. The function Z^j takes into account the fact that the damage to the resource depends not only on how much pollution national and foreign firms emit, but also on where those pollutants are generated. This type is function is reflected in what is called "transport matrix" which reflect the way in which pollutants are transported across countries[9]. This function reflects a physical relation, which does not depend on which type each country is since the latter is determined by consumers' characteristics and the proportion of firms of each type.

B. Domestic Situation (Level II)[10]

A first possible initial situation for an agreement is when there is no previous domestic regulation. In that case, firms emit the amount of pollution that makes their marginal abatement cost equal to zero: $\frac{\partial TC^j_f(.,x^j_{f,n})}{\partial x^j_{f,n}} = 0$. This result can be interpreted as an "occupational equilibrium" in which firms choose their "occupation" (i.e., level of pollution which maximizes their surplus) while consumers have no relevant occupational choice (Makowski and Ostroy, 1995). Firms and consumers interact in a Walrasian fashion in the market for the non-money commodity.

However, the usual situation is that governments at some point establish domestic regulations to control the harm caused by firms to consumers within their country. Those regulations depend clearly on the amount of information they possess and on the political pressure they suffer. An extreme case of incomplete information (not very realistic) would be a government which knows the mass of each type of firm and the number of types, but not the characteristics of each type (i.e., the possible cost functions). In such a situation, any attempt to internalize the real externality would be blocked by the information problem, and the classical welfare economics prescription would fail because while governments attempt to use domestic environmental policy to solve the real externality occurring within its country, firms anticipate the regulation and lie about their true costs (a formal explanation of this case is contained in Appendix A).

In general, however, governments do have some information about firms' costs (e.g., the possible abatement technologies). This more realistic situation is the one usually considered in the literature when referring to incomplete information. Formally, the regulator has information about the θ's represented by a probability distribution on the domain of possible types (which includes the mass of each type, their number, and the set of possible costs functions), while the specific value of its cost function parameter is private information of each firm. In this context, firms have fewer opportunities for misrepresentation, and governments can take into account this extra information to create a mechanism that makes firms reveal their costs truthfully[11].

The general implicit problem that governments (of each type) solve to decide their domestic environmental regulation is the following (here illustrated for simplicity with only two types of firms[12]):

$$\max_{\{x^j_{f,n},T^j_{f,n}\}_{f=1,2}} \left\{ \sum_h s^j_{h,n} \cdot \left[v^j_{h,n}(c^j_{h,n}, a^j) - p^j_n \cdot c^j_{h,n} \right] + \left(r^j_{1,n} \cdot T^j_{1,n} + r^j_{2,n} \cdot T^j_{2,n} \right) \right.$$

$$\left. + \alpha^j \cdot \left(r^j_{1,n} \cdot \left[\pi^j_1(.,x^j_{1,n}) \right] + r^j_{2,n} \cdot \left[\pi^j_2(.,x^j_{2,n}) \right] - \left(r^j_{1,n} \cdot T^j_{1,n} + r^j_{2,n} \cdot T^j_{2,n} \right) \right) \right\}$$

s.t. $a^j = Z^j(\bar{a}^j, r^1_{1,n} \cdot x^1_{1,n} + r^1_{2,n} \cdot x^1_{2,n}, \ldots, r^J_{1,n} \cdot x^J_{1,n} + r^J_{2,n} \cdot x^J_{2,n})$

s.t. $\pi^j_1(.,x^j_{1,n}) - T^j_{1,n} \geq 0$ (IR1)

s.t. $\pi^j_2(.,x^j_{2,n}) - T^j_{2,n} \geq 0$ (IR2)

s.t. $\pi^j_1(.,x^j_{1,n}) - T^j_{1,n} \geq \pi^j_1(.,x^j_{2,n}) - T^j_{2,n}$ (IC1)

s.t. $\pi^j_2(.,x^j_{2,n}) - T^j_{2,n} \geq \pi^j_2(.,x^j_{1,n}) - T^j_{1,n}$ (IC2)

s.t. $T^j_{1,n}, T^j_{2,n} \geq 0$

together with the non-negativity constraints for emissions by each type of firm. Political pressure appears as the α^j in the objective function, while the existence of incomplete information is indicated by taxes charged to firms according to what type they declare to be ($T^j_{1,n}$ and $T^j_{2,n}$).

As depicted, the problem implies that in each country there is a mechanism designer who has a continuous choice for allowed emissions and uses taxes as a "revelation instrument". There are basically two ways of thinking in that mechanism: governments can directly delegate the pollution decision to firms by specifying taxes [$T^j_{f,n}(x^j_{f,n})$], such that each firm chooses emissions according to its type [$x^j_{f,n}: \Theta \rightarrow \mathfrak{R}_+$], or firms are asked to announce their type (e.g., when they apply for a permit to pollute, they have to specify their abatement technologies) and with that information, governments set the amount of pollution allowed to each type and the corresponding tax. In that context, the governments' proposals are [$x^j_{f,n}(\hat{\theta}^j_{f,n}), T^j_f(\hat{\theta}^j_{f,n})$] for each type firms may report to be of ($\hat{\theta}^j_f$), and firms' strategies take the form: [$x^j_{f,n}: \Theta \rightarrow \Theta$]. The latter interpretation of the mechanism as a game of revelation seems to be better suited to think environmental regulation because licenses that specify the emissions allowed according to firms' request forms are a widespread regulatory instrument.

In addition, several restrictions are incorporated into the government's problem of maximizing domestic welfare. The first constraints are related to the fact that even when governments can force firms to participate in the regulation by requesting permits to pollute, it may be that the resulting restrictions on emissions are too high for firms to justify continuing their production. Therefore, if governments are not contemplating firms shutting-down because of environmental standards, the problem must include the corresponding individual rationality or participation constraints.

The second set of constraints is related to provisions such that firms do not benefit from lying about their types (incentive compatibility constraints)[13]. The resulting scheme has to be such that firms with a lower θ (the "cleaner" ones) are allowed less emissions but pay less taxes than "dirtier" firms[14]. For those constraints to be fulfilled, then, it has to be too expensive for cleaner firms to want to appear as dirtier ones even if that allows them a greater emissions, and the latter firms should not have incentives to receive the emissions which correspond to cleaner firms even if that implies lower taxes. The last inequality is linked to the government constraint and implies that firms pay taxes[15]. In this context, different scenarios for regulation can be considered:

1) Complete Information

If governments had complete information on firms' costs, they would allow emissions until the marginal abatement cost of each firm equals the utility loss of all *national* consumers due to the deterioration of the resource, provided the pressure firms can exercise:

$\sum_h \left[s^j_{h,n} \cdot \frac{\partial v^j_{h,n}(c^j_{h,n}, a^j)}{\partial a^j} \right] \cdot \frac{\partial a^j}{\partial x^j_{f,n}} = \alpha^j \cdot \frac{\partial TC^j_f(.,x^j_{f,n})}{\partial x^j_{f,n}}$. The problem is solved taking into account the resource constraint, the participation constraints and emissions non-negativity constraints.

Such a policy directly establishes the "occupational choice" of firms, leaving no ground for any other behavior. If all governments did the same, the corresponding situation could be interpreted as the equilibrium of a non-cooperative game among governments who establish restrictions on domestic emissions taking those of the other countries as given. In other words, this is a "Nash equilibrium in occupations" which results from the interaction of two agencies (governments) that establish environmental standards, merely coping with each other. If there was no political pressure ($\alpha^j = 1$), governments would be able to establish the domestic first-best environmental policy, but since such pressure in general exist, the domestically optimal emission levels is not attained[16]. Then, welfare for both countries lies between the completely unregulated situation and the one for which domestic environmental policies are established by governments without any kind of pressure.

2) Incomplete Information

If there was no political pressure, the above problem would be relatively easy to solve due to the "dissociation" between emissions and taxes. Governments can choose the domestically efficient emissions allowed for each type firms declare to be[17]. Then, if there is an implementable mechanism, taxes can be arranged such that the constraints hold and first-best domestic efficiency results. However, as there may be a range of such possible taxes, it may also be that there is none. In this last case, there is no implementable mechanism which "solves" the information problem. Then, the government should accept a pooling situation (where the two types pollute the same and pay the same taxes), which implies an efficiency loss due to the impossibility of solving the hidden characteristics' problem[18].

However, in general, governments have incomplete information about their cost functions *and* face political pressure by the firms. Then, the outcome of this mechanism is different because the government needs to set taxes to have revelation but also suffers those taxes as a cost because firms are weighted more heavily than consumers. There is then a tension between the incentive to tax firms as little as possible and the need to separate them in order not to loose efficiency (due to the effect of the informational problem on the solution of the real externality). Even if there is an implementable mechanism of this type, it may also be the case that (if alpha is large) the government decides not to separate the types. If taxes are used to induce firms to reveal truthfully, the distortion due to the political pressure remains and can even be exacerbated because taxes and emission levels are decided using a distorted welfare function. It is not clear where the resulting welfare for each country will lie in a graph of payoffs, it depends on the parameters of the objective functions.

The way of solving the problem also differs since taxes and emissions are "tied" into the objective function. Hence, the solution procedure cannot begin by establishing emissions and then adjusting the constraints with taxes, but just the opposite. The first step consists in characterizing the implementable mechanisms, and then choosing the optimal one from the point of view of the regulator[19]. In the case of two types where, for example, $\theta_1 < \theta_2$ (type 1 firm is the "cleaner" one), some simplifications can be made in order to solve the problem. First, the tax paid by the type 1 firm can be normalized ($T^j_{1,n} = 0$) since it will be the type which pays a lower tax. But type 1 is also the one who may have more incentives to lie (so its IC1 is binding). Then IC2 is likely to be non-binding and if that happens, IR2 is not binding either if $\pi^j_2(.,x^j_{1,n}) > 0$. Hence, the problem can be rewritten as:

$$\max_{\{x^j_{f,n},T^j_{f,n}\}_{f=1,2}} \Big\{ \sum_h s^j_{h,n}\cdot v^j_{h,n}(c^j_{h,n},a^j)+\alpha^j\cdot r^j_{1,n}\cdot\pi^j_1(.,x^j_{1,n})+\alpha^j\cdot r^j_{2,n}\cdot\pi^j_2(.,x^j_{2,n})$$

$$+(1-\alpha^j)\cdot r^j_{2,n}\cdot[\pi^j_1(.,x^j_{1,n})-\pi^j_1(.,x^j_{2,n})]\Big\}$$

subject to the resource and non-negativity constraints. Then, the FOC for pollution for firms of types 1 and 2 respectively are:

$$\sum_h\left[s^j_{h,n}\cdot\frac{\partial v^j_{h,n}(c^j_{h,n},a^j)}{\partial a^j}\right]\cdot\frac{\partial a^j}{\partial x^j_{1,n}}\cdot r^j_{1,n}=\alpha^j\cdot r^j_{1,n}\cdot\frac{\partial TC^j_1(x^j_{1,n})}{\partial x^j_{1,n}}+(1-\alpha^j)\cdot r^j_{2,n}\cdot\frac{\partial TC^j_1(x^j_{1,n})}{\partial x^j_{1,n}}$$

$$\sum_h\left[s^j_{h,n}\cdot\frac{\partial v^j_{h,n}(c^j_{h,n},a^j)}{\partial a^j}\right]\cdot\frac{\partial a^j}{\partial x^j_{2,n}}\cdot r^j_{2,n}=\alpha^j\cdot r^j_{2,n}\cdot\frac{\partial TC^j_2(x^j_{2,n})}{\partial x^j_{2,n}}-(1-\alpha^j)\cdot r^j_{2,n}\cdot\frac{\partial TC^j_1(x^j_{2,n})}{\partial x^j_{2,n}}$$

C. International Situation (Level I)

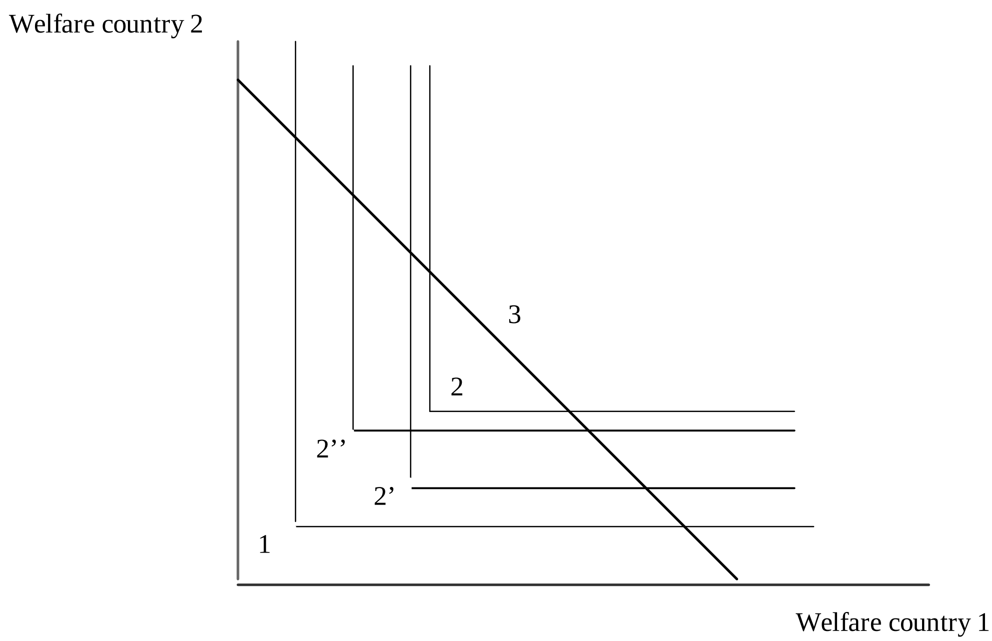
An international agreement should go further than the level II outcome, ideally making the marginal abatement cost of emissions by each type of firm equal to the utility loss to all consumers in the region due to the harm it caused to the resource. This is equivalent to the mechanism that a supranational planner would design to establish the emissions allowed for each type of firm in each country according to this rule: $\sum_h\left[s^1_h\cdot\frac{\partial v^1_h(c^1_h,a^1)}{\partial a^1}\right]\cdot\frac{\partial a^1}{\partial x^j_f}+...+\sum_h\left[s^J_h\cdot\frac{\partial v^J_h(c^J_h,a^J)}{\partial a^J}\right]\cdot\frac{\partial a^J}{\partial x^j_f}=\frac{\partial TC(y^j_f,x^j_f)}{\partial x^j_f}$ (or a similar one with political pressure).

However, no such planner can exist and so there are other possible outcomes which can be the result of international negotiations. The potential international environmental agreements are influenced by several factors linked to the domestic situation prior to negotiations and to the consequent implementability of the agreed policies: 1) countries' characteristics (consumers' preferences and firms' costs), 2) the existence or not of a previous national environmental regulations, and 3) the conditions under which those regulations are designed (in terms of political pressure and incomplete information).

An illustration for a case of two symmetric cases is illustrated in figure 2.1. Number 1 on the figure represents the case for which environmental regulations do not exist either at the domestic or at the international level. Point 2 is when both countries establish simultaneously a domestically optimal environmental policy. It can also be the case that only one of the countries regulates internally (which may appear as 2' and 2''). Each of these points depends on countries' fundamental characteristics (in the figure, both countries are assumed to be symmetric), and the position of points 2 also depends on the existence or nonexistence of political pressure by the firms (i.e., when there is complete information it is clear that the more the pressure, the closer these payoffs to point 1) and on the possibility of solving the information problem. Finally, a supranational planner would establish emissions such that both countries' welfare levels correspond to point 3. Along the frontier (the diagonal in the figure), the levels of emissions are the efficient ones, but only point 3 reflects a situation without transfers among countries[20].

It is clear from figure 1 that an agreement among countries is beneficial, basically because there is an externality to take into account. If countries decrease their firms' emissions slightly, then they both improve upon their original welfare (marked in the figure by the vertical and horizontal lines), even if full efficiency is only attained at the frontier. The problem is how to explain that those countries *do* improve over their domestic situation without any international agency. An alternative is to rely on time as a way of sustaining cooperation among countries[21]. Two interpretations of international negotiations may be considered: a repeated game argument or Rubinstein (1982)'s alternating-offers bargaining game.

Figure 1: Welfare levels for two symmetric countries under different initial situations



While thinking in international negotiations as an alternating-offer games seems appealing with the idea that countries seat in a negotiation table and make offers on aggregate levels of emissions and transfers, the assumptions of the model (and also its consequent result) do not provide a good way of illustrating how international agreements work (a more detailed explanation of these kinds of solutions is found in Appendix B)[22]. To consider international environmental cooperation as an infinitely repeated game among countries implies using the logic of the so-called "Folk Theorem". Under that reasoning, all the outcomes which give to all countries higher welfare levels than under the domestic level $[g_n^{j,I}(X^{j,I}, X^{-j,I}) + TR^{j,I} > g_n^{j,II}(X^{j,II}, X^{-j,II})]$ can be sustained as equilibria of a repeated game of cooperation among them, provided their discount factor is large enough. The justification of the fact that countries do cooperate is linked to the idea that they can commit themselves to strategies (emissions and transfers) such that cooperation is hindered if any single country deviates from the behavior prescribed by the agreement. In addition, these potential agreements have to be implementable domestically.

1) Complete Information

Treaties to sustain the vector of aggregate emissions and transfers (X^I, TR^I) require for every country that the long-run gains from a continuous cooperation are higher than the short-run gains from defecting. For example, that condition (for a "grim" strategy) can be expressed as:

$$g_n^{j,I}(X^{j,I}, X^{-j,I}) + TR^{j,I} > (1-\beta^j)\cdot\left[g_n^{j,I}(\tilde{X}_n^j, X^{-j,I}) + TR^{j,I}\right] + \beta^j \cdot g_n^{j,II}(X^{j,II}, X^{-j,II}),$$

where $\tilde{X}_n^j$ is country j's aggregate emissions in the case where it deviates from the agreement, $TR^{j,I}$ is the transfer received by country j under the treaty (note that the $\sum_j TR^{j,I} = 0$ every period), and β^j is the discount factor. In any case, a whole range of potential agreements can be derived from this way of looking at cooperation. The closer is the discount factor to one, the larger is that range[23].

2) Incomplete Information

Asymmetric information problems are not limited to the relationship between firms and governments. When negotiating an international environmental agreement, countries face incomplete information about other countries' characteristics. Each government may know its own type and be able to enforce internally the treaty that it signs with others (through some kind of mechanism like the one seen in the previous subsection), but each country can be of a number of possible types. Thus, no single government knows exactly the utility possibility set of the game that it is playing because it faces uncertainty about the other countries' characteristics.

However, the distinctive feature of this situation is that every country can deduce the aggregate emission levels of each neighbor almost costlessly by observing the state of the resource at each border and knowing the "transport matrix" of emissions. Thus, all the potential parties to an agreement know the original Bayesian Nash equilibrium of the game. This information is useful in the negotiation of an agreement because it is the starting point in the discussion and the point to which the parties can return if negotiations fail. The vector of emissions (X^{II}) allows them to draw some conjectures about the other countries' possible types. From there, it is not difficult to find vectors of pollution levels and transfers that all types of countries prefer to the original equilibrium. These solutions can be thought to be sustained as pooling equilibria of an infinitely repeated version of the game among countries (X^{I}, TR^{I}). Formally, X^{II} is the original Bayesian Nash equilibrium of the pollution game among all the countries negotiating the environmental agreement, $X^{j,II}$ is the best response to $X^{-j,II}$ for every type n of any country j. Then, there are vectors of pollution levels and money transfers (X^{I}, TR^{I}) that are accepted by every possible type of country.

The idea here is that each type of country should find that it is in its best interest to cooperate than to hinder that cooperation by cheating on the agreement, and that their resulting welfare $[g_n^{j,I}(X^{j,I}, X^{-j,I}) + TR^{j,I}]$ is greater than under the status quo. This result can be viewed as a version of the Folk theorem applied to games of multi-sided incomplete information. As a theoretical result it is weak, because it requires knowledge of the outcome of the original Bayesian Nash equilibrium, it only applies to payoffs which strictly dominate that outcome for all types, and it just considers solutions which can be implemented as pooling (rather than separating) equilibria. However, it allow to conclude that even under incomplete information and even in cases where the parties are not willing to reveal their types, countries may sign environmental agreements which improve the efficiency of the status-quo and are respected by everybody in equilibrium.

Though not surprising, this result provides an insight regarding the conditions under which countries act cooperatively no matter what their beliefs about the characteristics of the other parties in the agreement. Obviously, the set of equilibria that could be obtained in the case of complete information is larger. This happens since the existence of incomplete information requires the fulfillment of simple participation constraints by the individual governments so that all possible types in each country are better off than under the original static Nash equilibrium (i.e, every type should be better off with the agreement than without it). The set of equilibria under incomplete information could be enlarged if there was a way to separate countries, so that different types of countries pollute a different amount and receive a different transfer. To do that, a set of additional incentive-compatibility constraints designed by a supranational planner should be imposed which guarantees that each type of country is better off revealing its true characteristics (i.e, every type should be better off under "his agreement" than under "anybody else's agreement"). However, this would transform the game into a variant of a mechanism design problem, which is not considered feasible here for the level I (international) problem[24].

This line of reasoning does not contradict the practice of signing successive agreements among the same parties, which progressively improve the situation of a shared environmental resource. One can interpret that countries first try to enforce a relatively modest but sure outcome, which all possible types of every country will accept. Later on, because they learn more about the other parties' types, they aim at more ambitious measures and commit to stricter environmental standards. This "step-by-step" approach is widespread in the building of environmental treaties. The first step often involves the creation of an umbrella convention that broadly describes general obligations of the countries, and then in a further step more and more stringent requirements to reduce emissions by a specific amount by a certain date are agreed on. Furthermore, agreements are often explicitly open to periodic reviews (e.g., the Convention on Climate Change).

Nevertheless, it has still to be shown for this problem that the set of equilibria is not empty. All countries are assumed to have welfare functions which are linear in monetary transfers, so if there was complete information the result which has to hold is that the aggregate welfare can be increased with a coordinated reduction in pollution (because of the existence of a real externality problem), and such increase can be apportioned among the different countries through monetary transfers. For the case of incomplete information about the other countries' types it has to be shown that, for any possible combination of types among countries, aggregate welfare can be increased with a coordinated reduction in pollution. Even though it would appear that for a large number of extreme types it may be that the set of equilibria becomes empty, this seems to be precluded here. The reason is that there is a limit on how different these types can be, which is given by the fact that the original pooling equilibrium emission level is the same for every type. The numerical example in section IV is designed to better illustrate the above argument.

IV. Numerical Example

This section considers a simple numerical example with two of several possible types, each with two types of firms (θ_1 and θ_2, which exist in both countries' types but in different proportions) and one type of consumer per country. It is designed to illustrate some of the circumstances described in the model with incomplete information (but without political pressure). Profits of firms of the fth type in the jth country of the nth type ($\Pi^j_{f,n}$) and the surplus of the representative consumer in that country (S^j_n), are:

$$\Pi^j_{f,n} = \theta_f \cdot x^j_{f,n} - (x^j_{f,n})^2 \qquad \text{and} \qquad S^j_n = \gamma^j_n \cdot \left[\bar{a}^j - \psi_{jj} \cdot \left(r^j_{1,n} \cdot x^j_{1,n} + r^j_{2,n} \cdot x^j_{2,n}\right) - \psi_{-jj} \cdot X^{-j}\right]$$

where $x^j_{f,n}$ are the pollution levels of the firms, $r^j_{f,n}$ are the masses of those firms (such that $r^j_{1,n} + r^j_{2,n} = 1$), X^{-j} is the aggregate pollution level in the other country (which can also be of n possible types), the ψ's are parameters indicating the transport of pollution across borders, $\bar{a}^j$ is the pristine state of the resource, and γ^j is a parameter of the preferences (all are greater than zero). Under such circumstances, the welfare in the jth country of type n is (g^j_n) is:

$$g^j_n = \gamma^j_n \cdot \left[\bar{a}^j - \psi_{jj} \cdot \left(r^j_{1,n} \cdot x^j_{1,n} + r^j_{2,n} \cdot x^j_{2,n}\right) - \psi_{-jj} \cdot X^{-j}\right]$$
$$+ r^j_{1,n} \cdot \left[\theta_1 \cdot x^j_{1,n} - \left(x^j_{1,n}\right)^2\right] + r^j_{2,n} \cdot \left[\theta_2 \cdot x^j_{2,n} - \left(x^j_{2,n}\right)^2\right]$$

A. Domestic Level

When the governments regulate pollution so as to maximize the country's welfare (level II), they attempt to impose an emission standard on each type of firm:

$$x_{f,n}^{j,II} = \frac{\theta_f - \gamma_n^j \cdot \psi_{jj}}{2}.$$

In order to enforce that regulation, the governments need to establish a system of pollution taxes to be applied to the two types of firms such that it "separates" them. In a situation of asymmetric information where $r_{1,n}^j, r_{2,n}^j, \theta_1, \theta_2, \gamma_n^j, \psi_{jj}$ are known to each government j of type n (but each firm has private information about its type), implementing the domestically efficient levels of pollution requires finding taxes which satisfy the following constraints (in addition to the non-negativity ones constraints):

$$\frac{(\theta_1)^2 - (\gamma_n^j \cdot \psi_{jj})^2}{4} \geq T_{1,n}^j \qquad \text{(IR 1)}$$

$$\frac{(\theta_2)^2 - (\gamma_n^j \cdot \psi_{jj})^2}{4} \geq T_{2,n}^j \qquad \text{(IR 2)}$$

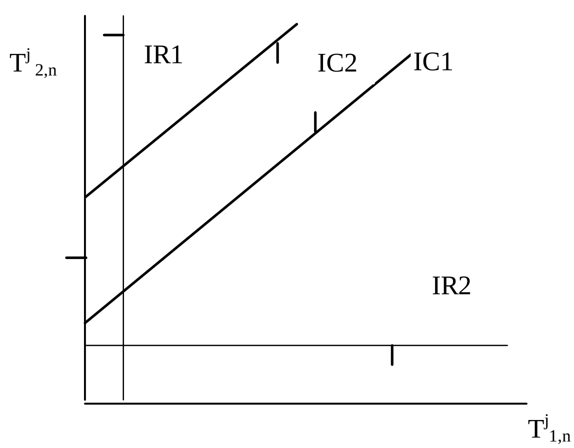
$$\frac{(\theta_2 - \theta_1) \cdot \gamma_n^j \cdot \psi_{jj}}{2} - \frac{(\theta_2 - \theta_1)^2}{4} \leq T_{2,n}^j - T_{1,n}^j \qquad \text{(IC 1)}$$

$$\frac{(\theta_2 - \theta_1) \cdot \gamma_n^j \cdot \psi_{jj}}{2} + \frac{(\theta_2 - \theta_1)^2}{4} \geq T_{2,n}^j - T_{1,n}^j \qquad \text{(IC 2)}$$

If firms of type 1 are cleaner than those of type 2 (i.e., $\theta_1 < \theta_2$), it can be safely assumed that IR 1 is always satisfied, and that it is always possible to find positive levels of T_1^j and T_2^j that simultaneously fulfill IC 1 and IC 2. However, it may happen that IR 2 and IC 1 cannot be satisfied at the same time (i.e, it is impossible to find taxes which make dirtier type 2 firms willing to produce and cleaner type 1 firms willing to reveal their true characteristics) as is shown in figure 2. Such incompatibility occurs if:

$$2\theta_2\theta_1 + [2(\theta_2 - \theta_1) + \gamma_n^j \cdot \psi_{jj}] \cdot \gamma_n^j \cdot \psi_{jj} - 2(\theta_2)^2 - (\theta_1)^2 > 4 \cdot T_{1,n}^j$$

Figure 2: Sketch of the IC and IR constraints when firms cannot be separated



If there is no incentive-compatibility mechanism for separating firms, the governments sets $T_{1,n}^j = T_{2,n}^j = 0$ and enforces a unique (weighted) average pollution level ($x_{1,n}^{j,II} = x_{2,n}^{j,II} = X_n^{j,II}$)

equal to:

$$X_n^{j,II} = \frac{r_{1,n}^j \cdot \theta_1 + r_{2,n}^j \cdot \theta_2 - \gamma_n^j \cdot \psi_{jj}}{2}$$

This solution has an efficiency cost due to the emergence of a pooling equilibrium among the different types of firms. The average pollution level it generates does not differ from the previous situation, but welfare does decrease.

B. International Level

In general, when countries negotiate an agreement about the levels of pollution that they impose on their common environmental resource (level I), they agree on the aggregate levels of emissions. It is convenient to express welfare as a function of these pollution levels in each pair of countries of different types ($X^{1,II}, X^{2,II}$). This requires defining first the following aggregate profit function:

$$\Pi_n^j(X_n^j) = \max_{x_{1,n}^j, x_{2,n}^j} \left\{ r_{1,n}^j \cdot \Pi_{1,n}^j + r_{2,n}^j \cdot \Pi_{2,n}^j \,/\, X_n^j = r_{1,n}^j \cdot x_{1,n}^j + r_{2,n}^j \cdot x_{2,n}^j \right\}$$
$$= \left(r_{1,n}^j \cdot \theta_1 + r_{2,n}^j \cdot \theta_2 \right) \cdot X_n^j - \left(X_n^j \right)^2 + K_n^j$$

where K_n^j value depends on the possibility of the domestic government to impose different pollution levels to the two types of firms, that is:

$$K_n^j = 0 \qquad \text{(if } x_{1,n}^j = X_n^j = x_{2,n}^j\text{)}$$
$$K_n^j = \frac{r_{1,n}^j \cdot r_{2,n}^j \cdot \left(\theta_2 - \theta_1\right)^2}{4} \qquad \text{(if } x_{1,n}^j = X_n^j - \frac{r_{2,n}^j \cdot (\theta_2 - \theta_1)}{2} < X_n^j < x_{2,n}^j = X_n^j + \frac{r_{1,n}^j \cdot (\theta_2 - \theta_1)}{2}\text{)}$$

In this situation, if the government cannot separate firms its own country's welfare decreases by K_n^j. If each country has already maximized its own welfare function when the negotiation of the agreement begins, each party has solved the following optimization problem:

$$g_n^j = \max_{X_n^j} \left\{ \gamma_n^j \cdot \left[\bar{a}^j - \psi_{jj} \cdot X_n^j - \psi_{-jj} \cdot X^{-j} \right] + \left(r_{1,n}^j \cdot \theta_1 + r_{2,n}^j \cdot \theta_2 \right) \cdot X_n^j - \left(X_n^j \right)^2 + K_n^j \right\}$$

and has therefore imposed $X_n^{j,II}$ as its average pollution level.

However, both countries can improve over this situation. If there was a supranational planner to find the optimal levels of pollution for all countries, it would maximize $g^1 + g^2$, and would impose a level of emissions which depends of the type the other party in the negotiation is:

$$X_{(n)}^{j,IP} = \frac{r_{1,n}^j \cdot \theta_1 + r_{2,n}^j \cdot \theta_2 - \gamma_n^j \cdot \psi_{jj} - \gamma^{-j} \cdot \psi_{j-j}}{2} = X^{j,II} - \frac{\gamma^{-j} \cdot \psi_{j-j}}{2} < X^{j,II}$$
.

where both γ^{-j} corresponds to the other country, so can also take different values according to the country's type.

However, since there is no such planner and there is usually two-sided incomplete information, the possible $X^{1,I}, X^{2,I}$ are very difficult to agree upon because each country knows some parameters of the optimal solution but not others. More precisely, both governments know values for $\theta_1, \theta_2, \psi_{11}, \psi_{12}, \psi_{21}, \psi_{22}$ (which are basically technical parameters of the production and pollution diffusion processes) but each government only knows with certainty the values of $\gamma_n^j, r_{1,n}^j, r_{2,n}^j$ (how much consumers like the resource and the masses of each type of firm) for its own type of country.

Then, if countries are assumed to be of two possible types (n = A, B), with countries of type A having consumers who are more environmentally-oriented but a lower proportion of cleaner firms ($\gamma_A^j > \gamma_B^j$ and $r_{1,A}^j < r_{1,B}^j$). Then, the possible values for each parameter in each country are: $\gamma_A^1, r_{1,A}^1, r_{2,A}^1$, $\gamma_B^1, r_{1,B}^1, r_{2,B}^1$, $\gamma_A^2, r_{1,A}^2, r_{2,A}^2$, $\gamma_B^2, r_{1,B}^2, r_{2,B}^2$. Nevertheless, all governments are able to deduce $X^{1,II}$ and $X^{2,II}$ by observing the state of the resource and by knowing the parameters of the "transport" of pollution across nations. Thus, they are also able to draw some inferences about the other country's parameter values using this information. Several different values for the parameter sets are consistent with the same status quo average pollution for both types[25]:

$$X^{j,II} = \frac{r_{1,A}^j \cdot \theta_1 + r_{2,A}^j \cdot \theta_2 - \gamma_A^j \cdot \psi_{jj}}{2} = \frac{r_{1,B}^j \cdot \theta_1 + r_{2,B}^j \cdot \theta_2 - \gamma_B^j \cdot \psi_{jj}}{2}$$

If an optimal agreement had to be reached, there are two alternative optimal values for each pollution level:

$$X_{(A)}^{j,IP} = X^{j,II} - \frac{\gamma_A^{-j} \cdot \psi_{j-j}}{2} \qquad \text{and} \qquad X_{(B)}^{j,IP} = X^{j,II} - \frac{\gamma_B^{-j} \cdot \psi_{j-j}}{2}$$

for which it holds that $X_{(A)}^{j,IP} < X_{(B)}^{j,IP} < X^{j,II}$. Note that $X_{(A)}^{j,IP}, X_{(B)}^{j,IP}$ subscripts refer to the possible type of the country other than j.

There are several combinations of parameters that depict the above situation. However, for concreteness of the example, one of such combination of parameter values is selected (for a case in which country 1 and 2 are symmetric):

$$\theta_1 = 4 \ ; \theta_2 = 8 \ ; \ a_0^1 = a_0^2 = 5 \ ; \ \psi_{11} = \psi_{22} = 1 \ ; \ \psi_{12} = \psi_{21} = 0.5 \ ;$$
$$\gamma_A^1 = \gamma_A^2 = 2 \ ; \ \gamma_B^1 = \gamma_B^2 = 1 \ ; \ r_{1,A}^1 = r_{1,A}^2 = 0.25 \ ; r_{1,B}^1 = r_{1,B}^2 = 0.5$$

For that case, it holds that:

$$X^{1,II} = X^{2,II} = 2.5, \qquad X_{(A)}^{1,IP} = X_{(A)}^{2,IP} = 2 \qquad \text{and} \qquad X_{(B)}^{1,IP} = X_{(B)}^{2,IP} = 2.25$$

To study possible environmental agreements in absence of a supranational planner requires defining the set of pooling sequential equilibria of the infinitely repeated game between the two countries. This set includes all the pollution combinations ($X^{1,I}, X^{2,I}$) whose corresponding welfare is greater than that obtained under $X^{1,II}, X^{2,II}$ *for all types of countries*. Since countries can make transfers among themselves, it can be said without any loss of generality that the following conditions have to hold:

$$g_A^{1,I}\left(X^{1,I}, X^{2,I}\right) + g_A^{2,I}\left(X^{1,I}, X^{2,I}\right) \geq g_A^{1,II} + g_A^{2,II}$$
$$g_B^{1,I}\left(X^{1,I}, X^{2,I}\right) + g_A^{2,I}\left(X^{1,I}, X^{2,I}\right) \geq g_B^{1,II} + g_A^{2,II}$$
$$g_A^{1,I}\left(X^{1,I}, X^{2,I}\right) + g_B^{2,I}\left(X^{1,I}, X^{2,I}\right) \geq g_A^{1,II} + g_B^{2,II}$$
$$g_B^{1,I}\left(X^{1,I}, X^{2,I}\right) + g_B^{2,I}\left(X^{1,I}, X^{2,I}\right) \geq g_B^{1,II} + g_B^{2,II},$$

The resulting conditions for this example, considering only those average emissions that are implementable by every type of countries both at the level II and I[26].

$$20+4\cdot X^{1,I}+4\cdot X^{2,I}-\left(X^{1,I}\right)^2-\left(X^{2,I}\right)^2\geq 27.5$$
$$15+4\cdot X^{1,I}+4.5\cdot X^{2,I}-\left(X^{1,I}\right)^2-\left(X^{2,I}\right)^2\geq 23.75$$
$$15+4.5\cdot X^{1,I}+4\cdot X^{2,I}-\left(X^{1,I}\right)^2-\left(X^{2,I}\right)^2\geq 23.75$$
$$10+4.5\cdot X^{1,I}+4.5\cdot X^{2,I}-\left(X^{1,I}\right)^2-\left(X^{2,I}\right)^2\geq 20$$

where $g_n^{1,II}+g_n^{2,II}$ are the aggregate gains from trade under ($X^{1,II},X^{2,II}$) for each type of possible matching among the different types of countries. The respective welfare levels in the case of a supranational planner are:

$$g_A^{1,IP}+g_A^{2,IP}=29.5$$
$$g_B^{1,IP}+g_A^{2,IP}=25.8125$$
$$g_A^{1,IP}+g_B^{2,IP}=25.8125$$
$$g_B^{1,IP}+g_B^{2,IP}=22.125$$

The situation described can be depicted in two graphs. Figure 3 shows the alternative levels of pollution that could be attained departing from the situation in level II when there is domestic environmental regulation ($X^{1,II}=X^{2,II}=2.5$). The broadest range of emissions which can be agreed upon (in the graph, the larger oval) is when both countries are of type A, and the smaller when both are of type B. If both countries are of the cleaner type in the sense that their consumers are more environment-oriented, so both countries are more willing to commit to lower levels of emissions. However, the equilibria which can be sustained in the case of incomplete information are those located within the intersection of the four possible ovals. The figure also illustrates which would be the overall optimum pollution levels in the two cases where countries are of the same type.

Figure 4 portrays the possible frontiers according to what type the countries are and compares more closely the four possible points in the welfare space which corresponds to emissions at the no-agreement situation (level II), and the possible gains from cooperation according to the real type of each country (from those points to the corresponding efficiency frontiers). In figure 4, the situation with the broadest possibility of gains from an agreement is when both countries are of type A, and the narrowest is when both are of type B. In that case, countries of any kind gain less by signing an agreement with a country with less environmentally-oriented consumers.

The same figures can be imagined for a case with more types of countries (i.e., $\gamma_n^j, r_{1,n}^j, r_{2,n}^j$ combinations). For example, if there were three or four types, there would be 9 or 16 ovals respectively, in figure 3, while figure 4 would include 6 or 10 frontiers. The key in that case is how much the introduction of additional types shrinks the set of pooling sequential equilibria. There are some limitations on the values of the parameters (and on the non-negativity of emissions) which come into play and prevent emptiness in the set of equilibria.

Figure 3: Alternative pollution agreements (Level I)

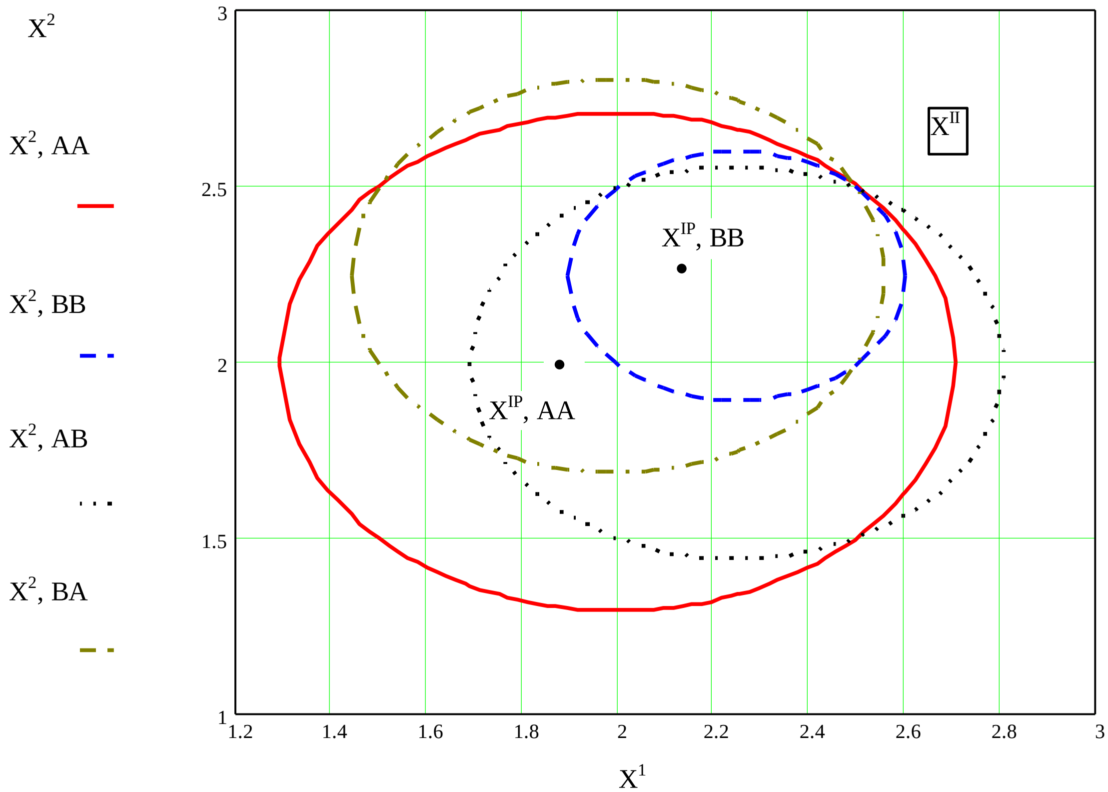
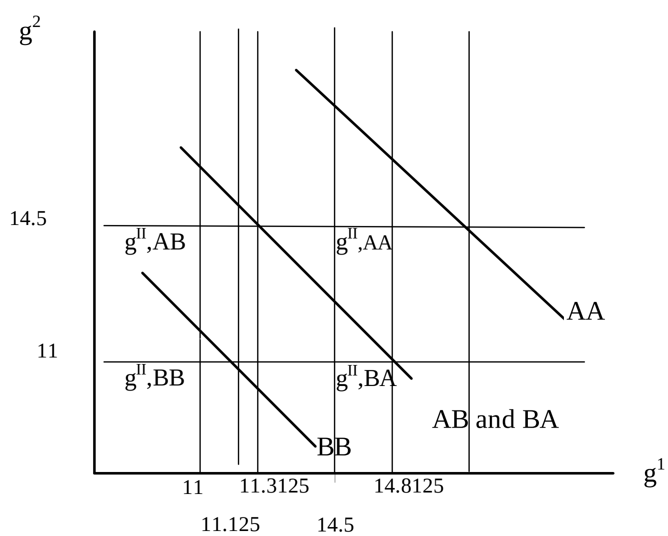


Figure 4: Alternative welfare levels



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More precisely, $X^{j,II} = 2.5$ for all types of countries, given $\theta_1 = 4$ and $\theta_2 = 8$, $\psi_{jj} = \psi_{-j-j} = 1$, $\psi_{-jj} = \psi_{j-j} = 0.5$, implies that γ^j_n is equal to:

$$\gamma^j_n = r^j_{1,n} \cdot 4 + r^j_{2,n} \cdot 8 - 5, \qquad n = A, B$$

Then, in order to have $\gamma^j_n > 0$ (i.e., consumers who like the natural resource) knowing that $r^j_{1,n} + r^j_{2,n} = 1$, it has to be true that $r^j_{1,n} < 0.75$. In addition, for $X^{j,IP}_{(n)} \geq 0$, $\gamma^j_n \leq 10$ is needed.

Thus, the limits for types of countries are: on one side, a type of country that is inhabited by consumers who like the environment a lot but has a low proportion of cleaner firms ($\gamma_n^j \to 10, r_{1,n}^j \to 0$), and on the other side, a type of country inhabited by consumers have a low preference for the environment and has a high proportion of cleaner firms ($\gamma_n^j \to 0, r_{1,n}^j \to 0.75$).

Even if there is the possibility of a country of this latter kind, there exist a set of pooling equilibria. In terms of figure 3, the “pure” ovals (AA, BB, etc) are included one into the other. This means that the “smaller” possible oval is the one determined by the combination of two countries of the limit type $\gamma_n^j \to 0, r_{1,n}^j \to 0.75$. Some portions of it are lost to the combinations with other possible types, but adding any number of types within the above limits is not sufficient to eliminate all possible equilibria. So, it is possible to sign agreements no matter how the possible types of countries are, but it remains true that the size of the set of possible equilibria depends on it.

<u>C. Domestic Level Again</u>

The fact that countries sign agreements obviously entails a change in domestic regulations because governments have to enforce the corresponding aggregate pollution level ($X_n^{j,I}$) by choosing different levels of $x_{1,n}^{j,I}$ and $x_{2,n}^{j,I}$ according to firms’ type. Table 2.1 describes those values for the aggregate emissions at both levels.

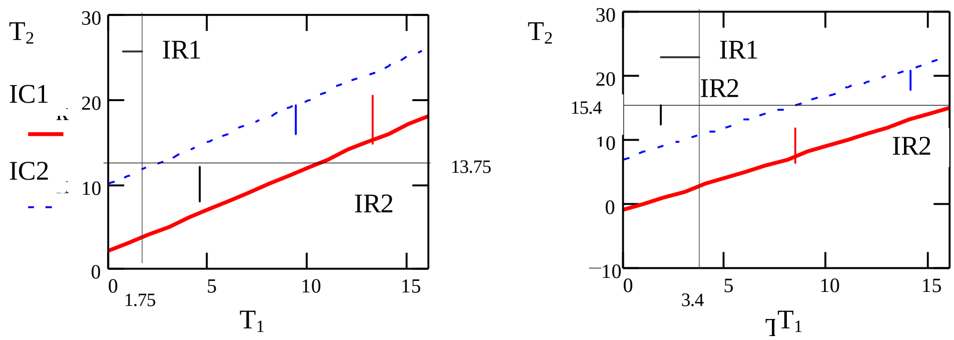
Table 1 Aggregate emissions and the corresponding domestic separating ones

	Level II		***Level I, Planner***	
	Type A	**Type B**	**Both Type A**	**Both Type B**
X_n^j	2.5	2.5	2	2.25
$x_{1,n}^j$	1	1.25	0.5	1.5
$x_{2,n}^j$	3	3.25	2.5	3.5

Figure 5: Combinations of feasible taxes

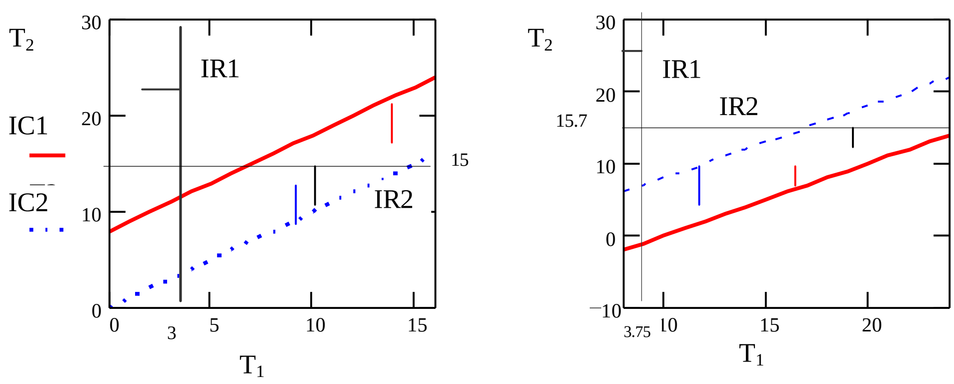
Level II

(a) Countries of Type A ***(b) Countries of Type B***



Level I, Planner

(c) Both Countries Type A ***(d) Both Countries Type B***



To enforce these emissions in a context of domestic asymmetric information, the government must implement a tax system that satisfies at the same time the participation and incentive-compatibility constraints for all the firms in the country (and taxes must be non-negative). At level II, such a mechanism was possible and marked the beginning of the negotiations. The feasible values for $T^j_{1,A}, T^j_{2,A}, T^j_{1,B}, T^j_{2,B}$ are given by the areas shown in graphs (a) and (b) in Figure 5 for countries of type A and B respectively. However, when an agreement is reached at the international level (e.g., X^{IP}), it may happen that governments in each country not only have to change what each type of firm should be allowed to pollute but also the taxes which support those allocations (graphs (c) and (d) in Figure 5).

V. Summary and Conclusions

This paper is based on the general framework provided by the literature on two-level games which considers that countries interact in international negotiations influenced by the domestic implementability of their commitments (under the existence of incomplete information and political pressure). However, this model reflects better both domestic and international environmental regulations because it reflects the fact that domestic factors not only affect the implementability of international agreements, they also determine the point of departure for any international negotiation.

The main claim in terms of environmental intervention is that governments can internally design some regulatory mechanism but that the same is not true at the international level. Hence, all international outcomes have to be achieved through some kind of non-cooperative bargaining among the countries. In that framework, the departure situation, the consequent agreements (and their implementability) vary with countries' consumers' preferences and firms' costs and with the existence or not of a previous environmental policy (i.e., the possible agreements are "better" if the countries involved have already in place some regulations).

The domestic situation is also different depending on the information available to the governments and on the level of political pressure suffered by them. Under incomplete information, governments may be able to design an efficient system of taxes and emissions such that they can allow different levels of emissions to cleaner than to dirtier firms. If such a mechanism is not possible, countries have to establish an single average level of emissions, whose lower efficiency is caused by the information problem. Under both incomplete information and political pressure, governments have no possibility of implementing an internally efficient mechanism but they can solve the information problem.

While it is true that the potential resulting environmental treaties depend on domestic conditions, they also vary according to the possible types neighbor countries can be (i.e., it may be better to sign an agreement with a country which is more "environment-oriented") and the rate at which countries discount the future. This research shows that albeit there is uncertainty about how the other parties of the negotiations are really like, international environmental agreements may still be reached (although their possible range becomes smaller and less efficient). Even in cases with multi-sided incomplete information where the parties are not willing to reveal their characteristics, countries may be able to sign environmental agreements that improve efficiency relative to the status-quo and are respected by everybody in equilibrium.

As international agreements continue to be signed, the framework presented in this paper provides a way of thinking more systematically the connection between the environmental negotiations among countries and their domestic situation. It also provides a rationale for the incidence of the lack of information and political pressure on domestic emissions' amounts and inter-country emissions' commitments, which are two day-to-day phenomena in environmental regulations. While domestic and international environmental rules proliferate, careful theoretical assessments of the links between them can only help the decision making of those who have to design the regulations.

Appendix A: Domestic Regulation with very Little Information

When governments do not know the characteristics of each type of firm, even though they know their number (and mass), any attempt to internalize the real externality is blocked by this information problem, and the classical welfare economics prescription fails because while governments attempt to use domestic environmental policy to solve the real externality problem occurring within their country, firms anticipate the regulation and lie about their true costs.

Formally, each government solves the same problem as if it had complete information, but there are parameters of the cost functions that it does not know. Then, firms are asked to reveal their costs and the government assigns them permits which establish their allowed emissions. Thus, the government's FOC for pollution by each type of firm can be written as:

$$\sum_h \left[s^j_{h,n} \cdot \frac{\partial v^j_{h,n}(c^j_{h,n}, a^j)}{\partial a^j} \right] \cdot \frac{\partial a^j}{\partial x^j_{f,n}} = \frac{\partial TC^j_{f,n}(.,x^j_{f,n},\hat{\theta}^j_{f,n})}{\partial x^j_{f,n}}$$

Governments then establish "domestically efficient" pollution amounts depending on the type that firms reveal: $x^j_{f,n}(\hat{\theta}^j_{f,n})$. As a result, firms implicitly solve the problem:

$$\max_{\hat{\theta}^j_{f,n}} \pi^j_{f,n} = p^j_n \cdot y^j_{f,n} - TC^j_{f,n}(.,x^j_{f,n}(\hat{\theta}^j_{f,n}))$$

Then, the revelation is such that the following FOC holds:

$$\frac{\partial TC^j_{f,n}(.,x^j_{f,n}(\hat{\theta}^j_{f,n}))}{\partial x^j_{f,n}} \cdot \frac{\partial x^j_{f,n}}{\partial \hat{\theta}^j_{f,n}} = 0$$

But, since $\frac{\partial x^j_{f,n}}{\partial \hat{\theta}^j_{f,n}} \neq 0$, the condition must be fulfilled by: $\frac{\partial TC^j_{f,n}(.,x^j_{f,n}(\hat{\theta}^j_{f,n}))}{\partial x^j_{f,n}} = 0$ which corresponds to the case of complete absence of any environmental policy. This result shows clearly the failure of such a naive solution to internalize the real environmental externality in the case of incomplete information. Firms can manipulate the mechanism that the government creates because the government has very little information. In addition, if there is political pressure, the allowed pollution depends on alpha, so, if firms were to choose that pressure, they could evidently manipulate the mechanism. That choice is not modeled here since α is only a parameter in the government's objective function.

Appendix B: Alternative Interpretation of International Negotiations

Governments can be thought as interacting by proposing levels of pollution and transfers. One government makes an offer, and the others can accept it, or reject it and make another offer. Under this view, the number of equilibria (or potential treaties) obtained can be reduced but only if some strict specifications of the game among countries are considered (Rubinstein, 1982). When there are two parties who have complete information, discount the future, and have no other bargaining costs than the delay, the best alternative is to reach an agreement in the first round of negotiation.

The idea behind that solution is a subgame perfect equilibrium in which the first player to make an offer proposes to the other player just what makes him indifferent between accepting and rejecting it. This means that the following equality has to be fulfilled (the subscripts n are simplified):

$$g^{\hat{j},I}(X^{\hat{j},I},X^{-\hat{j},I})+TR^{\hat{j},I}=(1-\beta^{d})\cdot g^{j,II}+\beta^{d}\cdot[g^{\breve{j},I'}(X^{\breve{j},I'},X^{-\breve{j},I'})+TR^{\breve{j},I'}],\quad j = 1, 2,$$

where $g^{\hat{j},I}(X^{\hat{j},I},X^{-\hat{j},I})+TR^{\hat{j},I}$ is the average welfare for country j if it accepts the offer made by country -j, $g^{j,II}$ is the welfare for country j if it stays at the pollution level established at level II, $g^{\breve{j},I'}(X^{\breve{j},I'},X^{-\breve{j},I'})+TR^{\breve{j},I'}$ is country j's welfare if its proposal is accepted one period later, β is the discount factor and d the duration of each round of negotiation (i.e., the time between offers). The sum of the two countries' transfers is zero in every period.

The solution for that game depends on the interval of time between offers and the order of play. The country that makes the first offer has the advantage of one period, and so there are two possible efficient equilibria depending on which country begins the negotiations. However, when the interval between offers is very small (or when the discount factor β tends to 1), the outcome becomes independent of the structure of the negotiations. In that case, the unique equilibrium of such a non-cooperative game of alternating offers coincides with the "Nash Bargaining solution", which is a cooperative concept (Binmore, 1980). This implies that the division of the gains from cooperation is implicitly made by solving the following problem:

$$\max_{\{TR^{j,IN},X^{j,IN},X^{-j,IN}\}}\left\{\left[g^{j,IN}(X^{j,IN},X^{-j,IN})+TR^{j,IN}-g^{j,II}\right]\cdot\left[g^{-j,IN}(X^{j,IN},X^{-j,IN})-TR^{j,IN}-g^{-j,II}\right]\right\},$$

where j = 1,2 and the superscript IN refers to the level I Nash Bargaining solution. The resulting pollution levels are efficient ones (because to maximize the Nash product, both terms have to be equal), but transfers are such that only one of the points on the frontier in figure 2.1 is attained. More precisely, the transfer from country -j to country j is: $TR^{j,IN}=\frac{\left[g^{-j,IN}-g^{-j,II}\right]-\left[g^{j,IN}-g^{j,II}\right]}{2}$.

However, while appealing, the alternating-offers way of looking at international agreements implies several limitations. More equilibria exist under small changes in the assumptions (e.g., players face fixed bargaining costs or even if more than two players participate in the negotiations). In addition, the fact is that in actual negotiations an agreement is never reached at the first round. Bargaining takes several years. As an example, it took more than 3 years to negotiate the Vienna Convention for the Protection of the Ozone Layer and the Rhine river negotiations have been going on for approximately 40 years.

When there is incomplete information (although possibly "small"), the set of equilibria defined in section III at level I for the game played by the countries that sign an environmental agreement does not give a determinate answer to the question of what such an agreement would be like. A unique solution to that question requires a more sophisticated structure for the game or thinking in a solution which satisfies some desirable properties. One alternative which parallels the approach followed for the case of complete information is the Generalized Nash bargaining solution (GNBS), due to Harsanyi and Selten (1972). This is defined for two countries as the vector $(X^{1,IG}, X^{2,IG}, TR^{1,IG})$ which maximizes the following product:

$$\prod_n \left(g_n^{1,IG}(X^{1,IG}, X^{2,IG}) + TR^{1,IG} - g_n^{1,II}(X^{1,II}, X^{2,II}) \right)^{p_n^1} \cdot \prod_n \left(g_n^{2,IG}(X^{1,IG}, X^{2,IG}) - TR^{1,IG} - g_n^{2,II}(X^{1,II}, X^{2,II}) \right)^{p_n^2},$$

where p_n^j is the probability of country j being of type n, and the superscript IG corresponds to the level I GNBS. In the example of section IV, this implies maximizing the following function:

$$GN = \left[g_A^{1,IG}\left(X^{1,IG}, X^{2,IG} \right) - g_A^{1,II} \right]^{p_A^1} \cdot \left[g_B^{1,IG}\left(X^{1,IG}, X^{2,IG} \right) - g_B^{1,II} \right]^{p_B^1} \cdot \left[g_A^{2,IG}\left(X^{1,IG}, X^{2,IG} \right) - g_A^{2,II} \right]^{p_A^2} \cdot \left[g_B^{2,IG}\left(X^{1,IG}, X^{2,IG} \right) - g_B^{2,II} \right]^{p_B^2}$$

where $p_A^1, p_B^1, p_A^2, p_B^2$ are probabilities associated with each of the two sets of parameters in the two countries. Assuming, for example, that: $p_A^1 = p_B^1 = p_A^2 = p_B^2 = 0.5$, the solution is an agreement with a symmetric allocation of pollution $(X^{1,IG} = X^{2,IG} = X^{IG})$ and no money transfers for which it holds that:

$$\frac{\partial GN}{\partial X^{IG}} = 4 \cdot (X^{IG})^3 - 25.5 \cdot (X^{IG})^2 + 53.5 \cdot X^{IG} - 36.875 = 0$$
$$\frac{\partial^2 GN}{\partial X^{IG}} = 12 \cdot (X^{IG})^2 - 51 \cdot X^{IG} + 53.5 < 0$$

where $X^{1,IG} = X^{2,IG} = X^{IG} = 2.19519$. Note that this pollution level lies in between $X_{(A)}^{j,IP}$ and $X_{(B)}^{j,IP}$ and is of course smaller than $X^{j,II}$. It represents an interior point in the set of pooling sequential equilibria, whose corresponding levels of welfare are:

$$g_A^{1,IG} + g_A^{2,IG} = 30.9238$$
$$g_B^{1,IG} + g_A^{2,IG} = 27.5214$$
$$g_A^{1,IG} + g_B^{2,IG} = 27.5214$$
$$g_B^{1,IG} + g_B^{2,IG} = 24.119$$

The corresponding levels of emissions for firms of type 1 and 2 respectively are: 0.69519 and 2.69519 in countries of type A, and 1.19519 and 3.19519 in countries of type B.

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[1] For example, in the case of the 1985 Helsinski Protocol (within the UN-ECE Convention on Long-range Transboundary Air Pollution) to reduce sulfur emissions by 30%, Poland did not sign the protocol because "of its lack of technology and equipment to control emissions" (Sjöstedt, 1993). Similar cases abound, while sometimes they merely represent strategic behavior on the part of the countries which do not want to commit to such strategies.

[2] Since 1972, there is an OECD program to measure long-range transport of air pollution which has been successful in providing transport estimates for the pollutants which cause acid rain. However, for climate change, the regional impacts cannot yet be predicted with sufficient confidence. In addition, some feel that such scientific uncertainty has been used by countries as an excuse for delaying expensive emission reductions (e.g., the US at the 1992 Convention on Climate Change).

[3] One common feature of the development of environmental policy in the 1970s was the use of traditional administrative regulatory procedures, and while it is true that some economic instruments are now used in several countries (e.g., emission taxes in Europe, or marketable permits in the US), the system of requiring permits which specify the emission allowances is still generalized.

[4] It is fair to recognize that pressure groups are also able to provide some information to the governments about foreign firms or about the neighbor countries. Moreover, domestic consumers may inform the regulator about domestic firms or international ecological groups (as Friends of the Earth, Greenpeace or WWF) can do the same for firms' costs in either country.

[5] The idea is the same as that of Baldwin (1987), who demonstrates the correspondence between tariffs chosen by lobbying-influenced policy makers and those selected by a government which gives too much weight to the profits of those influential groups (in its "politically realistic objective function").

[6] All the papers in this literature are such that level I has a single outcome result of a Rubinstein (1982) alternating offer game among countries or the Nash Bargaining Solution. Another example of this modeling strategy are the "nested games" in which, for example, there is competition between political coalitions (so, a single outcome), and then a game within them (Tsebelis, 1990).

[7] An example of a supranational mechanism designer is Feenstra and Lewis (1991), where the GATT is assumed as creating a scheme to prevent countries from misrepresenting the political pressure to which they are subjected. Such a solution is not considered possible for the problem presented in this paper, because at level II the domestic externality may be internalized through an optimal mechanism, but at level I this is not feasible because there is no supranational agency whose rulings all countries follow.

[8] This model relies on the use of a single-firm mechanism design, which can also be interpreted as a situation with a large number of small firms, each of whom interacts with the government but not with each other (Fudenberg and Tirole, 1991).

[9] There are several "integrated assessment models" for acid rain in Europe (e.g., RAINS) which use "transport matrices" to study the effects in term of environmental change and cost of specific emissions agreements.

[10] The analysis here leaves aside hidden action problems due to imperfect monitoring of emissions at the national level, and focuses on hidden characteristics. However, the model could be extended to a "hybrid" hidden actions/hidden characteristics model.

[11] This is another application of the optimal taxation literature initiated in the work of Mirrlees (1971).

[12] This same reasoning can be extended to more types or even a continuum of them. It may appear as with more constraints it will be more difficult to find an implementable mechanism. However, that is not the case because only some of the constraints bind.

[13] This condition can be thought as part of the conditions required to support a separating equilibrium in a signaling game, where the signals are the types announcements.

[14] This is the familiar sorting (or "single-crossing" or "Spence-Mirrlees") property employed in signaling

models.

[15] This mechanism is not budget balanced, there is a surplus of collected taxes.

[16] Note that in the case of no political pressure Walrasian prices could be interpreted as Lagrangian multipliers of the planner problem because (by the second theorem of welfare economics) being on the Pareto frontier it is possible to find equilibrium prices to support the Walrasian allocations. However, when there is political pressure, domestic efficiency is not reached and so the prices in the planner's problem cannot be interpreted in the same way.

[17] Those emissions determine the level of production by each type of firm in each country. Then, firms choose the production which maximizes their profits when they tell the truth and when they lie. The resulting supply functions depend on prices and the allowed pollution, so the market clearing condition in the market for the good (determined by what actually firms are) yields the equilibrium price, the quantity produced, and the amount of pollution. Once pollution is determined, firms' profits can be calculated under all the possible revelations (truthful or not).

[18] An alternative is that the regulator separates firms but accepts the violation of some of the participation constraints and have one type of firm to shut-down.

[19] For a continuum of types, Baron and Myerson (1982), and Guesnerie and Laffont (1984) expose structured ways of solving for optimal mechanisms following that two-step procedure. The main idea is to be able to simplify the number of constraints.

[20] When countries are different in terms of their consumers' preferences and firms' costs, it may happen that point 3 is to the South-East of point 1 (or 2, according to the initial situation) and so transfers are *necessary* for any efficient and individually rational international agreement on the environment.

[21] The problem discussed here deals with a situation different to the coordination problem in Makowski and Ostroy (1995). The supranational welfare function is not subadditive in emission choices made by countries, but that happens because of the way the solution to the externality problem is addressed. The real issue is the failure of full appropriation in the sense that the countries' welfare from any level of emissions (occupation) does not coincide with their "regional contribution" in that occupation.

[22] It is quite realistic to assume that countries negotiate aggregate levels of emissions and transfers (which in general take the form of technology to reduce pollution or even some concessions in other aspects of international policy different to the environmental ones). However, some treaties (particularly those on water) also have some provisions that the most pollutant industries must follow (e.g., firms in the pulp and paper or chemical sectors).

[23] One of the characteristics of environmental negotiations is that the parties which reach the agreement are not the same which benefit from the resource recovering. However, intergenerational concerns are usually considered in negotiations, and so are well represented by the problem as it is stated.

[24] The mechanism design approach has been used by some authors for two-sided incomplete information bargaining games (e.g, Myerson, 1984).

[25] The idea is that from the emission level it is not possible to derive exactly how each country is like.

[26] This means that K_n (equal to .75 for countries of type A and equal to 1 for countries of type B) are canceled because the emissions considered are those which governments can more efficiently implement at the national level and those which constitute an equally efficiently implementable treaty.