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Abstract:
Using a non cooperative climate policy game applied in the literature, we find that an agreement with international emissions trading leads to increased emissions and reduced efficiency.

Keywords: Climate change; international environmental agreements; emissions trading; non-cooperative game theory.

JEL classification: C7, Q2,Q4

Acknowledgements: This paper is an extended version of Holtsmark and Sommervoll (2012) discussing closely related literature in some more detail and giving more space to some cumbersome mathematical challenges.

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Sammendrag

Dette arbeidet anvender et ikkekooperativt spill brukt i litteraturen om internasjonalt klimasamarbeid, og finner at en internasjonal klimaavtale med kvotehandel innenfor denne teoretiske rammen gir høyere utslipp av klimagasser og effektivitetstap.

1 Introduction

Economic theory and common wisdom tell us that emissions trading may give immediate efficiency rewards as this market's invisible hand ensures that emission cuts occur where cutting costs are low. However, it complicates matters that in an international setting the initial allocation of emission quotas is not determined by nature or any supranational agency. Rather, the volume and distribution of permits must be approved by individual governments. The question we raise is whether targets will be set differently in anticipation of trade, and whether that would outweigh the potential gains from trade. We find that it does, giving higher global emissions and reduced efficiency compared to a game without trade.

Our analysis is based on a climate policy game which is characterized by lack of efficient bargaining when an international agreement on emission reductions is settled. We assume that the governments set their national emission targets individually based on national interests. The climate negotiations over the last years indicate that this approach is relevant. Recall, for example, that the national emission targets in the Copenhagen Accord, which have been leading in the subsequent negotiations, where quantified by individual governments *after* the Copenhagen meeting. Hence, those targets are not a result of negotiations and are therefore unlikely to maximize joint welfare, as most commonly assumed in the literature.

Our game represents an extension of the climate policy game found in Helm (2003). While he applied general functional forms, we adopt the linear quadratic model and assume that each country is composed of a varying number of identical firms.

Our result contrasts with Carbone et al. (2009) and a comment on their approach is therefore appropriate. Based on the simulations of a calibrated general equilibrium model of the world economy, they concluded that a system of internationally tradable emission permits could enhance abatement considerably. They found that total emission reductions in a noncooperative Nash equilibrium with trading is approximately twice the abatement level in a noncooperative Nash equilibrium without trading, and about two-thirds of the abatement level in a first-best agreement.

Holtsmark and Sommervoll (2009) found that whether emissions trading in this type of games leads to increased or reduced emissions depends on the relationship between the countries' marginal damage costs and the steepness of their marginal abatement cost functions. It follows that the assumptions in Carbone et al. (2009) with regard to the marginal damage cost parameters are crucial for their results. Carbone et al. (2009) were not very specific on how they estimated these parameters, other than saying that countries reveal their willingness to pay for emission reductions through their positions in the international climate negotiations. They assumed a marginal value of abatement (marginal damage costs) of 300 USD/tC for Western Europe, and 150 for Japan and the United States. Furthermore, assumed marginal damage costs of 50 USD/tC for the FSU and zero for China. In addition they analyzed a case where the marginal damage costs are adjusted upwards to 50 and 100 USD/tC in China and the FSU, respectively, resulting in very similar results to their main case.

For example, the fact that the permit price in the European permit market is currently (spring 2012) close to 25 USD/tC indicates that other values assigned to Europe also could be plausible. The other countries' and regions' assumed marginal damage costs could be discussed along the same lines, not least their suggestion that China does not expect any costs related to climate change, which is in contrast to literature suggesting that the developing countries will have to carry the highest costs of climate change; see for example Mendelsohn et al. (2006).

Another closely related paper is Godal and Holtsmark (2011). They extended the climate policy game introduced by Helm (2003) to include endogenous emission taxes. As emissions of CO_2 is closely connected to the quantities of fossil energy used, this could be interpreted as energy taxes, which are widespread in use. With their model Godal and Holtsmark (2011) found that if governments fully act on their incentives, international emissions trading will achieve no efficiency gains and emissions will be as in the situation without trade. However, Godal and Holtsmark (2011) found that emissions trading within their game will redistribute income away from countries with high marginal climate costs to countries with low marginal climate costs. Other closely related literature includes Cramton and Stoft (2010a, 2010b) and MacKenzie (2011). [1]

The next section presents the theoretical model and our result. The

[1] For an overview of other relevant literature, see Finus (2008).

subsequent section concludes. The proof of our result can be found in the Appendix.

2 Analysis

There is a set of countries $I = \{1, ..., n\}$. Each country $i \in I$ is composed of a government and m_i firms. Each firm has quadratic abatement costs

$$c_{ji}\left(a_{ji}\right) = \frac{\gamma}{2} a_{ji}^2, \tag{1}$$

where γ is a positive parameter and a_{ji} is the abatement carried out by firm j in country i. If abatement is carried out efficiently within each country, country i has abatement cost functions that could be written in the conventional quadratic format:

$$c_i(a_i) = \min_{a_{ji},\ j=\in\{1,...,m_i\}} \left(\sum_{j=1}^{m_i} \frac{\gamma}{2} a_{ji}^2 \right) = \frac{\sigma_i}{2} a_i^2, \tag{2}$$

where a_i is total abatement in country i and $\sigma_i := \gamma / m_i$. The countries experience linear benefits from global emission abatement $b_i \cdot \left(\sum_{i \in I} a_i \right)$, where b_i is a parameter. As benefits from global emission abatement is a public good, we assume that b_i is proportional to the size of economy i, reflected by the numbers of firms m_i. Hence, $b_i = \beta m_i$, for all $i \in I$, where β is a positive parameter.

Our main focus is on the following two-stage game, named the *game with permit trading* (superscript T is used to indicate the solution to this game):

Stage 1: Each government chooses its initial endowment of emissions permits ω_i (emission target, for shor) . The 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 abatement a_{ji}.

Note that even though we presume that all governments play individually and noncooperatively against all other governments, some items must still be negotiated and agreed upon. In particular, governments must agree that permits issued in any country are recognized as documents suitable for compliance in their own country. It is also assumed that governments comply with their obligations by enforcing firms to fully match their emissions with their corresponding number of permits.

We start with **stage 2** of the game. Abatement a_i in country $i \in I$ is determined such that each firm is maximizing its net income from permit sales minus its abatement costs. It follows that a_i satisfies

$$\frac{\partial c_i\left(a_i\right)}{\partial a_i} = p \ , \tag{3}$$

and the firms' marginal abatement costs will be equalized. Hence, there will be an efficient allocation of abatement efforts both within and across countries.

At **stage 1** each government $i \in I$ maximizes national welfare $\pi_i\left(\omega\right)$ with respect to ω_i, where

$$\pi_i\left(\omega\right) := b_i \sum_{j \in I} a_j\left(\omega\right) - \frac{\sigma_i}{2} a_i^2 + p\left(\omega\right)\left(\omega_i - \bar{e}_i + a_i\left(\omega\right)\right).$$

Hence, a Nash equilibrium is characterized by the first-order conditions

$$b_i \cdot \sum_{j \in I} \frac{\partial a_j}{\partial \omega_i} - c_i'\left(a_i\left(\omega\right)\right) \cdot \frac{\partial a_i}{\partial \omega_i} + \frac{\partial p}{\partial \omega_i}\left(\omega_i - \bar{e}_i + a_i\left(\omega\right)\right) + p\left(1 + \frac{\partial a_i}{\partial \omega_i}\right) = 0, \tag{4}$$

for all $i \in I$.

Next, sum the left hand side of (4) for all $i \in I$, taking into account that the price effect of increased supply of permits is the same irrespective of the additional permits' country of origin and that $\sum_{i \in I}\left(\omega_i - \bar{e}_i + a_i\left(\omega\right)\right) = 0$ as well as the first order condition (3). Then we have that

$$p = \bar{b}, \tag{5}$$

where $\bar{b} = (1/n)\sum_{j \in I} b_j$, see also MacKenzie (2011).

Using that $\sigma_i = \gamma / m_i$ as well as (2) and (3), we have that

$$a_i^T = \frac{m_i}{\gamma} p \tag{6}$$

for all $i \in I$. Define $\mathbf{m} :=\{m_1, ..., m_n\}$ and $M := \sum_{i \in I} m_i$. Note that (5) means that $p = (\beta/n)\sum m_i$. Thus, we have that

$$a_i^T = \frac{m_i}{\gamma}\frac{\beta}{n} M. \tag{7}$$

Global abatement follows:

$$a^T(\mathbf{m}) = \frac{\beta}{\gamma}\frac{1}{n}M^2. \tag{8}$$

Let $\bar{e}_i$ be the business–as–usual emissions of country i and $\omega := (\omega_1, ..., \omega_n)$ a profile of targets. Then ω and the market-clearing condition

$$\sum_{i\in I}(\bar{e}_i - a_i) = \sum_{i\in I}\omega_i \tag{9}$$

determine a unique equilibrium permit price $p(\omega) > 0$. Furthermore, from (6), this in turn determines the abatement $a_i(\omega)$ for all $i \in I$.

From the above results we have that global welfare in the equilibrium of the game described above is given by:

$$\pi^T(\mathbf{m}) = \frac{\beta^2}{\gamma}\left(\frac{n - \frac{1}{2}}{n^2}\right)M^3, \tag{10}$$

where $\pi^T := \sum_{i\in N}\pi_i^T$.

For comparison only, we next define a game of reference, labeled the *game without trade* (superscript N is used to indicate the solution to this game). This game follows the same procedure as of the game described above, with the exception that there is no international permit market. Hence, at the second stage of the game firms set their abatement levels such that $a_i^N = \omega_i^N$. At the first stage of the game the governments set their target ω_i to the level which maximizes $b_i\left(\sum_{i\in N}a_i\right) - c_i(a_i)$. Hence, the abatement levels become:

$$a_i^N = \frac{b_i}{\sigma_i}. \tag{11}$$

It follows that global emission abatement and welfare in the equilibrium of this game are:

$$a^N(\mathbf{m}) = \frac{\beta}{\gamma}\sum_{i\in I}m_i^2, \tag{12}$$

$$\pi^N(\mathbf{m}) = \frac{\beta^2}{\gamma}\left(M\left(\sum_{j=1}^{n}m_j^2\right) - \frac{1}{2}\sum_{j=1}^{n}m_j^3\right). \tag{13}$$

Our main result follows:

Proposition 1 *If there exists at least one pair* (i, j) *such that* $m_i \neq m_j$, $i, j \in I$, *then we have that*

$$a^N(\mathbf{m}) > a^T(\mathbf{m}),$$
$$\pi^N(\mathbf{m}) > \pi^T(\mathbf{m}).$$

.

Proof. See Appendix A.

Proposition 1 states that trade reduces efficiency and increases emissions. Certain intuitive conclusions flow from this result. In the game with trading, firms choose their emissions levels such that marginal abatement costs $c_i'(a_i)$ equal the international permit price $p = \bar{b}$. For instance, in the case of a large economy (above average number of firms) we have that $b_i > p = \bar{b}$, and this country will end up as a permit importer and $c_i'(a_i) < b_i$. Without trade we have that $c_i'(a_i) = b_i$. Hence, this country will reduce its abatement as trading is introduced. Correspondingly, small economies increase their abatement due to trade. Moreover, it follows from (2) and the definition of σ_i that small economies have steeper marginal abatement cost functions compared to larger economies, and consequently a large economy must therefore carry out a larger downward adjustment of its abatement level than small economies must adjust their abatement upwards. It follows that $a^N(\mathbf{m}) > a^T(\mathbf{m})$.

The intuition behind the result that $\pi^N(\mathbf{m}) > \pi^T(\mathbf{m})$ is more straightforward. In a non-cooperative equilibrium, global abatement is inefficiently low. International emissions trading will lead to even lower total abatement. Hence, emissions trading on the one hand gives an efficiency gain due to efficient cross-border abatement allocation, but on the other an inefficiently low abatement level is further reduced and this last effect dominates.

3 Concluding remarks

The world community is struggling to come together and negotiate an effective and ambitious climate agreement. The process for determining national emission quotas in the most recent agreements does not resemble efficient bargaining, and is possibly closer to a formalization of a classical noncooperative equilibrium. In this paper we have shown that within a simple climate policy game, emissions trading in this situation leads to increased emissions and reduced efficiency.

A Appendix

Proof. Proposition 1 claims that if there exists an i and j, such that $m_i \neq m_j$, i, $j \in N$, then

$$a^N(\mathbf{m}) > a^T(\mathbf{m}), \tag{A.1}$$

$$\pi^N(\mathbf{m}) > \pi^T(\mathbf{m}). \tag{A.2}$$

where we use $\mathbf{m} := \{m_1, ..., m_n\}$. In order to prove this, define a vector $\acute{\mathbf{m}}$ with n identical elements $\acute{m} = M/n$

$$\acute{\mathbf{m}} := \{\underbrace{\acute{m}, ..., \acute{m}}_{n \text{ elements}}\}. \tag{A.3}$$

It follows from (8), (10), (12) and (13) that

$$a^N(\acute{\mathbf{m}}) = a^T(\acute{\mathbf{m}}) = a^T(\mathbf{m}), \tag{A.4}$$

$$\pi^N(\acute{\mathbf{m}}) = \pi^T(\acute{\mathbf{m}}) = \pi^T(\mathbf{m}). \tag{A.5}$$

It follows that if

$$a^N(\mathbf{m}) > a^N(\acute{\mathbf{m}}), \tag{A.6}$$

$$\pi^N(\mathbf{m}) > \pi^N(\acute{\mathbf{m}}), \tag{A.7}$$

then (A.1) and (A.2) apply. In the following we will therefore show that (A.6) and (A.7) apply. Firstly, define

$$\bar{m}_k := \frac{1}{k}\sum_{j=1}^{k} m_j, \ \ k = 1, ..., n,$$

which is the basic building block in a set of $n-$element vectors $\bar{\mathbf{m}}_k$, $k \in \{1, ..., n\}$, where the first k elements are equal to the average size of $m_1, ..., m_k$ in the vector $\mathbf{m}$ such that

$$\bar{\mathbf{m}}_k := \{\underbrace{\bar{m}_k, ..., \bar{m}_k,}_{k \text{ elements}} m_{k+1}, ..., m_n\}.$$

Note that $\bar{\mathbf{m}}_1 = \mathbf{m}$ and $\bar{\mathbf{m}}_n = \acute{\mathbf{m}}$. In order to show that (A.6) and (A.7) apply, we will prove that we have two chains of inequalities where

$$a^N(\mathbf{m}) \geq a^N(\bar{\mathbf{m}}_2) \geq \ ... \ \geq a^N(\bar{\mathbf{m}}_{n-1}) \geq a^N(\acute{\mathbf{m}}), \tag{A.8}$$

$$\pi^N(\mathbf{m}) \geq \pi^N(\bar{\mathbf{m}}_2) \geq \ ... \ \geq \pi^N(\bar{\mathbf{m}}_{n-1}) \geq \pi^N(\acute{\mathbf{m}}), \tag{A.9}$$

and that if there exists at least one pair (i, j) such that $m_i \neq m_j$, then at least one of the inequalities in each of these two chains is strict. Consider firstly inequality number k in (A.8). We have

$$a^N(\bar{\mathbf{m}}_k) = \frac{\beta}{\gamma}\left(k\bar{m}_k^2 + m_{k+1}^2 + \sum_{j=k+2}^{n} m_j^2\right), \tag{A.10}$$

$$a^N(\bar{\mathbf{m}}_{k+1}) = \frac{\beta}{\gamma}\left((k+1)\,\bar{m}_{k+1}^2 + \sum_{j=k+2}^{n} m_j^2\right). \tag{A.11}$$

Subtracting the expression in (A.10) from the expression in (A.11) gives that

$$\begin{aligned} a^N(\bar{\mathbf{m}}_k) - a^N(\bar{\mathbf{m}}_{k+1}) &= \frac{\beta}{\gamma}\left(k\bar{m}_k^2 + m_{k+1}^2 + \sum_{j=k+2}^{n} m_j^2\right) \\ &\quad - \frac{\beta}{\gamma}\left((k+1)\,\bar{m}_{k+1}^2 + \sum_{j=k+2}^{n} m_j^2\right), \end{aligned}$$

which could be reformulated to

$$\frac{\beta}{\gamma}\left(k\bar{m}_k^2 + m_{k+1}^2 + \sum_{j=k+2}^{n} m_j^2 - (k+1)\,\bar{m}_{k+1}^2 - \sum_{j=k+2}^{n} m_j^2\right).$$

Hence, we have that

$$a^N(\bar{\mathbf{m}}_k) - a^N(\bar{\mathbf{m}}_{k+1}) = \frac{\beta}{\gamma}\left(k\bar{m}_k^2 + m_{k+1}^2 - (k+1)\,\bar{m}_{k+1}^2\right).$$

Recall that we have:

$$\bar{m}_{k+1} = \frac{1}{k+1}\sum_{j=1}^{k} m_j + \frac{1}{k+1} m_{k+1},$$

which gives that

$$\bar{m}_{k+1} = \frac{1}{k+1}\left(k\bar{m}_k + m_{k+1}\right).$$

Hence, we have that:

$$a^N(\bar{\mathbf{m}}_k) - a^N(\bar{\mathbf{m}}_{k+1}) = \frac{\beta}{\gamma}\left(k\bar{m}_k^2 + m_{k+1}^2 - \frac{1}{k+1}\left(\left(k\bar{m}_k + m_{k+1}\right)\right)^2\right),$$

which gives:

$$a^N(\bar{\mathbf{m}}_k) - a^N(\bar{\mathbf{m}}_{k+1}) = \frac{\beta}{\gamma}\frac{k}{k+1}(m_{k+1} - \bar{m}_k)^2. \tag{A.12}$$

Hence, we have shown that $a^N(\bar{\mathbf{m}}_k) \geq a^N(\bar{\mathbf{m}}_{k+1})$ for any $k \in \{1, ..., n\}$ and the inequality is strict if $m_{k+1} \neq \bar{m}_k$. Therefore, all inequalities in (A.8) apply, and because we assume there exists an i and j, such that $m_i \neq m_j$, i, $j \in N$, then (A.1) applies.

Next, we will show that (A.2) applies. Define $M_k := \sum_{i=1}^{k} m_i$. It follows from (13) and the definitions above that

$$\begin{aligned}\pi^N(\bar{\mathbf{m}}_k) &= \frac{\beta^2}{\gamma}\left(M_{k+1}\left(k\bar{m}_k^2 + m_{k+1}^2\right) - \frac{1}{2}\left(k\bar{m}_k^3 + m_{k+1}^3\right)\right) \\ &\quad + \sum_{j=k+2}^{n} \pi_j^N(\bar{\mathbf{m}}_k),\end{aligned}$$

$$\begin{aligned}\pi^N(\bar{\mathbf{m}}_{k+1}) &= \frac{\beta^2}{\gamma}\left(M_{k+1}(k+1)\bar{m}_{k+1}^2 - \frac{1}{2}(k+1)\bar{m}_{k+1}^3\right) \\ &\quad + \sum_{j=k+2}^{n} \pi_j^N(\bar{\mathbf{m}}_{k+1}),\end{aligned}$$

Using a similar procedure as used when finding (A.12), it is possible to show that

$$\begin{aligned}\pi^N(\bar{\mathbf{m}}_k) - \pi^N(\bar{\mathbf{m}}_{k-1}) &= \frac{\beta^2}{\gamma}\frac{k}{2(k+1)^2}(\bar{m}_k - m_{k+1})^2 \\ &\quad \cdot (kM_{k+1} + (k-1)(k+1)\bar{m}_k) \\ &\quad + \left[\sum_{j=k+2}^{n}\left(\pi_j^N(\bar{\mathbf{m}}_k) - \pi_j^N(\bar{\mathbf{m}}_{k+1})\right)\right].\end{aligned} \tag{A.13}$$

The square bracket is non-negative because (A.8) says that $a^N(\bar{\mathbf{m}}_k) \geq a^N(\bar{\mathbf{m}}_{k+1})$, which means that countries $k+2, ..., n$ will collect at least as large payoffs in the case with $\bar{\mathbf{m}}_k$ as with $\bar{\mathbf{m}}_{k+1}$. The rest of the right hand side of (A.13) is non-negative if $n > 2$, and strictly positive if $\bar{m}_k \neq m_{k+1}$. It follows that the inequality $\pi^N(\bar{\mathbf{m}}_k) \geq \pi^N(\bar{\mathbf{m}}_{k+1})$ applies, and is strict if $\bar{m}_k \neq m_{k+1}$.

The corresponding argument applies to all the inequalities in (A.9)). Hence, we have proven that (A.7) is true, which means that (A.2) is true as well. ■

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