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**The Role of Domestic Environmental Policies**

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# Abstract:

This paper uses a calibrated general-equilibrium model of North-South trade with carbon emissions to explore the strategic, open-economy implications of price and quantity based instruments for CO2 emission reduction. We compute non-cooperative environmental and trade policy equilibria and Nash bargaining outcomes in environmental policies with side payments of cash. Results show that quotas can lead to higher internalization levels in a non-cooperative zero-tariff equilibrium in comparison with emission fees. If tariffs are also chosen non-cooperatively, the form of policy instrument used affects equilibrium tariffs, with quotas leading to lower trade barriers, particularly under a regional carbon treaty.

Keywords:. International Free-Riding, Carbon Treaties, Tariff Wars.

*JEL* classification: Q3, Q4, F1.

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# Non-Technical Summary:

The choice of the most appropriate policy instrument to address environmental problems has been extensively debated by economists. Two broad approaches are usually distinguished: the incentive-based or price approach - which comprises policy instruments such as abatement subsidies and effluent charges - and the command-and-control or quantity approach - which comprises instruments such as processing standards and emission quotas and permits. Traditionally, this debate has focused on a closed-economy framework, where it has been argued that on economic efficiency grounds price instruments are superior to quantity instruments. Once the presence of trade flows and the possible use of trade-restricting policies are considered, however, the traditional ranking of environmental policy instruments may be altered.

This paper uses an applied general equilibrium model to compare the performance of different environmental policy instruments for CO2 emission reductions in an open-economy framework where countries might use trade restrictions as well as environmental restrictions in a strategic way. Countries are grouped in two blocs: OECD and non-OECD members. They can establish agreements on CO2 emission reduction either within a single bloc or - provided that each bloc has agreed a common position - between blocs. We also take account of the developed countries' higher valuation of CO2 emission reduction and the special nature of these emission - they deteriorate not only the environment of the emitting country but the global environment as well - a characteristic which gives rise to international free-riding in emission abatement. These features result in a higher degree of internalisation in the OECD bloc, and a strong tendency by non-OECD countries to free-ride. Consequently, an inter-bloc carbon treaty guaranteeing full internalisation of environmental emissions is mostly beneficial to OECD countries, and would only appeal to the South unless the North gives them some form of compensation in exchange.

Using this model, we find that if countries are unable to establish an agreement on emission reductions - either at a regional or inter-regional level - and can use trade-restrictive policies, each instrument's degree of correction (internalisation) of the environmental problem is very small, particularly for non-OECD members. When an intra-bloc agreement is implemented and countries are still able to use trade policy instruments, the degree of internalisation increases substantially, especially in the OECD bloc. In this scenario, the performance difference between emission quotas and taxes, in terms of their effects on global economic welfare is now significant and favourable to the former. The reason for this is that emission quotas lead to significantly lower levels of import tariffs, because they make export supply responses to changes in world commodity prices less elastic, and hence result in a less aggressive trade policy stance.

When countries cannot make use of trade policy instruments, the pattern of results described above remains basically unaltered. In this case, however, the degree of internalisation is much higher since, with direct instruments of trade policy being unavailable, countries use environmental policies as a substitute for trade policies in order to restrict imports. On the other hand, when trade policy instruments are not available and an intra or inter-bloc emission reduction agreement is in force, the difference in performance between emission quotas and taxes becomes very small but still favourable to a quota regime.

In conclusion, although in a closed-economy setting carbon taxes may be viewed as being superior to quotas or permits on efficiency grounds, when trade linkages and strategic trade responses are accounted for, the use of emission quotas, by promoting trade liberalization, could be preferable as a means of supporting a regional or global carbon treaty.

# 1 Introduction

This paper develops a calibrated model of North-South trade with carbon emissions to compare the implications of different domestic instruments for achieving CO2 emissions reductions in a strategic setting where economies are linked by trade flows.

The question of whether or not different instruments of environmental protection are equivalent has long occupied a central role in environmental economics. The literature usually distinguishes two broad approaches to address environmental problems: the incentive-based (or price) approach and the command-and-control (or quantity) approach. Associated with each there is a whole range of policy instruments such as subsidies, emission taxes and effluent charges, on the one hand, and standards, quotas and emission permits, on the other (see, e.g., Baumol and Oates, 1975). In a non-strategic, non-stochastic, full-information environment, incentive-based and command-and-control instruments are in principle equivalent (Weitzman, 1974; Adar and Griffin, 1976; Spulber, 1985), although differences may exist between the two in terms of ease of administration.[1] Once uncertainty is introduced, however, there is generally no longer an equivalence between fee-based and quantity-based instruments (Fishelson, 1976; Weitzman, 1974). If marginal valuation and marginal abatement cost schedules are not observable, incentive-based instruments can be more efficient in that they can achieve a given standard at a lower social cost (Baumol and Oates, 1971; Baumol, 1972; Schultze, 1977). On the other hand, in situations where firms have a high degree of market power, or where the need to act is particularly urgent, command-and-control instruments can be more effective (Baumol and Oates, 1975).

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[1] It has been argued that incentive-based instruments may be in some cases easier to administer (Baumol and Oates, 1975). In other cases, however, certain quantity-based instruments, notably tradeable emission permits, may have practical advantages over their incentive-based counterparts, offering greater control over the level of emissions both in a static and in a dynamic framework (Oates, 1994).

In spite of these considerations, policy makers—especially in North America—have shown a preference for command-and-control instruments in implementing environmental standards (Oates, 1986). Some literature has been devoted to explaining this preference from a political economy perspective (see, e.g., Buchanan, 1975; Mestelman, 1989).

Another reason why quantity and price based instruments may be non-equivalent is their differential impact on strategic trade policy interaction in an open economy framework: the responsiveness of supply decisions to trade policy changes is affected by the presence of environmental policies, and this effect is not the same for quantity and price based instruments. This may result in different non-cooperative trade policy outcomes, and, if environmental policies are used as substitutes for trade policies, in different levels of internalization. The non-equivalence between quantity and price based instruments in strategic contexts has been extensively analyzed both in the industrial organization literature—which has contrasted price and quantity setting behaviour (e.g. Singh and Vives, 1984)—as well as in the international trade literature—which has compared the implications of import tariffs and import quotas under trade policy retaliation (e.g., Rodriguez, 1974)—but not in the environmental literature.

In this paper we contrast the implications of quantity and fee-based instruments of environmental protection in a strategic, open-economy, North-South setting. For this purpose we use a calibrated model of world trade, benchmarked to 1990 data on trade, consumption and production. Into this we add global environmental externality effects from greenhouse emissions. We compute both non-cooperative Nash equilibria in trade and environmental policies when countries use tax or quota-based instruments, as well as Nash cooperative solutions where countries in both the North and the South regions jointly bargain over environmental policies in the presence of side payments of cash. Results of our numerical simulations allow us to compare non-cooperative and cooperative equilibria for alternative environmental policy regimes, and the associated North-South distribution of welfare gains and losses.

A recent paper which has introduced both international and strategic dimensions in environmental policy analysis is Copeland and Taylor (1995). In their model countries independently choose optimal emission quotas, which are implemented via tradeable permits. The authors use this setting to examine the impact of exogenous trade policy changes on environmental quality and welfare. Our analysis differs from theirs in several respects. First, our focus is the comparison of quantity and price-based environmental policy instruments. Second, we add a strategic dimension also to trade policy. Finally, we also examine cooperative outcomes.[2]

There has been considerable discussion in recent years about the institution of policies to respond to global climate change, a discussion frequently characterized by a strong North-South connotation. This reflects developed and developing countries' different views and priorities over global environmental management. Industrialized countries have argued that, because of the global nature of greenhouse emissions, both developed and developing countries should be expected to clean up, and that failure by developing countries to comply should be penalized through the imposition of trade restrictions.[3] Developing countries have objected that instituting more stringent environmental policies would slow down their economic growth, which could be both unequitable—since industrial countries have had an opportunity to develop without any environment-related constraints—and possibly dynamically inefficient—in consid-

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[2]Nordhaus and Yang (1997) examine market, cooperative and non-cooperative environmental strategies in a multi-region dynamic general-equilibrium setting. They compute non-cooperative Nash equilibria in environmental policies as well as cooperative equilibria where countries adopt globally efficient policies to reduce emissions. In their model, however, neither bargaining solutions nor interactions between trade and environmental policies are considered.

[3]In this respect, there have been formal proposals for trade sanctions provisions to be incorporated in international environmental agreements as a means of disciplining free-riders (see Uimonen and Whalley, 1997).

eration of the apparent "U-shaped" relationship between environmental quality and per capita income (Grossman, 1995).[4] The developing countries' position is thus that they should be either exempted from taking part in any substantive international environmental agreement or financially compensated (see Uimonen and Whalley, 1997; Whalley, 1997).[5] Although developed countries have shown some openness towards the idea of compensation, given the significance of the resource transfer involved (see Uimonen and Whalley, 1997), the compensation approach has eventually been rejected in favour of an "exclusion" approach in the 1997 Kyoto Protocol.

Even if these developments seem to point to an abandonment of the idea of formally sanctioning the use of trade measures as an enforcement mechanism, interaction between countries in trade policies still remains, implying that the effects of any environmental policy cooperation arrangement should be evaluated against the backdrop of strategic trade policy interaction. The debate on the North-South dimensions of global environmental issues usually abstract from which form of instruments should be used to achieve a given emission reduction target; but, as we have pointed out above, in a strategic open-economy setting the choice of instrument can affect non-cooperative trade policy outcomes, and hence the size and the international distribution of the gains from internalization. And since trade retaliation represents the "threat point" for bargaining, distributional outcomes under trade cooperation could also be affected.

Indeed, results of our numerical simulations show that, under free trade, differ-

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[4]The GATT (1992) itself has come close to endorsing at least a version of this argument when maintaining that growth could go hand-in-hand with higher environmental quality if additional income is spent on environmental protection. See also Whalley (1997).

[5]An alternative way (to direct cash transfers) of implementing compensation for developing countries is the redistribution of tax revenue (or quota rents) on the basis of population (see Whalley and Wigle, 1991).

ent instruments of CO2 emissions reduction are not equivalent; specifically, emission quotas (or equivalently country-specific permits) can lead to higher levels of internalization in a non-cooperative equilibrium than emission taxes do. The difference, however, is not very pronounced, which is simply a symptom of the weak linkage between carbon emissions and tradeables production as evidenced by production and trade data. We also find that if tariffs are endogenized, countries cease to use environmental policy instruments as substitutes for trade polices, but the choice of domestic environmental instruments does nevertheless affect non-cooperative tariffs levels, with carbon quotas leading to lower trade barriers than emission charges do. With reference to negotiated outcomes, when tariffs are endogenous and negotiations are restricted to environmental policies only, large trade barriers still remain. In this case, we also find that emission quotas lead to lower non-cooperative tariffs; and in a global environmental treaty with side payments of cash, the bargaining outcome is considerably more favourable to the South region if the treaty is supported by emission taxes rather than by emission quotas.

The plan of the paper is as follows. Section 2 describes the model. Section 3 presents a brief discussion of the implications of trade-environment linkages for non-cooperative and cooperative policy responses. Section 4 describes the data used for parameter calibration. Section 5 presents our numerical simulations and analyzes results. Section 6 summarizes our findings and concludes.

## 2 A Two-Region Model of North-South Trade with Carbon Emissions

We assume two regions in the model, $A$ and $B$, each respectively including $N^A$ and $N^B$ identical countries; we take region $A$ as representing the North and region $B$ the South. This North-South categorization is meant to reflect broad differences in technologies and preferences, while at the same time maintaining the dimensionality of the model at a minimum.

There are two goods produced in each region, a tradeable good $X$, a non-tradeable good $Y$, and two factors, value added $V$, and energy, $E$. Consumers in each country view the tradeables produced domestically and abroad as imperfect substitutes, and consume both domestic and imported varieties, together with non-tradeables and environmental quality. The latter is affected by the global emissions associated with the use of energy in production.

Preferences for domestic goods and imports in each country are represented via a three-level nested Cobb-Douglas/CES aggregation of the form

$$H^A(D_Y^A, D_X^A, M_A^A, M_B^A) \equiv$$
$$(D_Y^A)^{\theta^A} \left\{ \mu^A \left[ \delta^A (D_X^A)^{\frac{\sigma-1}{\sigma}} + (1-\delta^A)(M_A^A)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma(\rho^A-1)}{(\sigma-1)\rho^A}} \right.$$
$$\left. + (1-\mu^A)(M_B^A)^{\frac{\rho^A-1}{\rho^A}} \right\}^{\frac{\rho^A}{\rho^A-1}(1-\theta^A)}; \tag{1}$$

$$H^B(D_Y^B, D_X^B, M_B^B, M_A^B) \equiv$$
$$(D_Y^B)^{\theta^B} \left\{ \mu^B \left[ \delta^B (D_X^B)^{\frac{\sigma-1}{\sigma}} + (1-\delta^B)(M_B^B)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma(\rho^B-1)}{(\sigma-1)\rho^B}} \right.$$
$$\left. + (1-\mu^B)(M_B^B)^{\frac{\rho^B-1}{\rho^B}} \right\}^{\frac{\rho^B}{\rho^B-1}(1-\theta^B)}; \tag{2}$$

where $D_X^A$, $D_Y^A$, $D_X^B$, $D_Y^B$ are domestic consumption levels for domestically produced goods and $M_A^A$, $M_B^A$, $M_B^B$, $M_A^B$ are imports; $\theta^A$ and $\theta^B$ are share parameters for non-tradeables demand; $\mu^A$ and $\mu^B$ are share parameters relating to the share of same-region tradeables in total tradeables demand; $\delta^A$ and $\delta^B$ refer to the share of domestic goods in total same-region tradeables demand; $\rho^A$ and $\rho^B$ are elasticities of substitution between same region tradeables and tradeables produced in the other region; and $\sigma$ is the elasticity of substitution between domestically produced tradeables and same-region tradeables.

Preferences for consumption goods and global environmental quality, $Q$, are modelled through a Cobb-Douglas utility function:

$$U^A(Q, H^A) \equiv Q^{\eta^A}(H^A)^{1-\eta^A}; \tag{3}$$

$$U^B(Q, H^B) \equiv Q^{\eta^B}(H^B)^{1-\eta^B}; \tag{4}$$

where $\eta^A$ and $\eta^B$ represent the shares of environmental quality in utility. Note that for this specification the marginal valuation for environmental quality is proportional to (non-expanded) income.

The endowment of value added is constant in each region and respectively equal to $G^A$ and $G^B$. Value added can be transformed into energy at a constant marginal rate of transformation, which, without loss of generality, we assume to be equal to unity. Thus, net-of-tax prices of value added and energy are the same within each region, and are denoted respectively as $p^A$ and $p^B$. Each unit of energy employed in production generates an amount $\epsilon$ of global carbon emissions. If there are emission charges $\tau^A$ and $\tau^B$ in each region, we can express the gross-of-tax price of energy inputs as

$$p_E^A = p^A + \epsilon\tau^A; \tag{5}$$

$$p_E^B = p^B + \epsilon\tau^B. \tag{6}$$

In the rest of our model description in this section we shall restrict our attention to emission charges, and later discuss the modelling of quantity based instruments.

Value added and energy are both used as inputs in the production of tradeables and non-tradeables, through constant-returns-to-scale technologies. Thus, domestic prices of domestically produced goods are equal to unit costs:

$$p_X^A = c_X^A(p^A, p_E^A); \tag{7}$$

$$p_Y^A = c_Y^A(p^A, p_E^A); \tag{8}$$

$$p_X^B = c_X^B(p^B, p_E^B); \tag{9}$$

$$p_Y^B = c_Y^B(p^B, p_E^B). \tag{10}$$

For given output levels $S_X^A$, $S_Y^A$, $S_X^B$, $S_Y^B$, we can write aggregate domestic demands for energy (using Shephard's Lemma) as

$$D_E^A = S_X^A \frac{\partial c_X^A}{\partial p_E^A} + S_Y^A \frac{\partial c_Y^A}{\partial p_E^A}; \tag{11}$$

$$D_E^B = S_X^B \frac{\partial c_X^B}{\partial p_E^B} + S_Y^B \frac{\partial c_Y^B}{\partial p_E^B}. \tag{12}$$

For given energy demand levels, environmental quality is then

$$Q = \bar{Q} - \epsilon(N^A D_E^A + N^B D_E^B), \tag{13}$$

where $\bar{Q}$ denotes the initial endowment of global environmental quality (before emissions).

Each country in each region levies ad valorem import tariffs at rates $t_A^A$, $t_B^A$, $t_B^B$, $t_A^B$, where subscripts refer to the region where the trade flow originates, and superscripts refer to the importing region (where tariffs are levied). Thus, $t_A^A$ and $t_B^B$ are rates of tariffs levied on intra-regional trade flows, whereas $t_B^A$ and $t_A^B$ apply to external trade flows. The gross-of-tariff prices of imported tradeables in $A$ and $B$ become respectively

$$q_A^A = (1 + t_A^A)p_X^A; \tag{14}$$

$$q_B^A = (1 + t_B^A)p_X^B; \tag{15}$$

$$q_B^B = (1 + t_B^B)p_X^B; \tag{16}$$

$$q_A^B = (1 + t_A^B)p_X^A. \tag{17}$$

Consumers are assumed to behave as quantity takers with respect to the level of global environmental quality. Then, for given preferences, a given level of environmental quality $Q$, commodity prices, $p_X^A, p_X^B, p_Y^A, p_Y^B, q_A^A, q_B^A, q_B^B, q_A^B$, and expanded incomes, $I^A$, $I^B$, utility maximization yields uncompensated demands for domestic goods, $D_X^A$, $D_Y^A$, $D_X^B$, $D_Y^B$, and uncompensated import demands, $M_A^A$, $M_B^A$, $M_B^B$, $M_A^B$. The marginal valuation for environmental quality in each country, $v^A$, $v^B$, is also a function of the same variables.

Expanded income in each region can be written as the value of resource endowments, plus tariff revenue, plus carbon tax revenue, plus the (shadow) value of environmental quality (note that the latter is a function of income itself, which makes the definition of $I$ implicit):[6]

$$I^A = p_A G^A + t_A^A p_X^A M_A^A + t_B^A p_X^B M_B^A + \tau^A \epsilon D_E^A + v^A Q; \tag{18}$$

$$I^B = p_B G^B + t_B^B p_X^B M_B^B + t_A^B p_X^A M_A^B + \tau^B \epsilon D_E^B + v^B Q. \tag{19}$$

Market clearing requires

$$S_X^A = D_X^A + \frac{N^A - 1}{N^A} M_A^A + \frac{N^B}{N^A} M_A^B; \tag{20}$$

$$S_Y^A = D_Y^A; \tag{21}$$

$$S_X^B = D_X^B + \frac{N^B - 1}{N^B} M_B^B + \frac{N^A}{N^B} M_A^B; \tag{22}$$

$$S_Y^B = D_Y^B; \tag{23}$$

$$D_E^A + S_X^A \frac{\partial c_X^A}{\partial p^A} + S_Y^A \frac{\partial c_Y^A}{\partial p^A} = G^A; \tag{24}$$

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[6]The reason for using expanded income to derive consumer demand is that we model damage as a reduction in environmental quality, i.e. a good rather than as an economic "bad." To illustrate by reference to a different context, this is analogous to modelling labour supply by having leisure (the difference between time endowments and labour supply) entering as an argument (a good) of the utility function, instead of having labour supply entering directly as a bad. If we model labour supply in this way, then leisure also needs to be included in expanded income to derive consumer choices. The two specifications are fully equivalent.

$$D_E^B + S_X^B \frac{\partial c_X^B}{\partial p^B} + S_Y^B \frac{\partial c_Y^B}{\partial p^B} = G^B. \tag{25}$$

Governments in each country are assumed to choose policies so as to maximize the utility of the representative consumers in their respective countries, given the policies chosen by other countries, the general equilibrium condition described above, and the constraints on policy choices implied by any international coordination agreements that may apply. A non-cooperative Nash equilibrium is then a configuration of policies such that the policy chosen by each country is a best response to the policies chosen by all other countries.

In the numerical implementation of the model, functional forms are specified as follows. Unit cost functions for tradeables and non-tradeables production are a Constant-Elasticity-of-Substitution (CES) aggregation of energy and non-energy input prices:

$$c_X^A(p^A, p_E^A) \equiv \left[(1-\alpha_X^A)(p^A)^{1-\beta} + \alpha_X^A (p_E^A)^{1-\beta}\right]^{\frac{1}{1-\beta}}; \tag{26}$$

$$c_Y^A(p^A, p_E^A) \equiv \left[(1-\alpha_Y^A)(p^A)^{1-\beta} + \alpha_Y^A (p_E^A)^{1-\beta}\right]^{\frac{1}{1-\beta}}; \tag{27}$$

$$c_X^B(p^B, p_E^B) \equiv \left[(1-\alpha_X^B)(p^B)^{1-\beta} + \alpha_X^B (p_E^B)^{1-\beta}\right]^{\frac{1}{1-\beta}}; \tag{28}$$

$$c_Y^B(p^B, p_E^B) \equiv \left[(1-\alpha_Y^B)(p^B)^{1-\beta} + \alpha_Y^B (p_E^B)^{1-\beta}\right]^{\frac{1}{1-\beta}}. \tag{29}$$

where $\beta$ is the elasticity of substitution between energy and non-energy inputs, and the $\alpha$s are energy share parameters.

The above specification exploits symmetry across countries within regions to represent a situation where all countries within a region adopt identical trade and environmental policies. In our calculation of non-cooperative equilibria, however, we need to examine unilateral deviations in policy by individual countries in a region. For this purpose we need to distinguish a representative country in each region and distinguish its tariff and tax rates, output levels and prices form those of other countries belonging to the same bloc.

## 3 Strategic Implications of Trade-Environment Linkages

In what follows, we discuss some possible implications of trade-environment policy linkages—drawing on earlier literature and using the analytical structure we have just described as our frame of reference—to contrast effects of fee and quota-based instruments for non-cooperative policy outcomes.

A central proposition in the theoretical trade and environment literature is that, if tradeables production and environmental emissions are linked, countries would tend to use environmental policies as second-best substitutes for trade policies in order to manipulate terms of trade in their favour (Bhagwati, 1971; Markusen, 1975; Ludema and Wooton, 1994). Countries which are net importers of pollution intensive goods will have an incentive to under-internalize the externalities to simulate an import tariff, whereas exporters of pollution intensive goods will have an incentive to over-internalize to simulate an export tax. This effect is also present in our setting, with the strength of the linkage between emissions and trade depending on how concentrated emissions are in the exporting sector, as well as on abatement possibilities in that sector and on the level of domestic consumption for the exported good. If emissions only originate in the exporting sector and if there are no direct abatement possibilities (apart from reducing output), and if all the production of the sector is exported, then an emission tax will be fully equivalent to an export tax, and will thus represent a first-best instrument (from the point of view of a large exporting country) for affecting its terms of trade. If the exported good is also domestically consumed, then an emission tax will be equivalent to a production tax on the exporting sector, and its effectiveness as a commercial policy instrument will be accordingly reduced. Furthermore, if emissions are not limited to the exporting sector, or if there exist significant abatement possibilities within sectors, then the trade policy-environmental policy linkage is significantly weakened, and there is less scope for using environmental policies as a substitute for trade polices.

How this policy linkage affects welfare depends on its very strength. In the presence of a global externality, such as global warming, free-riding by individual countries would in itself leads to under-internalization. If trade-environmental policy linkages are not too strong, then the use of environmental policies as second-best trade policy instruments can help sustain higher rates of internalization. If, however, the linkage is strong, it could lead to the externality being overcorrected—a point also noted by Ludema and Wooton.

To the extent that environmental policies can be used as substitutes for trade policies in an open economy setting, emission charges and emission quotas or permits will have different implications for non-cooperative outcomes—much as tariffs and quotas do (Rodriguez, 1974)—owing to the different way in which they affect individual countries' optimal responses. On theoretical grounds, there would be a presumption that an emission quota would lead to higher a level of internalization than a tax-based instrument; this is because the imposition of an emission limit in a country makes its import demand for emission-intensive goods more inelastic in comparison with an emission charge. Under an emission tax, a rise in the price of imports can lead to substitution towards domestic production, whereas under an emission limit such substitution is not possible. Consequently, the optimal export tax—which, as discussed earlier, is implicit in the use of environmental instruments—is higher under an emission target than under an emission tax; accordingly, internalization levels in a non-cooperative equilibrium will be higher under a quantity based instrument.

Whether this difference between the effects of quantity and tax-based instrument in a strategic setting will lead to a more or less efficient non-cooperative outcome, again depends on the strength of the linkage discussed above. If this linkage is sufficiently strong and non-cooperative equilibria feature over-internalization, then emission targets will be worse, on efficiency grounds, than emission taxes; but in an under-internalization regime, emission quotas will be superior to a tax.

When direct trade policy instruments such as tariffs are available to trading partners, environmental policies will cease to be the tool of choice for achieving trade policy objectives, which implies that non-cooperative rates of internalization will be lower. Nevertheless, the presence of emission taxes or quotas will affect the tariff retaliation outcome; and, since taxes and quotas affect trade responses differently, they will have different impacts on non-cooperative tariff levels. Even when countries cooperate in environmental policies, emission taxes and quotas can still have different effects on trade retaliation. If environmental emissions are closely linked to output levels, environmental cooperation supported by emission targets will tend to dampen producer supply responses; in turn, this will narrow the scope for an aggressive trade policy stance, leading to lower non-cooperative tariffs. This dampening effect, however, would not be present under emission taxation.

Asymmetries in economic size across countries imply asymmetries in strategic incentives across policy dimensions: large countries tend to win the trade policy game—because of their greater market power—and to lose the environmental policy game—since small countries can more easily free ride on them. This asymmetry in incentives, in turn, will translate into differential effects for large and small countries following a shift from price to quantity based instruments. Specifically, since emission quotas tend to constrain trade retaliation, they will be relatively more favourable to small countries than to large ones.

In the next two sections, we shall explore these differences between fee and quota based instruments, and their underlying mechanisms, by means of numerical simulations using a calibrated version of the model described in Section 2.

## 4 Data and Parameters

This section briefly describes the data used to parameterize the model. Parameterization for the trade side is straightforward, but the same cannot be said about the environment side of the model, due to the lack of suitable data, especially for parameters having to do with environmental quality and damage.

The production and trade data used for the trade submodel—as well as the data on population and number of countries per region—comes from the World Bank's *World Development Report 1992*. To parameterize our two-sector, two-region model structure, we take the non-traded sector as corresponding to construction and services, and the North as coinciding with OECD countries, with the rest of the world representing the South. Intra-regional and inter-regional trade flows have been obtained from UNCTAD (1992). All trade and production data we use are for the year 1990. As for trade elasticities, we have taken the values used in Perroni and Wigle (1994). Finally, the value we use for the elasticity of substitution between energy and non-energy inputs is consistent with estimates which have traditionally been used in the applied trade literature (see, for instance, Perroni and Wigle, 1994; or Wigle and Whalley, 1991). The basic data for this part of the model is presented in Table 1.

Parameters for the environmental submodel (Table 2) have been obtained as follows. Sectoral emission coefficients are based on input-output data on energy consumption and carbon dioxide (CO2) emissions. The input-output data comes from the OECD (1995), and is based on the 1990 tables of Germany, United Kingdom and USA. The CO2 emissions data, in turn, was obtained from the OECD (1996). Input-output data has been used to compute energy consumption coefficients by sector. We have then applied their ratio to total CO2 emissions by OECD members to obtain emissions by sectors. These are then converted to the model units by multiplying them by the overall coefficient of energy consumption. In order to adjust for the fact that energy consumption in LDCs is often heavily subsidized, we have used the OECD energy coefficient ratio to compute sectoral emissions for non-OECD countries.

Marginal valuations for environmental quality are derived using a "revealed preference" argument. From Perroni and Rutherford (1993) we can obtain an estimate of the required unit carbon tax rate which would be needed to implement current proposals on CO2 emissions cuts. Assuming these proposals are indicative of an optimal policy, we can combine this information with that of total carbon emissions

Table 1: Trade and Production Data

| | North | South |
|---|---|---|
| GDP (billion US$) | 15,993.4 | 6,305.5 |
| Number of countries | 24 | 117 |
| Share parameters | | |
| Imports in tradeables demand | 0.523 | 0.247 |
| Non-tradeables in aggregate demand | 0.703 | 0.455 |
| Intra-regional trade in total trade | 0.770 | 0.357 |
| Elasticities | | |
| Armington elasticities | | |
| Bottom nest | 2.5 | 2.5 |
| Top level | 2.5 | 2.5 |
| Tradeables-nontradeables | 1.0 | 1.0 |
| Energy-nonenergy inputs | 1.0 | 1.0 |

Table 2: Parameters for Environment Submodel

| | North | South |
|---|---|---|
| Energy shares | | |
| Tradeables | 0.045 | 0.067 |
| Non-tradeables | 0.009 | 0.037 |
| Elasticity of marginal valuation | | |
| With respect to damage | 0.50 | 0.50 |
| With respect to income | 1.00 | 1.00 |

and production (income) to compute the tax that would fully internalize the global externality associated with CO2 emissions.

To obtain the marginal valuation for each bloc, we have assumed that it is proportional to per capita income, which implies an elasticity of unity with respect to this variable. The hypothesis that marginal valuation of environmental quality increases with per capita income has found some empirical support either directly (see Cicchetti and Smith, 1973; Desvouges et al., 1987) or indirectly (see Grossman, 1995). In a survey about the willingness to pay (WTP) for recreation in the Spanish Peaks Primitive Area (in Montana, USA), Cicchetti and Smith (1973) find that the revealed WTP by its users rises by about 0.013 per extra unit of household income. On the basis of this estimate, and of some others reported in the same study, we select a value of unity for the elasticity of marginal valuation with respect to income. This is consistent with evidence for a fairly broad range of household income level (for an income level of $1,000 the elasticity would be 1.019, while from an income level of $80,000 it would be 1.0002).

Finally, the value for the elasticity of damage with respect to emissions that we use is based on Perroni and Wigle (1994). This elasticity value, together with the marginal valuation, enables us to infer values for the share of environmental quality in demand and for the implied endowment of global environmental quality.

## 5 Simulations and Results

The parameterized model is used to numerically simulate non-cooperative and cooperative policy outcomes. To compute non-cooperative equilibria, we iterate over calculations of optimal policy responses by representative countries in both region, subject to a full set of general equilibrium constraints (as set out above) until convergence to a Nash equilibrium is achieved. For this purpose, we model alternative environmental policy instruments as follows. When emission charges are used, we compute optimal responses by a country assuming that the emission charges in other countries are maintained at a constant level. When computing optimal responses under emission quotas, emission levels in other countries are held constant, and taxes are allowed to adjust endogenously so as to meet the given target.

We also compute cooperative bargaining solutions associated with these games in the presence of side payments of cash, adopting Nash's (1953) axiomatic solution concept. In computing bargaining solutions, we take the non-cooperative Nash equilibrium solution utilities as representing the disagreement point, simulate the utilities possibilities frontier under cooperation, and apply the Nash criterion to the product of the differences in region utilities along the frontier and disagreement utilities.

Ten different scenarios are examined, both under an emission fee and an emission quotas regime:

1. No cooperation with free trade: obtained by iterative computation of optimal responses by individual countries in environmental policies under free trade until convergence to a non-cooperative equilibrium is reached;

2. Intra-regional cooperation in environmental policies with free trade: as for Scenario 1 but assuming coordinated optimal response in environmental policies by all countries in each region (optimal responses are computed by maximizing joint welfare for all countries in a region);

3. Intra-regional cooperation in environmental policies in the North with free trade: as for Scenario 2 but assuming coordinated optimal response in environmental policies only in the North region;

4. Global cooperation in environmental policies with free trade: all countries in each region adopt full-internalization emission taxes or quotas;

5. Nash bargaining over environmental policies with free trade and side payments of cash;

6. No cooperation with endogenous tariffs: obtained by iterative computation of optimal responses by individual countries in trade and environmental policies until convergence to a non-cooperative equilibrium is reached;

7. Intra-regional cooperation in environmental policies: as for Scenario 7 but assuming coordinated optimal response in environmental policies by all countries in each region;

8. Intra-regional cooperation in environmental policies in North region only: as for Scenario 8 but assuming coordinated optimal response in environmental policies limited to the North region;

9. Global cooperation in environmental policies with endogenous tariffs: all countries adopt full-internalization emission taxes or quotas;

10. Nash bargaining over environmental policies with side payments of cash.

Simulation results are summarized in Tables 3 to 6. Tables 3 and 4 show results when tariffs are frozen at zero (free trade) under emission taxes and quotas respectively. The non-cooperative outcome features under-internalization, suggesting a weak direct linkage between carbon emissions and tradeables production. Also, note that in the trade data intra-bloc trade flows dominate inter-bloc flows in terms of their size, which, since countries are treated symmetrically within blocs, limits the effects of asymmetries in incentives for net importers and net exporters of pollution intensive goods. If the linkage between emissions and tradeables production were sufficiently strong, and inter-bloc trade sufficiently large, the non-cooperative equilibrium could feature over-internalization. Indeed, we have performed experiments with our model (not shown) which confirm the possibility of such an occurrence; for example, over-internalization occurs in the North region, when environmental policies are coordinated within regions, if we assume that emissions are only generated in the tradeables sector, and if we increase the share of tradeables production which is exported in the North by one-half and by a factor four in the South.

Table 3: Non-cooperative and Cooperative Equilibria with Emission Taxes and Zero Tariffs

| | Scenario | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | | | % | | |
| Internalization rate* | | | | | |
| North | 6.66 | 72.39 | 73.53 | 100.00 | 100.00 |
| South | 0.75 | 29.80 | 0.82 | 100.00 | 100.00 |
| Welfare change** | | | | | |
| A. Relative to Scenario 1 | | | | | |
| North | 0.0 | 1.74 | 0.79 | 2.48 | 1.80 |
| South | 0.0 | 1.78 | 1.29 | 1.18 | 4.28 |
| B. Relative to zero taxes | | | | | |
| North | 0.42 | 2.16 | 1.21 | 2.90 | 2.22 |
| South | 0.43 | 2.21 | 1.72 | 1.61 | 4.71 |

* Ratio of emission tax to marginal emission damage

** Ratio of equivalent variation to GDP

Scenarios:

1. No cooperation (free trade)
2. Intra-regional cooperation in environmental policies
3. As for Scenario 2 but with cooperation in the North only
4. Global cooperation in environmental policies
5. Bargaining with side payments with 1 as disagreement point

Table 4: Non-cooperative and Cooperative Equilibria with Emission Quotas and Zero Tariffs

| | Scenario | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| | | | % | | |
| Internalization rate* | | | | | |
| North | 6.67 | 73.87 | 73.62 | 100.00 | 100.00 |
| South | 0.75 | 29.81 | 0.81 | 100.00 | 100.00 |
| Welfare change** | | | | | |
| A. Relative to Scenario 1 | | | | | |
| North | 0.0 | 1.74 | 0.79 | 2.48 | 1.80 |
| South | 0.0 | 1.79 | 1.29 | 1.18 | 4.28 |
| B. Relative to zero taxes | | | | | |
| North | 0.42 | 2.16 | 1.21 | 2.90 | 2.22 |
| South | 0.43 | 2.22 | 1.72 | 1.61 | 4.71 |

* Ratio of implicit emission tax to marginal emission damage

** Ratio of equivalent variation to GDP

Scenarios:

1. No cooperation (free trade)
2. Intra-regional cooperation in environmental policies
3. As for Scenario 2 but with cooperation in the North only
4. Global cooperation in environmental policies
5. Bargaining with side payments with 1 as disagreement point

As expected, internalization rates are higher under a quota regime, implying that quotas are superior on efficiency grounds. The difference in internalization rates, however, is only significant when policies are coordinated within regions (second and third columns of Tables 3 and 4), and even in this case it is not large enough to generate a significant difference between the two instruments in terms of welfare. Again, this is a reflection of the weak linkages between trade and carbon emissions.

If tariffs are endogenous (Tables 5 and 6), non-cooperative equilibria feature lower internalization rates than under free trade, regardless both of the policy instrument used and of country size. This is because, when direct instruments of trade policy are available, countries no longer need to use environmental policies as substitutes for trade policies. In this case fee and quota based instruments are equivalent when responses are fully uncoordinated (Scenario 6). But when environmental policies are coordinated within regions, a quota regime leads to significantly lower levels of non-cooperative tariffs, and is clearly superior to an emission charge in terms of welfare. Indeed, Tables 5 and 6 show that, for any form of environmental cooperation (regional or global), the tariff rates associated with a quota regime are lower than those implied by an emission tax. As mentioned earlier, this is due to the fact that, when countries must abide by agreed upon environmental policies, quotas make export supply responses less elastic.

In contrast, emission charges raise producer prices, making export supply responses more elastic (with reference to a partial equilibrium diagram, this effect can be thought of as an "upward shift" of supply curves); in turn, higher elasticities result in increased trade barrier. This effect is particularly dramatic under global environmental cooperation (fourth and fifth columns of Table 5), where non-cooperative tariffs in the South region are in excess of 100%.

Whatever the regime, internalization rates are consistently higher in the North, reflecting its higher valuation for environmental quality; the tendency to free ride is stronger for the South. Intra-bloc environmental cooperation significantly raises

Table 5: Non-cooperative and Cooperative Equilibria
with Emission Taxes and Endogenous Tariffs

| | Scenario | | | | |
|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 |
| | | | % | | |
| Internalization rate* | | | | | |
| North | 2.95 | 61.46 | 63.38 | 100.00 | 100.00 |
| South | 0.25 | 29.07 | 0.27 | 100.00 | 100.00 |
| Intra-regional tariffs | | | | | |
| North | 67.22 | 72.42 | 73.05 | 75.83 | 75.89 |
| South | 66.70 | 76.47 | 66.69 | 111.99 | 120.79 |
| Inter-regional tariffs | | | | | |
| North | 67.05 | 72.73 | 72.74 | 76.16 | 75.45 |
| South | 66.71 | 76.44 | 66.69 | 112.35 | 120.80 |
| Welfare change** | | | | | |
| A. Relative to Scenario 6 | | | | | |
| North | 0.0 | 1.54 | 0.63 | 1.67 | 0.92 |
| South | 0.0 | 1.59 | 1.23 | 0.50 | 2.29 |
| B. Relative to zero taxes and tariffs | | | | | |
| North | -2.12 | -0.58 | -1.49 | -0.45 | -1.20 |
| South | -1.49 | 0.10 | -0.26 | -0.99 | 0.80 |

* Ratio of emission tax to marginal emission damage

** Ratio of equivalent variation to GDP

Scenarios:

6. No cooperation
7. Intra-regional cooperation in environmental policies
8. As for Scenario 7 with cooperation in the North only
9. Global cooperation in environmental policies
10. Bargaining with side payments with 6 as disagreement point

Table 6: Non-cooperative and Cooperative Equilibria
with Emission Quotas and Endogenous Tariffs

| | Scenario | | | | |
|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 |
| | | | % | | |
| Internalization rate* | | | | | |
| North | 2.95 | 63.24 | 63.22 | 100.00 | 100.00 |
| South | 0.25 | 28.82 | 0.25 | 100.00 | 100.00 |
| Intra-regional tariffs | | | | | |
| North | 67.30 | 67.30 | 67.30 | 67.23 | 67.49 |
| South | 66.69 | 66.71 | 40.69 | 65.80 | 66.70 |
| Inter-regional tariffs | | | | | |
| North | 67.11 | 67.11 | 67.11 | 67.11 | 66.63 |
| South | 66.70 | 66.68 | 66.70 | 66.36 | 66.70 |
| Welfare change** | | | | | |
| A. Relative to Scenario 6 | | | | | |
| North | 0.0 | 1.84 | 0.85 | 2.44 | 1.57 |
| South | 0.0 | 1.90 | 1.37 | 1.27 | 3.75 |
| B. Relative to zero taxes and tariffs | | | | | |
| North | -2.12 | -0.28 | -1.27 | 0.32 | -0.55 |
| South | -1.50 | 0.40 | -0.13 | -0.23 | 2.25 |

* Ratio of implicit emission tax to marginal emission damage

** Ratio of equivalent variation to GDP

Scenarios:

6. No cooperation
7. Intra-regional cooperation in environmental policies
8. As for Scenario 7 with cooperation in the North only
9. Global cooperation in environmental policies
10. Bargaining with side payments with 6 as disagreement point

internalization rates and welfare, especially in the North. With endogenous tariffs, on the other hand, the North bloc experiences higher welfare losses than the South under non-cooperation, a finding that is in line with the fact that OECD countries trade more, especially among themselves.

Scenarios 3 and 8 correspond to a "Kyoto Protocol"-type arrangement, with commitments to reduce emissions only undertaken by developed economies. Even when environmental policy cooperation is limited to the North region, if countries do not cooperate in trade policies, there is still a significant difference between taxes and quotas, with both regions being better off if regional environmental cooperation is supported by quotas rather than by emission taxes (Tables 5 and 6, third column).[7]

Compared to the non-cooperative equilibrium, global environmental cooperation in the form of full internalization without side payments favours both regions but especially the North bloc (Scenarios 4 and 9). Compared to the zero-tax/zero-tariff scenario, however, with endogenous tariffs this type of environmental cooperation would still leave both regions worse off if an emission charge were used (Table 5, Scenario 9); switching to a quota regime would make the North bloc better off, but the South would still continue to lose (Table 6, Scenario 9).

In both regimes—emission charges and emission quotas—to induce full internalization by the South, the North would have to compensate them. Scenario 10 examines a global cooperation agreements supported as a Nash bargaining outcome through side payments. This outcome is clearly more favourable to the South in comparison with the no-side payments case; but the bargaining outcome is considerably more

[7]Note, however, that under the 1997 Kyoto Protocol international emissions trading is allowed, whereas in our model quotas are country-specific. Allowing for intra-bloc trading of emission quotas would result in output responses being more price elastic in comparison with a country-specific quota system, thus making quotas somewhat closer, in their implications for trade retaliation, to emission taxes. Furthermore, although commitments under the Kyoto Protocol are specified in terms of quantities, emission taxes may well be involved in its implementation.

favourable to the South region (and less unfavourable to the North) if the environmental treaty is supported by emission quotas rather than by emission taxes).

Our simulation results highlight the difficulties associated with global environmental cooperation in the form of full internalization given the strong regional asymmetry in terms of valuation of environmental quality. Global cooperation is obviously superior to no cooperation at all. However, in comparison with intra-regional cooperation, global environmental cooperation would be attractive for the North but not for the South; and the side payments required to make it appealing to the South would make it unattractive to the North, independently of both the environmental policy instrument used and whether or not tariffs are endogenously determined. A global negotiated outcome would be even less attractive to the North if side payments, rather than being based on bargaining, were based on a property rights principle, with revenues from taxes, or, equivalently, rents from tradeable permits, being distributed according to population: given our parameterization, the implied transfers from the North to the South would be about one third larger than under Nash bargaining. This seems to be consistent with the current *de facto* abandonment—under the 1997 Kyoto Protocol—of both the idea of the South adopting much more stringent environmental policies and that of the North compensating them for it. Our results also suggest that, with the 1997 Kyoto Protocol, the North may have settled for an option clearly inferior for them to both intra-regional and global cooperation but which would appear acceptable to the South's interests.

Our numerical findings should be qualified by stressing the high degree of uncertainty surrounding the parameter values used for calibration. Elasticity values, in particular, are a crucial determinant of the level of non-cooperative trade barriers; assuming lower (and possibly more realistic) trade elasticities would lead to considerably higher barriers and trade-related effects. Also, given the large per-capita income spread between the North and the South regions, a small change in the assumed value of the income elasticity of environmental quality valuation can lead to a dramatically different imputation of abatement benefits across regions.

We have explored the effects of these and other parameters through sensitivity analysis (not shown). Although assuming different parameter values affects non-cooperative policy levels, as well as the magnitude and distribution of welfare effects, the qualitative pattern of the results remains the same, and underscores the same general theme: in a strategic, open-economy setting, emission quotas are preferable to emission taxes on efficiency grounds, as they lead to higher rates of internalization under free trade, or to lower trade barriers when trade policies are determined non-cooperatively. Both regions, and particularly the South, could thus gain from a regime switch from carbon charges to carbon quotas or permits.

## 6 Summary and Conclusion

In this paper we have used a calibrated model of North-South trade with carbon emissions to compare the implications of quantity and fee based environmental policy instruments in a strategic, open-economy setting. We have computed both non-cooperative Nash equilibria in trade and environmental policies as well as Nash co-operative solutions where countries bargain over environmental policies.

Results of our numerical simulations show that, under free trade, different instruments of CO2 emissions reduction are not equivalent; specifically, under free trade, carbon quotas or permits can lead to higher levels of internalization in a non-cooperative equilibrium in comparison with carbon taxes. The difference, however, is not very pronounced, a symptom of the fact that the direct linkage between carbon emissions and tradeables production is rather weak. If tariffs are endogenized, carbon quotas and carbon taxes lead to similar levels of internalization, but non-cooperative tariffs are higher under a carbon tax regime. Thus, although in a full-information, closed-economy setting carbon taxes and quotas or permits may be viewed as being equivalent, when trade linkages and strategic trade responses are accounted for, emission quotas could be preferable as a means of supporting regional or global carbon treaties both for the North and the South.

In light of these results, the endorsement of an emission permit regime by the 1997 Kyoto Protocol appears to be a good choice where trade cooperation is concerned, although the stipulation in it of international tradeability for permits will make this regime rather more similar to an emission tax regime. On the other hand, even though both the North and the South stand to gain from the Kyoto agreement relatively to a non-cooperative scenario, gains are likely to be substantially larger for the South, who can free ride almost completely on the North's improved environmental management. Yet, there still seems to be scope for further global gains to be had from expanded participation under the U.N. Framework Convention; but, whatever the terms of such an enlarged agreement, the use of quotas rather than taxes to support it should reduce incentives for an aggressive trade policy stance, thereby affecting multilateral trade negotiation outcomes.

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