Permit trading: Merely an efficiency-neutral redistribution away from climate change victims?[*]

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Abstract

This paper presents a climate policy game with international emissions trading where governments first select their amounts of emissions permits. These permits are transferred to firms and then traded competitively on an international market. Compared with a game without trading, we find that the potential efficiency gains from permit trading that have been identified in other studies are totally undone if governments also employ a tax or subsidy on domestic emissions. The only effect of permit trading in this case is a redistribution of income away from those most affected by climate change.

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I Motivation

More than 15 years of international climate talks have so far not resulted in any binding agreement with broad participation and substantial emissions reductions. The Kyoto Protocol and Copenhagen Accord are examples par excellence of these inadequacies. Nevertheless, despite the notable absence of efficient cooperation, many measures aimed at mitigating emissions have been adopted. The purpose of this paper—which builds on the analysis by Helm (2003)—is to examine some possible consequences of *international emissions trading* in a

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noncooperative setting.[1]

Our point of departure—named policy A—is the classical case where governments decide voluntarily on their emissions levels without any subsequent trade. If they follow only their own interests, and if we abstract from problems of carbon leakage, the marginal benefit of domestic emissions becomes equal to the domestic marginal climate cost of aggregate emissions.

If countries are differently affected by climate change, policy A will lead to differences in marginal abatement costs between countries. To eliminate this source of inefficiency, one could combine an international emissions trading system (policy B) with policy A. Clearly, if countries' initial endowments of allowances—targets for short—were fixed at the emissions levels of policy A, trading would yield overall efficiency gains, to nobody's detriment. However, we assume that governments anticipate subsequent trade when targets are set. This creates incentives that are absent under policy A. That is, establishing a permit market when targets are endogenous generates prospects for revenues, albeit at a decreasing rate.

When studying policies A and B, Helm (2003) shows that less environmentally affected countries tend to choose less stringent targets and become permit exporters. Conversely, countries more interested in global emissions reductions access inexpensive abatement abroad; they choose more ambitious targets and become permit importers. The total effect on global emissions compared with policy A becomes ambiguous, i.e., parameter dependent, see Helm (2003).[2] This also applies to aggregate welfare. However, in a computable general equilibrium environment, Carbone et al. (2009) identify substantial emission reductions and welfare gains when policy B is combined with policy A.

In practice, the effective price of carbon is determined not only by the permit price. For instance, energy taxes or subsidies—which are in widespread use—may come into play. Such instruments are absent from the analysis by Helm (2003), and they are exogenous in Carbone et al. (2009). The contribution of our analysis is to make these policies part of the game, that is, to combine domestic emissions taxes or subsidies (policy C) with policies A and B.[3] Under the assumption that governments set targets and choose taxes/subsidies simultaneously and noncooperatively before competitive permit trading takes place internationally, the analysis of this paper shows that the resulting profile of emissions of the combined policies A, B and C is identical to that of policy A alone. This means that the possibility of imposing taxes and subsidies will totally undo any potential efficiency gains from international emissions trading, even though the permit market may flourish.

There are, however, distributional consequences of combining policies B and C with

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[1] Other closely related literature includes Carbone et al. (2009), Copeland and Taylor (1995), Cramton and Stoft (2010a), Cramton and Stoft (2010b) and Holtsmark and Sommervoll (2008). This line of research is somewhat different from the more classical one on international environmental agreements, see Section 4.

[2] Section 3 offers a simple example where emissions decrease.

[3] We do not model the energy markets. Nevertheless, as long as carbon emissions are proportional to fossil fuel consumption, emissions and energy taxes (or subsidies) remain much the same.

policy A. Countries with a low domestic marginal climate cost of aggregate emissions will have lower emissions than targets; they become permit exporters, and by receiving the associated revenues, they win. Conversely, countries with a high domestic marginal climate cost become permit importers and lose. This also means that within the structure of the model, one cannot get agreement on international emissions trading, except for the irrelevant symmetrical case.

These results are brought out next. To illustrate, a two-country example appears in Section 3. Section 4 contains bibliographic remarks, while Section 5 concludes.

II Analysis

The underlying fundamentals of our economy are identical to those in Helm (2003). There is a fixed and finite set of countries $I = \{1, ..., n\}$. Each country $i \in I$ is composed of a government and many price-taking firms that have a total benefit $\pi_i(e_i)$ from releasing $e_i \geq 0$ units of emissions. Moreover, each country is adversely affected by global emissions via climate change $v_i\left(\sum_{j\in I} e_j\right)$.

We consider the following two-stage game, which we name a *voluntary emissions game with international permit trading and domestic taxation* (policies A, B and C).

Stage 1: Each government chooses both an emissions tax t_i and a target ω_i (its initial endowment of emissions permits). These permits are transferred to the firms.
Stage 2: Firms, which all have access to an international permit market where the unit price is p, select their level of emissions e_i. The firms' cost of emitting one more unit equals $p + t_i$.[4]

It is assumed that the choice variables ω_i and t_i are both free. Should ω_i be negative, then more permits must be bought than the emissions than can occur. A subsidy is nothing but a negative tax and is simply referred to as a tax (unless ambiguity arises). We also assume that governments are indifferent to whether income accrues to themselves or to domestic firms. This means, in particular, that it does not matter how emissions permits are transferred to firms, i.e., whether they are sold or allocated free of charge.

Let $\boldsymbol{\omega} := (\omega_1, ..., \omega_n)$ be a profile of targets and $\mathbf{t} := (t_1, ..., t_n)$ a profile of taxes. It is essential for the analysis that for every possible pair of profiles $(\boldsymbol{\omega}, \mathbf{t})$ we have a unique equilibrium at stage 2, preferably in the interior. To ensure this, we invoke the assumption that $\pi_i : \mathbb{R}_+ \to \mathbb{R}$ is twice continuously differentiable with $\pi_i'(e_i) > 0$ and $\pi_i''(e_i) < 0$, as well as $\pi_i'(e_i) \to \infty$ as $e_i \to 0$ and $\pi_i'(e_i) \to 0$ as $e_i \to \infty$.

We start by analyzing **stage 2** of the game. Emissions e_i in country $i \in I$ are determined as if a representative national firm were maximizing $\pi_i(e_i) - (p + t_i)e_i + p\omega_i$, where the last

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[4] Alternative formulations of the game are discussed in our concluding remarks.

term may vanish if permits are auctioned. Whenever $(p + t_i) > 0$, it follows that e_i satisfies

$$\pi_i'(e_i) = p + t_i \text{ for all } i \in I, \tag{1}$$

while $e_i = \infty$ otherwise.

For any given $\mathbf{t}$, the first-order conditions (1) imply that aggregate permit demand is a strictly decreasing function of p, which approaches 0 as $p \to \infty$ and ∞ as $p \to -\min_{j \in I} t_j$. Hence, if $\sum_{j \in I} \omega_j > 0$, then $(\boldsymbol{\omega}, \mathbf{t})$ and the market-clearing condition

$$\textstyle\sum_{j \in I} e_j = \sum_{j \in I} \omega_j \tag{2}$$

determine a unique equilibrium permit price $p(\boldsymbol{\omega}, \mathbf{t}) > -\min_{j \in I} t_j$. Furthermore, from (1), this in turn determines the emissions $e_i(\boldsymbol{\omega}, \mathbf{t})$, which become strictly positive in all countries. If, in contrast, $\sum_{j \in I} \omega_j \leq 0$, then emissions and permit trading both vanish.

We write

$$s_i := \frac{1}{\pi_i''(e_i)} < 0 \text{ and } S := \sum\nolimits_{j \in I} s_j < s_i, \tag{3}$$

evaluated at equilibrium emissions. The following claims—which are proved in the Appendix—will be applied to sort out later results.

Lemma (Comparative statics) *Suppose* $\sum_{j \in I} \omega_j > 0$. *Then, under the assumed conditions for the functions* π_i, $i \in I$, *we have:*

$$\frac{\partial p}{\partial \omega_i} = \frac{1}{S} < 0 \qquad \frac{\partial e_i}{\partial \omega_i} = \frac{s_i}{S} \in (0, 1) \tag{4}$$

$$\frac{\partial p}{\partial t_i} = -\frac{s_i}{S} \in (-1, 0) \qquad \frac{\partial e_j}{\partial t_i} = -\frac{s_i s_j}{S} > 0 \textit{ if } j \neq i \qquad \frac{\partial e_i}{\partial t_i} = -\frac{s_i^2}{S} + s_i < 0 \tag{5}$$

$$\sum\nolimits_{j \in I} \frac{\partial e_j}{\partial \omega_i} = 1 \textit{ and } \sum\nolimits_{j \in I} \frac{\partial e_j}{\partial t_i} = 0. \tag{6}$$

Although the economic content and intuitions of each result in (4)–(6) confirm established literature on endowment manipulation in exchange economies and tariff retaliation in international economies, it is notable that $\frac{\partial e_i}{\partial \omega_i}$ is exactly the same as $-\frac{\partial p}{\partial t_i}$. This is so even though the first object deals with relative quantity changes, while the second concerns relative price effects. We next explain the intuition as to why this holds true, and we start with the interpretation of s_i. Ceteris paribus, a 'large' economy, which can spread out abatement among many economic activities, will typically have a relatively slowly decreasing marginal benefit function, i.e. $|\pi_i''(e_i)|$ will be smaller than that of a 'small' economy. Therefore, by (3) it follows that s_i/S is an indicator of country i's relative economic size. As such, it is intuitive that a perturbation in total permit supply will be absorbed by a large economy to a greater extent than by a small economy, i.e., that $\frac{\partial e_i}{\partial \omega_i}$ will be proportional to s_i. Similarly, a tax increase in a large economy will, when keeping the permit price fixed, have a more substantial effect on the demand for emissions compared with the effect of a tax increase in a small economy. Thus, the imbalance in the market that a tax increase will cause, becomes greater the larger is the economy. Therefore, when the permit price must ultimately equilibrate demand with supply, the resulting price reduction will increase with country i's relative economic size.[5]

Note that even though the *emissions* in country i as a function of the variables chosen at stage 1 depend on the whole profile $(\boldsymbol{\omega}, \mathbf{t})$ of targets and emission taxes, the *decisions* by firms depend solely on the international permit price and the national emission tax t_i.

We are now prepared for the analysis of the game at **stage 1**. There, each government $i \in I$ maximizes $W_i(\boldsymbol{\omega}, \mathbf{t})$ with respect to (ω_i, t_i), where

$$W_i(\boldsymbol{\omega}, \mathbf{t}) := \pi_i(e_i(\boldsymbol{\omega}, \mathbf{t})) - v_i\left(\sum\nolimits_{j \in I} e_j(\boldsymbol{\omega}, \mathbf{t})\right) + p(\boldsymbol{\omega}, \mathbf{t})(\omega_i - e_i(\boldsymbol{\omega}, \mathbf{t}))$$

whenever $\sum_{j \in I} \omega_j > 0$, and $W_i(\boldsymbol{\omega}, \mathbf{t}) := \pi_i(0) - v_i(0)$ otherwise, so that the function W_i is well defined for all pairs of profiles $(\boldsymbol{\omega}, \mathbf{t})$.

Assume next that the damage function $v_i : \mathbb{R}_+ \to \mathbb{R}$ is twice continuously differentiable with $v_i'(\cdot) > 0$ and $v_i''(\cdot) \geq 0$. Together with the assumptions made on π_i, this yields the result that a Nash equilibrium, if it exists, is characterized by the first-order conditions

$$\pi_i' \cdot \frac{\partial e_i}{\partial \omega_i} - v_i' \cdot \sum\nolimits_{j \in I} \frac{\partial e_j}{\partial \omega_i} + \frac{\partial p}{\partial \omega_i}(\omega_i - e_i) + p\left(1 - \frac{\partial e_i}{\partial \omega_i}\right) = 0 \tag{7}$$

and

$$\pi_i' \cdot \frac{\partial e_i}{\partial t_i} - v_i' \cdot \sum\nolimits_{j \in I} \frac{\partial e_j}{\partial t_i} + \frac{\partial p}{\partial t_i}(\omega_i - e_i) + p\left(0 - \frac{\partial e_i}{\partial t_i}\right) = 0 \tag{8}$$

together with (1)–(2) and the results in the Lemma. In (7)–(8), and what follows from them, the dependence of e_i and p on $(\boldsymbol{\omega}, \mathbf{t})$, the dependence of π_i' on e_i and the dependence of v_i' on $\sum_{j \in I} e_j$ have all been suppressed. Moreover, even though there exists no equilibrium with $\sum_{j \in I} \omega_j \leq 0$, it may well be that $\omega_i < 0$ for some $i \in I$.

Before presenting our main result, we shall, for comparison, describe two games of reference. We name the first a *voluntary emissions game* where there is no permit trading, referred to as policy A in Section 1. In this game, each government implements measures to maximize $\pi_i(e_i) - v_i\left(\sum_{j \in I} e_j\right)$ with respect to $e_i \geq 0$. Assume that this game has a unique Nash equilibrium. With the assumptions made on the functions π_i and v_i, it follows that $e_i > 0$ for all $i \in I$ in equilibrium, therefore satisfying

$$\pi_i'(e_i) - v_i'\left(\sum\nolimits_{j \in I} e_j\right) = 0 \tag{9}$$

for all $i \in I$.

The second game of reference combines policy A with trade and is named a *voluntary emissions game with international permit trading* (referred to as policies A and B in Section

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[5] Those readers interested in more general comparative statics results when utility is transferrable, as it is here, may consult Flåm et al. (2008).

1). This is the game studied by Helm (2003) and is a special case of our game, obtained by fixing $t_i = 0$ for all $i \in I$ and removing it as a decision variable in stage 1. Together with market clearing, and the condition that $\pi_i'(e_i) = p$ for all firms, an equilibrium profile $\boldsymbol{\omega}$ of this game satisfies

$$\pi_i'(e_i) - v_i'(\cdot) + \frac{\partial p}{\partial \omega_i}(\omega_i - e_i) = 0 \tag{10}$$

for all $i \in I$, see Helm (2003, p. 2741).

In preparation for our main result, we summarize our assumptions.

Assumptions

- *The functions π_i and v_i satisfy all the aforementioned conditions.*
- *There exists a unique Nash equilibrium in both the voluntary emissions game characterized by* (9) *and the voluntary emissions game with international permit trading and domestic taxation characterized by* (1)–(2) *and* (7)–(8).

By making use of the Lemma, it turns out that (7)–(8) reduce to (9), i.e., the following result (see the Appendix for proof).

Proposition 1 (On efficiency) *Given the assumptions, it follows that the equilibrium in the voluntary emissions game with international permit trading and domestic taxation (policies A, B and C) leads to the same emissions profile $(e_1, ..., e_n)$ as in the voluntary emissions game (policy A).*

In other words, the allocation of abatement efforts and climate damages with all policies combined is exactly the same as with policy A alone. This result implies that any efficiency gains associated with combining B with A are totally undone if countries are free to tax or subsidize domestic emissions, as when policies A, B and C are combined.

To describe the key mechanism leading to the result, it is best to take the *voluntary emissions game with international permit trading* (policies A and B) as a point of departure. In that game, where taxes are absent, firms chose their emissions levels such that marginal benefits equal the international permit price p. Hence, if countries have different marginal damages of aggregate emissions, the countries would face an after-trade situation where the marginal benefits of emissions $\pi_i'(e_i)$ differ from the marginal damages $v_i'(\cdot)$, see (10).

Now, take for instance a permit importer who will end up with $\pi_i'(e_i) < v_i'(\cdot)$ under policies A and B. Clearly, such a country would have an interest in reducing its emissions further. However, the only way to accomplish this when the tax instrument is unavailable is for the government to select a lower target ω_i in the first stage of the game. The reason this does not pay off is that the permit price will rise, and because the country is a permit importer, market expenses will also rise. Hence, in this regime, the government of a permit-importing country is confronted with a trade-off between improving the environment and keeping the permit price low. A similar, yet opposite, trade-off holds for a permit exporter. In both cases, governments must choose an ω_i that represents a compromise between considerations of environmental quality and market revenues/expenses.

Consider next the possibility to use the tax/subsidy instrument, i.e., policies A, B and C. Because the global emissions are determined by the total amount of permits, the choice of t_i does not influence environmental quality for a given $\boldsymbol{\omega}$. This makes it possible to dedicate the tax instrument to the terms-of-trade effects, while choosing ω_i based on environmental considerations. In short, the trade-off between achieving the desired environmental quality without adversely affecting revenues (or expenses) in the permit market, identified under policies A and B, disappears when governments also have the tax instrument available. This describes the essential mechanism leading to Proposition 1.

Because of the specific nature of this result, one may perhaps wonder whether there will be any trade in an equilibrium of our game. To address this, combine (7) with (4), (6) and Proposition 1, to obtain

$$(p - v_i') \cdot \left(1 - \frac{s_i}{S}\right) = -\frac{1}{S}\left(\omega_i - e_i\right). \tag{11}$$

Suppose now that there is no trade, i.e., that $e_i = \omega_i$ for all $i \in I$. By (11), this gives $v_i'(\cdot) = p$ for all $i \in I$. If marginal damages in equilibrium are different for at least one distinct pair i, j, then we get an impossibility, implying that there must be trade.

Another direct implication of (11) and Proposition 1 is the following.

Proposition 2 (On distributional effects) *Given the Assumptions, it follows that combining domestic taxation and international permit trading (policies B and C) with a voluntary emissions game (policy A) is to the advantage of countries with low domestic marginal climate costs and to the disadvantage of countries with high domestic marginal climate costs.*

The intuition behind this result is discussed next. We have already established by Proposition 1 that the emission benefits and climate damage costs that a country incurs under policies A, B and C are identical to those incurred under policy A alone. Hence, the only difference between the two policy combinations is the flows of permits and money in the market. Now, because the domestic marginal climate cost of aggregate emissions is the cost of supplying permits, while the common permit price is the associated benefit, countries with low domestic marginal climate costs have a comparative advantage in supplying permits. Such countries become permit exporters, and—compared with policy A—they win. Victims of climate change import permits and lose.

It must be emphasized though that a country's marginal damage cost is not merely a statement about its vulnerability to climate change, say on a per capita basis. To illustrate why, suppose that two identical countries decide to form a union. Then the marginal climate cost for the region as a whole will typically double as a consequence of aggregation. Thus, it may well be that a small country is heavily affected by climate change for each of its citizens, but that there are so few of them that, when adding the marginal damages up, the number is still small. As such, Proposition 2 indicates that combining policies B and C with policy A is to the disadvantage of ‘large’ countries, while ‘small’ countries will benefit.

Propositions 1 and 2 also imply that if we added a market participation stage to the game before stage 1, similar to Carbone et al. (2009) and Helm (2003), it follows trivially that any country that, if participating, would become a permit importer would be better off opting out of the market. Therefore, if a market participation stage is included in the game prior to stage 1, there will not exist any equilibrium with participation and trade.

III An example

To illustrate and offer further intuitions, this section presents a two-country example with linear climate damage costs $v_i(e_1 + e_2)$ and where the benefit functions are quadratic ‘to the left of their maxima’. The details are given in Table 1.

Table 1. *Benefit functions when* $e_1 \leq 10$ *and* $e_2 \leq 5$*, and damage functions for any emissions.*

Country	Benefits, $\pi_i(e_i)$	∂Benefits, $\pi_i'(e_i)$	Damages, $v_i(\cdot)$
1	$10e_1 - \frac{1}{2}(e_1)^2$	$10 - e_1$	$2(e_1 + e_2)$
2	$10e_2 - (e_2)^2$	$10 - 2e_2$	$6(e_1 + e_2)$

To rule out decreasing benefits, we posit that whenever $e_1 > 10$ and $e_2 > 5$, benefits are constant with $\pi_1(e_1) = 10(10) - \frac{1}{2}(10)^2$ and $\pi_2(e_2) = 10(5) - (5)^2$, respectively, so that margins are nil. Note that country 2 has a higher marginal climate damage and a steeper marginal benefit function than country 1.

The parameters have been selected in order to facilitate exposition by getting exact solutions in all the games and to illustrate that the voluntary emissions game with international permit trading (policies A and B) may yield lower global emissions than policy A alone.[6]

We start with the classical case without emissions trading, yielding marginal benefits equal to private marginal damages.

Table 2. *A voluntary emissions game (policy A).*

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[6] In the previous section, we suggested at an intuitive level that a ‘large’ country would typically have a flatter marginal benefit function and a higher marginal damage cost than a ‘small’ country. The example here has been parameterized oppositely: the high-damage country also has the steepest marginal benefit function. If, instead, aligning the example with the aforementioned intuition, then the combination of policies A and B yields higher emissions than policy A alone.

Country	e_i	$\pi_i'(e_i)$	$\pi_i(e_i)$	$-v_i(\cdot)$	Total payoff
1	8	2	48	-20	28
2	2	6	16	-60	-44
Total	10		64	-80	-16

Besides being inefficiently large, we see that emissions are inefficiently allocated, because they produce different marginal benefits.

We next look at the situation with international trade, as in Helm (2003), and where emissions taxes are absent.

Table 3. *A voluntary emissions game with international permit trading (policies A and B). The permit price equals 4.*

Country	ω_i	e_i	$\pi_i'(e_i)$	$\pi_i(e_i)$	$p(\omega_i - e_i)$	$-v_i(\cdot)$	Total payoff
1	9	6	4	42	12	-18	36
2	0	3	4	21	-12	-54	-45
Total	9	9		63	0	-72	-9

Compared with policy A, we see that when opening international trade, emissions are somewhat reduced, and welfare improves. This also illustrates the more general result in Holtsmark and Sommervoll (2008, Proposition 1), who find that policies A and B will lead to reduced global emissions if countries with steep marginal benefit functions also have the highest marginal damages. Moreover, the permit-importing country 2 has a marginal abatement cost that is *below* its marginal damage cost. This property holds true in the more general case for any permit importer, see (10). It also offers some intuitions as to why taxes—when included—will typically not vanish.

We complete this section with the game that has been our main concern.

Table 4. *A voluntary emissions game with international permit trading and domestic taxation (policies A, B and C). The permit price equals $4\frac{2}{3}$.*

Country	ω_i	t_i	e_i	$\pi_i'(e_i)$	$\pi_i(e_i)$	$p(\omega_i - e_i)$	$-v_i(\cdot)$	Total payoff
1	$9\frac{1}{3}$	$-2\frac{2}{3}$	8	2	48	$6\frac{2}{9}$	-20	$34\frac{2}{9}$
2	$\frac{2}{3}$	$1\frac{1}{3}$	2	6	16	$-6\frac{2}{9}$	-60	$-50\frac{2}{9}$
Total	10		10		64	0	-80	-16

The figures in Table 4 show that under policies A, B and C the emissions profile and efficiency are identical to those under policy A alone (illustrating Proposition 1), and that the high-damage country 2 transfers money via the permit market to the low-damage country 1 (illustrating Proposition 2). Moreover, the permit-exporting country subsidizes domestic emissions, while the permit importer employs a positive tax. This last property is not particular to the example but holds in the general case.

IV Bibliographic remarks

The strand of literature this paper belongs to—being Helm (2003), Carbone et al. (2009), Copeland and Taylor (1995), Cramton and Stoft (2010a), Cramton and Stoft (2010b) and Holtsmark and Sommervoll (2008)—has an international permit market explicitly at center stage, where the initial allocation of permits results from a noncooperative game, and where no group of agents ever engages in maximizing their joint objectives. On the contrary, each and every government always stands alone.

The more standard—and much larger—literature dealing with international environmental agreements, where joint welfare maximization is commonplace, may be divided into the following two main categories. One sets up the problem as a cartel formation game, applying the criteria of internal and external stability, as in the works by Barrett (1994), Botteon and Carraro (1991), Carraro and Siniscalco (1993), Finus (1998), Hoel (1992), Kolstad (2010), McGinty (2007) and Rubio and Ulph (2007). The other applies a suitable version of the core, named the gamma core, introduced by Chander and Tulkens (1995). They define the concept and prove the nonemptiness of the core in a constructive way by providing an explicit formula. Flåm (2006) and Helm (2001) offer more general conditions for a nonempty core, but their proofs are less constructive. The assumptions underlying the gamma core have been given a strong theoretical foundation in Chander (2007) and are extended in Chander and Wooders (2010), see also Germain et al. (2002). Bréchet et al. (2011) compare the two main concepts in a numerical environment, illustrating that they yield very different outcomes. The main explanation for this lies in the different assumptions that are made about what happens to a coalition should some members consider leaving. Osmani and Tol (2009) and Chander (2007) study that issue in more detail, the former by considering farsighted coalition stability, and the latter by drawing on the theory of infinitely repeated games. Other studies adopting this last perspective include Asheim et al. (2006), Asheim and Holtsmark (2009) and Froyn and Hovi (2008), where particular focus is on equilibria that are weakly renegotiation-proof. For a recent and good overview of the literature on climate change and game theory, see Wood (2010).

We have emphasized that emissions trading is at center stage in our game, as in Helm (2003). This does not mean that permit exchange has no home in the more standard literature—in particular, as a vehicle to facilitate side-payments, for instance, as in Chander (2003). But that literature rarely models explicitly that governments may account for how prices are affected by the commitments they find acceptable. That is, price derivatives are usually absent.

In terms of the tax instrument, our analysis is most closely related to Santore et al. (2001) and Bréchet and Peralta (2007), which both work in a partial equilibrium framework. Some papers study both taxes and quotas, although separately, such as Ishikawa and Kiyono

(2006), but they have no environmental externality. For transboundary pollution and taxes within a general equilibrium environment, see Copeland and Taylor (1994) and Copeland and Taylor (2004).

V Concluding remarks

Fundamental theorems on welfare economics provide good reasons for making rights to release greenhouse gases transferable. However, when the initial allocation isn't determined by nature or any central agency, the arguments are a bit more delicate. In particular, it complicates matters that the amount and distribution of permits must be approved by individual governments. Moreover, those bodies' demands could depend on whether trade is permitted.

This paper identified an incentive governments would have to use the tax instrument on domestic emissions, even for countries that participate in permit exchange. Our main finding was that if governments fully act on this incentive, it will affect their quota demands in such a way that international emissions trading will achieve nothing besides redistributing income away from countries with high marginal climate costs.

While our results complement and contrast earlier literature, they are sensitive to how the game was set up. Other specifications are clearly possible, including the following three.

- We assumed that governments' decisions were unconstrained. It would be interesting to investigate, say, the implication of banning subsidies, i.e., imposing $t_i \geq 0$ for all $i \in I$. Even though we do not have results for this case, it is clear that such constraints will come into effect.
- One can envisage other orders of moves. Suppose, for instance, a three-stage game where taxes are chosen secondly. While such a scenario seems perfectly reasonable, the analysis becomes analytically delicate, in particular if we insist on strategic behavior, subgame perfection and not sacrificing the generality of π_i and v_i.
- Also taken for granted was that firms in all countries had access to an international permit market. Thus, the only way a government could obtain a marginal abatement cost that would differ from the international permit price was to impose a domestic tax or subsidy. One could alternatively have supposed that only governments were engaged in international trade, and that domestic emissions were regulated directly. A government that behaved strategically on the international permit market could then achieve a marginal abatement cost that would be different from the international permit price—and without using the tax instrument. Such a scenario is widely studied for classical exchange economies, see, e.g., Postlewaite (1979) and Gabszewicz (2002, Section 4.4), and is discussed for permit markets in Godal and Meland (2010, Section 6). However, in that literature, which is free of environmental externalities, endowments are exogenous. Here, they are part of the game, and though it is straightforward to define such a game, its analysis becomes more complicated.

We do not think our exercise is sufficiently complete to warrant strong policy implications.[7] There are many and obvious reasons for this. Nevertheless, we emphasize that all the good properties of emissions trading programs applied to environmental problems confined to a single jurisdiction do not immediately carry over to an international setting in either theory or practice thus far. The generous targets allowed by the Kyoto Protocol are an obvious reminder of this. Moreover, even if permits were to be traded in large quantities, our analysis suggests that it does not automatically follow that the apparent efficiency gains will be an improvement over the policies that would otherwise have arisen.

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[7] Cramton and Stoft (2010a) and Cramton and Stoft (2010b) offer more material on this matter. They also set up an international price commitment game, showing, among other results, that it has a preferable outcome.

Appendix

Proof of Lemma Under the assumed conditions, there exists a continuously differentiable demand function $f_i := (\pi_i')^{-1}$ for each firm $i \in I$ such that

$$e_i = f_i\left(p\left(\boldsymbol{\omega}, \mathbf{t}\right) + t_i\right), \tag{A1}$$

where, by the Inverse Function Theorem, $f_i' = \frac{1}{\pi_i''}$. From (A1), it then follows that

$$\frac{\partial e_i}{\partial \omega_i} = \frac{1}{\pi_i''\left(e_i\right)} \frac{\partial p}{\partial \omega_i}, \qquad \frac{\partial e_i}{\partial t_i} = \frac{1}{\pi_i''\left(e_i\right)} \left(\frac{\partial p}{\partial t_i} + 1\right) \quad \text{and} \quad \frac{\partial e_j}{\partial t_i} = \frac{1}{\pi_j''\left(e_j\right)} \frac{\partial p}{\partial t_i}, \tag{A2}$$

where the last statement applies when $j \neq i$. Market clearing requires

$$\sum\nolimits_{j \in I} f_j\left(p\left(\boldsymbol{\omega}, \mathbf{t}\right) + t_j\right) = \sum\nolimits_{j \in I} \omega_j. \tag{A3}$$

Differentiating the last equality throughout with respect to ω_i and t_i yields

$$\frac{\partial p}{\partial \omega_i} = \frac{1}{\sum_{j \in I} \frac{1}{\pi_j''(e_j)}} \text{ and } \frac{\partial p}{\partial t_i} = -\frac{\frac{1}{\pi_i''(e_i)}}{\sum_{j \in I} \frac{1}{\pi_j''(e_j)}}, \tag{A4}$$

which takes care of the first statements in (4) and (5). Apply (A4) in (A2) together with definition (3) to get the remaining claims in (4) and (5). The results in (6) follow directly from (2) or alternatively from (4)–(5). □

Proof of Proposition 1 Combining the first-order optimality conditions (7) and (8) with definition (3) and the results from the Lemma, it follows that the said first-order optimality conditions reduce to

$$\left(\pi_i' - p\right) \frac{s_i}{S} + p + \frac{1}{S}\left(\omega_i - e_i\right) - v_i' = 0 \tag{A5}$$

and

$$\left(\pi_i' - p\right) \left(1 - \frac{s_i}{S}\right) - \frac{1}{S}\left(\omega_i - e_i\right) = 0, \tag{A6}$$

respectively. Add the left-hand sides of (A5) and (A6) to get $\pi_i' - v_i' = 0$, as in (9). The assumption on the existence of a unique equilibrium completes the proof. □

References

Asheim, G.B., Froyn, C.B., Hovi, J., and Menz, F. (2006), Regional versus global cooperation for climate control, *Journal of Environmental Economics and Management 51*, 93–109.

Asheim, G.B., and Holtsmark, B. (2009), Renegotiation-proof climate agreements with full participation: Conditions for Pareto-efficiency, *Environmental and Resource Economics 43*, 519–533.

Barrett, S. (1994), Self-enforcing international environmental agreements, *Oxford Economic Papers 46*, 878–894.

Botteon, M., and Carraro, C. (1991), Burden sharing and coalition stability in environmental negotiations with asymmetric countries, in C. Carraro (ed) *International environmental negotiations: Strategic policy issues*, Edward Elgar, Cheltenham, Great Britain.

Bréchet, T., Gerard, F., and Tulkens, H. (2011), Efficiency vs. stability in climate coalitions: A Conceptual and Computational Appraisal, *The Energy Journal 32*, 49–75.

Bréchet, T., and Peralta, S. (2007), The race for polluting permits, Discussion Paper 27/2007, Center for Operations Research and Econometrics, Université Catholique de Louvain, Belgium.

Carbone, J.C., Helm, C., and Rutherford, T.F. (2009), The case for international emission trade in the absence of cooperative climate policy, *Journal of Environmental Economics and Management 58*, 266–280.

Carraro, C., and Siniscalco, D. (1993), Strategies for the international protection of the environment, *Journal of Public Economics 52*, 309–328.

Chander, P. (2003), The Kyoto Protocol and developing countries: Strategy and equity issues, Chapter 13 in Toman, M.A., Chakravorty, U., and Gupta, S. (eds) *India and global climate change: Perspectives on economics and policy from a developing country*, Resources for the Future, Washington DC, USA.

Chander, P. (2007), The gamma-core and coalition formation, *International Journal of Game Theory 35*, 539–556.

Chander, P., and Tulkens, H. (1995), A core-theoretic solution for the design of cooperative agreements on transfrontier pollution, *International Tax and Public Finance 2*, 279–293.

Chander, P., and Wooders, M. (2010), Subgame perfect cooperation in an extensive game, Working Paper No. 10-W08, Department of Economics, Vanderbilt University, Nashville, USA.

Copeland, B.R., and Taylor, M.S. (1994), North–south trade and the environment, *Quarterly Journal of Economics 109*, 755–787.

Copeland, B.R., and Taylor, M.S. (1995), Trade and transboundary pollution, *American Economic Review 85*, 716–737.

Copeland, B.R., and Taylor, M.S. (2004), Trade, growth, and the environment, *Journal of Economic Literature 42*, 7–71.

Cramton, P., and Stoft, S. (2010a), International climate games: From caps to cooperation, Research Paper 10-07, Global Energy Policy Center, USA (http://www.global-energy.org/lib).

Cramton, P., and Stoft, S. (2010b), Price is a better climate commitment, *The Economists' Voice 7: Iss. 1, Article 3.*

Finus, M. (1998), Toward a positive theory of coalition formation and endogenous instrumental choice in global pollution control, *Public Choice 96*, 145–186.

Flåm, S.D. (2006), Balanced environmental games, *Computers and Operations Research 33*, 401–408.

Flåm, S.D., Jongen, H.Th., and Stein, O. (2008), Slopes of shadow prices and Lagrange multipliers, *Optimization Letters 2*, 143–155.

Froyn, C.B., and Hovi, J. (2008), A climate agreement with full participation, *Economics Letters 99*, 317–319.

Gabszewicz, J.J. (2002), *Strategic multilateral exchange: General equilibrium with imperfect competition*, Edward Elgar, Cheltenham, Great Britain.

Germain, M., Toint, P., Tulkens, H., and de Zeeuw, A. (2003), Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control 28*, 79–99.

Godal, O., and Meland, F. (2010), Permit markets, seller cartels and the impact of strategic buyers, *The B.E. Journal of Economic Analysis & Policy 10: Iss. 1 (Advances), Article 29.*

Helm, C. (2001), On the existence of a cooperative solution for a coalitional game with externalities, *International Journal of Game Theory 30*, 141–146.

Helm, C. (2003), International emissions trading with endogenous allowance choices, *Journal of Public Economics 87*, 2737–2747.

Hoel, M. (1992), International environment conventions: The case for uniform reductions of emissions, *Environmental and Resource Economics 2*, 141–159.

Holtsmark, B., and Sommervoll, D.E. (2008), Welfare-implications of emissions trading when endowments are endogenous, Discussion Paper 542, Statistics Norway, Oslo, Norway.

Ishikawa, J., and Kiyono, K. (2006), Greenhouse-gas emission controls in an open economy, *International Economic Review 47*, 431–450.

Kolstad, C.D. (2010), Equity, heterogeneity and international environmental agreements, *The B.E. Journal of Economic Analysis & Policy 10 : Iss. 2 (Symposium), Article 3.*

McGinty, M. (2007), International environmental agreements among asymmetric nations, *Oxford Economic Papers 59*, 45-62.

Osmani, D., and Tol, R. (2009), Toward farsightedly stable international environmental agreements, *Journal of Public Economic Theory 11*, 455–492.

Postlewaite, A. (1979), Manipulation via endowments, *Review of Economic Studies 46*, 255–262.

Rubio, S.J., and Ulph, A. (2007), An infinite-horizon model of dynamic membership of international environmental agreements, *Journal of Environmental Economics and Management 54*, 296–310.

Santore, R., Robinson, H.D., and Klein, Y. (2001), Strategic state-level environmental policy with asymmetric pollution spillovers, *Journal of Public Economics 80*, 199–224.

Wood, P.J. (2010), Climate change and game theory. Research Report No. 62, the Crawford School of Economics and Government, Australian National University, Canberra, Australia.