Trade of Permits for Greenhouse Gas Emissions; Bilateral Trade Need not Be the Answer

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Abstract

The Kyoto Protocol sets national quotas on GHG emissions and allows international trade of these quotas. Taking terms-of-trade effects into account, we argue that this trade is characterized by asymmetric, identity-dependent externalities, and show that bilateral trade of permits may not be sufficient for an efficient allocation of emissions. We derive conditions under which bilateral trade does improve the allocation of permits. The conditions are strong. In this sense, we argue that, for emissions permits, market design matters.

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1 Introduction

In 1997, at the summit of the United Nations Framework Convention on Climate Change held in Kyoto, thirty-nine countries agreed to reduce their greenhouse gas (GHG) emissions over the five year period 2008-2012. The agreement prescribed binding targets for each country while allowing international trade of these quotas.[1] Given that the effects of GHG emissions are independent of the location of these emissions, the possibility of trade has been welcomed as a key feature of the agreement which will guarantee that the Kyoto goals are attained at minimum cost.

Implicit in this optimism is the assumption that "market forces", if free to act, will induce cost efficiency. If the initial allocation of quotas does not minimize the cost of attaining the global emissions target, countries will gain from trading part of their quotas. Then the initial allocation of quotas may have distributional effects, but not efficiency effects. The experience with the 1990 U.S. Acid Rain Program reinforces this view. Within this program, SO_2 emission permits were initially allocated in proportion to historical emissions (*grandfathering*), but permits were tradable. According to most assessments,

[1]Besides explicit trade of quotas or "Assigned Amount Units", the treaty contemplates two other so called flexible instruments, Clean Development Mechanism and Joint Implementation. This project-based instruments allow countries to acquire CERs (Certified Emissions Reduction) and ERUs (Emissions Reduction Units) as an alternative to AAUs.

bilateral trade was successful in improving the efficiency of the allocation of emissions.[2]

There is an important difference between trade in permits in a closed economy, e.g., the U.S. SO_2 experience, and permit trade in an open, international setting, e.g., GHG permit trade. As noted in a recent paper by Copeland and Taylor (2005), in the latter, trade in permits has terms-of-trade effects.[3] That is, when two countries trade in emissions permits, and then change their emissions quotas, they also change their supplies of other commodities to the world market and this can affect international commodity prices.[4]

In this paper, we build on this insight and note that these effects con-

[2]See, for instance, Schmalensee et al., 1998, or Joskow et al. (1998).

[3]In fact, policies aiming at controlling the two types of emissions are difficult to disentangle, since both originate mainly from fossil combustion. This raises an important issue about the ancillary benefits of implementing the Kyoto protocol. These benefits, measured by the associated reduction of SO_2 emissions, can be substantial (see van Vuuren et al. 2006). Other co-benefits include health benefits and benefits to ecosystems. Besides being important, ancillary benefits will be affected by the allocation of GHG emissions permits. Part of these benefits will be internalized by trading parties, since they are mainly regional. However, a comprehensive study of the welfare consequences of GHG permit trade would have to consider these co-benefits, from which we abstract in the present paper.

[4]One consequence is that some countries may end up worse-off after trading in permits despite efficiency gains in production. Copeland and Taylor even show cases in which both parties exchanging quotas could be made worse off by this trade. Also, based on the results on the equivalence between trade in goods and trade in factors, they conclude that, for some economies, free trade in goods will make the rule for allocating initial quotas irrelevant for efficiency.

stitute an externality that countries impose on each other when they trade in permits. Moreover, terms-of-trade effects depend on the identity of the trading countries and affect other countries differently, depending on their respective position in international commodities markets. Thus, terms-of-trade externalities associated with trade in emissions permits are asymmetric and identity dependent.[5]

There is a literature on auction and mechanism design that examines the consequences of this type of externality.[6] One of the key lessons from this literature is that under asymmetric, identity-dependent, external effects, the willingness to pay for a good can be computed *only* in equilibrium.

This lesson applies directly to the model of Copeland and Taylor if we abandon their assumption that traders in the market for permits are small firms. That is what we do in this paper. We analyze a model where governments, not firms, may engage in permit trade. In our model when parties trade in permits they take into account how their trade will affect their own output and the other countries' outputs, and thus international commodity prices. This means that the willingness to pay for permits depends on the identity of the trading partner, and cannot be defined without reference to that identity. That is, the concept of price of a permit is meaningless.

Certainly, externalities of any kind usually cause inefficiencies because of

[5]Bagwell, Mavroidis and Staiger (2007) also consider terms-of-trade externalities as asymmetric and identity dependent. However, in their paper, these externalities are associated with retaliation against a trading partner that is in violation of a WTO commitment.

[6]See, for instance, Jehiel and Moldovanu (1996), (1999), and (2000), or Jehiel, Moldovanu, and Stacchetti (1996).

to too much or too little production or consumption of a good. However, in the case of emissions permits the effects on total emissions are not an issue because this output is fixed by the Kyoto target.[7] Yet, as the literature on auctions with identity-dependent externalities emphasizes, efficiency is still problematic in the case of permit trade. The country that is willing to pay the most for permits need not be the country where emissions are the most valuable or the most expensive to reduce, from a global point of view.

Under a cap-and-trade system as the one defined by the Kyoto agreements, permits become a tradable input with some important and special characteristics. First, permits can be traded with virtually no transaction costs. In that sense, they resemble -and are frequently considered- financial assets. Second, they constitute a crucial input for the production of a large variety of goods. Third, as we mentioned above, the total supply of them is fixed and does not respond to price signals. There are some inputs that share the second characteristic, like labor and energy. However, none of them share the other two. In particular, labor is generally a non tradable commodity. Energy, in the form of gas and oil, is tradable and their suppliers do enjoy market power. However, the demand side of energy markets can be

[7] Certainly, a country could decide not to sell its quota even if it does not fully use it. This will not be the case in the model analyzed below, since doing so would only imply higher production costs. In general, as long as the environmental externalities of GHG emissions on the rest of the world are sufficiently large, which is a reasonable assumption, no country would choose to buy or hold more permits than what they will use. Banking of permits is a different issue that has to do with intertemporal trading and allocation. These dynamic issues are beyond the scope of this paper.

appropriately described as competitive. In particular, the externality that a potential buyer causes on other buyers through terms-of-trade effects is negligible. Thus, these markets are not subject to the sort of inefficiencies that we will study.

Thus, we analyze a two-sector, two-input, n-country model. Inputs differ in how clean they are and sectors differ in how intensively they use the two inputs. Countries differ in their initial endowments of inputs, one of which emissions rights. We characterize efficient allocations of emissions rights, and identify conditions on the initial allocation of permits that guarantee that incentives to trade are aligned with efficiency. We show that these conditions are restrictive. In particular, they require that no country is completely specialized in producing *clean* commodities. Therefore, efficiency is too demanding a target for unregulated bilateral trade of emission permits. Our conclusion is that market design for permit trade is necessary in order to guarantee efficiency of the final allocation of emissions rights. Designing markets and market rules for permits is a delicate exercise. Much has been learned from regional or national experiences. Yet, the design of a global market with global rules requires overcoming political difficulties that are not present with decentralized, bilateral trading. Our paper argues that the failure to recognize the inefficiencies that could arise from simple bilateral trade could be very costly, particularly if a more stringent and comprehensive control on emissions is ever implemented.

The assumption that governments are the parties to the trade of permits is justified for the case of GHG emissions that motivates this paper. Emissions trading, mentioned in Article 17 of the Kyoto Protocol, allows *countries*, the

Parties, to trade permits for the purposes of fulfilling their commitments. Governments' regulations then determine the pattern of permit allocation to local firms. More importantly, the agreement does not attempt to organize a firm level, global market for permits similar to the European Union Greenhouse Gas Emission Trading Scheme, for instance.

There remains uncertainty about what will be accomplished, and how, during the Kyoto first "commitment period". Moreover, the UN Climate Change Conference in Copenhagen in December 2009 has just ended without a legally binding successor of the Kyoto agreement, and much remains to be discussed about how to reach such goal.[8] However, there are a few tentative conclusions that we can extract from the experience so far. First, with respect to the relevance of permit trade. Before 2008, different papers had attempted to estimate the volume and effect of trade in permits for the period 2008-2012. Springer (2003) surveys some of these attempts. The average estimate is approximately equivalent to 3% of total Annex B countries' quotas, when only these countries are assumed to trade.[9] The magnitude is comparable to the transactions value in the world copper market. Those estimates are perhaps excessive once we take into account the economic contraction that coincided with the beginning of the first commitment period. More recent computations (see Tuerk and Urge-Vorsatz, 2009) estimate the demand for these permits at approximately 2% of total Annex B countries' quotas (900

[8]The "Copenhagen Accord" leaves to the parties the responsibility to set their own emissions goal, and insists on the use of market mechanisms to attain cost efficiency.

[9]Note that we refer to bilateral trade (from country to country). That is, these figures do not reflect internal (national or regional) exchange of permits between final users.

Mt.).[10] Bilateral trade in Assigned Amount Units (AAUs, the permits) is taking place. For example, Japan, Spain or Austria are buying permits from Poland, Bulgaria or the Czech Republic. These trades are agreed in bilateral contacts and information about the negotiated prices for the permits is not public. Thus, it seems that bilateral permit trade is active, and should be expected to be active in a post-Kyoto scenario, if the instruments do not differ much from the present ones.

In the next section, we present the model and discuss the externalities generated by bilateral trade in permits in the presence of terms-of-trade effects. Then, in Section 3, we show how bilateral trade does not necessarily improve the allocation of permits. We identify conditions that guarantee the efficiency of bilateral trade. Section 4 interprets these conditions in terms of patterns of output and commodity trade across countries. The results from Sections 3 and 4 are proved in the appendix. Some concluding remarks close the paper.

[10] Permits surplus is much higher, estimated at aproximately 6.5 billion tons. This surplus is mainly associated with Eastern European and ex Soviet countries (Russia, above all). The quotas were estimated based on mid-nineties emissions, and in the case of these countries those emissions were linked mostly to obsolete plants that are not in place anymore. However, Russia has announced that it will not sell most of these permits, but rather bank them for the post-Kyoto future.

2 The model

Following Copeland and Taylor (2005), we model international trade and the environment in a Heckscher-Ohlin setup.[11] There are n countries in a two-good, two-factor world. Trade in commodities is assumed to be free among all countries. We denote output of each of the commodities by X and Y respectively. The two factors are human capital, h, and pollution, z. Thus, we treat pollution as an input as well as a global externality. Different countries have different endowments of human capital, which is inelastically supplied. These human capital endowments are the only fundamental differences across countries.

A quota on pollution is fixed for each country by an international agreement. Denote by z_j the quota on pollution fixed for country j. All countries are constrained by the international agreement. Thus, global emissions, defined by $Z = \sum_j z_j$, are fixed and their direct effect on the utility of consumers is exogenous.[12] Without loss of generality, we assume that $h_1/z_1 > h_2/z_2 > ... > h_n/z_n$. We will study incentives of each country to increase their quota by purchasing part or all the quota from other countries.

We assume the same technology for all countries, represented by

$$X_j = f(h_j^x, z_j^x)$$

[11]We present a sketch of the model. For a full treatment and motivation, see Copeland and Taylor (2005).

[12]Copeland and Taylor (2005) assume that some countries may not be constrained, and study the incentives of these countries to reduce emissions that derive from the trade of permits.

and

$$Y_j = g(h_j^y, z_j^y),$$

where h_j^T and z_j^T are human capital and pollution allocated to industry $T = X, Y$ located in country $j = 1, 2, ..., n$.

Both f and g are assumed to be strictly concave, and characterized by constant returns to scale. They are increasing in both arguments. Assume that the production of commodity X is more pollution intensive than the production of commodity Y. From now on, we call X the dirty commodity. Also assume that Y is the numeraire commodity and denote the international price of X by p.

With our assumptions, the profit maximizing behavior of price-taking firms can be summarized by the maximization of national income.[13] That is, firms' behavior in each country j can be obtained as the solution to

$$\begin{aligned} & \text{Max}_{\{h_j^x, h_j^y, z_j^x, z_j^y\}}\ pX_j + Y_j \\ \text{s.t.} \quad X_j &= f(h_j^x, z_j^x),\ Y_j = g(h_j^y, z_j^y), \\ z_j &= z_j^x + z_j^y,\ h_j = h_j^x + h_j^y. \end{aligned}$$

Let $G_j(p, h_j, z_j)$ be the maximum of the above problem, which then represents the national income function. Following Copeland and Taylor, we make the implicit assumption that the targeted level of pollution inside a country is attained efficiently.

[13] See, for instance, Dixit and Norman (1980), or Wong (1995), pp.40—50 for a recent text-book discusion.

The demand side is given by a representative consumer in each country j with utility function

$$U_j = U(x_j, y_j),$$

where x_j and y_j are, respectively, consumption of the dirty and clean commodities by the representative consumer of country j. We assume that U is identical for all countries. We also assume that both goods are essential in consumption. In addition, we assume that U is homothetic, strictly increasing in its arguments, and strictly quasi-concave.[14]

With homothetic preferences, the indirect utility function of the representative consumer can be expressed in terms of national income and a price index. Indeed, given that Z is assumed to be constant, the indirect utility of the representative consumer in country j can be written as $V_j = I_j/\Phi(p)$ where, I_j is national income in j, equal to G_j in equilibrium, and $\Phi(p)$ is the *true price index* for the private goods. Finally, denote the net imports of X by country j by m_j.

Welfare of a country j is given by the indirect utility of its representative consumer. Then we can compute the gross change in country j's welfare induced by an increase in its quota as

$$v_j \equiv dV_j/dz_j = \frac{1}{\Phi(p)^2}[\Phi(p)(\frac{\partial G_j}{\partial z_j} + \frac{\partial G_j}{\partial p}\frac{\partial p}{\partial z_j}) - G_j \frac{\partial \Phi(p)}{\partial p}\frac{\partial p}{\partial z_j}].$$

Note that $\frac{1}{\Phi(p)}$ is the marginal utility of income. Also, $\frac{\partial G_j}{\partial p} = X_j$ (see, for

[14]Again, the utility may depend on Z. However, given our assumption that global pollution Z is exogenously fixed by an agreement, we may disregard this environmental externality.

instance Wong, 1995, p. 44), so that applying Roy's identity we have that

$$\frac{1}{\Phi(p)^2}[-G_j\frac{\partial\Phi(p)}{\partial p}] = -\frac{1}{\Phi(p)}x_j,$$

where the left-hand side is the derivative of the indirect utility function with respect to price, taking income as given, and the right-hand side is the negative of demand times the marginal utility of income. Thus, we have[15]

$$v_j = dV_j/dz_j = \frac{1}{\Phi(p)}(\frac{\partial G_j}{\partial z_j} - m_j\frac{\partial p}{\partial z_j}). \tag{1}$$

As equation (1) shows, v_j can be decomposed in a direct effect on welfare from the increase in inputs and an indirect effect from changes on international terms-of-trade.[16]

One could be tempted to argue that v_j represents the willingness to pay of country j for a marginal increase in its emissions quota. That would be certainly the case if all countries were small, and then all price effects $\frac{\partial p}{\partial z_j}$ were zero. Then, free market forces should lead to trade in permits where the country that is willing to pay the highest price $v_j = \frac{\partial G_j}{\partial z_j}$ buys emissions rights from other countries. However, when countries are not small, the change in quota of country j has effects on other countries as well. Indeed, if country j acquires an additional unit of emission permits, this country will change its output and therefore cause a change in the international terms-of-trade.

[15]There could also be an effect on international prices of the change in demand associated with any transfer of income from buyer to seller. However, given our assumptions on utility functions, this change in total demand in international markets is absent.

[16]Notice that this expression coincides with (23) in Copeland and Taylor (2005), particularized to the case where Z is constant and the possible price paid for the permit is not taken into account.

Indeed, this increase in country j's quota will have an effect on country l's welfare, $l \neq j$, given by

$$-e_l(j) \equiv dV_l/dz_j = \frac{1}{\Phi(p)}(-m_l \frac{\partial p}{\partial z_j}). \qquad (2)$$

Notice that this indirect effect may be asymmetric across countries since it depends on the net imports of the dirty commodity by the country involved. It is also identity-dependent because it may depend on the identity of the country acquiring the emissions rights. Again, if countries took international prices as given, then all price effects would disappear: $e_l(j) = 0$.

Before we proceed with the analysis of the consequences of trade for efficiency, notice that, if we define $e_j(j) \equiv \frac{1}{\Phi(p)}(-m_j \frac{\partial p}{\partial z_j})$, then

$$\sum_l e_l(j) = \frac{1}{\Phi(p)} \frac{\partial p}{\partial z_j} \sum_l m_l = 0,$$

because the sum of the net imports is always zero. Also, the following straightforward remarks will be useful later on:

Remark 1: If country j is completely specialized in commodity Y (X), then country l is also specialized in that commodity for all l $(>) < j$.

Remark 2: If country j's imports of commodity X are positive (negative), then country l's imports are also positive (negative) for all l $(>) < j$.

3 Bilateral Trade and Efficiency

We now turn to analyzing the relationship between efficiency and the incentives to trade emission permits. If an allocation of permits is globally efficient, then a marginal redistribution of permits between any two countries must have a net zero effect on global welfare. Note that $e_j(i)$ is the effect of an increase in country i's permits on country j's welfare. Thus, the effect of a marginal increase in the permits of country i on total welfare is $v_i - \sum_{j \neq i} e_j(i) = \frac{\partial G_i}{\partial z_i}$. Thus, a condition for an interior efficient allocation of quotas is that $\frac{\partial G_i}{\partial z_i}$ is the same for all countries. In fact, given our convexity assumptions, this is a sufficient condition for efficiency.

Since preferences are identical and homothetic, and technologies are also identical and homogeneous, if country j is not specialized in any of the commodities, then $\frac{\partial G_j}{\partial z_j} = \frac{\partial g(1, \frac{z_j^y}{h_j^y})}{\partial z} = P \frac{\partial f(1, \frac{z_j^x}{h_j^x})}{\partial z}$. Thus, if no country is completely specialized and, by the Factor-Price Equalization Theorem, all countries use the same ratio $\frac{z^i}{h^i}$, for $i = x, y$, then the allocation of permits is efficient. Moreover, bilateral trade will not take place, since $\frac{\partial p}{\partial z_j}$ and v_j are also the same for all countries.[17]

The result that bilateral trade does not destabilize efficient allocations of permits is reassuring. Nevertheless, the real question is whether bilateral trade is enough to guarantee that efficiency will be attained starting from an inefficient allocation. Alternatively, if some countries are specialized in the production of one of the commodities, will countries have incentives to trade towards more efficient allocations of permits?[18]

[17] In this case, Copeland and Taylor argue that any rule for assigning emission permits is efficient.

[18] Political economy constraints may limit the amount of permits that each country can trade. Also, some parties, like the EU, have proposed a limit on the quota that can be traded. The Kyoto treaty limits the scope of trade. Article 17 states that: "Any such

To illustrate our answers to this question, consider the following example:

Example: There are three countries with Cobb-Douglas preferences and technologies:

$$U(x_j, y_j) = x_j y_j,$$

and

$$X_j = \left(h_j^x\right)^{\frac{1}{3}} \left(z_j^x\right)^{\frac{2}{3}},\ Y_j = \left(h_j^y\right)^{\frac{2}{3}} \left(z_j^y\right)^{\frac{1}{3}}.$$

Let the initial allocation be $(z_1, h_1) = (0.6, 3)$, $(z_2, h_2) = (1, 2)$, and $(z_3, h_3) = (1.5, 1)$. With these values, country 1 specializes in the clean commodity Y, and country 3 specializes in the dirty commodity X, whereas country 2 produces both commodities, but exports the dirty commodity.[19] We can compute $\Phi(p)\mathbf{v}$ and $\Phi(p)\mathbf{e}$. The results are shown in Table 1.

Table 1

	$i = 1$	$i = 2$	$i = 3$
$\Phi(p)v_i$	.88	.85	.67
$\Phi(p)e_1(i)$	$-$	$-.24$	$-.07$
$\Phi(p)e_2(i)$	$-.005$	$-$	.005
$\Phi(p)e_3(i)$	$-.09$	.23	$-$

trading shall be supplemental to domestic actions" towards reducing emissions. More recently, in the Bonn conference, an additional limit to permit trade was introduced: the "commitment period reserve".

[19]With these values, p=1.27. Country 1 uses a ratio of z to h of .2 in the production of Y, and country 3 uses a ratio 3/2 in the production of X, whereas country 2 uses, of course, a ratio between these two number in the production of each commodity.

With these values, $\Phi(p)\left[v_i - \sum_{j \neq i} e_j(i)\right]$ is 1.02, .86, and .745 respectively for $i = 1$, 2, and 3. Thus, any trade where country 1 sells permits is a trade away from efficiency. The same happens with any trade where country 2 sells to country 3. However, notice that country 1 would be willing to sell permits to country 2 at any price above $v_1 + e_1(2) = .64/\Phi(p)$, and country 2 would be willing to pay up to $v_2 + e_2(1) = .84/\Phi(p)$ to obtain permits from country 1. Thus, bilateral trade may move the allocation even further away from efficiency.

This is not the only possible trade with mutual advantage in this example. In fact, country 3 is willing to sell permits to country 1 at a price that country 1 is willing to accept, and this trade is efficient. Also, country 2 is willing to sell permits to country 3 at a price that country 3 is willing to accept, and this trade is inefficient. A richer model would be necessary to address the trades that would take place.[20]

The example illustrates the consequences of terms-of-trade effects associated with bilateral trade. The shadow price of emissions is higher in country 1 than in country 2, as shown by the fact that the former is specialized in the production of the clean commodity. However, when evaluating a poten-

[20] In the next section we will investigate some general conditions that gurantee that no inefficient trade will take place in any such richer, reasonable model. Note that in this particular example the gains from trade are highest in an inefficient trade: when country 2 sells to country 3. In the next section (Propostion 2) we obtain conditions that guarantee more than this. In terms of this example, we offer conditions such that both country 2 and country 3 could gain more by selling permits to country 1 than by selling them to the other country.

tial trade with country 2, country 1 takes into account how this will affect international trade. Country 1, which is specialized in the clean commodity, reduces its production of this clean commodity and country 2 increases its production of the dirty commodity, and reduces its own production of the clean commodity (as predicted by the Rybczynski theorem). This depresses the relative price of the dirty commodity, which improves the joint welfare of countries 1 and 2. This is the source of gains from this trade. What countries 1 and 2 do not internalize is the effect of this trade on country 3. Country 3's exports of the dirty commodity are large, and the transfer of permits from country 1 to country 2 implies a drastic reduction of the price of these exports. The terms-of-trade effects of such permits trade on country 3 are represented by the difference between $e_3(2)$ and $e_3(1)$, which means a worsening of $0.32/\Phi(p)$ of the welfare of country 3, if this trade materialized.

This example is not intended as a prediction of what trade will take place. The main point is that we cannot presume that bilateral trade alone will ensure that the goals of the Kyoto protocol are attained at minimum cost. In the absence of externalities associated to terms-of-trade effects, the fact that two countries are willing to trade means that there are gains from trade to be realized and these in turn can only come from an increase in welfare, i.e., from a lower cost of attaining the global emissions target. In the presence of externalities, it is well understood that this is not necessarily the case. Our example is only a particular illustration of this general principle.

The question then is whether this example is generic in some sense. Thus we investigate, for the particular case of trade in emission quotas,[21] the conditions that guarantee that bilateral trade will occur only when that trade is efficient, and whether these conditions are stringent.

For a given allocation of permits, let I^* be the set of all solutions to

$$i^* = \arg\max_i \left\{ v_i - \sum_{j \neq i} e_j(i) \right\} = \arg\max_i \frac{\partial G_i}{\partial z_i}.$$

Any trade where $i^* \in I^*$ sells permits to a country $j \notin I^*$ is an inefficient trade. A first step towards answering our question is given by the following lemma.

Lemma 1 *The gains from bilateral trade of permits from some $i^* \in I^*$ are non-positive if*

$$\sum_{l \neq i^*, j} e_l(i^*) \geq \sum_{l \neq i^*, j} e_l(j)$$

for all $j \neq i^*$. Also, if this condition is satisfied, there exists a price at which country j, $j \notin I^*$, sells to country i^* at mutual advantage.

Proof: As in the example, a necessary condition for a trade of quota from country i^* to country j is that $v_j + e_j(i^*) > v_{i^*} + e_{i^*}(j)$. Indeed, the left-hand side is the willingness to pay of country j for *this* bilateral trade, and the right hand side is the minimum ask price by country i^*. Now, from the definition of I^*, $v_{i^*} - \sum_{l \neq i^*} e_l(i^*) > v_j - \sum_{l \neq j} e_l(j)$ for all $j \notin I^*$. Thus, if $\sum_{l \neq i^*, j} e_l(i^*) \geq \sum_{l \neq i^*, j} e_l(j)$, summing these two inequalities we obtain

$$v_{i^*} - e_j(i^*) > v_j - e_{i^*}(j),$$

[21] Terms-of-trade externalities impose more structure than the mere existence of externalities. For instance, with terms-of-trade externalities it is satisfied that $\sum_l e_l(j) = 0$. This will be used below.

and this proves the first part of the lemma. The proof of the second part follows the same line of reasoning. QED.

The interpretation of Lemma 1 is intuitive. Countries i^* and j will trade without considering the externalities that their trade imposes on third countries. That is, the private incentive for trade is equal to the social incentive, i.e., the impact on total welfare, *minus* the externalities on third parties. Therefore, when the social incentive and the externalities on third countries are aligned, the private incentive and the social incentive have the same sign. Thus, trade would be impossible if all the social gains from trade had already been exhausted. Moreover, if social gains from trade had not been exhausted, a trade towards the efficient allocation would also improve the welfare of the countries. We also put this lemma in terms of international trade. Recalling that $\sum_l e_l(j) = 0$,

Corollary: *No inefficient bilateral trade involving the sale of permits by $i^* \in I^*$ can have a mutual advantage if, for all $j \neq i^*$,*

$$(m_{i^*} + m_j)\left(\frac{\partial p}{\partial z_{i^*}} - \frac{\partial p}{\partial z_j}\right) \leq 0.$$

Also, if this condition is satisfied, there exists a price at which country j, $j \notin I^*$, sells to country i^* at mutual advantage.

4 Trade, Specialization, and the Efficiency of Trade

Lemma 1 and its corollary show conditions that guarantee some sort of stability of the efficient solution. These conditions are set in terms of net trades and the impact of permits on international prices. The latter may be difficult to observe. In this section we relate the conditions in the previous section with the structure of output of the different countries.

From now on, let us denote by $\widehat{\imath}$ the country with lowest rate z/h. That is, $\widehat{\imath}$ denotes the country most intensive in h among the countries that are not specialized.[22] Thus, all countries $j < \widehat{\imath}$ will produce only the clean commodity Y. Moreover, all countries specialized in Y will import commodity X, so that $m_j > 0$ for these countries.

Under constant returns to scale, the productivity of an input in the production of one commodity depends inversely on the ratio of that input to the other input used in that production. When a country is completely specialized in one commodity, this ratio is simply the ratio of the endowments. With little more than this observation, we can show that

Lemma 2: $1 \in I^*$. *If* $\widehat{\imath} \neq 1$, *then* $I^* = \{1\}$. *If* $\widehat{\imath} = 1$, *then* I^* *coincides with the set of countries that are not specialized in production.*

Proof: See the Appendix.

Lemma 2 is intuitive. If two countries are producing the same good, it is efficient to assign additional permits to the country that is producing with the greatest ratio of h to z. For the case of commodity X one of these countries is $\widehat{\imath}$. But for country $\widehat{\imath}$ the slope of the production possibilities frontier is equal to the price. Then, it follows almost immediately that countries which face scarcity of the input z relative to the market transformation rate should be the ones that are assigned any extra amount of such input. Thus, efficiency

[22] There may be extreme cases where all countries are specialized. This is a simple case that follows the same line of analysis.

requires that this input is assigned to country 1 if this country is completely specialized in Y, or else to some country that produces both commodities. The signs of price effects and their relative sizes are also well behaved for similar reasons, :

Lemma 3: $\frac{\partial p}{\partial z_j} > \frac{\partial p}{\partial z_{j'}} > 0$ *for all* $j < j' < \widehat{i}$. *Also, if country* $j > \widehat{i}$ *is completely specialized in commodity* X, *then* $\frac{\partial p}{\partial z_{\widehat{i}}} < \frac{\partial p}{\partial z_{j'}} < 0$.

Proof: See the Appendix.

Notice that the effect on the price of X of an increase in emissions permits of country $\widehat{i}$ is negative, which follows from Rybczynsky's theorem. A simple corollary of this theorem is that this effect is the same for all countries that produce both goods. In fact, the largest, negative effect on the price is obtained by assigning new emission permits to any of these countries. Lemma 3 is partly a consequence of the fact that, under our assumptions on preferences and technologies, consumers in each country spend the same proportion of their income in each of the commodities. Then, each country $j < \widehat{i}$ spends the same proportion of their income in imports of the dirty commodity, and each country j that is completely specialized in X exports the same proportion of their output.

We can now relate the conditions of Lemma 1 to the pattern of outputs and trades.

Proposition 1: *For* $i^* \in I^*$, $(m_{i^*} + m_j)\left(\frac{\partial p}{\partial z_{i^*}} - \frac{\partial p}{\partial z_j}\right) \leq 0$ *for all* $j \neq i^*$ *if and only if* $\widehat{i} = 1$, *that is, if and only if country 1 produces both commodities.*

Proof: See the Appendix.

The next proposition analyzes conditions such that the gains from trade are not only positive when trade is efficient, but are also maximized by such trade.

Proposition 2: *Assume that for $i^* \in I^*$, $(m_{i^*} + m_j)\left(\frac{\partial p}{\partial z_{i^*}} - \frac{\partial p}{\partial z_j}\right) \leq 0$ for all $j \neq i^*$ (and then $\widehat{i} = 1$). For any $j \notin I^*$ the gain from trading emission permits with i^* is positive and larger than the gain from trading with any other country not in I^*.*

Proof: See the Appendix.

Proposition 1 establishes necessary conditions for Lemma 1 to apply, so that efficient trades of permits are feasible and no trade involving the sale of permits by their most efficient user is feasible. Yet, as in our example, other permit trades between countries not in I^* may be feasible even under the conditions of Proposition 1. We do not know whether those trades would be efficient or not. Would a country sell permits to another country not in I^*, instead of selling to a country in I^*? Again, we would need a model of how countries find trade partners, which is beyond the scope of this paper. However, Proposition 2 suggests that such models would predict the right trades under the conditions of Lemma 1.

Summarizing our results, we can be certain that bilateral trade would lead initial allocations toward more efficient ones only when the country with the highest relative endowment of h is not too intensive in h and/or is sufficiently large so as to not specialize in any commodity.

When these conditions are not satisfied, permit trade need not guarantee that the goals of the Kyoto protocol will be attained at minimum cost. A laissez-faire approach which simply sets a cap on total GHG emissions expecting the "market" to find the right distribution of emissions, may be too optimistic. The initial allocation of permits and the trade mechanism may have an effect on the size of the cost of the program, and not only on how this cost is shared across countries.

5 Concluding remarks

This paper has shown that free market forces, understood as the unregulated, decentralized bilateral trade between countries, are not sufficient to guarantee an efficient allocation of GHG emission quotas. The corollary is that market design should be a key ingredient to attain this efficiency goal.

The main feature of permit trade that accounts for this result is the presence of identity-dependent, asymmetric, external effects. Different countries may have different preferences about which country obtains additional permits, if they themselves do not.

There are three assumptions that are essential for our results. The first one is openness of the international commodities market. The second is that traders, in this case countries, are not small in the permit market. Indeed, if they were small, a country could not influence the allocation of permits. The third is that countries are not small in the commodities market either. If they were, international prices in these markets would not be affected by changes in production of an individual country, and therefore externalities through terms-of-trade would not be an issue.

In the above analysis we have assumed that countries buy permits only to use them, and do not trade for purely speculative reasons.[23] Also, the results

[23]If countries can buy permits for purely speculative motives, then bilateral trade results

were obtained under several simplifying assumptions on the technology and preferences. However, we think that our arguments are sufficiently robust to support the claim that bilateral trade may not be a good substitute for the design of a market for permits.

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in the same final allocation independent of the initial distribution (Jehiel and Moldovanu, 1999) but in general this allocation is not efficient. Therefore bilateral trade would not even be desirable.

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7 Appendix

Proof of lemma 2: All countries $i = 1, ..., \widehat{i} - 1$ specialize in commodity Y. That is, $G_j(p, h_j, z_j) = g(h_j, z_j)$. Thus,

$$\frac{\partial G_j}{\partial z_j} = \frac{\partial g(1, \frac{z_j}{h_j})}{\partial z}, \forall j < \widehat{i},$$

Since g exhibits decreasing returns in each of its inputs, and $\frac{h_j}{z_j} > \frac{h_{j'}}{z_{j'}}$ for $j < j'$, this excludes $2, ..., \widehat{i} - 1 \in I^*$. Similarly, we show that $\frac{h_j}{z_j} \leq \frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}}$ for all j that specialize in commodity X. That is, country $\widehat{i}$ produces commodity X using h more intensively than country j. Indeed, since $\widehat{i}$ produces both commodities,

$$P \cdot \frac{\partial f(\frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}}, 1)}{\partial h} = \frac{\partial g(\frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}}, 1)}{\partial h}.$$

Thus, if $\frac{h_j}{z_j} > \frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}}$, then

$$P \cdot \frac{\partial f(\frac{h_j}{z_j}, 1)}{\partial h} < \frac{\partial g(\frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}}, 1)}{\partial h},$$

so that country j would increase its national income by switching an infinitesimal amount of inputs from the production of X to the production of Y in the proportion $\frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}}$.

Now, applying the envelope theorem, $\frac{\partial G_{\widehat{i}}}{\partial z_{\widehat{i}}} = P \cdot \frac{\partial f(h^x_{\widehat{i}}, z^x_{\widehat{i}})}{\partial z} > P \cdot \frac{\partial f(h_j, z_j)}{\partial z} = \frac{\partial G_j}{\partial z_j}$. This excludes $i^* > \widehat{i}$ and specialized in production of X. We need only excluding $1 < \widehat{i} \in I^*$. Notice that $\widehat{i} \in I^*$ implies that $\frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}} > \frac{h_{\widehat{i-1}}}{z_{\widehat{i-1}}}$, since $\frac{\partial G_j}{\partial z_j} = \frac{\partial g(1, \frac{z^y_j}{h^y_j})}{\partial z_j}$ for $j \leq \widehat{i}$, and $\frac{\partial^2 g}{\partial z^2} < 0$. On the other hand, since

$\frac{h_{\widehat{i-1}}}{z_{\widehat{i-1}}} > \frac{h_{\widehat{i}}}{z_{\widehat{i}}}$ it is immediate that $\frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}} < \frac{h_{\widehat{i-1}}}{z_{\widehat{i-1}}} (< \frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}})$. Also, notice that country $\widehat{i}-1$ could always switch a small amount of inputs z and h in the proportion $\frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}}$, without reducing the ratio $\frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}}$. Then, since $P \cdot \frac{\partial f(\frac{h^x_{\widehat{i}}}{z^x_{\widehat{i}}},1)}{\partial z} = \frac{\partial g(\frac{h^y_{\widehat{i}}}{z^y_{\widehat{i}}},1)}{\partial z} > \frac{\partial g(\frac{h_{\widehat{i-1}}}{z_{\widehat{i-1}}},1)}{\partial z}$, country $\widehat{i}-1$'s income would increase, which contradicts one of the equilibrium conditions. Lemma 2 follows.

The last part of the Lemma follows from the result just proved that $\frac{\partial G_{\widehat{i}}}{\partial z_{\widehat{i}}} > \frac{\partial G_j}{\partial z_j}$, for $j > \widehat{i}$ if j is specialized in production of X, together with the fact that, from the factor price equalization theorem, $\frac{\partial G_i}{\partial z_i} = \frac{\partial G_h}{\partial z_h}$ for all j, h that are not completely specialized in production. QED.

Proof of Lemma 3: Consider the market clearing condition

$$\sum_{l=1}^{n} m_l = 0.$$

Totally differentiating in this equilibrium condition, we obtain

$$\frac{\partial p}{\partial z_j} = -\frac{\partial \sum_{l=1}^{n} m_l / \partial z_j}{\partial \sum_{l=1}^{n} m_l / \partial p}.$$

Now, since U is homothetic, increasing and quasi-concave in all its arguments, the domestic demand of commodity X is

$$x_j(P, G_j) = \alpha(P) \frac{G_j}{P},$$

where $\alpha(P) \in (0,1)$. Also, country $j's$ output of commodity X is $f(h_j, z_j) = \frac{G_i}{P}$ if j is specialized in commodity X, and 0 if $j < \widehat{i}$. Thus,

$$m_j = x_j - X_j = \begin{cases} \alpha(P)\frac{G_i}{P} = \alpha(P)\frac{g(h_j,z_j)}{P} & \text{if } j < \widehat{i} \\ \alpha(P)\frac{G_i}{P} - \frac{G_i}{P} = f(h_j, z_j)\left(\alpha(P) - 1\right) & \text{if } j \text{ specialized in } X \end{cases}$$

Notice that $\frac{\partial \sum_{l=1}^{n} m_l}{\partial p} < 0$. Also, $\frac{\partial \sum_{l=1}^{n} m_l}{\partial z_j} = \frac{\partial m_j}{\partial z_j}$. Homogeneity of degree 1 of both g and f, and decreasing returns in each of the inputs again allow us to conclude that $\frac{\partial p}{\partial z_j} > \frac{\partial p}{\partial z_{j'}} > 0$ for all $j < j' < \widehat{\imath}$ and $\frac{\partial p}{\partial z_j} < \frac{\partial p}{\partial z_{j'}} < 0$ for all countries $j < j'$ completely specialized in commodity X. Thus, the only thing that is left to analyze is $\frac{\partial m_{\widehat{\imath}}}{\partial z_{\widehat{\imath}}}$. For that purpose, we first show that $\frac{h_j}{z_j} \leq \frac{h^x_{\widehat{\imath}}}{z^x_{\widehat{\imath}}}$ when j is completely specialized in commodity X. That is, country $\widehat{\imath}$ produces commodity X using h more intensively than country j. Indeed, since $\widehat{\imath}$ produces both commodities, and since partial derivatives of the production function are homogeneous of degree 0, then

$$P \cdot \frac{\partial f(\frac{h^x_{\widehat{\imath}}}{z^x_{\widehat{\imath}}}, 1)}{\partial h} = \frac{\partial g(\frac{h^y_{\widehat{\imath}}}{z^y_{\widehat{\imath}}}, 1)}{\partial h}.$$

Thus, if $\frac{h_j}{z_j} > \frac{h^x_{\widehat{\imath}}}{z^x_{\widehat{\imath}}}$, then

$$P \cdot \frac{\partial f(\frac{h_j}{z_j}, 1)}{\partial h} < \frac{\partial g(\frac{h^y_{\widehat{\imath}}}{z^y_{\widehat{\imath}}}, 1)}{\partial h},$$

so that country j would increase its national income by switching an infinitesimal amount of inputs from the production of X to the production of Y in the proportion $\frac{h^y_{\widehat{\imath}}}{z^y_{\widehat{\imath}}}$.

But , applying the envelope theorem, $\frac{\partial G_{\widehat{\imath}}}{\partial z_{\widehat{\imath}}} = P \cdot \frac{\partial f(h^x_{\widehat{\imath}}, z^x_{\widehat{\imath}})}{\partial z} > P \cdot \frac{\partial f(h_j, z_j)}{\partial z} = \frac{\partial G_j}{\partial z_j}$. Thus, $m_j = f(h_j, z_j)\,(\alpha(P) - 1)$, and $m_{\widehat{\imath}} = \frac{G_j}{P}\alpha(P) - f(h^x_{\widehat{\imath}}, z^x_{\widehat{\imath}}) = f(h^x_{\widehat{\imath}}, z^x_{\widehat{\imath}})\,(\alpha(P) - 1) + \frac{\alpha(P)}{P} g(h^y_{\widehat{\imath}}, z^y_{\widehat{\imath}})$. Also, $\frac{\partial g(h^y_{\widehat{\imath}}(z), z^y_{\widehat{\imath}}(z))}{\partial z} < 0$, from Rybczynski's Theorem, where $h^y_{\widehat{\imath}}(z)$ and $z^y_{\widehat{\imath}}(z)$ are quantities of inputs used in the production of y, as function of the total endowment of z of country $\widehat{\imath}$. Thus, $\frac{\partial f(h^x_{\widehat{\imath}}(z), z^x_{\widehat{\imath}}(z))}{\partial z} > \frac{\partial f(h^x_{\widehat{\imath}}, z^x_{\widehat{\imath}})}{\partial z}$, since country $\widehat{\imath}$ would not be maximizing national income otherwise, and since $\alpha(P)-1<0$, then $\frac{\partial m_{\widehat{i}}}{\partial z_{\widehat{i}}} < \frac{\partial f(h^x_{\widehat{i}}, z^x_{\widehat{i}})}{\partial z}(\alpha(P)-1) < \frac{\partial m_j}{\partial z_j} < 0$. QED

Proof of Proposition 1: First we prove the only if part. Assume that $\widehat{i}>1$. If $\widehat{i}>2$, then $m_1+m_2>0$ and $\frac{\partial p}{\partial z_1}-\frac{\partial p}{\partial z_2}>0$ as well. Thus, we need consider only $\widehat{i}=2$. If $m_2>0$, again $m_1+m_2>0$ and $\frac{\partial p}{\partial z_1}-\frac{\partial p}{\partial z_2}>0$. If $m_2<0$, then for all $j>2$, we have that $m_j<0$ as well, from our remark 2. Thus, only country 1 imports. Thus, we still have $m_1+m_2>0$, $\frac{\partial p}{\partial z_{i^*}}-\frac{\partial p}{\partial z_2}>0$.

Now we turn to the if part. Notice that if $i^*=1$ is the only country that is not specialized in the production of a single commodity, then country 1 is the only country that produces commodity Y and the only country that imports X, so that $m_{i^*}+m_j>0$ for all j. Also, $\frac{\partial p}{\partial z_{i^*}} < \frac{\partial p}{\partial z_j} < 0$ for all j. Thus, $(m_{i^*}+m_j)\left(\frac{\partial p}{\partial z_{i^*}}-\frac{\partial p}{\partial z_j}\right) \leq 0$. QED.

Proof of Proposition 2: We need to show that, under the assumptions of Lemma 1, $v_{\ i^*}+e_{\ i^*}(j)-[v_j+e_j(\ i^*)] > v_l+e_l(j)-[\ v_j+e_j(l)]$ for all $j,l \notin I^*$. Notice that, if the assumption of Lemma 1 is satisfied, then $v_{\ i^*}+e_{\ i^*}(j) > v_l+e_l(j)$. Thus, we need only showing that $e_j(l) > e_j(\ i^*)$. That is, $m_j(\frac{\partial p}{\partial z_l}-\frac{\partial p}{\partial z_{\ i^*}}) > 0$. This follows from the assumption that $\widehat{i}=1$, which implies that all $j \notin I^*$is specialized in the production of the dirty commodity so that $m_j<0$. QED.