An International Trade Network Analysis of the Environment

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Abstract

The paper uses the new advances of the International Trade Network literature to analyze the relationship between international trade and the environment in a global context. This framework shows that bilateral agreements can either increase or decrease local pollution depending on the current trade network structure, and that the environment is benefited when there is some degree of international trade integration. The article also shows that the stability of the international trade system is strongly affected when environmental considerations are included in the welfare function.

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1. Introduction

The research studying the relationship between international trade and the environment is heterogeneous. In general terms, the existing studies can be classified according to four main dimensions. The first one corresponds to the type of environmental damage which includes global warming, habitat destruction and species extinction, and industrial pollution (Copeland and Taylor, 2004). The second dimension is related to the type of market structure which includes both competitive and oligopolistic markets (see, for instance, Polasky *et al.*, 2004, and Regibeau and Gallegos, 2004). The third dimension corresponds to the type of international agreement that countries are supposed to have. In most of the cases, researchers consider two countries in autarky signing a bilateral agreement with each other (Polasky *et al.*, 2004, Smulders *et al.*, 2004, and Regibeau and Gallegos, 2004). Finally, the fourth dimension is related to specific mechanisms for which free trade affects the environment. Researchers have considered four effects arising from these mechanisms: (1) the scale effect; (2) the technique effect; (3) the composition effect; and (4) the strategic behavior effect. The scale effect corresponds

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to the negative environmental consequences of the increase in the economic activity due to trade liberalization (Barbier, 2004, and Karp *et al.*, 2003). The technique effect, on the other hand, corresponds to the environmental improvement originated from the adoption of cleaner technologies when income increases as a consequence of trade liberalization. This idea has been analyzed considering the Porter hypothesis and the Kuzness curve (Chintrakarn and Millimet, 2006, and Campbell, 2003). The composition effect corresponds to the increase of the concentration of polluting industries in some countries as a consequence of the specialization stimulated by trade liberalization. This effect relies on what is called the Pollution Haven hypothesis (Ederington *et al.*, 2004, and Copeland and Taylor, 2004). Finally, the strategic behavior effect studies the effect of trade liberalization on the strategic behavior of governments in terms of establishing environmental regulations (Regibeau and Gallegos, 2004, and Burguet and Sempere, 2003). Researchers normally choose one aspect of each dimension to analyze a particular feature of the complex interaction between international trade and the environment.

The objective of this paper is to expand these research possibilities by introducing a new dimension which, to the best of our knowledge, has not been considered so far: the relationship between environmental considerations and the international trade system as a whole. Introducing this dimension is important for several reasons. First, the related research analyses the case in which two countries pass from autarky to free trade by forming a bilateral agreement with each other (*i.e.* the autarky tradition). However, from an international network point of view, this is only one possibility of many. In fact, a country can also sign an additional international agreement when having, *ex-ante*, a large number of existing agreements, and there is no any reason to assume that the results obtained in this case are the same than those obtained when assuming countries in autarky. Thus, analyzing the relationship between international trade and the environment from a global perspective can provide the contexts in which the results obtained by the traditional research hold. Second, the introduction of a framework representing the international trade system not only can be used to determine the effects of trade liberalization on the environment as the related research normally does, but also to analyze the effects of environmental considerations on the architecture and stability of the whole international trade network. In fact, there are few contributions studying the effects of environmental damage on trade, and this is what makes our framework a useful extension to fill this gap. Third, the introduction of a framework representing the international trade system can be used to determine the stability of some relevant international trade structures such as global free trade. This is interesting because one of the objectives of the World Trade Organization (WTO) is to stimulate international trade. Thus, the research that is proposed in this paper can contribute to the spirit of the WTO by determining under which conditions global free trade is consistent with the incentives of countries in a world where firms generate environmental damage. Finally, our framework can be used to identify a subset of international trade networks that are relatively less polluting. If these networks are not stable, then we can use this framework to design political instruments that could be used to reach and stabilize these desirable networks.

In order to analyze environmental issues in terms of the international trade system, this article uses the new advances of the international social network literature. In particular, it considers the basic international social network model (ISN) of Goyal and Joshi (2006) and the stability concept proposed by May (2008). The paper introduces the ISN model by studying a simple case based on the following combination of dimensions: (i) local pollution; (ii) oligopolistic markets; (iii) bilateral agreement; (iv) the scale effect; and (v) the relationship between local pollution and the international trade network system. This benchmark setting can be extended by introducing other environmental considerations such as global warming, loss of biodiversity, the composition effect, the technique effect, or the strategic behavior effect. We leave all these important extensions for future research.

The paper is organized as follows. Section 2 presents the ISN model. Sections 3 and 4 analyze the relationship between international trade and the environment under the assumption of exogenous and endogenous tariffs, respectively. Section 5 provides some comments on the assumptions and policy implications of the model. Finally, section 6 concludes the paper.

2. The ISN model with local pollution

2.1. The basic ISN model (Goyal and Joshi, 2006)

The ISN model of Goyal and Joshi (2006) is presented as follows: an international agreement between countries i and j is described by a link, given by a binary variable $g_{ij} \in \{0,1\}$. If $g_{ij} = 0$, then no agreement exist between countries i and j. If $g_{ij} = 1$, then an agreement exists between them. A network $g \in \{(g_{ij})_{ij \in \mathcal{N}}\}$ is a description of the international agreements that exist between the countries in $\mathcal{N}$, where $\mathcal{N} = \{1, 2, ..., N\}$ is the set of identical countries, and N is the total number of countries. Network g^c is the complete network ($g_{ij} = 1 \; \forall \, i,j \in \mathcal{N}$) and corresponds to global free trade, and network g^e is the empty network ($g_{ij} = 0 \; \forall \, i,j \in \mathcal{N}$) and corresponds to the network in which all countries are in autarky. Let G denote the set of all possible networks of international agreements between countries. Let $Ni(g) = \{j \in \mathcal{N} : g_{ij} = 1\}$ be the set of countries with whom country i has an international trade agreement in network g. Assume that $i \in Ni(g)$. That is, $g_{ii} = 1$. The cardinality of $Ni(g)$ is denoted by $\eta_i(g)$. In this model $\eta_i(g)$ is also the number of active firms in country i and in network g because of the assumption that each country has only one firm. Let $L_i(g) = \{(g_{ij})_{ij \in \mathcal{N}}\} : j \in Ni(g)\}$ be the set of links existing in country i in network g. Note that $g_{ii} \in L_i(g)$. Let $h_i \subset L_i(g) - \{g_{ii}\}$ be a link subset, and let μ_i be the cardinality of h_i. Finally, let $W_i(g)$, $CS_i(g)$, $\pi_i(g)$ and $TR_i(g)$ be welfare, consumer surplus, total profit and tariff revenue, respectively, in country i and in network g.

In this article we introduce the following weighted welfare function when domestic firms generate local pollution:

$$W_i(g) = a_i CS_i(g) + b_i(g) \pi_i(g) + c_i TR_i(g) - \theta_i \Omega_i (E^i(g)) \tag{1}$$

where $E^i(g)$ denotes total emission; $\Omega_i(E^i(\mathrm{g}))$ is the environmental damage caused by the local pollution emitted by the domestic firm of country i in network g; and a_i, b_i, c_i and θ_i are exogenous weights that the government puts on consumer surplus, total profits, tariff revenue and environmental damage, respectively.

2.2. Market structure (Goyal and Joshi, 2006)

Assume a lineal inverse demand given by $P_i(g) = \alpha_i - Q_i(g)$, where $P_i(g)$ is the price of the homogeneous good in the domestic market of country i and in network g, α_i represents the size of this market, and $Q_i(g)$ is the total output demanded in this country in network g. Let γ_i be the marginal cost of the firm of country i. Assume that countries are symmetrical (*i.e.*, $\alpha_i = \alpha$ and $\gamma_i = \gamma$ for all $i \in \mathcal{N}$) and that $\alpha - \gamma = 1$. In this model it is assumed that firms play Cournot in each market where they compete.

Under the assumption of exogenous tariffs (*i.e.* prohibitive tariffs), the output of equilibrium that is produced by the firm of country i in the domestic market and in network g is $Q_{ii}(g) = 1/(\eta_i(g) + 1)$, and the total output of equilibrium in this market is given by $Q_i(g) = \eta_i(g)/(\eta_i(g) + 1)$. Likewise, the output of equilibrium produced by the firm of country i and that is sold in country j and in network g is $Q_{ij} = 1/(\eta_j(g) + 1)$. Finally, the total output produced by the domestic firm of country i is $Q^i(g) = \sum_{j \in Ni(g)} Q_{ij}(g)$. From these definitions, it is possible to obtain the following expressions for consumer surplus and profit made by firm i in country j, respectively: $CS_i(g) = Q_i(g)^2/2 = \eta_i(g)^2/2(\eta_i(g) + 1)^2$; and $\pi_{ij}(g) = (P_j(g) - \gamma)Q_{ij}(g) = 1/(\eta_j(g) + 1)^2$. Finally, the total profit that the firm of country i makes in network g is: $\pi_i(g) = \sum_{j \in Ni(g)} \pi_{ij}(g)$.

Let's now assume endogenous tariffs. Let $T_{ij}(g)$ be the tariff faced by country i in country j and in network g. Because both $T_{ij}(g) = T_{ji}(g) = 0$ for all $j \in Ni(g)$ and $Q_{ki}(g) = Q_{li}(g)$ for all $k, l \notin Ni(g)$, it holds that $T_{ki}(g) = T_i(g)$ for all $k \notin Ni(g)$. The Cournot equilibrium outputs in the domestic market of country i are: (i) $Q_{ji}(g) = [1 + (N - \eta_i(g))T_i(g)]/(N + 1)$ for all $j \in Ni(g)$; and (ii) $Q_{ki}(g) = [1 - (\eta_i(g) + 1)T_i(g)]/(N + 1)$ for all $k \notin Ni(g)$. From these expressions we obtain: $CS_i(g) = [N - (N - \eta_i(g))T_i(g)]^2/2(N + 1)^2$; $\pi_{ij}(g) = [1 + (N - \eta_j(g))T_j(g)]^2/(N + 1)^2$ for all $j \in Ni(g)$; $\pi_{ik}(g) = [1 - (\eta_k(g) + 1)T_k(g)]^2/(N + 1)^2$ for all $k \notin Ni(g)$; and $TR_i(g) = \{(N - \eta_i(g))T_i(g)[1 - (\eta_i(g) + 1)T_i(g)]\}/(N + 1)$. Finally, the total profit that the firm of country i makes in network g is: $\pi_i(g) = \sum_{j \in Ni(g)} \pi_{ij}(g) + \sum_{k \notin Ni(g)} \pi_{ik}(g)$.

2.3. Local pollution and welfare

In this setting the total emission generated by the domestic firm of country i in network g, $E^i(g)$, is equal to the sum of the emissions generated by the production of the outputs that are exported to the domestic markets of the countries $j \in Ni(g)$. We call each of these emissions the single emission. That is, $E^i(g) = \sum_{j \in Ni(g)} E_{ij}(g)$, where $E_{ij}(g)$ is the single emission generated by the production of the output destined to country j, $Q_{ij}(g)$. We also assume that $E_{ij}(g)$ is proportional to $Q_{ij}(g)$ (Regibeau and Gallegos, 2004, and Damania *et al.*, 2003). In other words, $E_{ij}(g) = \lambda Q_{ij}(g)$ for all $j \in Ni(g)$. By normalizing $\lambda = 1$, the total emission is defined as: $E^i(g) = \sum_{j \in Ni(g)} Q_{ij}(g)$.

On the other hand, we assume that the environmental damage is an increasing and convex function of each single emission (Burguet and Sempere, 2003). This assumption is captured in our setting in the following quadratic expression: $\Omega_i(E^i(g)) = \sum_{j \in Ni(g)} Q_{ij}(g)^2 = \sum_{j \in Ni(g)} 1/(\eta_j(g)+1)^2$. Finally, global environmental damage in network g is defined as $\Omega(g) = \sum_{i \in \mathcal{N}} \Omega_i(E^i(g))$.

From the expressions derived in section 2.2, if tariffs are exogenous, welfare becomes:

$$W_i(g) = a_i \frac{1}{2} \frac{\eta_i(g)^2}{(\eta_i(g)+1)^2} + (b_i - \theta_i) \sum_{j \in Ni(g)} \frac{1}{(\eta_j(g)+1)^2} \tag{2}$$

On the other hand, if tariffs are determined endogenously, welfare becomes:

$$\begin{aligned} W_i(g) = {} & a_i \frac{1}{2} \left[\frac{N-(N-\eta_i(g))T_i(g)}{N+1} \right]^2 + c_i (N-\eta_i(g)) T_i(g) \left[\frac{1-(\eta_i(g)+1)T_i(g)}{N+1} \right] \\ & + (b_i - \theta_i) \left\{ \sum_{j \in Ni(g)} \left[\frac{1-(N-\eta_j(g))T_j(g)}{N+1} \right]^2 + \sum_{k \notin Ni(g)} \left[\frac{1-(\eta_k(g)+1)T_k(g)}{N+1} \right]^2 \right\} \end{aligned} \tag{3}$$

2.4. Stability (May, 2008)

May (2008) proposes the use of *strongly pairwise stability* to study international trade networks.[1] Formally, strongly pairwise stability is defined as follows: (a) the marginal benefit of country i when deleting at the same time $h_i \subset L_i(g) - \{g_{ii}\}$ international agreements is: $D_i(g, h_i) = W_i(g) - W_i(g - h_i)$; (b) a network $g \in G$ is *strong link deletion proof* if for every player $i \in \mathcal{N}$ and every $h_i \subset L_i(g) - \{g_{ii}\}$ it holds that $D_i(g, h_i) \geq 0$; and (c) a network $g \in G$ is *link addition proof* if for all $i,j \in \mathcal{N}$: $W_i(g + g_{ij}) > W_i(g)$ implies that $W_j(g + g_{ij}) < W_j(g)$. A network $g \in G$ is *strongly pairwise stable* if g is strong link deletion proof as well as link addition proof.

3. Exogenous tariffs

This section analyzes two main issues under the assumption of exogenous tariffs: (*i*) the effects of bilateral agreements on the environment; and (*ii*) the effects of including environmental damage in the welfare function on the international trade system.

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[1] The original ISN model of Goyal and Joshi (2006) considers pairwise stability. Unfortunately this equilibrium concept is not suitable to study international trade networks because it uses the unrealistic assumption that countries can only break one agreement at a time. On the contrary, strongly pairwise stability allows countries to break multiple links simultaneously.

3.1. The effects of bilateral agreements on the environment

It is recognized the fact that when two countries in autarky form a bilateral agreement, the domestic output produced in each of them increases. This is accompanied by an increase in the emission of local pollution. This result has been used to argue that bilateral agreements damage the environmental. For example, Burguet and Sempere (2003) argue:

> *"As a result of a reduction in tariffs one would expect total output in each country to increase. This means higher marginal damage to the environment and lower prices (p.26)."*

The following proposition shows that a bilateral agreement can also reduce the domestic output produced by one of the countries that participates in the agreement, as this result depends on the relative number of active firms existing in both partner countries:

Proposition 1. *If two countries, i and k, form a bilateral agreement with each other, and if* $\eta_k(g) > (\eta_i(g) + 1)(\eta_i(g) + 2) - 2$, *then the total output produced by the domestic firm of country i decreases after the agreement is signed.*

Proof. It has to be proved that $Q^i(g) > Q^i(g + g_{ik})$ holds when $\eta_k(g) > (\eta_i(g) + 1)(\eta_i(g) + 2) - 2$. Because $Q^i(g) = \sum_{j \in Ni(g)} Q_{ij}(g) = Q_{ii}(g) + \sum_{j \in Ni(g) - \{\mathrm{i}\}} Q_{ij}(g)$, and $Q^i(g + g_{ik}) = \sum_{j \in Ni(g + gik)} Q_{ij}(g + g_{ik}) = Q_{ik}(g + g_{ik}) + \sum_{j \in Ni(g + gik) - \{k\}} Q_{ij}(g + g_{ik}) = Q_{ii}(g + g_{ik}) + Q_{ik}(g + g_{ik}) + \sum_{j \in Ni(g) - \{\mathrm{i}\}} Q_{ij}(g)$, it holds that $Q^i(g) > Q^i(g + g_{ik})$ when $Q_{ii}(g) - Q_{ii}(g + g_{ik}) - Q_{ik}(g + g_{ik}) > 0$. Now, since $Q_{ii}(g) = 1/(\eta_i(g) + 1)$, $Q_{ii}(g + g_{ik}) = 1/(\eta_i(g) + 2)$ and $Q_{ik}(g + g_{ik}) = 1/(\eta_k(g) + 2)$, we conclude that $Q^i(g) > Q^i(g + g_{ik})$ when $\eta_k(g) > (\eta_i(g) + 1)(\eta_i(g) + 2) - 2$.

The intuition of this result is as follows. When countries *i* and *k* sign a bilateral agreement with each other, the domestic firm of country *i* suffers a loss of market power which implies a reduction of the quantum that is sold in the domestic market. That is, it always holds that $Q_{ii}(g) > Q_{ii}(g + g_{ik})$. May (2008) refers to this decrease of domestic output as the competition effect (CE). On the other hand, the agreement gives this firm the opportunity to export part of its production to the new partner country. That is, it is able to export $Q_{ik}(g + g_{ik})$ to country *k*. May (2008) refers to this market expansion as the expansion effect (EE). A bilateral agreement between countries *i* and *k* will reduce the total output produced in country *i* when the CE offsets the EE in this country, and this result depends on the relative number of active firms competing in each country.

A natural question arising from this result is whether a bilateral agreement can reduce the joined production of the domestic firms of the signatory countries. The answer to this question is given in the following proposition:

Proposition 2. *For all* $g - \{g^c\} \in G$ *it holds that* $Q^i(g) + Q^k(g) < Q^i(g + g_{ik}) + Q^k(g + g_{ik})$.

Proof. Note that $Q^i(g) + Q^k(g) - Q^i(g + g_{ik}) - Q^k(g + g_{ik}) = Q_{ii}(g) - Q_{ii}(g + g_{ik}) - Q_{ik}(g + g_{ik}) + Q_{kk}(g) - Q_{kk}(g + g_{ik}) - Q_{ki}(g + g_{ik}) = 1/(\eta_i(g) + 1) - 2/(\eta_i(g) + 2) + 1/(\eta_k(g) + 1) - 2/(\eta_k(g) + 2) = -\eta_i(g)/[(\eta_i(g) + 1)(\eta_i(g) + 2)] - \eta_k(g)/[(\eta_k(g) + 1)(\eta_k(g) + 2)] < 0$. But this implies that $Q^i(g) + Q^k(g) < Q^i(g + g_{ik}) + Q^k(g + g_{ik})$.

According to this proposition, even when a bilateral agreement can reduce the domestic production of a country, the joined output produced by the domestic firms of the signatory countries increases. Note, however, that this result does not imply that international trade is associated with larger global production. The reason is due to the fact that bilateral agreements do also reduce the output of third countries, a result that we have called the externality effect (EXE). As an example, suppose that countries i and j have an agreement with each other. If countries i and k decide to form a bilateral agreement, then the domestic market of country i becomes more competitive affecting negatively the profitability of country j. As a result, the latter country reduces its domestic production. This externality effect on third countries is what explains why global free trade is not really the network having the largest global production. To see that, let us consider the following example. Let g be a network such that for all countries $j,k \in \mathcal{N} - \{i\}$, $g_{jk} = 0$ (i.e., countries different from i do not have an agreement with each other), and $g_{ij} = 1$ for all $j \in \mathcal{N} - \{i\}$ (i.e. all countries of the world have an agreement with country i). It is straightforward to show that the global output produced in network g is given by $Q(g) = (2N^2 + 3N - 2)/3(N + 1)$. Since the global output produced in network g^c is $Q(g^c) = N/(N + 1)$, it is concluded that $Q(g) > Q(g^c)$ for all $N > 1$.

What are the consequences of these changes of domestic output on the environmental damage generated by the emission of local pollution? The answer is obvious: it depends on how we model the environmental damage generated by this local pollution. In particular, if we assume that the environmental damage is an increasing monotonic function of the total output produced in a country, then the same results given in Proposition 1 hold: depending on the international trade network structure, a bilateral agreement can either increase or decrease the environmental damage generated by the emission of local pollution in one of the partner countries. As a consequence, we argue that the results provided by some related researches under the autarky tradition must be considered with caution because they only hold in some particular contexts of the international trade system.

On the other hand, we could argue from propositions 2 that bilateral agreements damage the environment in the aggregate because the joint domestic production of the signatory countries always increases. However, we explain above that this outcome is influenced by the EXE for which global free trade is not necessarily the most polluting network. In order to illustrate this fact, let us consider the following concept. Let $\Delta(\xi(g)) \subset \mathcal{N}$ be a subset of countries of size $\xi(g) \geq 1$ in network g. We say that a block $\Delta(\xi(g))$ is exclusive when: (i) for all $i,j \in \Delta(\xi(g))$ it holds that $g_{ij} = 1$; and (ii) if $i \in \Delta(\xi(g))$ and $k \notin \Delta(\xi(g))$, then $g_{ik} = 0$. We show in the following proposition that global free trade is the less polluting network among the networks in which countries are organized in exclusive blocks.

Proposition 3. *Among the networks in which countries are organized in exclusive blocks of free trade, the complete network is the less polluting network.*

Proof. The total environmental damage generated by the domestic firm of country $i \in \Delta(\xi(g))$ is: $\Omega_i(E^i(g)) = \xi(g)/(\xi(g) + 1)^2$. On the other hand, $\Omega_i(E^i(g^c)) = N/(N+1)^2$. From these definitions we conclude that $\Omega_i(E^i(g)) > \Omega_i(E^i(g^c))$ when $(N - \xi(g))(N\xi(g) - 1) > 0$, which holds for all $N > \xi(g)$. Finally, because the size of the block is arbitrary, we conclude that g^c is the less polluting international networks among the networks in which countries are organized in exclusive blocks of free trade.

The results shown in this section provide an important lesson. That is, the fact that a particular bilateral agreement increases the environmental damage does not mean that international trade is bad for the environment. What really matters is the international network context in which this bilateral agreement is signed. In this context, the externality effect plays an important role in reducing the global environmental damage. To the best of our knowledge, this result has not been reported as most of the related investigations consider two isolated countries forming a bilateral agreement.

3.2. The effects of environmental considerations on the trade system

This part considers a particular case in terms of the weights that governments put on the components of the welfare function given in equation 2. The objective of introducing this simplification is to illustrate the main idea of this novel research without complicating the model in excess: environmental considerations can strongly affect the stability of the international trade system.

Proposition 4. *If $b_i = \theta_i$ in the welfare function, then the unique strongly pairwise stable network is the complete network.*

Proof. If $b_i = \theta_i$, then equation 2 becomes $W_i(g) = a_i CS_i(g)$. Now, because $\partial CS_i(g)/\partial \eta_i(g) = \eta_i(g)/(\eta_i(g) + 1)^3 > 0$, we conclude that $D_i(g, h_i) > 0$ for all $h_i \in L_i(g) - \{g_{ii}\}$ and all $g \in G - \{g^c\}$. But this implies that the unique strongly pairwise stable network is g^c.

This result is interesting for three reasons. First, it proves that incorporating environmental consideration in the welfare function can strongly affect the stability of the whole international trade system. To see that, note that when the environmental damage is omitted (*i.e.* $\theta_i = 0$) and when $b_i > a_i$, global free trade is not stable (Proposition 1 of May 2008). The reason is due to the fact that domestic firms have always an incentive to deviate from g^c. This is because there always exists a subset of links $h_i \in L_i(g) - \{g_{ii}\}$ such that $\pi_i(g^c - h_i) > \pi_i(g^c)$ (*i.e.* the CE dominates the EE). On the contrary, when $b_i = \theta_i$, the positive effect on total profit that is verified when deviating from network g^c to network $g^c - h_i$ is fully compensated by the negative effect of this deviation on the environment affecting the stability of the whole trade system. In this case the relevant variable that the government considers in the welfare function is consumer surplus. Because this latter always increases when countries sign additional agreements, governments will sign international agreements until global free trade is reached.

Second, this result is an example of the compatibility of international trade and the environment. That is, because global free trade is not the most polluting network for the case of exogenous tariffs (see Proposition 3), the stability of g^c can be seen as a beneficial and ensured outcome arising when governments care about the environment.

Finally, the reason for which governments sign additional agreements in this case is not related to corruption and political bias as can be inferred from the discussion given above. As a result, we cannot support the argument explaining that corrupted governments have incentives to form international agreements when there are environmental externalities (Barbier, 2004, and Damania *et al.*, 2003). While this argument holds for some types of environmental damages, this is not an appropriate explanation for the example provided in this paper.

4. Endogenous tariffs

Unfortunately, we were unable to provide a general analysis for the case of endogenous tariffs because the model becomes untractable in mathematical terms, a fact that has formally recognized by Goyal and Joshi (2006):

> *" Given the complexity of the computations involved, we have been unable to completely characterize the nature of stable networks in this setting (p.768)."*

Nonetheless, it is still possible to show that some of the results obtained for the case of exogenous tariffs hold by using simulations under the assumption that $a_i = b_i = \theta_i = 1$. In this case, welfare becomes:

$$W_i(g) = \frac{1}{2}\left[\frac{N-(N-\eta_i(g))T_i(g)}{N+1}\right]^2 + c_i(N-\eta_i(g))\,T_i(g)\left[\frac{1-(\eta_i(g)+1)T_i(g)}{N+1}\right] \qquad (4)$$

It is easy to show that $\partial W_i(g)/\partial T_i(g) > 0$ and that $\partial^2 W_i(g)/\partial T_i(g)^2 < 0$ for $c_i > N/(N+1)$. This implies that the tariff that maximizes welfare in country i is:

$$T_i^*(g) = \frac{c_i(N+1)-N}{2(\eta_i(g)+1)(N+1)\,c_i-(N-\eta_i(g))} \qquad (5)$$

To avoid having negative tariffs, it is assumed: (1) $T_i^*(g) > 0$ for all $c_i > N/(N+1)$; and (2) $T_i^*(g) = 0$ for all $c_i \leq N/(N+1)$.

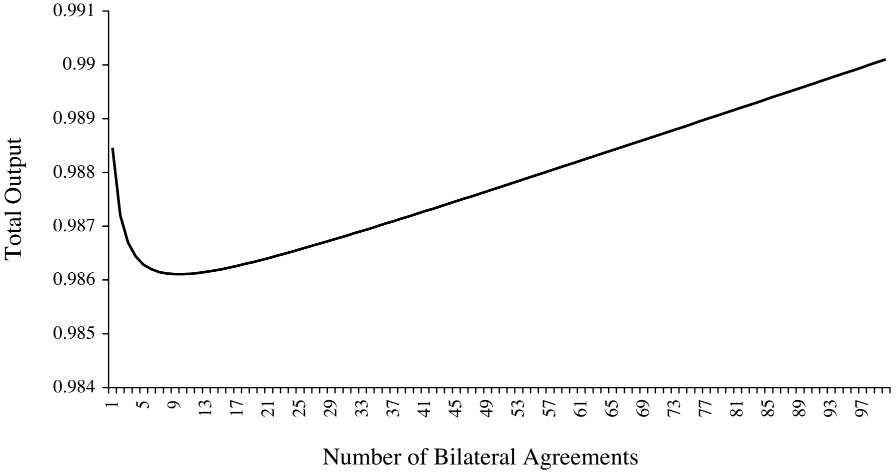
4.1. The effects of bilateral agreements on the environment

In order to show that a bilateral agreement can reduce local pollution depending on the international trade structure, we consider a network in which all countries $j,k \in \mathcal{N} - \{i\}$ have an agreement with one another, but country i is connected only with some of them. Assume additionally that $c_i = 1$. From the expressions derived in section 2.2, the total output produced by the domestic firm of country *i* in network *g* is:

$$Q^i(g) = Q^i_i(g) + \sum_{j\in N_i(g)-\{i\}} Q^i(g) + \sum_{k\notin N_i(g)} Q^i(g) = \frac{(N-\eta_i(g))\,(T_i(g)-NT_k(g))+N}{N+1} \qquad (6)$$

where $T_k(g)$ is the tariff that country *i* faces in country $k \notin N_i(g)$. From equation 5, we derived expressions for $T_i(g)$ and $T_k(g)$. Using these expressions and equation 6, and assuming $N = 100$, we developed a simulation with the objective to determine the effects of increasing the number of bilateral agreements on the total output produced by the domestic firm of country *i*. The simulation is shown in Figure 1:

Figure 1: Effect of increasing the number of agreements on the total output of country *i*



According to Figure 1, when the number of agreements is smaller (larger) than 10, signing a bilateral agreement reduces (increases) the total output produced by this firm, and so the environmental damage when this is an increasing function of total output. This implies that depending on the current international trade structure, a bilateral agreement can either benefit or damage the environment.

On the other hand, we explain in section 3.2 that most of the related researches analyze the case in which two countries in autarky form a bilateral agreement. The main conclusion is that these agreements increase local pollution because they increase the domestic output of the signatory countries. However, Figure 1 shows that when a country in autarky (country *i*) forms a bilateral agreement with another country having ex-ante a significant number of international agreements, the domestic output of the former decreases. As a result of this opposite outcome with respect to the traditional research, we argue that political generalizations should be considered with caution, as they depend on the context of the current international trade system.

On the other hand, Figure 1 shows that the most polluting network for country i (*i.e.* the network in which the domestic output in country i is the largest) is the complete network. But this holds only when considering the set of networks in which all countries other than country i have an agreement with one another. Nevertheless, there are less integrated networks that generate more local pollution in this country than the complete network. As an example, consider a particular network g in which $g_{ij} = 1$ for all $j \in \mathcal{N}$, and $g_{jk} = 0$ for all $j,k \in \mathcal{N} - \{i\}$. That is, this is the network in which country i has an agreement with all countries of the world, but the remaining countries $j \neq i$ do not have an agreement with one another. Because $Q^i(g) = \{1 + (N-1)[1 + (N-2)T_k(g)]\}/(N+1)$ and $Q^i(g^c) = N/(N+1)$, as it can be inferred from the definitions given in section 2.2, we conclude that $Q^i(g) > Q^i(g^c)$ for all $N > 2$ and all $T_k(g) > 0$. But this implies that $\Omega_i(E^i(g)) > \Omega_i(E^i(g^c))$ which confirms the statement arguing that g^c is not the most polluting network for country i.

4.2. The effects of environmental considerations on the trade system

Figure 2 uses the same example given in subsection 4.1 to simulate the effects of bilateral agreements on welfare of country i. This simulation assumes unbiased countries ($a_{\mathrm{i}} = b_i = c_i = \theta_i = 1$) and $N = 100$.

Figure 2: Welfare effects of bilateral agreements: the case of unbiased governments

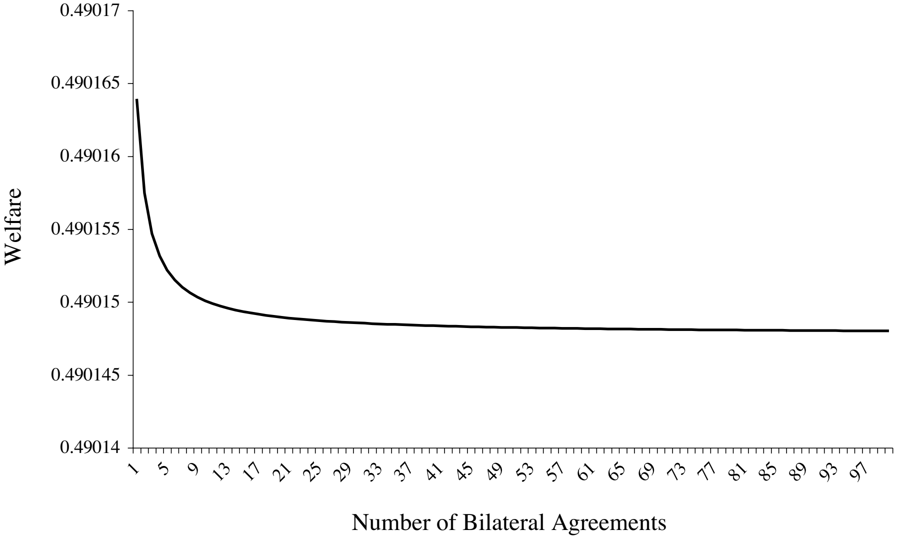


Figure 2 shows that global free trade is not stable as $W_i(g^c - h_i) > W_i(g^c)$ for all $h_i \in L_i(g) - \{g_{ii}\}$. This happens because tariff revenue has a strong influence on welfare. That is, because governments can only obtain tariff revenue when the world is not in the complete network, they have an incentive to deviate from global free trade. Nonetheless, our simulations show that the stability of the network system is strongly affected by governments' biases. For example, it can be shown that when c_i is lightly smaller than 1 (*e.g.*, $c_i = 0.99$), global free trade is stable.

5. Comments on the assumptions and policy implications

It is important to bear in mind that our results and the associated political implications depend on the assumptions of the model used in the article: (*i*) homogeneous goods; (*ii*) symmetric countries; and (*iii*) homogeneous governments' biases. Nonetheless, even when our framework is bounded by these assumptions, it constitutes a first building step toward a more general analysis of the complex relationship between international trade and the environment. A possible extension is the introduction of heterogeneous goods in the ISN model. This is particularly interesting to study the architecture of the trade network when some differentiated goods are produced with cleaner technologies. Perhaps a suitable framework to introduce this extension is the ISN model of Furusawa and Konishi (2007) which considers a more general market structure. On the other hand, the introduction of asymmetry in terms of market size, marginal cost and governments' biases can strongly affect the architecture of the network and the associated political implications. In fact, it is possible to show that under asymmetry, some networks are less polluting than both the complete and the empty network. This can be seen in the following simple example. Consider a world formed of four countries i, j, k and l in which tariffs are determined endogenously. Assume both that country i has a small domestic market and that its government is biased in favor of the domestic firm. In particular, assume: (1) $\alpha - \gamma = 0.8$ for i and $\alpha - \gamma = 1$ for j, k, l; and (2) $a_i = c_i = \theta_i = 0$ and $b_i = 1$ for i, and $a_j = b_{,} = c_j = \theta_j = 1$ for j, k, l. From the expressions provided in sections 2.2 and 2.3, and by noting that the optimal tariff for country i is the prohibitive tariff (*i.e.* the government of this country only cares about profits which is maximized in the domestic market under the prohibitive tariff), the global environmental damage in networks g^c and g^e are, respectively, $\Omega(g^c) = (N^2 - 0.36N)/(N + 1)^2 = 0.582$ and $\Omega(g^e) = 8/50 + [3(1 + 3T_k(g^c))^2]/(N + 1)^2 + [9(1 - 2T_k(g^c))^2]/(N + 1)^2 = 0.606$, where $T_k(g)$ is the tariffs in country k (see equation 5). Let g be the network in which country i has an agreement with countries j and l (*i.e.*, $g_{ij} = g_{il} = 1$ and $g_{ik} = g_{jl} = g_{jk} = g_{lk} = 0$). In this case $\Omega(g) = 3/25 + [4(1 + 2T_j(g))^2]/(N + 1)^2 + [3(1 - 2T_k(g))^2]/(N + 1)^2 + (1 + 3T_k(g))^2/(N + 1)^2 + [4(1 - 3T_j(g))^2]/(N + 1)^2 = 0.580$. Since in this example $\Omega(g^e) > \Omega(g^c) > \Omega(g)$, we conclude that under some types of asymmetry, only an intermediate degree of international integration can benefit the environment globally.

On the other hand, our results were derived from a partial equilibrium framework that considers oligopolistic markets. The introduction of perfect competition in a general equilibrium setting could extend our research to analyze the trade network system with pollution under the existence of comparative advantages. This can be used, for example, to determine whether the Pollution Haven hypothesis holds in some particular network structures. A model that considers a world formed of five countries having either different endowment of resources ore different property rights on some natural resources would be appropriated to explore this case.

It is difficult to determine an optimal environmental policy in this setting because a policy can also affect the stability of the international trade system. For example, a tax that is established with the objective to reduce pollution in the current network could eventually destabilize it, leading to another stable but dirtier network making this policy a useless tool. Thus, an effective environmental program would consist on a set of policies that could be used both to reduce pollution and to stabilize a desirable network. In this direction, May (2008) proved that it is possible to stabilize g^c in many situations by using transfer intranodes (*i.e.* domestic redistributive policies). A related approach could be considered in order to stabilize desirable networks. That is, an environmental policy could be used to reduce pollution in a convenient network, and a transfer could be used to stabilize this network and to neutralize the potential destabilizing effect of the environmental policy.

6. Conclusions and Remarks

The article introduces the new advances of the International Trade Network literature to analyze the complex relationship between international trade and local pollution. The most important results obtained from this framework when assuming exogenous tariffs are described as follows. First, bilateral agreements can either increase or decrease the domestic output produced in one of the signatory countries depending on the architecture of the current international trade system. This implies that if local pollution is an increasing function of the domestic output, then a bilateral agreement can either increase or decrease the associated environmental damage. Second, the joint total output produced by the domestic firms of two countries always increases when they form a bilateral agreement. However, bilateral agreements do also exercise an externality effect on third countries when decreasing the market power in the domestic markets of the signatory countries. This effect is sufficiently strong to make global free trade a less polluting network than less integrated ones such as the empty network. Third, when governments put the same weights on total profits and the environmental damage in the welfare function, global free trade is the unique stable network and this stability is not associated with the existence of corrupted governments.

The study partially extends the analysis for the case of endogenous tariffs by using a simulation that considers a subset of networks. The analysis was focused on the effects of bilateral agreements on both the environmental damage and welfare of a particular country. The following results were obtained. First, as in the case of exogenous tariffs, we found that depending on the current trade network, bilateral agreements can either increase or decrease the domestic output produced by this country. Second, from the perspective of this country, global free trade is the most polluting network among the networks used in the simulation. However, we also show that there are other more polluting networks than global free trade. Finally, we found that the stability of the trade system is strongly affected by the governments' biases.

The research also partially analyses the case of asymmetric countries. We found that under asymmetry in terms of market size and governments' biases, there exist networks different from both the complete and the empty network that produce less global environmental damage. Given this fact, we argue that it is more appropriate to say that international trade and the environment are compatible for some levels of international integration. It is for this reason that a statement arguing that international trade is either good or bad for the environment has to be considered under the context of the current international trade system.

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