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Essays on International Environmental Policy

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Sommaire

Le format adopté pour ce travail est une thèse constituée de trois articles qui traitent de problèmes environnementaux mondiaux.

Mon premier essai, qui est intitulé «*Regulating Man-Made Sedimentation in Riverways*», traite du problème de la sédimentation du lit des voies navigables, dont les conséquences peuvent être coûteuses pour les populations riveraines. Cette sédimentation est souvent provoquée par l'érosion résultant des pratiques agricoles. Je propose une solution basée sur l'imposition d'une taxe « spatiale », variant selon la position de chaque exploitant par rapport au cours d'eau. En outre, cette taxe soulève des questions reliées à l' «éco-conditionnalité». Aussi, elle met en relief des éléments d'arbitrage qui existent entre la productivité des terrains et l'érosion des sols au fur et à mesure que les activités agricoles sont éloignées de la rive.

Mon deuxième essai, qui est intitulé "*A Trade-Environment Coalition Game*", traite des interconnexions entre les problèmes environnementaux et les blocs commerciaux dans un contexte multilatéral. Je propose un modèle qui relie la coopération internationale en matière d'environnement avec les questions de commerce international. Dans le modèle, une coalition commerciale et environnementale de pays est formée. Je trouve que la coalition économique créée par le volet commercial de l'accord génère une externalité négative vis-à-vis des non-signataires. En outre, je trouve que l'effort de mitigation de la pollution découlant de la partie environnementale de l'accord génère des externalités positives sur les non- membres (de la coalition), ce qui crée des incitations de risquillage. Par conséquent, je trouve que le fait d'inclure des liens commerciaux dans les accords internationaux sur l'environnement est susceptible de neutraliser les effets pervers des incitations de risquillage qui affecte ce type d'accords comme par exemple le protocole de Kyoto, parmi beaucoup d'autres.

Mon troisième article est intitulé "*2×2 Axiomatic Bargaining in Trade-Environment*

Negotiations ". Je traite de la question des négociations bilatérales entre les nations pour lesquelles les thèmes de négociation sont reliés. Je développe un modèle de négociation à deux joueurs et je l'utilise pour étudier les négociations internationales sur le commerce et l'environnement. Celles-ci sont souvent mises sur la table de négociation en tandem. Je formalise les concepts de concessions et gains croisés. Je prouve que si le point de désaccord résultant d'une question (environnement) engendre un bien-être social global inférieur a celui résultant d'une autre question (commerce), alors tout joueur profite davantage des négociations reliées si son pouvoir de négociation est amélioré sur la question du commerce. En conséquence, la taille relative des points de désaccord (commerce contre environnement) joue un rôle important dans la détermination du niveau du bien-être final. Mes résultats reflètent des éléments importants dans les négociations internationales sur le commerce et l'environnement. Ainsi mon modèle aide à mieux comprendre les mécanismes qui gouvernent ces négociations.

Summary

With the growing talk about the need to establish a new framework to deal with international environmental governance, it becomes relevant to shed some light on the interconnected landscape that characterizes environmental policy making. This three-essay dissertation deals with the impact of issue linkage among other factors on the outcome of international environmental policies.

In what follows is a brief summary of my dissertation.

My first essay, which is entitled *"Regulating Man-Made Sedimentation in Riverways"*, deals with the problem of river bed sedimentation. Such sedimentation negatively affects downstream water delivery and related ecosystem services, and is often the outcome of land erosion caused by agricultural activities along waterways. My essay, investigates one possible market-based remedy to this problem, namely a "spatial" tax on farming activities which decreases as such activities take place farther upstream away from the population center. Also, this tax highlights important 'eco-conditionality' aspects and the trade-off that exists between land productivity and soil erosion as farming activities are moved away from the riverbank.

My second essay, which is entitled *"A Trade-Environment Coalition Game"*, deals with interconnections between international environmental problems and trade blocks in a multilateral context. I identify several interconnections between international environmental problems and trade issues. Inspired by the work of Barrett (1997), I propose a model that links the problem of forming International Environmental Agreements (IEAs) with International Trade Agreements. I broaden Barrett's model by considering a more general form of trade coalition with trade sanctions in the form of differential tariff treatment instead of complete trade-bans. Such scenario is currently under discussion as a potential post-Kyoto framework after the year 2012. I introduce a linked-game with two stages. The first one is an environmental coalition formation game. The second one is a trade-production game. I compute the stability function of the IEA, and I find that the existence of positive spillovers (public good effect) when IEAs are formed exacerbates free riding incentives and leads to less cooperation. However, since countries are linked via trade, tying-in environmental and trade agreements generates negative spillovers over defectors. I find that these negative spillovers can potentially neutralize the perverse free riding incentives and as such sustain larger environmental coalitions.

Finally, my third essay, which is entitled *"2 × 2 Axiomatic Bargaining in Trade-Environment Negotiations"*, deals with issue linkages in the context of bilateral bargaining among nations. I develop a two-issue-two-players axiomatic bargaining model to explore and formalize the concepts of cross-issue concessions and gains. Unlike what has been done so far in the literature, I consider normalized bargaining sets with non-normalized disagreement points. I propose two complementary solutions. My first solution describes the case where linked bargaining results in gains on both issues, while the second one describes the case where gains entail partial concessions over the other. I find that the relative size of disagreement points (e.g. trade versus environment) plays an important role in determining under which issue it pays more to have an improvement in negotiation power. I discuss my results in the light of international trade and environmental negotiations, which are often put on the bargaining table in a linked fashion. My results capture important features in international trade-environment negotiations, and help clarify some of the mechanisms behind the outcome of those negotiations.

Key words: International environmental Agreements; trade coalitions; issue linkages, environmental taxation, erosion, farming externalities, spatial taxes, multi-issue Bargaining, axiomatic solutions.

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"...in order for a writer to produce something which is original and correct, it is not absolutely necessary that his predecessors have been wrong." "Baumol's sales-maximization model: reply". American Economic Review 54(6), December 1964, p. 1081

To my parents who believed in me

To my advisors who supported me all along my academic journey

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General Introduction

The main motivation of this doctoral dissertation is the study of specific issues related to international environmental governance. The approach is interdisciplinary in nature and uses both microeconomic and game theoretic approaches and consists of three essays in the field of Environmental Economics. More specifically, my essays raise both positive and normative questions about a number of global environmental issues, like climate change negotiations and trade-environment linkages. In each essay, I adopt a different modeling technique to tackle the unique nature of the questions I raise. I use and improve upon a number of microeconomic tools borrowed from various literatures including Industrial Organization and Public Economics. In the first essay, I use the theory of environmental taxation to deal with soil erosion problems in the context of riverway-ecosystems around the world. In the second, I use the theory of non-cooperative membership games to model international environmental agreements that are linked to trade agreements. Finally, in the third, I use cooperative bargaining theory to model trade-environmental negotiations between two countries. My work leads to well-defined models that are used to derive policy recommendations aimed at environmental governance.

My research focuses on three main axes that characterize the international landscape in which important environmental problems are handled by policymakers. I focus on the international context and implications of these problems and propose new perspectives to study these problems. These axes are space and location, the lack of well defined supra-national regulatory authorities, and interconnections and linkages between issues.

The first axis relates to the relevance of spatial dimensions (geography) of point-source environmental externalities. These dimensions are important at both local and international policymaking levels. In my first essay, although the model I propose is on a local/national level, the main reason that motivated my work is the potential trans-boundary scope of location-related environmental externalities. I study the soil erosion and sedimentation problems around riverways, which are environmental externalities that can affect more than one country who share a common river basin. Indeed, silt build-up behind river dams is an important environmental obstacle worldwide. Around the world, 261 rivers constitute internationally shared basins. Currently, there are several hundred rivers in the world that are dammed, among which 37 are major rivers . Most of those dammed and farmed river ecosystems are farmed not only downstream, vis-à-vis the dam, but also upstream causing serious soil erosion and damaging the rivers' water sources and imposing negative externalities on city centers who use those rivers as sources for both power and fresh water.

The second axis relates to the lack of well defined supra-national authorities. Indeed, multi-country decision-making is characterized by the lack of well defined property rights over global commons with an absence of a supra-national institution to enforce policy. In my second essay, I consider a version of the familiar "free-riding" problem in international environmental agreements and extend the framework to include trade linkages. I also explore the links between trade and environmental negotiations in both my second and third essays.

The third axis relates to interconnections and linkages. I highlight the relevance of the trade-environment trade-off that influences policy makers tasked with negotiating international environmental issues. I explore that trade-off in a multilateral setting in my second essay and then in a bilateral one in my third. As a matter of fact, increased interdependencies among countries are a fact of life, in particular, interconnections between international environmental problems and trade issues. A central point made in my thesis is that the economic literature on trans-boundary environmental problems has been mainly environment standpoint-relative, where the main focus has centered on modeling International Environmental Agreements (IEAs) while ignoring parallel non-environmental international agreements or issues, mainly trade.

While my essays are self-contained, each one falls in line with the general motivation of my dissertation. A special attention is drawn in my essays to the three aforementioned axes, which highlight the context of international environmental governance. .

Essay 1

Regulating Man-Made Sedimentation in Riverways

1. Introduction

River bed sedimentation results naturally from the erosion of waterfronts. It is now well-known, however, that waterside farming activities involving deforestation and the replacement of perennial plants by annual crops tend to aggravate this phenomenon, thereby often imposing significant costs on local residents (Bockstael and Irwin 2000). The importance of this negative externality was recently stressed by The Economist magazine, in an article concerning the Panama canal[1].

> Deforestation allows more sediment and nutrients to flow into the canal [river]. Sediment clogs the channel directly. Nutrients do so indirectly, by stimulating the growth of waterweeds. Both phenomena require regular, and expensive, dredging.

In addition to raising the maintenance costs of waterways, the erosion of river banks also causes silt build-up in downstream dam reservoirs, which reduces water retention and particularly affects electricity generation. This is a growing matter of concern for many people around the world, as hundreds of rivers are currently dammed, with dozens of major ones (such as the Nile) flowing across several countries[2]. This paper's objective is to investigate market remedies that would alleviate this environmental problem.

To the extent that this external cost depends on where farming activities are taking place along the river (the more upstream farms with respect to the river dam generally contribute more to river bed sedimentation and silt build-up than the more downstream ones), an optimal corrective measure should take into account the location of such activ-

[1] "Environmental economics, Are you being served?," *The Economist*, April 21st 2005. This article was reporting on the findings of scientists at the Smithsonian Tropical Research Institute in Panama who had studied land erosion along the Panama riverway.

[2] "International River Basins of the World," Transboundary Freshwater Dispute Database, http://www.transboundarywaters.orst.edu/ .

ities.[3] Tietenberg (1974) and Hochman et al. (1977) were among the first economists to emphasize that policy instruments like taxes should take into account local variations in both pollution emanations and impacts. Dealing with air pollution in a circular city model, Henderson (1977) accordingly suggested to impose a higher emission tax on polluting firms situated closer to the city center. This path was next pursued by Hochman and Ofek (1979), who proposed a simpler spatially differentiated tax scheme in the context of a linear city model.[4] In a framework closer to ours, finally, Chakravorty et al. (1995) introduced a water conveyance model where water is provided by a regulator to spatially differentiated users located along a canal. Their main finding is that, if water conveyance losses are high, then the introduction of water markets will bias the distribution of benefits from public investments in favor of closer (i.e., downstream) users.

Building on this literature where policy variables depend explicitly on location and distance, this paper will now consider how to regulate man-made sedimentation and silt build-up in waterways, using a Pigouvian taxation scheme. In the manner of Barnett (1980), a variant (and generalization) of this tax is also proposed to deal with the widespread situation where farmers form large farming cooperatives and can collectively exercise market power. This variant takes explicitly into account local features such as soil productivity and the contribution of a given field to erosion.

The paper unfolds as follows. The upcoming section presents the model. Spatial erosion taxes are derived in section 3, assuming farmers are price-takers. Section 4 considers next the case where farmers collude. Section 5 contains concluding remarks.

2. The model

[3] This paper centers on the part of the river that goes from the source to the dam. The remaining downstream part of the river is ignored for the time being.

[4] Hochman and Ofek (1979) also argued that zoning regulation can achieve the same efficiency results as taxation, because it creates property rights that land owners can use to collect rents equivalent to the amount of the pollution tax.

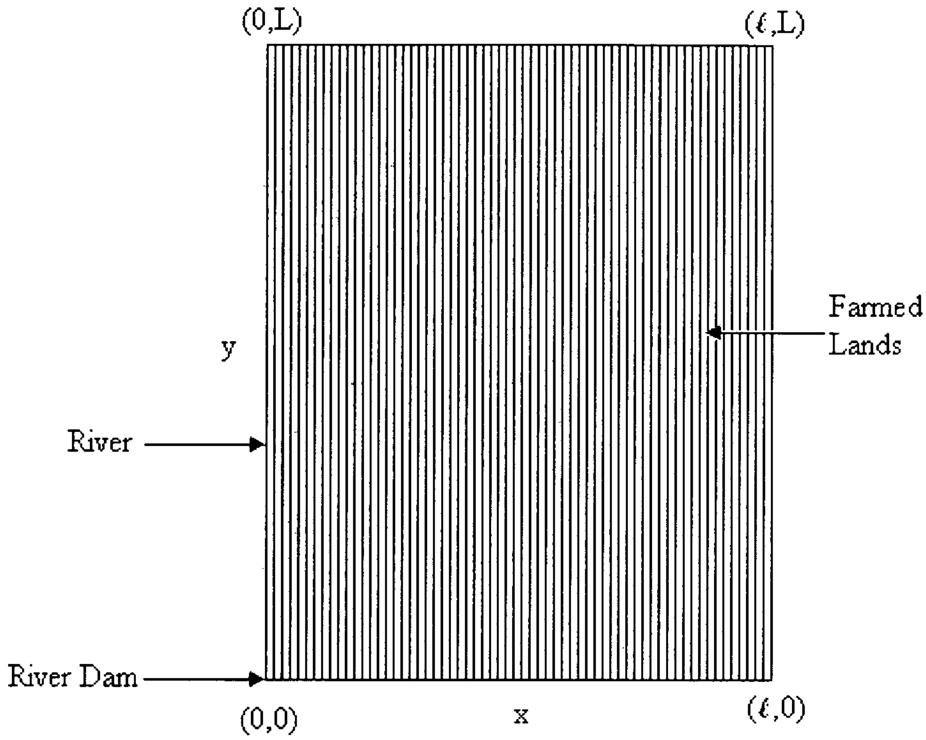

Figure 1: The farmed landscape

Consider a rectangular landscape composed of a river, a farmed right-hand-side bank and a downstream city. Let Figure 1 represent this landscape, so the origin $(0, 0)$ is where the city is located and where a dam serves the purposes of hydroelectric power generation and residential water retention. The total length of the river is L, and y is the vertical distance from the dam. The maximal width of the landscape is ℓ, and x gives the distance away from the riverbank. Let the whole surface area be normalized to unity, so $L = \frac{1}{\ell}$.

In this model, farmers are geographically dispersed while urban citizens (thereafter also called consumers) are all located at the origin $(0, 0)$. The latter suffer a disamenity caused by riverbed sedimentation and silt build-up at the river dam, which are mainly the result of the soil erosion provoked by farming activities. Depending on its location, however, each farm contributes differently to erosion.

2.1 The farmers

Assume all farmers deliver some homogeneous crop, and denote $z(x, y)$ the output of a farm situated at (x, y). Total farming production is thus given by

$$\mathbf{Z} = \int_0^L \int_0^\ell z(x, y) dx dy \tag{1}$$

At an output level $z(x, y)$, the corresponding farmer incurs a cost $C(z, x)$ which depends on how far his field is from the river. This cost function is strictly increasing and convex in both z and x, and its cross derivative is such that $C_{zx} > 0$. Convexity in the distance x, and the assumption that the marginal cost of production increases in x, mean that fields located farther away from the river banks are usually less fertile and increasingly costly to irrigate.

Suppose, however, that a farm's contribution to river sedimentation and silt build-up is given by the function $f(z, x)$, which is increasing and convex in z. This reflects the fact that soil-eroding clearing and excavation activities are increasing in the production effort. Also, the erosion function satisfies $f_x < 0$ and $f_{zx} < 0$. The latter inequalities indicate that, all things equal, the damaging erosion caused by a farmer is less important when his farm is more distant from the river. To simplify matters, we assume that this negative externality does not affect the other farms. Moreover, let's impose that the total derivatives $df/dy = 0$ and $dC/dy = 0$, which means that the agricultural landscape is homogenous in the vertical dimension as far as soil erosion and production possibilities are concerned.[5] By considering this formulation, we abstract from transportation costs, which are normalized to zero. The overall sediments and silt generated by farms located at a distance y from the river dam

[5]In sum, what makes a difference for farmers in this model is not the distance between their respective fields and the level of the dam or the city, but rather how far those fields are from the river.

are now given by

$$E^y = \int_0^{\ell} f(z,x)dx \ .$$

If not all sediments reach the dam reservoir but rather disperse at rate δ, then

$$S = \int_0^L e^{-\delta y} E^y dy = \int_0^L \int_0^{\ell} e^{-\delta y} f(z,x) dx dy \tag{2}$$

measures the total amount of sediment which finally accumulates downstream. To be sure, this will have a detrimental effect on consumers.

2.2 Urban citizens

Urban citizens, located at the origin $(0,0)$, consume all the farms' production Z. Let $p(\mathbf{Z})$, with $p'(\mathbf{Z}) < 0$, denote their inverse demand for this produce. They also endure a disamenity $a(S)$ when a quantity S of silt decreases the storage capacity of the reservoir used to generate hydroelectric power, increases the maintenance cost of the river dam, and reduces the quality of potable water. (This might directly be reflected in more expensive water and electricity bills.) Let $a(S)$ increase linearly with the amount of sediments, i.e. $a = vS$ with some positive coefficient v.[6]

We shall now turn to computing the optimal erosion taxes in this setup, assuming at first that farmers are price-takers.

3. An optimal erosion tax

In the absence of erosion taxes, each farmer maximizes profits given by

$$\pi(z) = pz - C(z,x).$$

So his marginal cost is set equal to the market price

$$p(\mathbf{Z}) = C_z(z,x).$$

[6]Sedimentation is of course also caused by nature, but we normalize this extra disamenity to zero.

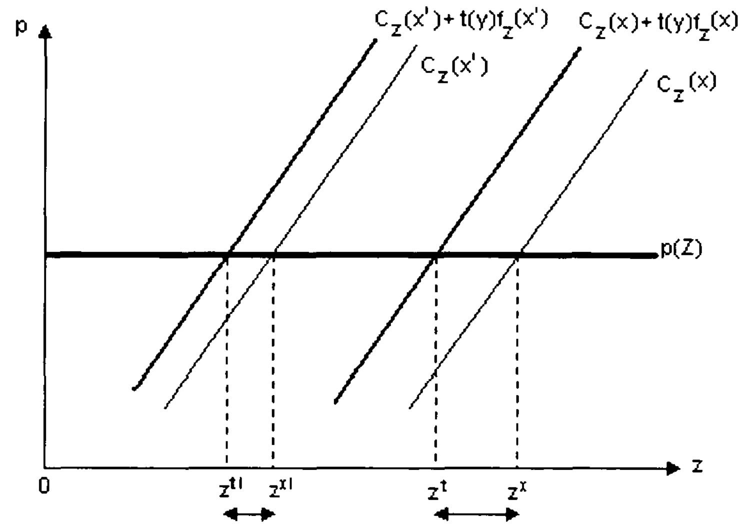

Figure 2: The effect of taxation on marginal costs ($x\prime > x$)

Since the marginal cost increases with the distance from the riverbank, i.e. $C_{zx} > 0$, then a more remote farm delivers less crop. This situation is depicted in Figure 2 (under quadratic cost, but satisfying all the model's assumptions).
It follows that the derivative $z_x < 0$.

If a positive tax t per unit of eroded soil is imposed, on the other hand, a farmer situated at (x, y) will maximize the profit function

$$\pi(z) = pz - C(z,x) - tf(z,x) \ ,$$

thereby setting his production level in order to satisfy the first-order condition

$$p(\mathbf{Z}) = C_z + tf_z \ . \tag{3}$$

This necessarily entails a lowering of output.

Let this erosion tax be set by a benevolent and informed regulator who seeks the largest sum of consumer surplus and farming benefits minus the social disamenity. Ignoring redistribution and income transfer issues, and replacing S by the right-hand-side formula in (2), the tax should therefore maximize

$$W = \int_0^{\mathbf{Z}^t} p(u)du - \int_0^L \int_0^\ell C(z^t, x)dxdy - v\int_0^L \int_0^\ell e^{-\delta y} f(z^t, x)dxdy \ , \tag{4}$$

where the superscript t refers to the farmers' adjusted output once they bear the tax. The necessary and sufficient first-order condition for an optimal policy is now

$$W'(t) = \int_0^L \int_0^\ell \left(p(\mathbf{Z})\frac{dz}{dt} - C_z\frac{dz}{dt} - ve^{-\delta y} f_z \frac{dz}{dt} \right) dxdy = 0 \ , \tag{5}$$

and this equation holds only when

$$p(\mathbf{Z})\frac{dz}{dt} - C_z\frac{dz}{dt} - ve^{-\delta y} f_z \frac{dz}{dt} = 0 \tag{6}$$

is true at every point $(x, y) \in [0, \ell] \times [0, L]$ (but on a set of Lebesgue measure 0)[7].

Substituting (3) into (6) yields the general formula for the optimal tax rule:

$$t(y) = ve^{-\delta y} \tag{7}$$

According to this rule, a farm faces a lower tax per unit of eroded soil when its vertical distance to the river dam is larger. This finding constitutes our first proposition.

Proposition 1 *A farmer sited in (x, y) should face a tax per unit of eroded soil equal to the marginal social disamenity adjusted by the proportion of sediments that reach the dam, where the latter varies according to the spatial coordinate y.*

This rule seems to neglect an important piece of geographical information, since farms sharing the same spatial coordinate y but located at different distances from the river will face the same tax $t(y)$. Under such a rule, however, expression (3) becomes

$$p(\mathbf{Z}) = C_z(z, x) + t(y) f_z(z, x) \ .$$

[7] This step is authorized by the fact that the integrand in (5) never changes sign over $[0, \ell] \times [0, L]$. If this were the case, this would mean that the market price does not cover marginal cost is some areas; some farmers would then abandon production while others remain, which cannot happen in this model.

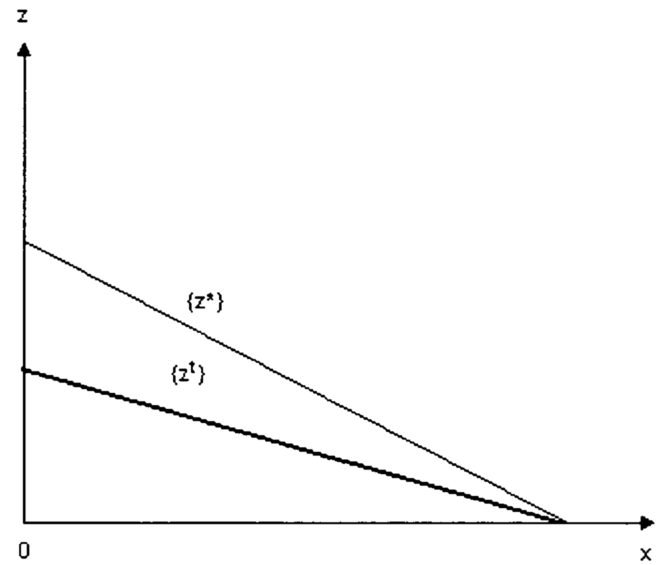

Figure 3: The effect of taxation on production distribution

Since the marginal contribution to soil erosion f_z decreases in x, a more distant farmer needs to adjust proportionally less than one who is located by the river. The most productive units are thus penalized the most. In other words (see Figure 3), the main effect of this spatial tax is to render the distribution of the outputs $z(x, y)$ flatter.[8]

Let us now turn to the situation where farming units belong to a single cooperative which then constitutes a monopoly.

[8]Another possible consequence might be to force the farther and less productive farmers to exit the market. We do not consider this issue here, as it would make total farmland endogenous to the optimal taxation problem.

4. Coping with an agricultural cooperative

Suppose that all the farmers of the present landscape collude to form a cooperative.[9] Their objective is now to maximize the joint profits

$$\Pi(\mathbf{Z}) = p(\mathbf{Z})\,\mathbf{Z} - \int_0^{\mathbf{L}} \int_0^{\ell} C(z,x)dxdy - t\int_0^{\mathbf{L}} \int_0^{\ell} f(z,x)dxdy \ .$$

In this case, the production levels of every farming unit (x, y) must altogether satisfy the following first-order condition:

$$\int_0^{L} \int_0^{\ell} \left[p'(\mathbf{Z})z + p(\mathbf{Z}) - C_z - tf_z\right] dxdy \ = 0 \ . \tag{8}$$

This requires that

$$p'(\mathbf{Z})z + p(\mathbf{Z}) - C_z - tf_z = 0 \tag{9}$$

at every point $(x, y) \in [0, \ell] \times [0, L]$ (but on a set of Lebesgue measure 0).[10] Substituting (9) into (6) then yields the general formula for the optimal tax per unit of eroded soil:

$$t(x,y) = ve^{-\delta y} + \frac{p'(\mathbf{Z})z\frac{dz}{dt}}{f_z\frac{dz}{dt}} \ . \tag{10}$$

The second term on the right-hand side of this formula is an amendment to the tax rule that was proposed in the previous section. It is negative, so the new tax rate is actually smaller. This agrees with the classical results of Buchanan (1969) and Barnett (1980). The underlying intuition is now well-known: when polluters are not price-takers, the optimal corrective tax must be set lower than the marginal social cost of damage in order to alleviate the consequent strategic reduction in output. Expression (10) can in fact be rewritten as

$$t = ve^{-\delta y} - \frac{\frac{p(\mathbf{Z})}{|\varepsilon|}\frac{z}{\mathbf{Z}}\frac{dz}{dt}}{f_z\frac{dz}{dt}} \ ,$$

[9] This means that the agricultural cooperative is managed as one business entity. Therefore, in this section, the meaning of location (x, y) is slightly different than in the competitive case. For instance, here location (x, y) can be simply interpreted to be a farming plot instead of an individual farmer. Subsequently, all profit redistribution issues become an internal managerial problem.

[10] This is true because the argument of footnote 7 holds again, so the integrand in (8) must always be nonnegative.

where ε denotes the price-elasticity of demand. As demand becomes less elastic, the size of the downward adjustment tends therefore to increase. This property limits the exercise of market power by the cooperative and prevents consumer surplus from falling too drastically.

With respect to the literature on Pigouvian taxation, however, formula (10) exhibits a specific feature: its downward adjustment term takes into account the respective impacts of each field according to its location. It follows directly from our assumptions that $z_y = 0$.[11] Hence, the sensibility of the erosion tax to the spatial coordinate y is given by

$$\frac{\partial t}{\partial y} = -\delta v e^{-\delta y} + p'(\mathbf{Z}) \left(\frac{f_z - z f_{zz}}{(f_z)^2} \right) z_y = -\delta v e^{-\delta y} \ , \tag{11}$$

so $\frac{\partial t}{\partial y} < 0$. This yields our next proposition.

Proposition 2 *When farmers collude, holding everything else constant, the regulator must decrease the optimal tax level when the farming unit's distance y increases, the adjustment being* the same *as in the competitive case.*

This result suggests that, in both the competitive and cooperative cases, the optimal tax rule encourages farmers/farming units to shift part of the production away (upstream) from the river dam.

Comparative statics with respect to spatial coordinate x implies, furthermore, that

$$\frac{\partial t}{\partial x} = p'(\mathbf{Z}) \left(\frac{z_x (f_z - z f_{zz}) - z f_{zx}}{(f_z)^2} \right) \tag{12}$$

The sign of (12) depends on the sign of $A = z_x (f_z - z f_{zz}) - z f_{zx}$. Straightforward manipulations reveal that

$$A \lesseqgtr 0 \Leftrightarrow \frac{z_x}{z} (1 - \eta) \lesseqgtr \frac{f_{zx}}{f_z} \Leftrightarrow \frac{\partial t}{\partial x} \gtreqless 0 \tag{13}$$

where $\eta = \frac{f_{zz}}{f_z} z$ is the elasticity of a farm's marginal contribution to river sedimentation with respect to output z. This supports the following proposition.

[11] We assumed in Section 2 that the agricultural landscape was homogeneous in the y coordinate. Production decisions should thus remain unchanged as one moves along the y-axis while staying at the same distance from the river.

Proposition 3 *When farmers collude, holding everything else constant, the regulator must increase (decrease) the erosion tax when the spatial coordinate x of a farm goes up if and only if the adjusted rate of change of output in the x dimension* $\left(\frac{z_x}{z}(1-\eta)\right)$ *is smaller (larger) than the rate of change of the marginal contribution to sedimentation in the x dimension* $\left(\frac{f_{zx}}{f_z}\right)$.

The elasticity coefficient η spans in fact two distinct intervals. In the high range where $\eta > 1$, the marginal contribution to river sedimentation is very responsive to output. We have from (13) that

$$\frac{z_x}{z}(1-\eta) > \frac{f_{zx}}{f_z} \Leftrightarrow \frac{\partial t}{\partial x} < 0 \, ,$$

so the optimal erosion tax must decrease in the distance x unambiguously. In the inelastic range where $0 < \eta < 1$, i.e. when the marginal contribution to river sedimentation is not too responsive to an increase in output, on the other hand, the trade-off highlighted in proposition 3 holds. If output $z(x, y)$ drops by a larger amount than the marginal contribution to sedimentation for a given increase in the distance x from the river, then the optimal erosion tax is set to augment with x. In this case, the tax rule provides reduced incentives for the cooperative to shift production from lower to upper grounds, where larger production costs will translate into higher prices for consumers with relatively little compensation on the environmental side. The opposite occurs when the marginal contribution to river sedimentation drops by a larger amount than production as x increases: the optimal tax is set to decrease with the distance x, for the positive impact on welfare of shifting production away from the riverbank outweighs the negative impact this has on consumer prices.

5. Concluding remarks

This paper proposed a spatial tax in order to regulate farming activities that exacerbate sedimentation and silt build-up in a riverway. The tax is proportional to the social cost of man-made sedimentation; it also depends on observables such as the location of a farm relative to the dam, the local productivity of land, the erosion associated with the given crops and farming practices, and the capacity of the river to disperse silts and sediments.

The model we developed may not deal with all the complex dynamics of soil erosion, and additional research might indeed be necessary before implementing the above tax scheme in a concrete setting. Simple as it is, however, our model appears to have general ramifications for other environmental policies to mitigate the effects of agricultural erosion.

First, the erosion tax we recommend contains suggestions for the design of zoning regulation. Typically, zoning would create a buffer zone free of farming activities near the dam and/or the river bank.[12] When farmers are price-takers, our tax rule then suggests that this buffer zone should depend only on the vertical distance y from the dam, so pushing farmers away from the dam would be sufficient. When farmers regroup to form a cooperative, however, a trade-off similar to the one outlined in proposition 3 would determine the design of the buffer zone, and the high sensitivity to output of the marginal contribution to river sedimentation (so $\frac{\partial t}{\partial x} < 0$), for instance, would make it preferable to push farms away from the river bank.

Second, our spatial tax might inform current discussions on "eco-conditionality," or whether and how much to reward farmers for their "environmental services" (such as safeguarding the beauty of rural areas and sheltering endangered species). Note that the above tax t and environmental cost ν can be negative and correspond thereby respectively to a

[12] Zoning can of course take various forms. It may consist in a complete ban on all farming activities, or it may just require farmers to offset erosion by planting trees and other soil preserving plants in specific areas.

subsidy and an environmental amenity enjoyed by urban citizens (which becomes smaller when it is generated from farther away). In this case, the paper would recommend to tailor subsidies around each individual farm based on its location and other verifiable features, and to make subsidies smaller if farmers collude.

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Essay 2

A Trade-Environment Coalition Game

1. Introduction

International Environmental Agreements (IEAs) deal with transboundary environmental issues such as climate change caused by the emissions of greenhouse gases, or the destruction of the ozone layer. The global public good nature of international environmental problems exhibits a number of distinctive features. These features mainly include: interdependence e.g. trade and environment, multi-country decisions characterized by lack of property rights, the existence of diffused and multilateral externalities and the absence of a supra-national institution to enforce policy.

Our main objective is to study the effects of trade linkages in environmental negotiations within a tractable game theoretic model. As a matter of fact, the importance of issue linkage and more specifically trade linkage to IEAs was highlighted in the WTO's Doha round Development Agenda (2001):

> "There are over 250 multilateral environmental agreements (MEAs) dealing with various environmental issues which are currently in force. About 20 of these include provisions that can affect trade. For instance, they may contain measures that prohibit trade in certain species or products, or that allow countries to restrict trade in certain circumstances."[1]

An important example of an IEA being integrated into the WTO framework is the Cartagena Protocol on Bio-safety. It should be noted that some elements of it are already included or being integrated into the WTO's Settlement of Dispute Body' (court) rules. Against this backdrop, a number of legal experts, policymakers, and stakeholder within the WTO and IEAs are working on negotiations relating trade and environmental policies. Specifically, the questions of tying-in trade measures to environmental cooperation. In the Doha round's declaration on trade and environment, it is also suggested that ascensions

[1] http://www.wto.org/english/tratop_e/envir_e/envir_neg_mea_e.htm

to full membership of the WTO be tied to the implementation of a certain number of IEAs. This opens a new door for the use of trade restrictions against free riders on the environment.[2]

In the economic literature on transboundary environmental problems, due to the absence of a supra-national authority, it is argued that agreements are self-enforcing when they are stable and profitable for each member country. One standard stability concept used to study IEAs is based on the cartel stability literature. This concept, first introduced by D'Aspremont et al. (1983), defines stability in terms of immunity to unilateral deviations. This can be achieved only when the coalition is internally stable with no incentive to withdraw, and externally stable with no incentive to further participate by any one member. The main observation is that the existence of positive spillovers when IEAs are formed (positive externality games) especially in a global context naturally exacerbates free riding incentives and leads to less global cooperation. This has also been confirmed by stylized facts suggesting that a number of IEAs were in reality prone to failure. These observations have sparked a large research interest over the past 20 years, which led to the appearance of a wide body of literature on IEAs and international environmental games.

In this paper, we link a model of international environmental cooperation with a model of international trade with sanctions. The idea is to include trade effects and study under which conditions these can help increase/decrease the chances of success of environmental cooperation. Such idea was recently advocated by Barrett and Stavins (2003) in a policy discussion paper[3]. In our model, negative issue linkages are illustrated by the use of trade

[2]Joseph E. Stiglitz alluded to this point several times. In 2006, he noted that: "Globalization has its costs, but it also has its benefits, and among those is an international trade framework that can be used to enforce emission reductions."

http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/09/17/INGEJL4C1T1.DTL

[3]Barrett and Stavins (2003) note that: "Providing positive incentives for participation and compliance is not difficult, but such provision is not sufficient to overcome the severe free-riding problems that plague efforts to address this global public goods problem. Negative incentives are also required." (p.370)

measures as is the case in Barrett's (1997) model on the Montreal Protocol on CFCs. However, by contrast to Barrett (1997) who considers complete trade bans, we consider a general trade sanction framework where tariffs on imports are applied. This is closer to the case of the WTO-Kyoto linkage that is being advocated by a number of policy-makers as we move beyond 2012, which is the date where a new post-Kyoto framework is set to take effect.

We introduce a game with two components. The first stage is an environmental game, where first countries decide on the membership and then choose simultaneously the abatement levels. The second stage is a trade game, where each representative firm decides its production and export levels given the abatement standard set by its own country. Given this, we consider an international agreement over both the environment and trade. This agreement foresees that a signatory country decides its optimal abatement level by maximizing the aggregate welfare of the coalition and sets to zero the tariffs on the goods imported from all other signatories but it keeps them against nonmember countries[4]. As such, on the one hand, the trade coalition generates a negative externality towards the non-signatories. On the other hand, members enjoy positive spillovers resulting from cost reductions in terms of tariffs. We solve first the firms' game, then the governments' one by backward induction. We, then, compute the stability function of the coalition, and we find that the existence of positive spillovers when countries cooperate over the environment exacerbates free riding incentives and leads to less environmental cooperation. However, since countries are linked via trade, tying-in environmental and trade agreements generates negative spillovers over defectors. We find that these negative spillovers can potentially neutralize the perverse free riding incentives and therefore sustain larger environmental coalitions among which the

[4]An example of such trade restrictions can be found for instance in The International Treaty on Plant Genetic Resources for Food and Agriculture. This agreement deals with reducing barriers to the exchange of seeds needed to produce major crops. As such, the agreement creates an economic coalition that gives its members free access to seeds, while non members have to incur an extra cost.

grand coalition for high enough tariff rates. Therefore, our results reinforce the argument in favor of WTO-Kyoto linkage beyond 2012 as a tool to insure better cooperation over global pollution abatement.

The paper unfolds as follows. Section 2 discusses the related literature. Section 3 presents the model and solves the firms' and the governments' problems under coalition formation. Section 4 derives the stability conditions and presents the stability analysis. Finally, section 5 includes concluding remarks.

2. Related literature

Issue linkages, a term first coined by Cesar and De Zeeuw (1994), within environmental coalition formation games has been the subject of a number of studies varying in scope and approach. As a matter of fact, the negative results about environmental cooperation found in the literature on IEAs has prompted the development of this strand of literature. The literature on IEAs without linkages can be divided into two main branches, the pure cooperative game theoretic approach and the pure non-cooperative approach. This literature contains two contradictory results. In the pure cooperative approach, as formalized by Chander and Tulkens (1995, 97), it is found that full cooperation can prevail and a Pareto efficient state can be achieved where no blocking coalition exists as long as the complement of the coalition acts as strategic singletons. While, a main result when using the pure non-cooperative approach is the so-called puzzle of small coalitions. In fact, this parallel literature is more developed and includes Cournot or simultaneous games like those proposed by Carraro and Siniscalco (1993), De Cara and Rotillon (2001), Finus and Rundshagen (2001), and Rubio and Casino (2001). Also, leadership games a la Stackelberg include Barrett's (1994a) canonical model, and more recently Diamantoudi & Sartzetakis (2006) who address the issue of non-negativity of emissions ignored by Barrett (1994) and find that the stable coalition is very small. In all these models, the first movers are countries that ratified the treaty, while individuals outside will wait before they decide on emissions.

It should be noted that the papers we listed so far model an emissions/abatement only game, or a single subject game. The single issue IEA models are mainly descriptive in nature. However, our approach in this paper will focus on the concept of issue linkage to achieve stability. This approach is both descriptive and prescriptive as is the case with IEA models with issue linkages. Here, as noted by Finus (2003), a distinction must be made between issue linkage under compliance models with repeated games and issue linkage under membership models a la Cournot or Stackelberg, which is the framework adopted in our paper. Membership models with issue linkage include Hoel and Schneider (1997) and Cabon-Dhersin and Ramani (2006) who attempt to model issue linkage by introducing exogenous reputation effects. These attempts to solve the small coalitions puzzle in IEAs in the non-cooperative game context suggest that reputation costs resulting from defection can be costly enough to act as deterrents. As such larger coalitions become plausible. In policy discussion papers, Barrett (1994b) proposes to link environment discussions with trade negotiations, while Carraro and Siniscalco (1995) propose linking IEAs with R&D cooperation. Both these proposals rely on the idea of linking the environmental game to a stable club good game. One type of issue linkage studies R&D effects on the cost of abatement. This strand of literature is based on the observation (Carraro and Siniscalco, 1997) that the inherent instability of the emissions game can be offset by linking it to an inherently stable game like a club good game where R&D cooperation is a prime example[5].

[5] Carraro and Siniscalco (1997) use an IEA model with R&D effects on abatement technology and find that this linkage may not increase participation, while Katsoulacos (1997) finds the opposite. Botteon and Carraro (1998) consider R&D linkage with 5 heterogenous players/countries to study the impact of R&D linkage on the stability of IEAs and on profitability of participants when linkage is used as a strategy. Using calibration and two different cost sharing rules among coalition members (Nash and Shapley), they find that the stable coalition is usually larger under linked negotiations, but it may not be optimal. The optimal coalition is found to be smaller than the stable one. And due to heterogeneity, countries may disagree on the coalition they find optimal, as such no equilibrium may exist.

Conconi and Perroni (2002) introduce a cooperative game theoretic framework that models the trade-environment link explicitly. They propose a multidimensional core concept and apply it to a generic trade-environment game. Their results suggest that linking trade and environmental decisions into one super-agreement can have positive effects in terms of better cooperation only if environmental problems are relatively small in terms of welfare costs and benefits when compared to the costs and benefits of trade policies. Closer to our framework, the link to trade agreements was studied by Barrett (1997) using an N players Stackelberg model of emissions abatement with complete trade bans. Using simulations, his main finding is that linking an IEA to trade restrictions can increase participation as was the case with the Montreal protocol on CFCs. In contrast, in this paper, we derive an analytical form for the stability function to study the various trade effects on stability. Also, we consider a more general framework without complete trade-bans, which is suggest by stylized facts on the current state of reflections about how IEAs and trade agreement ought be tied-in. Finus and Rundshagen (2000) use a different framework, which is endogenous coalitions formation, to look into the pollution-haven-hypothesis and issue linkage. They use a three country game with trade tariffs and endogenous location of polluting firms. In contrast, they find that linking trade to environmental negotiations can potentially reduce both welfare and participation.

3. The trade-environment coalition

Let us assume there are N identical countries and N identical firms, with one firm residing in each country and firms' location being fixed. Each firm produces a homogeneous globally traded good and contributes positively to transboundary global pollution as a result of its production efforts.[6] The trade-environment coalition is formed as the result of an

[6] We acknowledge that the symmetry and homogeneity assumptions are limitations to our model. However, we wish to keep the model tractable enough in order to isolate the coalition's negative and positive

international agreement, which deals with both global pollution and global trade. Countries that sign the agreement cooperate over the environment by coordinating abatement and benefit from preferential tariff treatment. The international agreement is established when a coalition $S \subseteq N$ is formed. All countries, both participants and non-participants, have to choose a level of abatement given that they all suffer from a global environmental damage. We call any country $i \in S$ a signatory country. We also assume that all signatories are similar, while any country $i \notin S$ is called non-signatory where we also assume that all complement $(N \backslash S)$ members are similar. The complement has a partition formed out of singletons.[7],[8] Given the agreement, we assume that a coalition $S \subseteq N$ of countries of size s is formed[9]. Signatory countries choose a level that maximizes the aggregate welfare of the coalition while non-signatory countries decide their abatement by maximizing their individual welfare.

The part of the agreement related to international trade is modeled as follow. Consider a representative importing country i and a representative exporting firm j located in country j. i.e. a two country World. Trade restrictions are imposed by setting a trade sanction

$$T_j = \tau_j^i(x_j - x_j^j) = \tau_j^i x_j^i,$$

with x_j being the total quantity produced by firm j and x_j^i being the quantity produced by firm j in country j and sold in the market of country i, and τ_j^i being the tariff rate applied by country i on firm's j exports. The following summarizes plausible tariff rate structures:

$\tau_{j^s}^{i^s}$: applied by a signatory country on imports from a firm j^s located in a signatory country

$\tau_{j^{ns}}^{i^s}$: applied by a signatory country on imports from a firm j^s located in a non-signatory country

spillover effects.

[7]We denote by s a representative signatory and by ns a non-signatory.

[8]We will denote by $\sum^N$, $\sum^S$, and $\sum^{N \backslash S}$, sum over N, over S and over the complement $N \backslash S$ respectively.

[9]For the purpose of deriving the analytical model we allow s to take non-integer values.

$\tau^{i^{ns}}_{j^{ns}}$: applied by a non-signatory country on imports from a firm j^s located in a non-signatory country

$\tau^{i^{ns}}_{j^s}$: applied by a non-signatory country on imports from a firm j^s located in a signatory country

Since countries that join the coalition become members of a free trade zone, we have a zero tariff policy inside the coalition, which means that the coalition In other words,

$$\tau^{i^s}_{j^s} = 0,$$

which means that the tariff applied by a signatory country on imports from a firm j^s located in another signatory country is set to zero. By symmetry of importers we get

$$\tau^{i^s}_{j^{ns}} = \tau^s,$$

with $\tau^s > 0$, where the tariff applied by a signatory country on imports from a firm j^s located in a non-signatory country is the same for all signatory countries. This means that the trade-union has a uniform tariff policy. Finally, also by symmetry we get

$$\tau^{i^{ns}}_{j^{ns}} = \tau^{i^{ns}}_{j^s} = \tau^{ns},$$

with $\tau^{ns} > 0$. This means that a non-signatory gives a similar treatment to all its trading partners without any distinction between members and non-members of the IEA.

For ease of notation, we consider the following notation

$$\tau^{ns} = \beta\tau^s = \beta\tau$$

with some positive parameter β, which could be less or greater than one. Therefore, β, which is a ratio, reflects the gap between the two tariffs or the complement members tariff reaction where $\tau^{ns} \gtrless \tau^s$ for $\beta \gtrless 1$. In all what follows τ represents the tariff set by coalition members and $\beta\tau$ the one set by complement members.

Our general formulation of the tariff structure allows us to understand the effects of tariff changes on the trade-environment coalition.[10]

In what follows, we solve first for the firms' problem who take the abatement standard set by their own countries as given, then we solve for the governments' problem who maximize countries' social welfare by choosing the level of abatement. Each firm j has to choose its total production level x_j a la Cournot, while each government j decides its abatement standard q_j.

3.1 The firms' game

3.1.1 The firms' profits

Each firm j has to choose its production level a la Cournot given the abatement standard q_j set by its own country. Let X be the total quantity produced and consumed in the world so that the inverse demand function is given by

$$p(X) = a - bX,$$

with a, $b > 0$, and $X = \sum^N x_j$, where x_j is firm's j total output. We assume that, for a given firm, production costs are linear and given by

$$C(x_j) = cx_j,$$

with $a > c > 0$, where c is the constant marginal cost. The abatement standard q_j ,chosen by the government of country j, imposes costs on the local firm who must abide by the standard. This is represented by

$$A(q_j) = \frac{1}{2}\phi q_j^2.$$

[10]In Barrett (1997), since complete trade bans are imposed strategic interactions between the coalition and its complement are lost. Barrett indicates that: "...signatories cannot influence the abatement choices of non-signatories or the output choices of non-signatory firms." (p.354)

Production activity carried out by firms contributes to global pollution in the form of emissions

$$e_j = \alpha x_j - q_j,$$

where $\alpha > 0$ is the emissions-output ratio.[11] Thus, emissions are increasing in output and decreasing in the abatement level. Global emissions are given by

$$E = \sum^N e_j.$$

Each country's output x_j is divided among the local market h_j and foreign markets f_j, such that

$$x_j = h_j + f_j.$$

Since in our model the same countries take part in the linked trade and environment games, we assume that no country is excluded from trade, where every one trades with everyone, and that exports f_j are equally divided among trading partners.

In the trade game, coalition and non-coalition member firms are affected differently in terms of profit vis-à-vis the export destination due to the differential tariff treatment. Specifically, if a firm j is located in a signatory country j member of S it will maximize the following profit by choosing its production level. Formally it will maximize

$$\pi_s = p(X)x_s - C(x_s) - A(q_s) - \tau^{ns}\left(\frac{N-s}{N-1}\right)f_s,$$

where $\left(\frac{N-s}{N-1}\right)f_s$ is the total quantity exported to non-coalition members, and a such subject to tariff τ^{ns}.

For a firm j located in a non-signatory country, the profit maximization problem becomes

$$\pi_{ns} = p(X)x_{ns} - C(x_{ns}) - A(q_{ns}) - \tau^{ns}\left(\frac{N-s-1}{N-1}\right)f_{ns} - \tau^{s}\left(\frac{s}{N-1}\right)f_{ns}.$$

[11] In Barrett (1997) this ratio is normalized to unity.

In this case, $\left(\frac{N-s-1}{N-1}\right) f_{ns}$ is the total quantity exported to non-coalition members, and a such subject to tariff τ^{ns}, and $\left(\frac{s}{N-1}\right) f_{ns}$ is the total quantity exported to coalition members, and a such subject to tariff τ^{s}.

3.1.2 The firms' reaction functions

The firms' production game represents the last stage of our overlapped game.

Firms take the abatement standard q_j as given and the relationship $\tau^{ns} = \beta\tau^{s} = \beta\tau$ as given from their governments and then choose their production levels a la Cournot

A firm j located in a signatory country j member of S will maximize its total profit by choosing the optimal level of productions h_s, destined to the home market, and f_s, which are exports sold in foreign markets. Therefore, the local production reaction function of a representative member firm with respect to the total quantities produced by non-member firms $\left(\sum^{N\backslash S} x_k\right)$ and exports of coalition members $\left(\sum^{S} f_k\right)$ is

$$h_s = \frac{(a-c) - b\sum^{S} f_k}{b\,(s+1)} - \frac{b\sum^{N\backslash S} x_k}{b\,(s+1)}. \tag{1}$$

While, the exports reaction function of a representative member firm with respect to the total quantities produced by non-member firms $\left(\sum^{N\backslash S} x_k\right)$ and local production of coalition members $\left(\sum^{S} h_k\right)$ is

$$f_s = \frac{(a-c) - b\sum^{S} h_k - \left(\frac{N-s}{N-1}\right)\beta\tau}{b\,(s+1)} - \frac{b\sum^{N\backslash S} x_k}{b\,(s+1)}. \tag{2}$$

A firm j located in a non-signatory country will also maximize its total profit by choosing h_{ns} and f_{ns}. Then, the local production reaction function of a representative non-member firm with respect to the total quantities produced by member firms $\left(\sum^{S} x_k\right)$ and exports of non-coalition members $\left(\sum^{N\backslash S} f_k\right)$ is

$$h_{ns} = \frac{(a-c) - b\sum^{N\backslash S} f_k}{b\,(N-s+1)} - \frac{b\sum^{S} x_k}{b\,(N-s+1)}. \tag{3}$$

While, the exports reaction function of a representative non-member firm with respect to the total quantities produced by member firms $\left(\sum^S x_k\right)$ and local production of coalition members $\left(\sum^S h_k\right)$ is

$$f_{ns} = \frac{(a-c) - b\sum^{N\backslash S} h_k - \left(\frac{s-\beta+N\beta-s\beta}{N-1}\right)\tau}{b\,(N-s+1)} - \frac{b\sum^S x_k}{b\,(N-s+1)}. \tag{4}$$

3.1.3 The firms' equilibrium

The Subgame Perfect Nash Equilibrium is computed by solving simultaneously (1), (2), (3), and (4). The equilibrium local production of a representative member firm is

$$h_s^* = \frac{(a-c)\,(N-1) + (N-s)\,(s+N\beta-\beta)\,\tau}{b\,(2N^2-N-1)}, \tag{5}$$

and the equilibrium exports are given by

$$f_s^* = \frac{(a-c)\,(N-1) - (N-s)\,(2\beta+N\beta-s)\,\tau}{b\,(2N^2-N-1)}. \tag{6}$$

The total output defined over $s \in [2, N]$ is

$$x_s^* = h_s^* + f_s^* = \frac{2\,(a-c)\,(N-1) - (N-s)\,(3\beta-2s)\,\tau}{b\,(2N^2-N-1)}. \tag{7}$$

The equilibrium local production of a representative non-member firm is

$$h_{ns}^* = \frac{(a-c)\,(N-1) + (N-s)\,(s+N\beta-\beta)\,\tau}{b\,(2N^2-N-1)}, \tag{8}$$

and the equilibrium exports are given by

$$f_{ns}^* = \frac{(a-c)\,(N-1) + \left(\beta - s + 2s\beta - N^2\beta - Ns - s^2 + Ns\beta\right)\tau}{b\,(2N^2-N-1)}. \tag{9}$$

The total output defined over $s \in [1, N-1]$ is

$$x_{ns}^* = h_{ns}^* + f_{ns}^* = \frac{2\,(a-c)\,(N-1) - \left(s-\beta+N\beta-3s\beta+2s^2\right)\tau}{b\,(2N^2-N-1)}. \tag{10}$$

Equilibrium conditions (5) through (10) reflect the game theoretic effects at play in the trade game.

Proposition 1 *Both members and non-members firms sell the same quantity locally i.e.* $h_s^* = h_{ns}^*$.

This result is straightforward since firms are identical and there is no tariff applied in the home market. As long as the choke price exceeds the marginal cost of production, this local quantity is always positive for any given tariff rate.

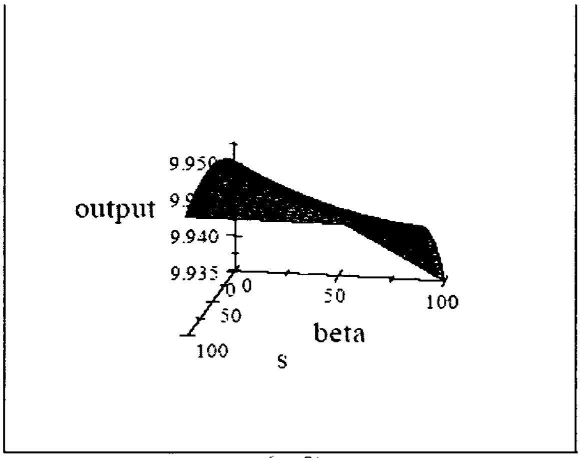
Proposition 2 *The gap in exports between a signatory and a non-signatory country* $(f_s^* - f_{ns}^*)$ *is increasing in the coalition size* s*, the tariff rate of the coalition* τ*, and decreasing in the tariff reaction of complement members* β*.*

Total exports of a coalition member $f_s^*(s)$ and total exports of a non-coalition member $f_{ns}^*(s)$ can become zero or negative (cessation of exports) for extremely high tariff rates , which defines an autarkic situation . Simple manipulations yield the following[12]

$$s - \beta \gtrless 0 \Rightarrow f_s^* \gtrless f_{ns}^* \text{ over } [s, N]. \tag{11}$$

Looking at (11), we notice that when $\beta \leq 2$, coalition members always export more for any given size s. Otherwise, when $\beta > 2$, for some small coalitions of size $s < \beta$, members export less than non-members. This is indeed the case because a large β means that the reaction of non-members to the coalition formation is severe. Moreover, this means that a minimum number of participants is needed before coalition formation starts to become viable. A lower β, thus, confers greater economic sanction power to the coalition. And since $h_s^* = h_{ns}^*$, then production levels' difference $x_s^* - x_{ns}^*$ follows exports' difference $f_s^* - f_{ns}^*$, where $s - \beta \gtrless 0 \Rightarrow x_s^* \gtrless x_{ns}^*$, which establish that once the size is $s = \beta$ the coalition

[12] See Appendix A



$x_s(s,\beta)$

Figure 4: Signatory output, $[N = 100,\ b = 1,\ A = 1000,\ \tau = 1\%]$

becomes viable for its members generating negative externalities over non-members who reduce their exports in reaction to the increasing size s. Functional analysis in *Appendix A* indicates that for any given β, as the size s of the coalition increases, the total production of a member either monotonically increases over the range $[2, N]$ or reaches a maximum inside this range before the quantity starts to decrease to reach the full cooperation outcome (see Figure 4). This latter behavior is due to the existence of a 'club good effect'. As the number of the trade-union members becomes very large internal competition increases which causes eventually an output contraction. Also, since $\frac{\partial x_s^*}{\partial \beta} \leq 0$, then member countries decrease their output as the size of external tariffs increase. Moreover, for low values of β, the output of non-members is decreasing over the range $[\beta, N-1]$, while for extremely high values of β, output peaks inside the range before decreasing again as the value of s becomes high enough. (see Figure 5).

Looking at *polar cases*, we find that for the case of full defection when no country joins

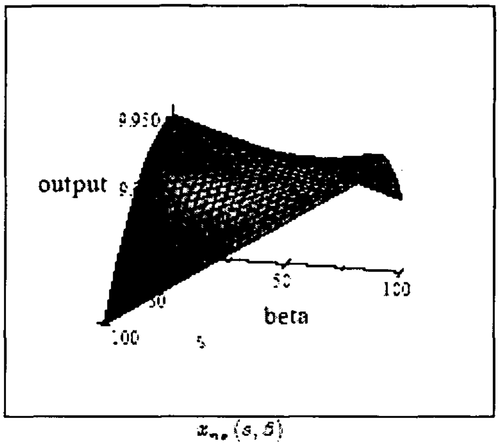


Figure 5: Non-signatory output, $[N = 100,\ b = 1,\ A = 1000,\ \tau = 1\%]$

the coalition i.e. $s = 0$ in (10) the fully non-cooperative outcome is

$$x^{nc} = \frac{2(a-c) - \beta\tau}{b(2N+1)}. \tag{12}$$

For the full cooperation case, when all countries join i.e. $s = N$ in (7), the grand coalition outcome is

$$x^{c} = \frac{2(a-c)}{b(2N+1)}. \tag{13}$$

Clearly from (12) and (13), $x^c > x^{nc}$, which is due to the absence of any tariffs in the case of full cooperation, where the agreement generates a tariff-free market.

Proposition 3 *Firms produce more under full cooperation than under full defection .*

Therefore, the formation of the grand coalition is beneficial from a pure trade perspective.

Another way to derive the polar cases is to rework the firms' problem. The first case is when no tariffs are paid. Resolving the firms' problem we get in equilibrium the same total production outcome found in (13), which is the full cooperative case, with

$$h_s^* = h_{ns}^* = f_s^* = f_{ns}^* = \frac{(a-c)}{b(2N+1)}.$$

Here, the total output in both members and non-members countries is split in half among exports and domestic use.

The second extreme case is when every firm is paying a business as usual tariff rate $\beta\tau$ on all its exports. Resolving the firms' problem we get in equilibrium the same total production outcome found in (12), which is the full defection case. Namely,

$$h_s^* = h_{ns}^* = \frac{(a-c) + N\beta\tau}{b(2N+1)}.$$

and

$$f_s^* = f_{ns}^* = \frac{(a-c) - (N+1)\beta\tau}{b(2N+1)}.$$

All countries export the same quantity, which is less than the part they keep at home, as opposed to the other extreme case where the two quantities were equal. These results can be summarized by the following:

Proposition 4 *Under full cooperation, all firms produce the same quantity, which is split in half among exports and domestic sales, which corresponds to a situation with no tariffs. Under full defection, all firms produce the same quantity, however, they always export less than the quantity sold domestically, which correspond to a situation with a uniform tariff paid by all players.*

This means that free trade stimulates both production and exports, which is in line with relevant stylized facts on trade agreements.

At this stage, when both equilibrium output and export levels of both members and non-members' firms are known, we can calculate the global output and price, and therefore equilibrium profits.

The global equilibrium output is $X^* = \sum^N x_j^* = sx_s^* + (N-s)x_{ns}^*$. Plugging back the equilibrium outputs, x_s^* given by (7) and x_{ns}^* given by (10), we get

$$X^* = \frac{2(a-c)N(N-1) - (N-s)(s-\beta+N\beta)\tau}{b(2N^2-N-1)}. \tag{14}$$

where $X^*(s)$ is a concave function defined over $s \in [0,N]$. Simple manipulations reveals that if $\beta \leq 1$, then X^* has a minimum inside the interval $[0,N]$. While, if $\beta > 1$, then $X^*(s)$ is always increasing over the interval $[0,N]$. In sum, no matter the tariff structure as the size of the coalition is increased global output will eventually increase.

The global equilibrium price is $P^* = a - bX^*$. Plugging back the global equilibrium output X^*, given by (14), we get

$$P^* = a - \frac{2(a-c)N(N-1) - (N-s)(s-\beta+N\beta)\tau}{2N^2-N-1}. \tag{15}$$

We notice that the equilibrium price is increasing in τ. Global tariff rate increases result in higher price levels.

Proposition 5 *An increase (decrease) in the tariff rate τ leads to an increase (decrease) in the global price level P^* and a decrease (increase) in the global output X^*.*

3.1.4 The firms' profits

The equilibrium profit of a firm in a signatory country for any given abatement level q_s is

$$\pi_s = (P^* - c)\,x_s^* - A(q_s) - \tau^{ns}\left(\frac{N-s}{N-1}\right)f_s^*.$$

Once we substitute back the values of P^* from (15), x_s^* from (7), and f_s^* from (6), we get[13]

$$\pi_s(P^*, x_s^*, f_s^*, q_s). \tag{16}$$

[13] See appendix A

The equilibrium profit of a firm in a non-signatory country for any given abatement level q_{ns} is

$$\pi_{ns}^{*} = (P^{*} - c)\, x_{ns}^{*} - A\left(q_{ns}\right) - \tau^{ns}\left(\frac{N-s-1}{N-1}\right) f_{ns}^{*} - \tau^{s}\left(\frac{s}{N-1}\right) f_{ns}^{*}.$$

Similarly, substituting back the values of P^{*} from (15), x_{ns}^{*} from (10), and f_{ns}^{*} from (9), we get[14]

$$\pi_{ns}\left(P^{*}, x_{ns}^{*}, f_{ns}^{*}, q_{ns}\right). \tag{17}$$

3.1.5 The consumers' surpluses

For both consumers in a signatory or non-signatory country, given the linear demand, the consumers surplus is equal to $\frac{b}{2}Q^{2}$ where Q is the total local consumption. The local consumption in a member country is

$$Q_{s}^{*} = h_{s}^{*} + \left(\frac{s-1}{N-1}\right) f_{s}^{*} + \left(\frac{N-s}{N-1}\right) f_{ns}^{*},$$

with h_{s}^{*}, given by (5), being the total equilibrium non-exported quantity of the local firm, $\left(\frac{s-1}{N-1}\right) f_{s}^{*}$ the total imported quantity from other coalition members, and $\left(\frac{N-s}{N-1}\right) f_{ns}^{*}$ the total imported quantity from non-members. Where f_{s}^{*} and f_{ns}^{*} are given, respectively, by (6) and (9). Therefore, the equilibrium consumers surplus in a representative member country is[15]

$$CS_{s}^{*}\left(h_{s}^{*}, f_{s}^{*}, f_{ns}^{*}\right) = \frac{b}{2} Q_{s}^{*2}. \tag{18}$$

Analogously, the local consumption in a non-member country is[16]

$$Q_{ns}^{*} = h_{ns}^{*} + \left(\frac{s}{N-1}\right) f_{s}^{*} + \left(\frac{N-s-1}{N-1}\right) f_{ns}^{*},$$

[14] See appendix A
[15] See appendix A
[16] See appendix A

with h^*_{ns} given by (8). The equilibrium consumers surplus in a representative non-member country is

$$CS^*_{ns}\left(h^*_{ns}, f^*_s, f^*_{ns}\right) = \frac{b}{2} Q^{*2}_{ns}. \tag{19}$$

3.1.6 Tariff revenues

The equilibrium tariffs revenues of a signatory country are given by

$$TR_s = (N-s)\tau^s \left(\frac{\frac{s}{N-1} f^*_{ns}}{s} \right),$$

where $\left(\frac{\frac{s}{N-1} f^*_{ns}}{s} \right)$ is the quantity imported from a representative non-member and subject to tariff τ. Then[17]

$$TR_s = \tau \left(\frac{N-s}{N-1} \right) f^*_{ns}. \tag{20}$$

Instead if a country is a non-signatory, then it collects tariff from all N trading partners and its equilibrium tariffs revenues are given by

$$TR_{ns} = s \left(\frac{\frac{N-s}{N-1} f^*_s}{N-s} \right) \tau^{ns} + (N-s-1) \left(\frac{\frac{N-s-1}{N-1} f^*_{ns}}{N-s-1} \right) \tau^{ns},$$

where $\left(\frac{\frac{N-s}{N-1} f^*_s}{N-s} \right)$ is the quantity imported from a representative member country and subject to tariff $\beta\tau$, while $\left(\frac{\frac{N-s-1}{N-1} f_{ns}}{N-s-1} \right)$ is the quantity imported for a representative non-member country and also subject to tariff $\beta\tau$. Then[18]

$$TR_{ns} = \beta\tau \left(\left(\frac{s}{N-1} \right) f^*_s + \left(\frac{N-s-1}{N-1} \right) f^*_{ns} \right). \tag{21}$$

[17] See appendix A

[18] See appendix A

3.1.7 Emissions levels

Total emissions for signatory countries are given by $E_s = \sum^S e_s$. Thus the equilibrium emissions for given abatement standard are[19]

$$E_s(x_s^*) = s(\alpha x_s^* - q_s), \tag{22}$$

and for non-signatory countries they are $E_{ns} = \sum^{N \setminus S} e_{ns}$, thus the equilibrium emissions for a given abatement standard are[20]

$$E_{ns}(x_{ns}^*) = (N - s)(\alpha x_{ns}^* - q_{ns}). \tag{23}$$

We already established that the environmental damage, which is suffered equally by all countries, is $D = \omega E$, where $E = E_s + E_{ns}$. Combining (22) and (23), the damage function, at the equilibrium emissions level, can be rewritten as follows[21]

$$D(X^*) = \omega(\alpha X^* - sq_s - (N - s)q_{ns}). \tag{24}$$

With no abatement efforts the damage $D(X^*)$ function defined over s follows the shape of global output $X^*(s)$ defined in (14). One conclusion is that if the coalition is formed, while no abatement is performed then global pollution under the grand coalition when $s = N$ will be obviously larger than in the case of full defection when $s = 0$. This is the case when only the trade part of the agreement is acted upon totally disregarding the environmental part. This situation reflects the pure club good effect of the trade coalition.

3.2 The governments' game

3.2.1 Membership and abatement

Each country j (government) chooses its abatement standard q_j. This choice depends on government j's welfare function, which is equal to consumer surplus CS_j, plus firm j's

[19] See appendix A
[20] See appendix A
[21] See appendix A

profits π_j, plus tariff revenues from imports TR_j, less environmental damage $D_j = \omega E$, with ω being the marginal environmental damage, and E being the global pollution level, which negatively affects every country in the World. In other words each country will choose its abatement level by maximizing

$$W_j = CS_j + \pi_j + TR_j - D_j.$$

Since we consider that ω is the same across countries we implicitly consider that $D_j = D$ $\forall j$.

The governments's game represents the first stage of the linked-game. Governments decide first whether or not to join the coalition S of size s. This defines the membership game. Next, if a country chooses to join then it decides its abatement level q_s by maximizing the collective welfare of S:

$$\max_{q_s} sW_s = s\left(CS_s + \pi_s + TR_s - D\right).$$

Since CS_s, π_s, and TR_s do not depend on the level of abatement, it is easy to obtain the optimal abatement level

$$q_s^* = \frac{s\omega}{\phi}. \tag{25}$$

The optimal abatement standard q_s^* is increasing in the size of the coalition s and in the marginal environmental damage ω. However, it is decreasing in the cost of abatement as reflected by a larger value of ϕ.

A representative non-coalition member country will maximize his own welfare

$$\max_{q_{ns}} W_{ns} = CS_{ns} + \pi_{ns} + TR_{ns} - D,$$

where it is straightforward to obtain the optimal abatement level

$$q_{ns}^* = \frac{\omega}{\phi}. \tag{26}$$

Clearly looking at (25) and (26), $q_s^* > q_{ns}^*$ $\forall s$.

Proposition 6 *A signatory country always chooses a higher abatement standard (level) than a non-signatory one.*

The formation of the IEA increases environmental cooperation by reinforcing the abatement efforts of countries.

3.2.2 Derivation of the optimal welfare functions

Once both games are solved by backward induction, the optimal abatement levels of both signatories and non-signatories are known and given by (25) and (26). Knowing the optimal abatement levels, we can determine the optimal profits and emissions.

We substitute back the optimal abatement level of a signatory country given by (25) into the equilibrium profit given by (16). Then, the optimal profit of a member firm is

$$\pi_s\left(P^*, x_s^*, f_s^*, q_s^*\right). \tag{27}$$

Similarly, We substitute back the optimal abatement level of a non-signatory country given by (26) into the equilibrium profit given by (17). Then, the optimal profit of non-member firm is

$$\pi_{ns}\left(P^*, x_{ns}^*, f_{ns}^*, q_{ns}^*\right). \tag{28}$$

In addition, we substitute the optimal abatement level of a signatory country given by (25) into the equilibrium emissions function of all signatories given by (22). Then, the optimal emissions level of the coalition is

$$E_s\left(x_s^*, q_s^*\right) = s\left(\alpha x_s^* - q_s^*\right). \tag{29}$$

Similarly, We substitute the optimal abatement level of a non-signatory country given by (26) into the equilibrium emissions function of all non-signatories given by (23). Then, the optimal emissions level of the complement is

$$E_{ns}\left(x_{ns}^{*}, q_{ns}^{*}\right) = (N-s)\left(\alpha x_{ns}^{*} - q_{ns}^{*}\right). \quad (30)$$

The optimal environmental damage[22] is obtained by rewriting (24)

$$D\left(X^{*}, q_{s}^{*}, q_{ns}^{*}\right) = \omega\left(\alpha X^{*} - s q_{s}^{*} - (N-s) q_{ns}^{*}\right). \quad (31)$$

As we noticed in (24), even though global output/unregulated pollution $X^{*}(s)$ is increasing in s (trade game effect), we have also that the abatement effort q_{s}^{*} is increasing in s. This means that the net global pollution when the trade-environment coalition is formed and enlarged is less than the pollution level when only the trade coalition is formed. This makes linkage beneficial for the environment.

Once optimal outputs, emissions and damages are known, we can determine the optimal welfare levels.

Therefore, the optimal welfare of a representative signatory country is given by

$$W_{s}^{*}(s) = CS_{s}^{*} + \pi_{s}^{*} + TR_{s}^{*} - D^{*}. \quad (32)$$

where CS_{s}^{*} is defined by (18), π_{s}^{*} is defined by (27), TR_{s}^{*} is defined by (20), and D^{*} is defined by (31). Similarly, the optimal welfare of a representative non-signatory country is given by

$$W_{ns}^{*}(s) = CS_{ns}^{*} + \pi_{ns}^{*} + TR_{ns}^{*} - D^{*}. \quad (33)$$

Where CS_{ns}^{*} is defined by (19), π_{ns}^{*} is defined by (28), TR_{ns}^{*} is defined by (21), and D^{*} is defined by (31).

[22] As we noticed in (24), even though global output/unregulated pollution $X^{*}(s)$ is increasing in s (trade game effect), we have also that the abatement effort q_{s}^{*} is increasing in s. This means that the net global pollution when the trade-environment coalition is formed and enlarged is less than the pollution level when only the trade coalition is formed.

4. Stability Study

To study coalitional stability we use the optimal welfares (32) and (33) derived by solving the trade and the environmental games. In order to compute the stable size of the coalition we use the D'Aspremont et al. (1983) stability concept, where a coalition is stable if it is both internally and externally stable. Formally, internal stability implies that: $W_s^i(s) \geq W_{ns}^i(s-1)\ \forall i \in S$ i.e. there are no incentives for any one member to leave the coalition, where $W_s^i(s)$ is defined by (32) and $W_{ns}^i(s-1)$ is derived from (33) by replacing s by $s-1$. While external stability implies that $W_{ns}^i(s) \geq W_s^i(s+1)\ \forall i \in N \backslash S$ i.e. there are no further incentives for any non-member to join the coalition, where $W_{ns}^i(s)$ is defined by (33) and $W_s^i(s+1)$ is derived from (32) by replacing s by $s+1$. For the purpose of our analysis, it is helpful to define a stability function as in Hoel and Schneider (1997), which is represented by the following[23]

$$\Phi_i(s) = W_s^i(s) - W_{ns}^i(s-1), \tag{34}$$

noting that internal stability implies

$$(i)\ \ \Phi_i(s^*) \geq 0\ \forall i \in S,$$

and external stability

$$(ii)\ \ \Phi_i(s^*+1) < 0\ \forall i \in N \backslash S.$$

The stable size of the coalition S is s^*, which is the largest integer equal to or smaller than the value at which the stability function Φ becomes null and is decreasing around this value.

In our model, $\Phi_i(s)$ as defined in (34) is a forth degree polynomial in s with only one potential root where the function goes from being positive to negative over the interval $s \in [2, N]$. Other possible stable roots beyond N suggest the trivial case of full cooperation and as such are excluded from our analysis. When we find this root, we can determine the

[23]See appendix B

stable coalition size $s^* \in [2, N]$, which reflects the case of partial cooperation that will help us understand the economic effects of the different structural parameters on stability.

When we set all tariffs to zero, the stability function simplifies to

$$\Phi_i(s) = -\frac{1}{2\phi}\omega^2\left(s^2 - 4s + 3\right),$$

with roots equal to 1 and 3.

Proposition 7 *In the absence of trade linkages, the only stable coalition is of size* $s^* = 3$.

When no trade linkages are imposed on the IEA, we go back to the 'puzzle of small coalitions' found in the literature on environmental membership games it is indicated that the stable size is between 2 and 4 as is the case in Carraro and Siniscalco (1993), De Cara and Rotillon (2001), Finus and Rundshagen (2001), and Rubio and Casino (2001) among others. Without trade linkages, free ridding incentives are large enough to cause the IEA to fail. Indeed, setting tariffs to zero collapses the trade game and keeps only the environmental one. A zero tariff across the board removes all the trade punishment mechanisms and incentives from the model.

For the structural parameters $(a, b, c, \omega, \phi, \alpha, \beta, \tau)$, we perform a sensitivity analysis on $\Phi_i(s)$ for a given stable size s^* all while respecting the non-negativity constraint of output and emissions. We derive numerically the signs of the partial derivatives of $\Phi_i(s)$, which are not all possible to derive analytically due to the complex form taken by the stability function. As such, our numerical analysis is equivalent to doing comparative statics, which indicate the effect of each parameter on the stability function and thus indirectly the effects on the stable size of the coalition.

We vary all the structural parameters of the model other than the slope b of the demand function, which is normalized to 1 since it is only a scaling parameter. We also fix the marginal cost c at zero because it enters the welfare functions in a linear fashion vis-a-vis a. As such, we use $(a-c)$, which is a measure of profitability, with a being the choke price.

It should be noted that it is possible to derive analytically the partial derivatives of $\Phi_i(s)$ with respect to two parameters only.

The partial derivative with respect of the abatement cost parameter ϕ is

$$\frac{\partial \Phi_i(s)}{\partial \phi} = \frac{\omega^2}{2\phi^2}\left(s^2 - 4s + 3\right) \geq 0 \ \ \forall s \geq 3. \tag{35}$$

[24]. Therefore *a global increase in ϕ the slope of the marginal cost of abatement induce larger participation* in the trade-environment coalition. Indeed, coalition members enjoy economies of scales in abatement by virtue of being members of the trade-union. Joining the coalition becomes more appealing as ϕ increases even if the abatement standard q^*_{ns} outside S is lower.

The partial derivative of $\Phi_i(s)$ with respect to emissions-output ratio α is

$$\frac{\partial \Phi_i(s)}{\partial \alpha} = \omega\tau \frac{(N - N\beta - 2s + \beta + 1)}{b\left(2N^2 - N - 1\right)}. \tag{36}$$

It is not possible to sign (36) analytically. However, our sensitivity analysis indicates that the variation in emission-output ratio, which reflects the effectiveness of the pollution i.e. the prevailing technology does not affect the stable size. For the purpose of our analysis,

We conduct the sensitivity analysis under two scenarios[25]. We fix the number of players at $N = 100$, we assume that each unit of output corresponds to a unit of emissions i.e. $\alpha = 1$, we also fix $b = 1$ and $\phi = 2$ since the effect is already known. Finally, we define $A = a - c$ to be a measure of firms' profitability since the difference between the choke price a and the marginal cost of production c enter in a linear fashion into the stability function.

First when $\beta \leq 1$ i.e. when coalition members charge a higher tariff than complement members, we find the following effects:

[24]This indicates that an increase in ϕ causes an upward shift in $\Phi_i(s)$, which increases the stable size s^* since $\Phi_i(s)$ is downward sloping around the stable root.

[25]See appendix B

$\beta \leq 1$	
$N = 100$; $\alpha = 1$; $b = 1$; $\phi = 2$; $A = a - c$	
increase in the value of the parameter	effect on the stable size s^*
ω	$-$
τ	$+$
A	$+$
β	$-$

Under coalition formation the following effects *induce larger participation* in the trade-environment coalition: *(1) a decrease in the value of marginal environmental damage; (2) an increase in the tariff rate set by the coalition; (3) an increase in profitability of firms; (4) an increase in the gap between the two tariff rates.*

Indeed, when he marginal environmental damage parameter ω, which reflects environmental dimension of the game, plays a pivotal role. A high marginal environmental damage increases the free-ridding incentives in the abatement game, which puts downward pressure on the stable size of the coalition. While the opposite is true for a low marginal environmental damage. Moreover, an increase in the punishment power of the coalition (increase in the tariff rate set by the coalition τ^s) , has positive effects on the stable size of the coalition. Also, we find a cartel effect when firms' profitability changes. When the tariff revenue of complement members is lower than that of the coalition, firms have added incentives to be part of the trade-union when their profitability is jeopardized. In other words the lure to join the coalition is increased given that each entity is making an arbitrage between lost tariff revenues collected from everyone and access to tariff free market when it joins the coalition. In addition, when $\beta \leq 1$, an increase in the gap reinforces the incentives to join the coalition because the punishment set by coalition members increases. Therefore, joining the coalition shields countries against this form of punishment/sanctions, which is set by the coalition S. Also, this positive effect is reinforced since tariff revenues are reduced.

Our second numerical scenario is conducted when $\beta > 1$, i.e. when coalition members charge a lower tariff than complement members, we find the following effects:

$\beta > 1$	
$N = 100;\ \alpha = 1;\ b = 1;\ \phi = 2;\ A = a - c$	
increase in the value of the parameter	effect on the stable size s^*
ω	$-$
τ	$+$
A	$-$
β	$+$

Also in this case we find the same effects for the parameters ω and τ. However, *(1) an increase in profitability has a negative impact of participation.* This is case also because of the arbitrage done by a prospective coalition member. In this case, an increase in A reduces the lure to join the coalition since this improvement in profitability reinforces the incentives to stay outside and collect high tariff revenues from everyone. Also, we find that *(2) an increase in the tariff difference increases the incentives to join the coalition* since the punishment set by non-signatories increases. In this case also, joining the coalition shields countries against that other form of sanctions, which is set by the complement of coalition $N \backslash S$.

The main conclusion derived from our results is summarized by the following:

Proposition 8 *In the presence of tariffs, tying-in environmental and trade agreements generates negative spillovers over defectors, which can be large enough to sustain large environmental coalitions.*

Therefore, by contrast to the IEA formation game without linkage in *proposition 7*, we find that the game with linkage does not suffer from the puzzle of small coalitions. This result has both descriptive and prescriptive implications. Indeed IEAs with linkages like the Montreal protocol had more success than others as was pointed out by Barrett (1997). Moreover, our analysis suggests that the existence of implicit trade-environment linkages like in the European Union favors larger participation into IEAs. This has implication for the design of future IEAs. From our analysis it is also found that for a high enough tariff rate set by the coalition members (τ^s) and for a high enough tariff gap (β) it is possible to achieve full cooperation i.e. $s^* = N$. This last result suggests that tariff difference between signatories and non-signatories can potentially provide a punishment mechanism that is strong enough to lead alone to full cooperation. In addition, the trade-union suggested in our model by setting the internal tariff rate to zero among coalition members plays a complementary role by providing positive incentives that reinforce the negative ones suggested by the tariff gap. Our results shed light on the recent experience of Saudi Arabia who joined the WTO in 2005 around the same time as signing the Kyoto protocol. WTO members is such a case benefited from the tariff gap that exists between members and non-members. The fact that members are treated more favorably in terms of tariff than non-members provides WTO members with extra tools of pressure to make a non-member cooperate over the environment. This is also reflected in ongoing negotiations with Russia on gaining full WTO membership. Indeed, OECD rich countries are trying to extract concessions using the WTO framework to make Russia increase its cooperation over the environment by signing in to more IEAs like Kyoto among others.

5. Concluding remarks

We linked an international environmental agreement (IEA) with an international trade agreement and we captured two opposing game theoretic related externalities. The trade game generates negative externalities that affect the complement of the coalition via a club good effect, which reduces free riding incentives in the environment game. While the abatement game generates positive externalities on the complement via a public good effect, which creates free riding incentives. We found that having trade linkages with IEAs can 'neutralize' these perverse free riding incentives. Therefore, larger IEAs can be potentially sustained under this scenario. We also found that, recently, elements of such effects were at play for countries like Saudi Arabia and Russia who were trying to join the WTO. This suggests that issue linkages, especially trade related ones, can help increase cooperation over environmental issues like climate change or bio-safety. This reinforces the argument in favor of introducing explicit trade linkages into IEAs in general and into a post-Kyoto agreement in particular. Given our results, one plausible scenario as we move beyond Kyoto is to deepen the WTO agreement by turning it into a global trade-union with gradual membership, while creating a new IEA on climate change in parallel, where countries that sign in benefit also from being part of the new trade-union. Such a gradual approach can be also coordinated on a regional scale as a first step. As a matter of fact, on a smaller scale past experiences favor this path. Tying-in trade and environmental agreements proved and is proving to be an important policy tool in the European Union. Indeed, our analysis sheds light on the European experience. All 27 EU countries maintained their decisions to uphold ambitious goals for fighting climate change, which were agreed upon in March 2007. These goals go beyond the requirement of Kyoto and call for cutting $CO2$ emissions by 20% below 1990 levels. In that case, the trade coalition i.e. the EU provided a club good for its members via preferential trade relationships inside the union. While, the tariff gap that existed between EU members and EU candidates generated negative externalities on those non-members as they filed for membership over the years. Those incentives are indeed strong enough to force more cooperation on environmental policies since defection cannot be a single dimensional issue. Thus, issue tie-in reduces free riding incentives over the environment by making it more costly to defect since defection becomes two-dimensional.

Appendix A

Exports:

Signatory exports $f_s^*(s)$ is a concave function defined over $s \in [2, N]$ with a maximum $\frac{1}{2}(N + (2 + N)\beta)$. Non-signatory exports $f_{ns}^*(s)$ is also a concave function defined over $s \in [1, N-1]$ that could become negative for some large values of tariff rate τ. This function has a maximum at $\frac{1}{2}(\beta(N+2) - (N+1))$. When we take the difference between the values in (6) and (9) we get

$$f_s^* - f_{ns}^* = \frac{1}{b}\tau\frac{s-\beta}{N-1} \Rightarrow s - \beta \gtrless 0 \Rightarrow f_s^* \gtrless f_{ns}^*.$$

Outputs:

Signatory output $x_s^*(s)$ given by (7) is a concave function defined over $s \in [2, N]$ with a maximum $\frac{1}{2}\left(N + \frac{3}{2}\beta\right)$. The function reaches a maximum inside the range for any value of $\beta \in \left[0, \frac{2}{3}N\right]$. Non-signatory output $x_{ns}^*(s)$ defined in (10) is also a concave function defined over $s \in [1, N-1]$ that could become negative for some large values of tariff rate τ. This function has a maximum at $\frac{1}{4}(3\beta - 1)$. It is monotonically decreasing over the range for any value of $\beta \in \left[0, \frac{5}{3}\right]$.

It is also straightforward that

$$x_s^* - x_{ns}^* = \frac{1}{b}\tau\frac{s-\beta}{N-1} \Rightarrow s - \beta \gtrless 0 \Rightarrow x_s^* \gtrless x_{ns}^*.$$

Profits:

$$\pi_s = \frac{(N-s)^2\left(2N^2\beta^2 - 6s\beta + 5\beta^2 + 2N\beta^2 + 2s^2\right)\tau^2 + 2A(N-1)(N-s)(2s-3\beta)\tau + 2A^2(N-1}{b(2N+1)^2(N-1)^2}$$
$$-\frac{1}{2}\phi q_s^2$$

$$\pi^*_{ns} = \frac{1}{b\left(2N+1\right)^2\left(N-1\right)^2} \left(\begin{array}{c} \left(\begin{array}{c} 2N^4\beta^2 - 4N^3s\beta^2 + 4N^3s\beta - 2N^3\beta^2 + 2N^2s^2\beta^2 - 4N^2s^2\beta \\ +2N^2s^2 - N^2\beta^2 + 2Ns^2\beta^2 - 2Ns^2\beta + 2Ns^2 - 2Ns\beta \\ +2s^4 - 6s^3\beta + 2s^3 + 5s^2\beta^2 - 6s^2\beta + s^2 + 4s\beta^2 - 2s\beta + \beta^2 \end{array} \right)\tau^2 \\ -2A\left(N-1\right)\left(s - \beta + N\beta - 3s\beta + 2s^2\right)\tau \\ +2A^2\left(N-1\right)^2 \end{array} \right) - \frac{1}{2}\phi q_{ns}^2$$

Consumers' surpluses

$$CS_s = \frac{1}{2b}\left(\frac{\left(4N\beta - 4s\beta - N^2\beta - 3Ns + 3s^2 + Ns\beta\right)\tau + 2A\left(N-1\right)^2}{\left(2N+1\right)\left(N-1\right)^2}\right)^2$$

$$CS_{ns} = \frac{1}{2b}\left(\frac{\left(s - \beta + 2N\beta - 4s\beta - N^2\beta - Ns + 3s^2 + Ns\beta\right)\tau + 2A\left(N-1\right)^2}{\left(2N+1\right)\left(N-1\right)^2}\right)^2$$

Tariff revenues

$$TR_s = \left(\frac{N-s}{N-1}\right)\tau\left(\frac{A\left(N-1\right) + \left(\beta - s + 2s\beta - N^2\beta - Ns - s^2 + Ns\beta\right)\tau}{b\left(2N^2 - N - 1\right)}\right)$$

$$TR_{ns} = \left(\frac{1}{N-1}\right)\beta\tau \left(\frac{\left(s - \beta + N\beta - 3s\beta + Ns^2 - N^2s + N^2\beta - N^3\beta + 2s^2 - Ns\beta + N^2s\beta\right)\tau + A\left(N-1\right)^2}{b\left(2N^2 - N - 1\right)}\right)$$

Emissions

$$E_s = s\alpha\left(\frac{2A\left(N-1\right) - \left(N-s\right)\left(3\beta - 2s\right)\tau}{b\left(2N^2 - N - 1\right)}\right) - sq_s$$

$$E_{ns} = (N-s)\alpha \left(\frac{2A\,(N-1) - \left(s - \beta + N\beta - 3s\beta + 2s^2\right)\tau}{b\,(2N^2 - N - 1)} \right) - (N-s)q_{ns}$$

$$D = \omega \left(\alpha \frac{2AN\,(N-1) - (N-s)\,(s - \beta + N\beta)\,\tau}{b\,(2N^2 - N - 1)} - sq_s - (N-s)q_{ns} \right)$$

Appendix B

$$
\begin{aligned}
\Phi_i(s) \quad = \quad & \frac{1}{2b}\left(\frac{\left(4N\beta-4s\beta-N^2\beta-3Ns+3s^2+Ns\beta\right)\tau+2A\left(N-1\right)^2}{\left(2N+1\right)\left(N-1\right)^2}\right)^2 \\
& +\frac{1}{b\left(2N+1\right)^2\left(N-1\right)^2} \\
& \left(\begin{array}{c} \left(N-s\right)^2\left(2N^2\beta^2-6s\beta+5\beta^2+2N\beta^2+2s^2\right)\tau^2 \\ +2A\left(N-1\right)\left(N-s\right)\left(2s-3\beta\right)\tau+2A^2\left(N-1\right)^2 \end{array}\right) \\
& -\frac{1}{2}\phi\left(\frac{s\omega}{\phi}\right)^2 \\
& +\left(\frac{N-s}{N-1}\right)\tau\left(\frac{A\left(N-1\right)+\left(\beta-s+2s\beta-N^2\beta-Ns-s^2+Ns\beta\right)\tau}{b\left(2N^2-N-1\right)}\right) \\
& -\omega\left(\alpha\frac{2AN\left(N-1\right)-\left(N-s\right)\left(s-\beta+N\beta\right)\tau}{b\left(2N^2-N-1\right)}-\frac{1}{\phi}\omega\left(s^2-s+N\right)\right) \\
& -\frac{1}{2b\left(\left(2N+1\right)\left(N-1\right)^2\right)^2} \\
& \left(\begin{array}{c} \left(\left(s-1\right)-\beta+2N\beta-4\left(s-1\right)\beta-N^2\beta-N\left(s-1\right)+3\left(s-1\right)^2+N\left(s-1\right)\beta\right)\tau \\ +2A\left(N-1\right)^2 \end{array}\right)^2 \\
& -\frac{1}{b\left(2N+1\right)^2\left(N-1\right)^2} \\
& \left(\begin{array}{c} \left(\begin{array}{c} 2N^4\beta^2-4N^3\left(s-1\right)\beta^2+4N^3\left(s-1\right)\beta-2N^3\beta^2+2N^2\left(s-1\right)^2\beta^2 \\ -4N^2\left(s-1\right)^2\beta+2N^2\left(s-1\right)^2-N^2\beta^2+2N\left(s-1\right)^2\beta^2-2N\left(s-1\right)^2\beta \\ +2N\left(s-1\right)^2-2N\left(s-1\right)\beta+2\left(s-1\right)^4-6\left(s-1\right)^3\beta+2\left(s-1\right)^3 \\ +5\left(s-1\right)^2\beta^2-6\left(s-1\right)^2\beta+\left(s-1\right)^2+4\left(s-1\right)\beta^2-2\left(s-1\right)\beta+\beta^2 \end{array}\right)\tau^2 \\ -2A\left(N-1\right)\left(\left(s-1\right)-\beta+N\beta-3\left(s-1\right)\beta+2\left(s-1\right)^2\right)\tau \\ +2A^2\left(N-1\right)^2 \end{array}\right) \\
& +\frac{1}{2}\phi\left(\frac{\omega}{\phi}\right)^2 \\
& -\left(\frac{1}{N-1}\right)\frac{\beta\tau}{b\left(2N^2-N-1\right)}A\left(N-1\right)^2 \\
& -\left(\frac{1}{N-1}\right)\frac{\beta\tau^2}{b\left(2N^2-N-1\right)} \\
& \left(\begin{array}{c} \left(s-1\right)-\beta+N\beta-3\left(s-1\right)\beta+N\left(s-1\right)^2-N^2\left(s-1\right) \\ +N^2\beta-N^3\beta+2\left(s-1\right)^2-N\left(s-1\right)\beta+N^2\left(s-1\right)\beta \end{array}\right) \\
& +\omega\left(\begin{array}{c} \alpha\frac{2AN(N-1)-(N-(s-1))((s-1)-\beta+N\beta)\tau}{b(2N^2-N-1)} \\ -\frac{1}{\phi}\omega\left(\left(s-1\right)^2-\left(s-1\right)+N\right) \end{array}\right)
\end{aligned}
$$

A	s^*	ω	s^*	τ	s^*	$\beta > 1$	s^*
10	59	0.0005	63	0.0055	45	2.75	38
20	58	0.001	62	0.006	45	3	39
30	57	0.0015	61	0.0065	46	3.25	41
40	56	0.002	60	0.007	47	3.5	42
50	55	0.0025	58	0.0075	48	3.75	44
60	54	0.003	56	0.008	48	4	45
70	53	0.0035	55	0.0085	48	4.25	46
80	52	0.004	53	0.009	49	4.5	47
90	51	0.0045	51	0.0095	49	4.75	49
100	**50**	**0.005**	**50**	**0.01**	**50**	**5**	**50**
110	49	0.0055	48	0.0105	50	5.25	51
120	48	0.006	47	0.011	50	5.5	52
130	47	0.0065	45	0.0115	51	5.75	53
140	46	0.007	44	0.012	51	6	54
150	45	0.0075	43	0.0125	51	6.25	54
160	44	0.008	41	0.013	52	6.5	55
170	43	0.0085	40	0.0135	52	6.75	56
180	42	0.009	39	0.014	52	7	57
190	41	0.0095	38	0.0145	52	7.25	57
200	40	0.01	37	0.015	53	7.5	58

A	s*	ω	s*	τ	s*	$\beta \leq$ **1**	s*
10	16	0.0005	100	0.0055	22	0.05	34
20	18	0.001	100	0.006	22	0.1	34
30	19	0.0015	100	0.0065	23	0.15	33
40	21	0.002	83	0.007	24	0.2	32
50	22	0.0025	64	0.0075	25	0.25	32
60	24	0.003	51	0.008	26	0.3	31
70	25	0.0035	43	0.0085	27	0.35	31
80	27	0.004	37	0.009	28	0.4	30
90	28	0.0045	33	0.0095	29	0.45	30
100	**29**	**0.005**	**29**	**0.01**	**29**	**0.5**	**29**
110	30	0.0055	27	0.0105	30	0.55	29
120	32	0.006	26	0.011	31	0.6	28
130	33	0.0065	23	0.0115	31	0.65	28
140	34	0.007	21	0.012	32	0.7	28
150	35	0.0075	19	0.0125	33	0.75	27
160	36	0.008	18	0.013	34	0.8	27
170	38	0.0085	17	0.0135	34	0.85	27
180	39	0.009	16	0.014	35	0.9	27
190	40	0.0095	15	0.0145	36	0.95	27
200	41	0.01	15	0.015	36	1	27

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Essay 3

2x2 Axiomatic Bargaining in Trade-Environment Negotiations

1. Introduction

Traditionally, bargaining has been modeled as a single issue problem. However, bargaining often deals with several different issues at once. For instance, international trade and environmental negotiations have often been put on the bargaining table in a linked fashion. From Kyoto in 1997 to Cartagena in 2003, international environmental agreements were negotiated with the lurking spectre of trade agreements like the WTO. Stylized facts suggest that countries' negotiation powers over each specific issue (trade or environment) plays an important role in shaping the final outcome of international negotiations. For instance, we notice that the genetically modified organisms (GMOs) dispute between the USA, Canada and Argentina on one side and the European Union on the other was settled in favor of the former group, where trade concerns trump environmental ones. Moreover, trade-environment disputes, and more generally any form of two-issue bargaining, take place under one of the following two scenarios. First, when a negotiating side who benefits from an improvement in his bargaining abilities in one issue makes gains eventually over both issues. Second, when a negotiating side who benefits from an improvement in his bargaining abilities in one issue makes gains on this same issue while making partial concessions[1] over the other.

The literature on bargaining is divided into two strands: one follows a non-cooperative approach a la Rubinstein (1982) and another follows a cooperative or axiomatic approach a la Nash (1950). The literature includes a number of attempts to model multiple-issue bargaining, which has been mostly a theoretical exercise that fails to capture the importance of changes in the negotiation power and the resulting spillovers between issues. An important general observation is that cooperative models have neglected the role played by disagreement points, which are normalized to zero. Meanwhile, stylized facts suggest that these

[1] By partial we mean that the value of those concessions are less than the gains made in the former issue.

points are pivotal in negotiations since they acts as a threat points[2]. Moreover, the idea of concessions exchange that arises in non-cooperative models is also neglected in multi-issue cooperative models. Against this background, we propose in this paper a two-player[3], two-issue cooperative bargaining model with non-normalized disagreement points. We propose two solution concepts that exploit the geometry of these disagreements points and the relevance of potential concessions and bargaining spill-overs across issues. Our first solution describes the case where linked bargaining results in gains on both issues, while the second one describes the case where gains entail partial concessions over the other. We find that the relative size of disagreement points (e.g. trade versus environment) plays an important role in determining under which issue it pays more to have an improvement in negotiation power. Our results capture important features in international trade-environment negotiations, and help clarify some of the mechanisms behind the outcome of those negotiations.

The paper unfolds as follows. Section 2 discusses the related literature and the theoretical contribution of our paper. Section 3 presents the two-issue bilateral bargaining model and lists the axioms. Section 4 presents our two solutions, which link either the disagreement points or the ideal points. Section 5 contains concluding remarks.

2. Related literature

On the theoretical side, Nash (1950) first formalized the concept of axiomatic bargaining, which lays the foundations of the cooperative approach. Most of the work on multiple-issue bargaining uses two players models and attempts to generalize existing solution concepts relevant to single-issue problems. In the axiomatic framework, this is done by proposing new axioms that qualify or replace classical ones found in the literature on single issue

[2]See Harrison and Rutström (1991) for a discussion about the importance of the disagreement point in trade wars and trade negotiations in the pre-NAFTA context.

[3]All cooperative and non-cooperative multi-issue models assume bilateral bargaining.

problems. Then, separate and global bargaining situations are compared. Axiomatically, there are basically two paths for generalization. The first one is when agents' preferences are represented by a utility function. Then, the global bargaining problem can be reduced to a classical bargaining problem with utility allocations. Therefore, in order to study the global problem it becomes important to understand the structure of the bargaining set of each single issue. Using this approach, it is assumed that utilities are additive across issues so that comparing the links between the classical solutions (applied separately to the issues) and solutions (applied to the global set) becomes possible. Axioms such as Independence of Irrelevant Alternatives or Individual Monotonicity are replaced by specific linked axioms. As such, the Nash solution can be generalized when the Independence of Irrelevant Alternatives axiom is replaced , as well as the symmetric utilitarian solution with equal weights when the invariance axiom is replaced (Ponsatí and Watson, 1997). Also, Kalai's (1977) extended family of proportional solutions and Harsanyi and Selten's (1972) extended family of non-symmetric Nash solutions were generalized to multi-issue bargaining by Peters (1986) by introducing linked axioms related to additivity and homogeneity. Both Peters (1986) and Ponsatí and Watson (1997) are concerned with finding an axiomatic interpretation of the simultaneous implementation of sequential multi-issue bargaining i.e. a la Rubinstein (1982). Another approach has been, more recently, proposed by Mármol and Ponsatí (2008). They consider solutions that apply directly to the global bargaining situation with maximin and leximin preferences. They argue in favor of such solutions when information about preference is limited or when those preferences do not admit a utility representation. Mármol and Ponsatí (2008) follow Bossert et al. (1996) and Bossert and Peters (2001) by modeling the global bargaining problem as the Cartesian product of classical (single issue) bargaining problems.

On the applied side, the idea of exchange of concessions is stressed by Horstmann et al. (2005) who present a stylized non-cooperative bargaining model that links two issues (trade and environment) among two countries. They contrast negotiation outcomes when they are dealt with separately (both sequentially and simultaneously) and globally. They find that linking (global negotiation) may be beneficial. Linkage helps a country extract "concessions" from the other party on an issue that is important domestically in exchange for ceding concessions that is important for the other.[4]

Finally it is important to understand that under multiple issue bargaining there are in fact three possible families of axioms. First, there are axioms that are related to changes in the bargaining set. These are dealt with by Peters (1985, 1986), and Ponsatí &Watson (1997) among others, where the disagreement points are normalized to zero. Second, there are axioms related to changes in the population on which the literature has been mostly silent since bilateral bargaining is assumed. Finally, axioms related to changes in the disagreement points have so far not been dealt with under multiple issue bargaining. In this paper, we will explore the relevance of those disagreement points, which will constitute the contribution of our model on the theoretical side. It should be noted that Thomson (1987, 1994) and Chun and Thomson (1990, 1992) introduce axioms related to the disagreement point but for single-issue bargaining only.

3. The 2×2 bargaining model

3.1 The model

Consider a two-player ($i = 1, 2$), two-issue (X and Y) bargaining problem. Assume that bargaining is done over two feasible utility outcome sets X and Y, with two disagreement points d^x and d^y respectively where $d = (d^x, d^y)$. We assume that players' preferences

[4] The authors call it "comparative interest", which is analogous to Ricardian comparative advantage. The gist of their argument is that: "when linking is not beneficial to a country it is either because the linked issue has very large (relative to other issues) negative value or because the country can gain by bargaining issues sequentially. In this latter case, sequential bargaining beginning with the issue of importance to the country alters relative bargaining costs in a way that makes the country better off". p.199

admit an additively separable utility representation, therefore utilities are comparable across issues.[5] A *global bargaining set* is a set

$$Z = X + Y,$$

such that $z = x + y$ where $x \in X,\ y \in Y$, and $z \in Z$.

The *single issue bargaining problem* over X (or Y) is defined as follows: (i) a bargaining set $X \subset \mathbb{R}^2_+$ which includes all feasible utility pairs, (ii) a disagreement point $d^x \in \mathbb{R}^2_+$, (iii) X is a 2-simplex with a least one point in X that strictly dominates d^x i.e. $\exists\ x \in X$ such that $x_i > d^x_i\ \forall i = 1, 2$, and where its Pareto efficient frontier is $PEF^x = \left\{(x_1, x_2) \in \mathbb{R}^2_+ \mid x_1 + x_2 = 1\right\}$, and (iv) X is d^x comprehensive meaning that $\exists\ x \in X$ such that $x_i \geq x'_i \geq d^x_i\ \forall i = 1, 2$, then $x' \in X$. (See Figure 6). Let Σ be the set of all such bargaining sets, and let B be the set of all such single issue bargaining problems. Therefore, the size of bargaining 'cake' X is one, and the total size of the 'cake' Z is equal to two.

Definition 1 *A* 2×2 bargaining problem *is a global (linked) problem* $(Z, d) \in B^2$ *where* B^2 *be the set of all global bargaining problems.*

Definition 2 *A* bargaining solution *to the* 2×2 *problem is a function* $F : B^2 \longrightarrow \mathbb{R}^2_+ \times \mathbb{R}^2_+$ *such that* $F(Z, d) \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$ *for all* 2×2 *problems, where* $Z \in \Sigma \times \Sigma = \Sigma^2$, *and* $d \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$.

For the sake of graphical representation, we present the bargaining sets X and Y mirrored against each other on the $\mathbb{R}^2$ quadrant where $Z = X + Y$ such that $Y = -X$ and $-d^y \in \mathbb{R}^2_+$. Let the utility u_1 of player 1 be measured on the x-axis, and u_2 be measured on y-axis. X is represented in the positive orthant[6], while Y is represented in the negative orthant[7]. Therefore, both sets share the same origin $(0, 0)$. (See Figure 7)

[5] See Myerson RB (1977) and Peters H (1985, 1986) for discussion on the additivity of utilities in bargaining.

[6] where both $u_1 \geq 0$, and $u_2 \geq 0$

[7] where both $u_1 \leq 0$, and $u_2 \leq 0$. Of course, here we measure utilities in absolute terms.

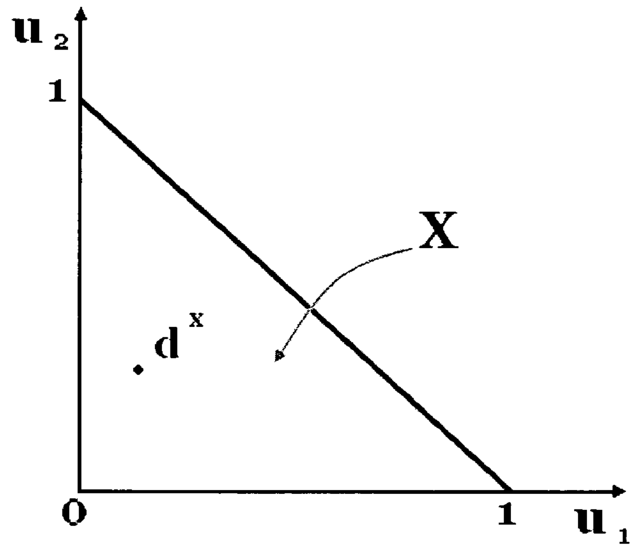

Figure 6: Single issue bargaining set

Given the above defined 2×2 problem, a solution will exploits the global problem to assign one solution for each issue. In other words, $F : B^2 \longrightarrow \mathbb{R}^2_+ \times \mathbb{R}^2_+$ such that $f^x(d) \in X$ and $f^y(d) \in Y$ for all $X, Y \in \Sigma$.[8] Where, player's i overall welfare is given by the sum of utility outcomes across both issues

$$F_i = f_i^x(d) + f_i^y(d) \qquad \forall i = 1, 2.$$

The notion of the ideal point will be important in what follows. In general, the ideal point of the bargaining set X depends on both the shape of the set and on the location of the disagreement point d^x. However, in our model we normalize to unity and fix each bargaining set to be a 2-simplex where we can express the ideal point solely as a function of its corresponding disagreement point. The ideal point of the set α is the point

$$a_i^\alpha \equiv \max\{x_i \mid x \in X;\ x \geqq d^\alpha\} \qquad \forall i,\ \forall \alpha = X, Y.$$

[8] Since the shapes of both bargaining sets X and Y are given by the the symmetric 2-simplex, we define our functions in the model in terms of only one variable, which is the disagreement point.

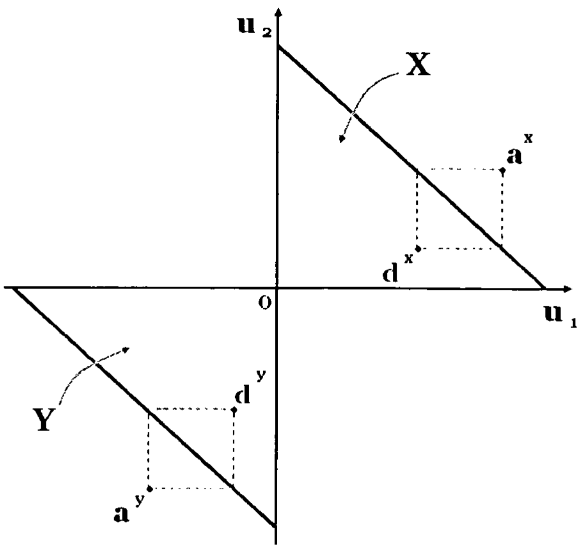

Figure 7: Two issues bargaining set

Let $a^{\alpha} = \binom{a_i^{\alpha}}{a_j^{\alpha}}$ and $d^{x} = \binom{d_i^{\alpha}}{d_j^{\alpha}}$. Given the normalized bargaining set $\alpha = X, Y$, we know that the coordinate $\binom{a_i^{\alpha}}{d_j^{\alpha}} \in PEF^{\alpha}$, such that $a_i^{\alpha} + d_j^{\alpha} = 1$, in other words

$$a_i^{\alpha} = 1 - d_j^{\alpha} \qquad \forall i = 1, 2; i \neq j.$$

3.2 Axioms

3.2.1 The bargaining framework

We propose new axioms related specifically to issue linkages when the disagreement points are taken into consideration. In this context, it is very important to draw the distinction between separate and linked Pareto efficiency. Classical axioms that are applied to single-issue problems are based on the idea of separate/local Pareto efficiency, where it is enough for the solution to be on the Pareto frontier of each set to be efficient[9]. Given our normalization

[9]This is the case when both issues are seen separately. The idea of global efficiency only makes sense when linkage is considered.

of the bargaining sets, any solution located on the Pareto frontiers maximizes the sum of players utilities across issues X and Y and is thus Pareto efficient. In a more general context, Peters (1985) and Ponsatí and Watson (1997) discuss the idea of global efficiency in the context of multi-issue bargaining. They argue that efficiency demands that no possible gains from cooperation are lost, which means that each local solution must belong to Pareto frontier of each local set. In what follows, we interpret disagreement points to be proxies for players' negotiation power.

Definition 3 *The* bargaining power *of player $i = 1, 2$ over issue $\alpha = X, Y$ is measured by the disagreement outcome d_i^α. The total bargaining power of i is measured by $D_i = d_i^x + d_i^y$.*

Stylized facts suggest that any improvement in the bargaining power of a player will increase his overall welfare after bargaining. However, such improvement can happen under two different contexts. Given a linked bilateral bargaining situation, the effects of an improvement in the bargaining power of a player over one issue will depend on the degree of complementarity between bargained issues X and Y. High complementarity suggest that a positive shock in the negotiation power of player i will lead to welfare gains over both issues, thus there is no need to make any concessions. Low complementarity suggests that, although overall welfare gains are always positive, partial concessions will be made over the other issue.

In what follows we measure the social welfare outcome of disagreement over issue α, $\forall \alpha = X, Y$ by

$$D^\alpha = d_i^\alpha + d_j^\alpha.$$

D^α can also be interpreted to be the fall-back point or the non-cooperative Nash outcome.

3.2.2 Bargaining without concessions

Linked bargaining without concessions means that any improvement in the bargaining power of player i over any one issue will increase his utility over both issues. In this context, it is relevant to focus on the bargaining positions of players which are summarized by their bargaining power, which they bring to the negotiation table. Thus, players bargaining power will govern the result of linked bargaining. In what follows, we present axioms that will play an important role in describing the normative attributes of our solution.

Axiom 1 Proportionality in relative bargaining power: $\frac{F_i}{F_j} = \frac{D_i}{D_j}$

Axiom-1 indicates that overall gains are proportional to the total bargaining power of each player. Player i's overall gain F_i is increasing in his total bargaining power D_i and decreasing in D_j.

Axiom 2 Equality in relative local net gains: $\frac{f_i^\alpha - d_i^\alpha}{f_i^\beta - d_i^\beta} = \frac{f_j^\alpha - d_j^\alpha}{f_j^\beta - d_j^\beta}$

Looking at *Axiom-2* we notice that the net gains $(f_i^\alpha - d_i^\alpha)$ of player $i = 1,2$ over issue $\alpha = X, Y$ are decreasing in player $j \neq i$'s net gains $\left(f_j^\beta - d_j^\beta\right)$ over issue $\beta \neq \alpha$ where players care about the gains they make above their disagreement outcome. Moreover, *Axiom-2* is an axiom of neutrality vis-a-vis the issues. If for example $\frac{f_i^\alpha - d_i^\alpha}{f_i^\beta - d_i^\beta} > \frac{f_j^\alpha - d_j^\alpha}{f_j^\beta - d_j^\beta}$ then this means that player i has an *a priori* advantage over j over issue α and vis-versa j has an *a priori* advantage over i over issue β regardless of the bargaining power of each player, which is an undesirable property. Therefore, this condition must hold at equality to ensure neutrality with respect to issues.[10].

[10] *Axiom 1* and *Axiom 2* imply disagreement point monotonicity. Indeed, Thomson (1987, 1994) notes that an improvement in the disagreement outcome of player i over issue α will increase his utility over α. Thomson (1987) proposes an axiom in the classical single-issue case, which is called Disagreement Point Monotonicity. Given the definition of the bargaining power, we can generalize this axiom and name it Linked Bargaining Power Monotonicity, which is defined as follows: $\forall\ (Z, d) \in B^2$, $\forall\ d \in \mathbb{R}_+^2 \times \mathbb{R}_+^2$, if $d_i'^\alpha \geq d_i^\alpha$ and $d_j'^\alpha = d_j^\alpha$; $d_j'^\beta = d_j^\beta$; $d_i'^\beta = d_i^\beta$, then $f_i^\alpha(d') \geq f_i^\alpha(d)\ \forall i = 1,2;\ \forall \alpha \neq \beta,\ \alpha = X, Y$

3.2.3 Bargaining with concessions

Linked bargaining with concessions means that any improvement in the bargaining power of player i over any one issue will increase his utility over this issue, decrease it over the other, all while having a net overall increase in utility. In this context, players will focus on their bargaining positions with respect to their aspirations (ideal outcome). The intuition being that each players knows that some concession is required and therefore his bargaining depends on what he aspires for from the bargaining game. In other words, players care about ideal gains beyond what is feasible given that concessions will be made. The following axioms are relevant in such a context.

Axiom 3 Proportionality in relative potential gains: $\frac{F_i}{F_j} = \frac{w-D_j}{w-D_i}$

Where $w = 2$ is the total size of the bargained 'cake' $Z = X + Y$. *Axiom-3* indicates player i 's overall gain F_i is increasing in player j's potential gain gap $(w - D_j)$. The higher this gap, the weaker the bargaining position of j. Also, this axiom indicates that player i's overall gain F_i is increasing in his total bargaining power D_i and decreasing in D_j.

Axiom 4 Equality in relative local aspired gains: $\frac{a_i^\alpha - f_i^\alpha}{a_j^\alpha - f_j^\alpha} = \frac{a_i^\beta - f_i^\beta}{a_j^\beta - f_j^\beta}$

Where $(a_i^\alpha - f_i^\alpha)$ are the aspired gains of player $i = 1, 2$ over issue $\alpha = X, Y$. *Axiom-4* analogously to *Axiom-2* is a fundamental axiom of neutrality vis-a-vis the issues.

Notice that *Axiom-1* and *Axiom-2*, or *Axiom-3* and *Axiom-4* imply *d-symmetry*[11].

4. Solutions

4.1 The linked-d solution

Our first solution consists of linking the two disagreement points with a straight line and extending that line into the Pareto frontier of each set. We call it the *linked-d solution.*

[11] For all 2 × 2 problems if $d_i^\alpha = d_j^\alpha$, $\forall i \neq j$, $\alpha = X, Y$, then $f_i^\alpha(d) = f_j^\alpha(d)$.

(See Figure 8). Formally,

Definition 4 *The* linked-d solution $G(Z,d)$ *to all* 2×2 *problems is the tuple of Pareto efficient points belonging to sets* X *and* Y *on the line connecting* d^x *and* d^y.

In other words, the solution is a function $G : B^2 \to \mathbb{R}^2_+ \times \mathbb{R}^2_+$ such that $G^Z(d) = \binom{g^x(d)}{g^y(d)} \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$ for all $(Z,d) \in B^2$, where $Z \in \Sigma \times \Sigma = \Sigma^2$, and $d \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$. Let $d^x = \binom{d^x_1}{d^x_2} \in X$, $d^y = \binom{d^y_1}{d^y_2} \in Y$, $g^x_i(d) = x_i$; $g^y_i(d) = y_i$ $\forall i = 1,2$. The solution $x \in PEF^x$ is described by the following system: $\begin{cases} x_1 = d^x_1 + \lambda\left(d^x_1 + d^y_1\right) \\ x_2 = d^x_2 + \lambda\left(d^x_2 + d^y_2\right) \\ x_1 + x_2 = 1 \end{cases}$, and $y \in PEF^y$ is described by : $\begin{cases} y_1 = d^y_1 + \mu\left(d^y_1 + d^x_1\right) \\ y_2 = d^y_2 + \mu\left(d^y_2 + d^x_2\right) \\ y_1 + y_2 = 1 \end{cases}$.

We characterize the solution by solving the system of equations from the definition. We get $\lambda = \frac{1-D^x}{D^x+D^y} \geq 0$, $\mu = \frac{1-D^y}{D^x+D^y} \geq 0$. By substitution, $\forall i = 1,2$, $\forall \alpha = X,Y$ we get

$$g^\alpha_i = d^\alpha_i + \frac{D_i}{D_i + D_j}\left(1 - D^\alpha\right).$$

The linked-d solution indicates that the local surplus over the disagreement outcome: $(1 - D^\alpha)$ is shared by the players proportionally to their negotiation power.

The linked-d solutions also yields,

$$G_i = \frac{2D_i}{D^x + D^y} > D_i.$$ [12]

The overall bargained outcome is always better than the overall disagreement outcome.

The linked-d solution describes situations of 2×2 bargaining without concessions.

Theorem 1 *A solution satisfies* Proportionality in relative bargaining power *and* Equality in relative local net gains *if and only if it is the linked-d solution.*

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[12] $\frac{2D_i}{D^x+D^y} - D_i = \frac{\left[2-\left(D_i+D_j\right)\right]D_i}{D_i+D_j} > 0$ since by feasibility $D_i + D_j < 2$, where 2 is the size of the cake Z.

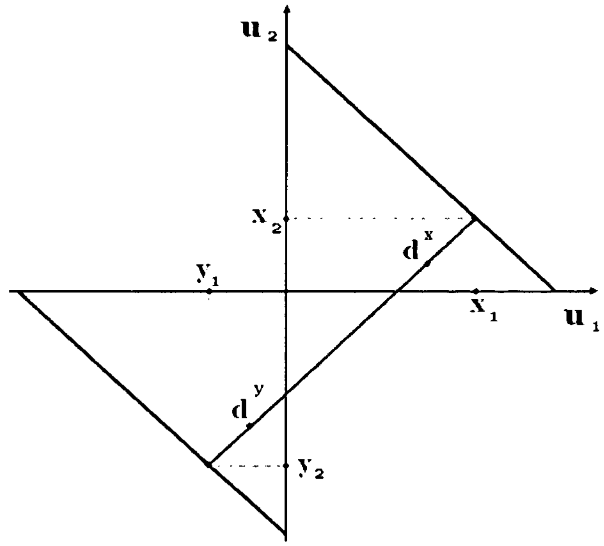

Figure 8: The linked-d solution

Proof. See appendix A. ■

When issues are put on the bargaining table in a linked fashion any improvement in the bargaining power of player i over issue α will increase his utility over both issues α and β. An improvement in the bargaining power of player i over issue α is simply an increase in the value of d_i^α, holding everything else constant. In other words, $d_i'^\alpha \geq d_i^\alpha$ and $d_j'^\alpha = d_j^\alpha$, $d_i'^\beta = d_i^\beta$ and $d_j'^\beta = d_j^\beta$, where $d' = \left(\left\{ {d_1'^x \atop d_2^x} \right\}, \left\{ {d_1^y \atop d_2^y} \right\}\right) \in \mathbb{R}_+^2 \times \mathbb{R}_+^2$. For the linked-d solution we can define the *benefit ratio* of player i, when issue α is linked to issue β for $i = 1, 2;\ i \neq j, \alpha = X, Y;\ \beta \neq \alpha$ by

$$b_i^\alpha = \frac{g_i^\beta(d') - g_i^\beta(d)}{g_i^\alpha(d') - g_i^\alpha(d)} \in (0, 1)\,.$$

In addition, b_i^α is a measure of the *degree of complementarity* or the magnitude of the spillover across issues. The higher the ratio b_i^x, the higher the additional gain player i makes in issue Y relative to X when the negotiation power of i improves over the issue X.

Axiom-1 and *Axiom-2*, which characterize the linked-d solution, take into account the existence of positive spillovers across issues when linkage is considered. The gains in negotiation power $(d_i'^x - d_i^x)$ resulting from a shift in the disagreement point d^x in favor of player i leads to positive spillovers in the other issue (Y). These spillovers are measured by b_i^x. In this case, any improvement in negotiation power over any one issue leads to a global improvement in gains over both issues. Simple algebraic manipulation reveal that for the linked-d solution

$$b_i^\alpha = \frac{1 - D^\beta}{1 + D^\beta}.$$

We notice that as the ratio b_i^α becomes smaller, cross issues spillovers decrease. Comparative statics on b_i^α yield $\frac{\partial b_i^\alpha}{\partial d_i^\beta} < 0$, $\forall \alpha = X, Y;\ \alpha \neq \beta$.This reveals that the magnitude of the spillovers flowing from X to Y, which are generated -for instance- when the negotiation power of player i improves in X, are themselves decreasing in his own negotiation power in Y. In other words, the impact on issue Y of linking X to Y decreases as i has more bargaining power in Y. And vice versa.

Proposition 1 *Given the* linked-d solution, *if* $D^x > D^y$ *then* $b_i^x > b_i^y \quad \forall i = 1, 2$.

This means that if the disagreement outcome in issue Y provides a worse social outcome than the disagreement outcome in issue X, then player i benefits more from issue linkage when his negotiation power is improved in X rather than Y. Stylized facts suggest that the disagreement outcome over the environmental issue can be catastrophic and therefore much lower than that of trade, which corresponds to a trade war. This suggests that it pays more for a country to improve its negotiation power over trade issues (investing in trade-sanctions) than to improve its negotiation power over environmental issues (investing to improve environmental standards). Therefore, the 'direction' in which trade-environmental negotiations are approached matters and affects who eventually gains most from negotiations. This helps us shed light on the GMOs dispute. The USA, Canada, and Argentina eventually won the dispute having invested in improving their trade sanction power rather than their environmental standards as was the case in the EU.

4.2 The linked-a solution

The second solution, links the two ideal points with a straight line and finds the points of intersections of this line with the Pareto efficient frontiers. We call it the *linked-a solution.* (See Figure 9). Formally,

Definition 5 *The* linked-a solution $H(Z,d)$ *to all* 2×2 *problems is the tuple of Pareto efficient points belonging to sets* X *and* Y *on the segment connecting* a^x *and* a^y.

In other words, the solution is a function $H : B^2 \to \mathbb{R}^2_+ \times \mathbb{R}^2_+$ such that $H^Z(d) = \binom{f^x(d)}{f^y(d)} \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$ for all $(Z,d) \in B^2$, where $Z \in \Sigma \times \Sigma = \Sigma^2$, and $d \in \mathbb{R}^2_+ \times \mathbb{R}^2_+$. Let $d^x = \binom{d^x_1}{d^x_2} \in X$, $d^y = \binom{d^y_1}{d^y_2} \in Y$, and $h^x_i(d) = x_i$; $h^y_i(d) = y_i$ $\forall i = 1,2$. The solution $x \in PEF^x$ is described by the following system: $\begin{matrix} x_1 = a^x_1 + \lambda\left(a^x_1 + a^y_1\right) \\ x_2 = a^x_2 + \lambda\left(a^x_2 + a^y_2\right) \\ x_1 + x_2 = 1 \end{matrix}$, and $y \in PEF^y$ is described by $: \begin{matrix} y_1 = a^y_1 + \mu\left(a^y_1 + a^x_1\right) \\ y_2 = a^y_2 + \mu\left(a^y_2 + a^x_2\right) \\ y_1 + y_2 = 1 \end{matrix}$.

We characterize the solution by solving the system of equations from the definition.

We get $\lambda = \frac{1-D^x}{D^x+D^y-4} \leq 0$, $\mu = \frac{1-D^y}{D^x+D^y-4} \leq 0$. By substitution, we get

$$h^\alpha_i = d^\alpha_i + \frac{D_i - 2}{D_i - 2 + D_j - 2}\left(1 - D^\alpha\right).$$

The linked-a solution also indicates that the local surplus over the disagreement outcome: $(1 - D^\alpha)$ is shared by the players proportionally to their potential negotiation power.

The linked-d solutions also yields,

$$H_i = \frac{4 - 2D_j}{4 - (D^x + D^y)} > D_i.^{13}$$

[13] Since by feasibility $D_i + D_j < 2$, where 2 is the size of the cake Z.

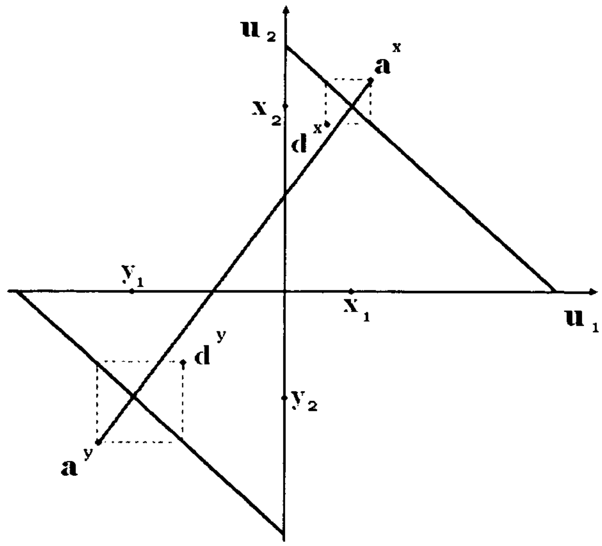

Figure 9: The linked-a solution

The overall bargained outcome is always better than the overall disagreement outcome. The linked-a solution describes situations of 2×2 bargaining with concessions.

Theorem 2 *A solution satisfies* Proportionality in relative potential gains *and* Equality in relative local aspired gains *if and only if it is the linked-a solution.*

Proof. See appendix B. ■

When issues are put on the bargaining table in a linked fashion any improvement in the bargaining power of player i over issue α will increase his utility over issues α while decreasing it over β by a lesser amount. Thus, total utility is always increasing in the bargaining power. It also indicates that players weigh their aspirations over both issues before making informed concessions. We can define the *concession ratio* of player i, when issue α is linked to issue β for $i = 1, 2;\ i \neq j, \alpha = X, Y;\ \beta \neq \alpha$ by

$$c_i^\alpha = \frac{\left|h_i^\beta(d') - h_i^\beta(d)\right|}{h_i^\alpha(d') - h_i^\alpha(d)} \in (0, 1)\,.$$

In addition, c_i^α is a measure of the *degree of substitution* across issues. The higher the ratio c_i^x, the higher the additional concessions player i makes in issue Y relative to X when the negotiation power of i improves over the issue X.

Axiom-3 and *Axiom-4*, which characterize the linked-a solution, take into account the existence of negative spillovers across issues when linkage is considered. The gains in negotiation power $(d_i'^x - d_i^x)$ resulting from a shift in the disagreement point d^x in favor of player i leads to negative spillovers in the other issue (Y). These spillovers are measured by c_i^x. In this case, any improvement in negotiation power over any one issue leads to concessions but maintains a global improvement in gains over both issues. Simple algebraic manipulation reveal that for the linked-a solution

$$c_i^\alpha = \frac{D^\beta - 1}{D^\beta - 3}.$$

We notice that as the ratio c_i^α become smaller, cross issues spillovers decrease. Comparative statics on c_i^α yield $\frac{\partial c_i^\alpha}{\partial d_i^\beta} < 0,\ \forall \alpha = X, Y;\ \alpha \neq \beta$. As the player becomes stronger over the other issue, the size of the concessions made will be decreasing. The impact on issue Y of linking X to Y decreases as i has more bargaining power in Y. And vice versa.

Proposition 2 *Given the* linked-a solution, *if* $D^x > D^y$ *then* $c_i^x < c_i^y \;\; \forall i = 1, 2$.

The same interpretation as in *Proposition 1* holds. The only difference being that concessions are reduced instead of positive spillovers being increased. A good illustrative example is the Tuna War I (1991) between the USA and Mexico.[14] The US having invested in trade sanctions against Mexico was able to reduce the concessions made to Mexico over the environmental protection of marine life in the Pacific. Although, the GATT court eventually ruled against the US, which failed to impose a complete ban on non-dolphin-

[14]The legal aspect of Tuna War I is discussed in details in Arbour J-M and Lavallee S (2006), Droit International de l'Environnement, in: Yvon Blais (eds).

friendly fishing, the American side was able to force changes over the way Tuna fishing is practiced by Mexico.

5. Concluding remarks

We have developed a two-issue bilateral bargaining model. In our model we have opened the black box of disagreement points in a cooperative construct. Our solutions are complementary and help better understand the context in which this form of negotiations takes place. Our analysis reveals that exploiting the disagreement points as potential fall-back points is very relevant in Trade-Environment talks. Stylized facts suggest that indeed negotiating parties use these disagreement outcomes as tools to size up and eventually improve their bargaining powers. As an extension to our work, it would be interesting to work on extending the bilateral case to a n-player bargaining situation. This would allow for the definition of another family of axioms related to population in addition to those related to the disagreement points.

Appendix A

Given any 2×2 problem, let F be a solution satisfying axioms 1 and 2.

By *Axiom-2* we have: $\frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha} = \frac{f_i^\beta - d_i^\beta}{f_j^\beta - d_j^\beta} \Rightarrow f_i^\alpha = d_i^\alpha - \left(f_j^\alpha - d_j^\alpha\right) \frac{f_i^\beta - d_i^\beta}{f_j^\beta - d_j^\beta}$. Then $F_i = f_i^\alpha + f_i^\beta = D_i - \left[\left(f_j^\alpha - d_j^\alpha\right) \frac{f_i^\beta - d_i^\beta}{f_j^\beta - d_j^\beta} + \left(f_j^\beta - d_j^\beta\right) \frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha}\right]$. It follows that

$$F_i - D_i = \left[\left(f_j^\alpha - d_j^\alpha\right) \frac{f_i^\beta - d_i^\beta}{f_j^\beta - d_j^\beta} + \left(f_j^\beta - d_j^\beta\right) \frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha}\right] \tag{I}$$

and

$$F_j - D_j = \left[\left(f_i^\alpha - d_i^\alpha\right) \frac{f_j^\beta - d_j^\beta}{f_i^\beta - d_i^\beta} + \left(f_i^\beta - d_i^\beta\right) \frac{f_j^\alpha - d_j^\alpha}{f_i^\alpha - d_i^\alpha}\right]. \tag{II}$$

Using *Axiom-1* we have: $\frac{F_i - D_i}{F_j - D_j} = \frac{F_j \frac{D_i}{D_j} - D_i}{F_i \frac{D_j}{D_i} - D_j} = \frac{D_i^2 (F_j - D_j)}{D_j^2 (F_i - D_i)} \Rightarrow$

$$\frac{F_i - D_i}{F_j - D_j} = \frac{D_i}{D_j} \tag{III}$$

Plugging back (I) and (II) into (III) yields

$$\frac{\left(f_j^\alpha - d_j^\alpha\right) \frac{f_i^\beta - d_i^\beta}{f_j^\beta - d_j^\beta} + \left(f_j^\beta - d_j^\beta\right) \frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha}}{\left(f_i^\alpha - d_i^\alpha\right) \frac{f_j^\beta - d_j^\beta}{f_i^\beta - d_i^\beta} + \left(f_i^\beta - d_i^\beta\right) \frac{f_j^\alpha - d_j^\alpha}{f_i^\alpha - d_i^\alpha}} = \frac{D_i}{D_j} \tag{IV}$$

Using *Axiom-2*, we can rewrite (IV) as follows:

$$\frac{\frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha} \left(\left(f_j^\alpha - d_j^\alpha\right) + \left(f_j^\beta - d_j^\beta\right)\right)}{\frac{f_j^\alpha - d_j^\alpha}{f_i^\alpha - d_i^\alpha} \left(\left(f_i^\alpha - d_i^\alpha\right) + \left(f_i^\beta - d_i^\beta\right)\right)} = \frac{D_i}{D_j}$$

Then $\frac{\left(f_i^\alpha - d_i^\alpha\right)^2 (F_j - D_j)}{\left(f_j^\alpha - d_j^\alpha\right)^2 (F_i - D_i)} = \frac{D_i}{D_j}$. From (III) we get $\left(\frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha}\right)^2 = \left(\frac{D_i}{D_j}\right)^2$. It follows that:

$$\frac{f_i^\alpha - d_i^\alpha}{f_j^\alpha - d_j^\alpha} = \frac{D_i}{D_j}. \tag{V}$$

$(V) \Rightarrow \left(f_i^\alpha - d_i^\alpha\right) D_j = D_i \left(f_j^\alpha - d_j^\alpha\right)$. By feasibility we have $f_j^\alpha - d_j^\alpha = 1 - f_i^\alpha - d_j^\alpha$. Following some manipulations regrouping the disagreement points finally yields

$$f_i^\alpha = d_i^\alpha + \frac{D_i\left(1 - D^\alpha\right)}{D_i + D_j} = g_i^\alpha$$

■

Appendix B

Given any 2×2 problem, let F be a solution satisfying axioms 3 and 4.

By *Axiom-4* we have $\frac{a_i^\alpha - f_i^\alpha}{a_j^\alpha - f_j^\alpha} = \frac{a_i^\beta - f_i^\beta}{a_j^\beta - f_j^\beta} \Leftrightarrow \frac{1-d_j^\alpha - f_i^\alpha}{1-d_i^\alpha - f_j^\alpha} = \frac{1-d_j^\beta - f_i^\beta}{1-d_i^\beta - f_j^\beta}$. Then $f_i^\alpha = a_i^\alpha - \left(f_j^\alpha - a_j^\alpha\right)\frac{f_i^\beta - a_i^\beta}{a_j^\beta - f_j^\beta}$. It follows that $F_i = f_i^\alpha + f_i^\beta = a_i^\alpha + a_i^\beta + a_j^\alpha\left(\frac{f_i^\beta - a_i^\beta}{a_j^\beta - f_j^\beta}\right) + a_j^\beta\left(\frac{f_i^\alpha - a_i^\alpha}{a_j^\alpha - f_j^\alpha}\right) - f_j^\alpha\left(\frac{f_i^\beta - a_i^\beta}{a_j^\beta - f_j^\beta}\right) - f_j^\beta\left(\frac{f_i^\alpha - a_i^\alpha}{a_j^\alpha - f_j^\alpha}\right)$. Rearranging terms we get

$$F_i - (2 - D_j) = (F_j - (2 - D_i))\left(\frac{a_i^\alpha - f_i^\alpha}{a_j^\alpha - f_j^\alpha}\right).$$

Therefore,

$$\frac{F_i - (2 - D_j)}{F_j - (2 - D_i)} = \left(\frac{a_i^\alpha - f_i^\alpha}{a_j^\alpha - f_j^\alpha}\right). \tag{I}$$

Axiom-3 indicates that $\frac{F_i}{F_j} = \frac{2-D_j}{2-D_i}$. Plugging back into (I) the values for F_i and F_j, we get

$$\frac{F_i - (2 - D_j)}{F_j - (2 - D_i)} = \frac{F_j\frac{2-D_j}{2-D_i} - (2 - D_j)}{F_i\frac{2-D_i}{2-D_j} - (2 - D_i)}.$$

It follows that

$$\frac{F_i - (2 - D_j)}{F_j - (2 - D_i)} = \frac{2 - D_j}{2 - D_i}.$$

Then from (I):

$$\frac{a_i^\alpha - f_i^\alpha}{a_j^\alpha - f_j^\alpha} = \frac{2 - D_j}{2 - D_i} \tag{II}$$

(II) implies that $f_i^\alpha = a_i^\alpha - a_j^\alpha\frac{2-D_j}{2-D_i} + \frac{2-D_j}{2-D_i} - f_i^\alpha\frac{2-D_j}{2-D_i}$. Replacing a_i^α by $1 - d_j^\alpha$, and a_j^α by $1 - d_i^\alpha$, and rearranging terms yields

$$f_i^\alpha = d_i^\alpha + \frac{2 - D_i}{2 - D_i + 2 - D_j}(1 - D^\alpha) = h_i^\alpha$$

■

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General conclusion

This dissertation emphasized the importance of integrating the spatial, economic and political dimensions of global environmental policies. The context of global environmental governance is one characterized by the lack of supra-national authority as it has been discussed in this thesis. However, knowing this fact is not enough to fully understand how environmental issues are being tackled on the international level. Indeed, I have shown in this work that without careful consideration of linkages, stakeholders will be missing relevant information partially obscuring their analysis. Opening the "black boxes" of linkages between environmental and trade issues is one effort that helps clarify both the constraints and opportunities that arise in the design of global environmental policy. As a matter of fact, the lack of a coherent structure governing the international environmental agreements (IEAs) that have multiplied over the years in a disordered fashion mars today's debate on global environmental governance. Two main lines of thought have emerged advocating the linking of issues as a potential proxy for the lack of a supra-national regulatory authority. The first one indicates the need to establish a new 'World Environment Organization' modeled along the lines of the existing World Trade Organization (WTO) with its own dispute body in charge of applying rules and regulations and arbitrating potential international environmental disagreements. A second and more realistic approach, recently emphasized by Joseph Stiglitz, advocates the efficient integration of past IEAs into the WTO framework, which proved its merit along with its trade 'Dispute Settlement Body'. The merits on this view were outlined by the genetically modified organism (GMOs) lawsuit against the EU. Indeed, in 2003, The United States, Canada, and Argentina, all large producers of GMOs, filed a lawsuit at the WTO court in Geneva against the EU for imposing a ban on the import of GMOs. In September 2006, the court ruled in favor of the plaintiffs demonstrating the efficiency of such mechanism. These proposals for the future design of global environmental governance focus on linking environmental to other trade or economic issues. Thus, such proposals indicate that policymakers actually deal with environmental disputes and negotiations within a comprehensive rather than a standalone setting.

The main lesson learned from this dissertation is that focusing on linkages in environmental economics can help sharpen our understanding of the context of the environmental problems we face and the effects this can have on the failure/success of environmental regulation. The aim would be the implementation of better policies that take a more holistic approach. Given the models introduced in this work, one can notice that specific theoretical and applied extensions are warranted. Mainly, it is interesting to expand modeling other type of linkages like political pressure on the length of commitment to abate pollution in IEAs given different pollution stock levels. This will require the use of a dynamic setting, which is now the case of the nascent literature on dynamic IEA models. Moreover, although mostly theoretical, this work included some empirical components. With this in mind, I wish to explore to what extent the recommendations I derive can be used in future designs of international environmental policy. And, since part of this work includes axiomatic constructs, I indent to measure how viable these methods are in practice by working on deriving more general axioms in the context of linked bargaining. Another path is to continue working on 'spatial' economics. The explicit integration of spatial variables is recently becoming in vogue and for good reasons knowing that all environmental externalities are generated within a spatial context. I find that there's a lot to be done in this field and certainly there's room for theoretical contributions. Finally, working on this dissertation allowed me to mature as a researcher and an economist interested in environmental economics and more generally in resource economics.