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The European Union's potential for strategic emissions trading in a post-Kyoto climate agreement

Abstract:
The literature suggests that Russia and Ukraine may become large sellers of greenhouse gas emissions permits under the Kyoto Protocol and might exploit their market power to maximize trading profits. The EU countries taken together will probably be net buyers of permits. For any given global target for emission, participation by developing countries with low-cost abatement options would benefit the net buyers of permits because the market price for carbon permits would go down. We explore how the EU could benefit from a broader participation through specific bilateral agreements with developing countries in the post-Kyoto period. The bilateral agreement involves a minimum permit sales requirement which is compensated by a financial transfer from EU to the developing country. Such bilateral agreement enables the EU to act strategically in the permit market on behalf of its member states, although firms in each member state are assumed to be price takers in the permit market. In a numerical simulation we show that an appropriately designed bilateral agreement between the EU and China can cut EU's total compliance cost by one third.

Keywords: emissions permits, post-Kyoto climate agreement, strategic permit trading

JEL classification: D43, Q54

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1. Introduction

The purpose of this paper is to study the optimal strategy a group of net buyers of emission permits (for instance the EU) under a future international climate agreement, i.e. a follow-up agreement to the Kyoto Protocol. In 1997, the Kyoto Protocol was signed during the third Conference of the Parties (CoP) of the United Nations Framework Convention on Climate Change (UNFCCC). 39 signatories of the Protocol, listed in the so-called Annex-B, and representing about two thirds of global emissions in 1990, promised to reduce their emissions of six greenhouse gasses by 5.2 percent compared to 1990 levels by 2008-2012 (the so-called first commitment period). The Protocol does not impose binding emission targets on developing countries signatories[1]. Despite persistent refusal by the USA (and until recently also by Australia) to ratify it, the Kyoto Protocol came into force in 2005.

These observations lead to the identification of at least two important shortcomings of the Kyoto agreement[2]. First, the global emission reduction achieved by the Kyoto Protocol will be very limited[3]. Second, this global emission reduction will not be produced in a cost efficient manner due to two reasons. First, the number of countries participating is limited meaning that many low-cost abatement options in developing countries will not be fully exploited[4]. Secondly, a number of studies have concluded that Russia, and other former Soviet republics and Eastern European countries, will become large sellers of permits, see: Criqui et al. (1999), Weyant and Hill (1999), Weyant (1999) and Sager (2003). Böhringer (2002) concludes that the Former Soviet Union can significantly increase its benefit of the Kyoto agreement by exploiting its market power in the permit market, which implies that marginal abatement cost are not equalized across the participating countries. In this paper, we address this second shortcoming of the Kyoto protocol.

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[1] The explanations for the Kyoto protocol's inability to deter free-riding is inter alia given in Barret (1999).

[2] Another important shortcoming is the lack of incentives for investment in R&D. This problem is inter alia addressed in Golombek and Hoel (2006).

[3] The share of the ratifying Annex-B countries in global emissions is projected to decrease to about one third by 2012 because of fast growth of emissions in non-Annex-B countries. The poor global emission reduction achieved by the Kyoto Protocol is, inter alia, discussed in Böhringer (2002), Hagem and Holtsmark (2001), den Elzen and de Moor (2002a) and Eyckmans, Van Regemorter and van Steenberghe (2005).

[4] According to the Kyoto protocol, industrialized countries with quantified emission target are allowed to meet part of their reduction commitment through investments in emission reducing projects in developing countries (the Clean Development Mechanism CDM). However, the CDM is a project–based mechanism that cannot ensure that all low cost options can be exploited as there are several abatement options that cannot be attributed to any specific investment project (for instance in the transport sector). See http://unfccc.int/kyoto_protocol/mechanisms/items/1673.php for guidelines to validation of CDM-projects.

In November-December 2007, the international negotiators at the 13th Conference of the Parties (CoP) of the UNFCCC in Bali have agreed upon a roadmap for negotiations that should lead to a new climate agreement for the post-Kyoto period, i.e. 2013 and beyond. However, no consensus has been reached yet on the group of signatories, the global future emission target, let alone the regional burden sharing. Therefore, we are forced to make assumptions on the provisions of a possible follow-up climate agreement. In particular, we assume that the same group of countries that accepted binding emissions ceilings in the Kyoto Protocol will continue to do so in the post-Kyoto period and we focus on possible expansions of this group. Because of the relatively poor global emission reduction achieved by the 1997 Kyoto Protocol for the first commitment period, we find it reasonable to assume that a future climate agreement will specify more stringent emission targets for its ratifiers. In particular, we assume an emission target for the ratifying countries that is 20% below 1990 emissions levels[5].

Concerning market power, we assume that also in the post-Kyoto period, there is at least one (group of) large permit seller(s) that behaves strategically, i.e. that withholds some supply out of the market in order to drive up the permit price and their permit trading profits. Our analysis will focus on the possible strategies of the European Union EU as a group of net buyers of permits, but firms in each individual EU country are assumed to act as competitive price taking agents in the permit market[6].

Furthermore, we assume that developing countries are invited to join the treaty[7]. If they join, they receive an allocation of permits, and are allowed to trade on the permit market on equal terms as the developing countries. A sufficiently large allocation of permits to the developing countries ensures that their benefit of joining is non-negative. These assumptions are not crucial for our theoretical analysis but do, of course, affect the final numbers in our simulation exercise.

There is a large literature on International Environmental Agreements (IEA) and the stability of such agreements see, e.g. Barrett (1999) and Chander and Tulkens (1995) or Finus (2003). The stability of

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[5] Minus 20% is in line with the proposal made by the EU after the 2007 Spring meeting of Ministers of Environment, for a new international climate agreement for the post-Kyoto period.

[6] The EU has designed its own emission trading scheme, and it is thus at the time being not obvious that there will be trade in emission permits across countries participating and non-participating in EU's trading scheme. However, the starting point for this paper is that all permits assigned by the Protocol are fully tradable and accepted by all countries. Since the number of participants for the first Kyoto period (2008-2012) is decided, we find our study relevant for the period after 2012. Restriction on EU member states' opportunity to purchase permits from Russia, or other countries with low abatement cost, increases the cost of implementing the agreement. We assume that if the Kyoto agreement continues after 2012, EU does not deny the member states to meet their obligations by permits purchased from other countries participating in the agreement.

[7] We ignore the possibility for the use of the CDM for the post-Kyoto period. Due to possible high transaction costs, and problems connected with estimating real emission reduction, the CDM mechanism has met much criticism, See, among others, Bohm (2002), Fischer (2005) and Repetto (2001). Ignoring CDM does not affect the qualitative results of our paper, but affects the quantitative results, as the CDM mechanism reduces the equilibrium permit price.

an IEA is not the prime focus of this paper. We assume that signatories to the Kyoto protocol also participate in the post-Kyoto agreement. However, we assume that if any developing country chooses to join the treaty, they cannot be worse off than by not participating. The focus of this paper is on market power in the permit market and the subsequent distribution of compliance costs across agreement members, and not on the environmental benefit of the agreement. We therefore simplify the analysis by assuming that developing countries choosing to join the agreement are allocated an amount of emissions permits equal to their business-as-usual emissions. Because of this assumption, we can ignore environmental benefits of an enlargement of the climate agreement, as global emissions are unaffected by increased participation. Furthermore, it ensures that participation cannot decrease the developing countries' welfare, compared to not participating.

Broader participation would benefit the EU countries for two reasons. First, the developing countries (assumed to have low-cost abatement options) become net sellers of permits causing a decrease in the international permit price. Second, the entrance of large sellers on the market reduces the market power of the incumbent strategic sellers (annex B-countries like Russia and Ukraine), lowering the market price of permits even further. In addition to this obvious beneficial effect of developing countries' participation, we show that the EU can benefit substantially from making appropriately designed bilateral agreements with developing countries. Such bilateral agreements should specify a minimum amount of permits that the developing countries should sell in the market and it enables the EU to act strategically on behalf of its member states. The bilateral agreements can therefore be interpreted as a way for the EU to exercise market power. Similar ideas where put forward by Ellerman and Wing (1999) in the framework of the supplementarity discussion in the aftermath of the signing of the 1997 Kyoto Protocol.

The rest of the paper is organized as follows. In the section 2 we derive the allocation of emissions and abatement cost across countries before possible participation by developing countries. We first characterize emission behavior by price taking market participants (section 2.1) and then turn to non-competitive market behavior (section 2.2). In section 3, we consider the outcome of the permit market in the case of participation from a large developing country. The outcome of the permit market in the case where EU makes a bilateral agreement with the large developing country is analyzed in section 4. A numerical illustration of our model is given in section 5. Section 6 summarizes our main findings.

2. Permit market without participation from developing countries

Let $N = \{1, 2, \ldots, n\}$ denote the set of all countries in the World and $K = \{1, 2, \ldots, k\} \subseteq N$ the subgroup of countries participating in a post-Kyoto climate agreement. Let $e_i \in \left[0, e_i^{BAU}\right]$ denote emissions from an individual country i and let ε_K denote the constraint on total emissions from all countries participating in the post-Kyoto agreement. The total emissions constraint for the agreement members is therefore given by:

$$(1) \qquad \sum_{i \in K} e_i \leq \varepsilon_K$$

A system of tradable emissions permits is implemented among the members of the agreement and permits are grandfathered, i.e. given for free to the participants. Let $\left(\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_k\right)$ denote the distribution of emission permits which should satisfy the group's total emissions constraint:

$$(2) \qquad \sum_{i \in K} \varepsilon_i = \varepsilon_K$$

We assume that members of the post-Kyoto climate agreement choose their emissions level in order to maximize net benefits of emissions:

$$(3) \qquad W_i = B_i\left(e_i\right) + p \cdot \left[\varepsilon_i - e_i\right] \qquad i \in K$$

where $B_i\left(e_i\right)$ denotes the benefits of emissions function and p is the market price of emissions permits. We assume that the benefits functions are increasing and strictly concave: $B_i' \geq 0, B_i'' < 0$. In the absence of climate policies, countries would emit up to their so-called business–as–usual emission level e_i^{BAU} which is defined as the level of emissions satisfying $B_i'\left(e_i^{BAU}\right) = 0$, i.e. the welfare maximizing emissions level if permits were free. Countries that are not a member of the post-Kyoto climate agreement are assumed to emit their business–as–usual amount of emissions since they face no price for carbon.

2.1. Competitive market participants

We assume that there is a nonempty subset of agreement members that behave as price takers in the permit market. This subset of countries will be called the competitive *fringe* and is denoted by $F \subseteq K$. Every fringe member takes the price of permits as given and chooses its emissions level in order to maximize individual benefits:

(4) $\qquad \max_{e_f} \quad W_f = B_f(e_f) + p \cdot [\varepsilon_f - e_f] \qquad \forall f \in F$

The solution of this maximization exercise gives rise to the following first-order conditions:

(5) $\qquad B'_f(e_f) = p \qquad \forall f \in F$

For every price taking member of the fringe, the first-order condition (5) defines an implicit emissions function:

(6) $\qquad e_f = B'^{-1}_f(p), \qquad \dfrac{de_f}{dp} = \dfrac{1}{B''_f} < 0, \qquad \forall f \in F$

Aggregating these emissions functions over all fringe members and inverting, yields a downward sloping, inverse aggregate emissions permit demand function for the fringe:

(7) $\qquad p = p(e_F), \qquad p' = \sum_{f \in F} B''_f < 0$

2.2. Noncompetitive market participants

However, for large players in the permit market, the assumption of price taking behavior is hard to maintain. The group of strategic permit traders is denoted by $S \subseteq K$ and together with the fringe, these two subsets are forming a partition of the set of post-Kyoto climate agreement members: $F \cup S = K$ and $F \cap S = \varnothing$. The total emission constraint (2), can now be rewritten as:

(8) $\qquad \sum_{f \in F} e_f + \sum_{s \in S} e_s \equiv e_F + e_S \leq \varepsilon_K$

We assume that the strategic choice variable of the noncompetitive agent(s) is (are) emissions quantities. Hence, we are assuming Cournot competition if there is more than one large noncompetitive permit trader.

The maximization problem of a large strategic permit trader s is given by:

(9) $\qquad \max_{e_s} \quad W_s = B_s(e_s) + p(e_F) \cdot [\varepsilon_s - e_s]$

subject to (7) and (8).

The first-order condition for this maximization problem is given by:

(10) $\qquad B'_s = p + p' \cdot [\varepsilon_s - e_s] \qquad \forall s \in S$

And the corresponding second-order condition for a maximum is:

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(11) $\qquad B_s'' + 2 \cdot p' + p'' \cdot [\varepsilon_s - e_s] < 0$

We assume in the following that the second-order condition is always satisfied. Furthermore, to ensure the existence of a unique stable equilibrium, we assume throughout the paper, that the aggregate reaction function is downward sloping with an absolute value less than unity[8].

The first-order condition in (10), shows the standard result that dominant sellers supply too few permits (hence emit too much) in order to drive up the market price. Dominant sellers' marginal benefits of emissions are therefore lower than marginal benefit of emissions in the fringe, and emissions are not cost effectively distributed across countries[9]:

(12) $\qquad B_s' < B_f' = p \qquad \forall s \in S$ for which $\varepsilon_s > e_s$

3. Permit market with participation from a developing country

In this section, we consider the case where developing countries can voluntarily join the Kyoto agreement (opt-in) under the condition that they accept binding emission constraints. We assume that a developing country that opts in is given an allocation of tradable permits equal to its business–as–usual emissions. Furthermore, we restrict our attention to one large developing country with low cost abatement options. China is a relevant example of a large developing country which has low cost abatement options and may gain a lot from participating in the agreement (provided that the allocation of permits is a generous as we assume here). We refer to this country as c (for China).

The developing country's endowment of permits is given by:

(13) $\qquad \varepsilon_c = e_c^{BAU}$

Hence, the total emission constraint of the expanded climate agreement becomes:

(14) $\qquad e_S + e_F + e_c = \varepsilon_K + \varepsilon_c \equiv \varepsilon_K^+$

China has many low cost abatement options, and an initial endowment of permits corresponding to China's business–as–usual emissions makes China a large seller of permits. It is therefore reasonable to assume that also China seeks to exploit its market power in the permit market. The group of

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[8] That is (in general), $-1 < \partial \sum_{j \in S, j \neq s} e_j \Big/ \partial e_r < 0 \quad \forall s \in S$.

[9] A similar, but reverse, argument applies to dominant permit buyers who have an interest in limiting their demand for permits in order to drive down the market price.

strategic Cournot players is therefore expanded by China. Welfare maximization gives the following first-order conditions for each of the original strategic permit traders and China;

$$(15) \qquad B'_s(e_s) = p\left(\varepsilon_K^+ - [e_S + e_c]\right) + p' \cdot [\varepsilon_s - e_s] \qquad \forall s \in S$$

$$(16) \qquad B'_c(e_c) = p\left(\varepsilon_K^+ - [e_S + e_c]\right) + p' \cdot [\varepsilon_c - e_c]$$

China's participation increases the supply of permits and reduces the equilibrium permit price. This implies that that the buyers of permits are better off than without participation from China. The EU countries are typical examples of net buyers of permits and therefore benefit from China's participation. In the next section we will focus on the EU countries and show how they can benefit even more if they make a bilateral agreement with China before it enters into the post-Kyoto climate agreement.

4. Bilateral agreement between China and EU

Throughout the paper we assume that the EU cannot force it member state to act strategically on the permit market when purchasing permits. However, we assume that the EU Commission acts on behalf of the EU member states and starts bilateral negotiations with China before it enters into the permit market. These negotiations can be modeled as a two stage game. In the first stage, the regulator designs a contract it offers to China on a take-it-or-leave-it basis. In the second stage emission permits are traded and the equilibrium price and sales are determined by the market taking into account Cournot behavior of the dominant suppliers. We assume that in the first stage, all agents have perfect foresight about the equilibrium solution in the second stage. To explore this contract it is necessary to split the fringe countries' set F into two parts: EU members and non EU members:

$$(17) \qquad e_F = e_{eu} + e_{RF}$$

where subscript eu refers to the EU countries taken together and subscript RF refers to the rest of the fringe countries. Figure 1 shows how the set of all countries N in the World is partitioned into agreement members K and non-members N\K, how K is partitioned into the fringe F and strategic players S, and how F is partitioned into eu and rest of the fringe RF.

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Figure 1: Partitioning the set of countries
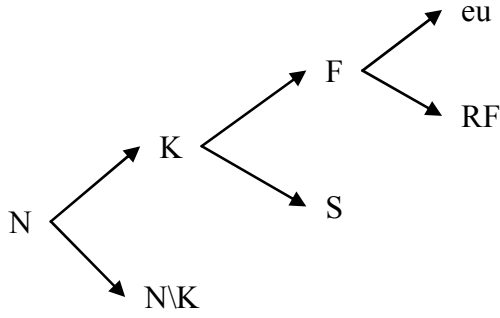
In terms of permit allocation, it should hold that:

(18) $\qquad \varepsilon_F = \varepsilon_{eu} + \varepsilon_{RF}$

EU can offer China a contract that specifies a fixed transfer (T) plus a minimum sales constraint. This corresponds to a contract which specifies a fixed monetary transfer and a maximum amount of emissions in China in the second stage. Hence China faces the following emission constraint in stage two:

(19) $\qquad e_c \leq \overline{e}_c$

where $\overline{e}_c$ denotes the maximum emission level in China specified in the bilateral contract. We assume in the following that China's emission constraint is binding such that emissions from China in stage two equals $\overline{e}_c$ [10].

In order for China to accept this contract, it must be at least as well off with the contract as without. China's participation constraint is given by:

(20) $\qquad W_c\left(\overline{e}_c, T\right) = B_c\left(\overline{e}_c\right) + p \cdot \left[\varepsilon_c - \overline{e}_c\right] + T \geq W_c\left(e_c^*, \varepsilon_c\right) = B_c\left(e_c^*\right) + p^* \cdot \left[\varepsilon_c - e_c^*\right]$

where e_c^* is China's optimal emission level in the case of no bilateral contract (i.e. the case where the equilibrium permit trade is characterized by (15) and (16)). Since financial transfers are costly for the EU, it will ensures that (20) is satisfied with equality, and this implies that the transfer T is a function of the emission restriction specified in the contract. Let $T(\overline{e}_c)$ denote the financial transfer which ensures that (20) is satisfied with equality, that is;

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[10] e_c is given by (16) if China's emission constraint is not binding.

(21) $T(\overline{e}_c) = B_c(e_c^*) + p^* \cdot [\varepsilon_c - e_c^*] - [B_c(\overline{e}_c) + p \cdot [\varepsilon_c - \overline{e}_c]]$.

The other large strategic traders' optimizing problem in stage two is given by:

(22) $\max\limits_{e_s} \quad W_s = B_s(e_s) + p(\varepsilon_K^+ - [e_S + \overline{e}_c]) \cdot [\varepsilon_s - e_s] \qquad \forall\, s \in S$

and the corresponding first-order condition is given by:

(23) $B_s' = p(\varepsilon_K^+ - [e_S + \overline{e}_c]) + p' \cdot [\varepsilon_s - e_s] \qquad \forall\, s \in S$

leading to the optimal emission levels $e_s(\overline{e}_c)$. The second-order conditions $B''(e_s) + 2p' + p'' \cdot (\varepsilon_s - e_s) < 0$ are assumed to be always satisfied.

We can now turn to analyzing the first stage of the game in which the EU optimizes the contract variable it offers to China:

(24) $\underset{\overline{e}_c}{\text{Max}} \quad W_{eu} = B_{eu}(e_{eu}) + p(e_F) \cdot [\varepsilon_{eu} - e_{eu}] - T(\overline{e}_c)$

subject to (7), (14), (17), (18), (21), and where $e_s(\overline{e}_c)$ can be found from (23).

Inserting from the first order condition for the fringe, given by (5), we can write the first order condition of EU's optimization problem as:[11]

(25) $p' \cdot \dfrac{\partial e_F}{\partial \overline{e}_c} \cdot \left[\varepsilon_{eu} - e_{eu}(\overline{e}_c)\right] = -\dfrac{\partial T}{\partial \overline{e}_c}$.

The right hand side of (25) equals the regulator's cost of demanding one unit larger sale of permits from China. The left hand side of (25) equals the regulator's marginal benefit of the lower permit price, following from one unit higher permit sale from China.

We show in appendix A that (25) can be written as

(26) $-p' \cdot \left[1 + \dfrac{\partial e_S}{\partial \overline{e}_c}\right] \cdot [\varepsilon_c + \varepsilon_{eu} - [e_{eu} + \overline{e}_c]] = p - B_c'$.

From (26), we derive the following proposition:

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[11] See appendix A for the derivation of (26).

Proposition 1

The optimal contract for EU is characterized by $p = B'_{eu} < B'_c$ *if EU and China jointly becomes net buyers of permits, and is characterized by* $p = B'_{eu} > B'_c$ *if they jointly become net sellers of permits.*

Proof of Proposition 1: See appendix B

Proposition 2

The optimal bilateral contract between EU and China leads to higher supply of permits from China and a lower equilibrium permit price, than without a bilateral contract.

Proof of Proposition 2: See appendix B

EU cannot force its member states to act strategically on the permit market when purchasing permits in the second stage. However, EU may act strategically trough negotiations with China in the first stage. Demanding a larger permit sale from China than what is optimal for China (given no bilateral contract), drives the permit price down, which benefits EU member states. However, driving down the permit price has a cost as China has to be compensated for its restriction in permit sale. EU faces a trade off between increased permit sale, hence lower equilibrium permit price, and the financial transfer to China in order to satisfy China's participation constraint. As long as net demand for permits from the EU countries is higher than the supply of permits from China, it is optimal for EU to manipulate the permit price by increasing permit sale from China such that marginal benefit of emissions in China is higher than the permit price. Hence, EU acts as a strategic buyer of permits. On the other hand, if net permit purchase from EU is lower than the permit sale from China, EU act as a strategic seller of permits and determine the permit sale from China such that marginal benefit from emission in China is lower than the permit price. However, although EU may manipulate the permit price such that the equilibrium price becomes higher than in case of a competitive supply of permits from China (characterized by $p = B'_c$), the bilateral contract leads to a increase in permit sale and a fall in the permit price compared to no bilateral contract. There are two reasons for this.

First, the bilateral contract makes China a Stackelberg leader in the output market. This effect ceteris paribus increases the total supply of permits. Second, for any given amount of permit sale from China, the net supply of permits from EU and China *jointly* is lower, as the EU countries are net buyers. This increases the marginal revenue of permit sale and leads to a larger equilibrium permit sale from China.

The optimal contract leaves EU member states better off than without, and China equally well off with the contract as without. China faces a minimum sale restriction, but is compensated by a financial transfer. Russia is worse off under the bilateral contract between EU and China since the contract leads to larger supply of permits from China.

Since the regulator cannot determine the permit trade from EU countries, marginal benefit of emission differ between China and EU countries. This implies that the emission reductions in the China/EU coalition are not distributed in a cost effective way. Hence, there would be room for further cost reductions if the EU also could determine the emission reductions among EU countries. However, that is assumed not to be an option for the EU regulator.

5. Numerical illustration

5.1. Description simulation model
In this section we describe the numerical simulation exercise illustrating the theoretical results that were derived in the previous sections. The exercise is based on a stylized numerical simulation model of the major players in the Kyoto carbon emission permit market. Each participant in the Kyoto carbon permit market is characterized by a marginal carbon emission benefit function with the following functional form:

$$(27) \qquad B_i'(e_i) = \gamma_i \ln\left(\frac{e_i}{e_i^{BAU}}\right) \qquad \text{with } \gamma_i < 0$$

The benefit function is concave in emissions since $B_i''(e_i) = \gamma_i \dfrac{e_i^{BAU}}{e_i} < 0$. Note that marginal benefits are zero when emissions equal their BAU level ($B_i'(e_i^{BAU}) = 0$) and that marginal benefits tend to infinity when emissions are approaching zero ($\lim_{e_i \to 0} B_i'(e_i) = +\infty$).

The marginal benefit of emission functions can be reinterpreted as the marginal cost of cutting back emissions by one more percent by defining a new variable $r_i \equiv 1 - e_i / e_i^{BAU}$ as the emission reduction relative to business–as–usual (BAU) emissions:

$$(28) \qquad C_i'(r_i) \equiv \gamma_i \ln(1 - r_i) = \gamma_i \ln\left(\frac{e_i}{e_i^{BAU}}\right) = B_i'(e_i)$$

Hence, marginal benefit of emissions functions are the mirror images of marginal cost of abatement functions. This is important for our purposes because it implies that we can easily calculate the parameter γ_i of the marginal benefit functions from estimates of marginal emission reduction costs derived from, for instance, simulations with large scale general equilibrium models.

For every region in our model, the individual benefit maximization exercise can therefore be written as:

$$(29) \qquad \max_{0 \leq e_i \leq e_i^{BAU}} \quad B\left(\frac{e_i}{e_i^{BAU}}\right) + p \cdot [\varepsilon_i - e_i] = \gamma_i \ln\left(\frac{e_i}{e_i^{BAU}}\right) + p \cdot [\varepsilon_i - e_i]$$

where, as before, p denotes the international market price for carbon permits and ε_i the initial assignment of permits of player i.

For the price taking players of the competitive fringe, the first-order condition for an interior solution to the benefit maximization exercise can be used to derive the following relationship between emission levels and permit price:

$$p = \gamma_f \cdot \ln\left(\frac{e_f}{e_f^{BAU}}\right) \qquad \forall f \in F$$

$$(30) \qquad \Rightarrow e_f = e_f^{BAU} \cdot \exp\left(\frac{p}{\gamma_f}\right) \qquad \forall f \in F$$

$$\Rightarrow e_F \equiv \sum_{f \in F} e_F = \sum_{f \in F} e_f^{BAU} \cdot \exp\left(\frac{p}{\gamma_f}\right)$$

The latter expression can be interpreted as the aggregate demand for carbon emissions function of the price taking fringe countries. For $p = 0$, no emission reduction is performed and actual emissions coincide with BAU emissions. If the price of emission permits tends towards infinity, emissions tend to zero. Aggregate demand for emissions of all fringe countries together depends negatively on the price of permits since:

$$(31) \qquad p' = \frac{dp}{de_F} = \left[\sum_{f \in F} \frac{e_f^{BAU}}{\gamma_f} \cdot \exp\left(\frac{p}{\gamma_f}\right)\right]^{-1} < 0$$

For the noncompetitive players in the model, we can write the following first order condition for an interior solution to their benefit maximization exercise:

$$(32) \qquad B_s' \left(\frac{e_s}{e_s^{BAU}} \right) = p + p' \cdot [\varepsilon_s - e_s] \quad \forall s \in S$$

However, interior solutions are not guaranteed in general for this maximization problem.[12] Therefore, we make use of a generic algorithm to compute Cournot-Nash equilibria in the oligopoly model with competitive fringe. In every iteration step, the algorithm sequentially considers every noncompetitive player and chooses an emission strategy that maximizes — subject to the fringe's behavior summarized by expression (31) and the overall post-Kyoto emission ceiling — its net benefits while keeping fixed the emission strategies of the other noncompetitive players. This procedures is repeated until the Euclidian distance between the nonfringe's emission vectors of two consecutive iterations is smaller than a given tolerance level.

In order to calculate the optimal bilateral contract variables for the EU to offer to China, a separate welfare optimization problem is solved for EU, taken as given the relevant first-order conditions for F and S and the participation constraint for China.

5.2. Regions and Data

Table 1 describes the regional aggregation used in the simulation model. Only countries that accepted quantified emission reductions according to Annex-B of the 1997 Kyoto Protocol (Annex- B countries) are included plus China. The choice of aggregation of these countries into regions was motivated more by arguments of similarity in economic development and emission efficiency of production than by political considerations.

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[12] In particular, nonfringe countries with "hot air", i.e. countries for which $\varepsilon_r > e_r^{BAU}$, might be tempted not to reduce their emission and even to withhold some of their hot air permits in order to drive up the sales price.

Table 1: Regional aggregation

EU15	Europe Union 15 members	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, UK
EEU	Eastern Europe	Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia
OEU	Other Europe	Iceland, Malta, Norway and Switzerland
RUS	Russia	
UKR	Ukraine	
CAN	Canada	
JAP	Japan	
AUS	Australia	
NZL	New Zealand	
CHN	China*	
USA	United States of America**	
ROW	Rest of the World***	

* China is not an Annex-B country.
** We excluded USA because they did not ratify the Protocol.
*** Belarus, Kazakhstan and Turkey are not included because their status in the Kyoto Protocol remains unclear.

Table 2 shows the basic data input for the model which consists of estimates of the cost function parameter and projected BAU emissions in the future. The projections were constructed using the aggregate growth rates in the United States Department of Energy (DoE) International Energy Outlook (IEO) 2005 (reference case, see http://www.eia.doe.gov/oiaf/archive/ieo05/) and detailed data of individual countries GDP (purchasing power parity) and emissions of carbon dioxide from fossil fuel use taken from the World Resources Institute (WRI) Climate Analysis Indicator Tool (CAIT) (see http://cait.wri.org/). The cost parameters were estimated on a set of simulation runs with the GEM-E3 World general equilibrium model (see http://www.gem-e3.net for more detailed information)[13].

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[13] We are grateful to Denise Van Regemorter (Center for Economic Studies, Katholieke Universiteit Leuven) for providing us with the necessary cost data to estimate the cost functions.

Table 2: Data input

	E1990	AAU%	AAU	E2015	gE	hot	Y2015	gY	γ
EU15	4,085	74.9	3,060	4,261	0.17	–	12,987	2.30	-258
CEU	1,281	75.9	973	1,197	-0.27	–	1,732	3.00	-96
OEU	104	80.5	84	115	0.40	–	516	2.30	-448
RUS	2,916	84.0	2,449	2,475	-0.65	–	1,906	3.70	-65
UKR	926	81.1	751	675	-1.26	11.31	442	4.90	-65
JAP	1,212	79.1	959	1,418	0.63	–	3,822	1.10	-253
CAN	649	84.2	546	964	1.60	–	1,176	2.30	-188
AUS	416	88.3	367	632	1.69	–	764	2.90	-200
NZL	65	112.3	73	95	1.50	–	118	2.90	-200
CHN	3,993	274.4	10,956	10,956	4.12	–	13,623	6.50	-126
USA	5,573	146.5	8,167	8,167	1.54	–	14,497	2.90	-136
ROW	17,048	204.6	34,881	34,881	2.90	–	25,965	5.30	-153
KYOTO	11,654	79.48	9,263	11,831	0.06	–	23,463	2.31	–
TOTAL	38,268	165,33	63, 267	65,836	2.19	–	77,547	3.99	–

E1990: emissions 1990 of all 6 greenhouse gases CO_2, CH_4, N_2O, PFCs, HFCs, SF_6 including land use changes in million tonnes of CO_2 equivalent; **AAU%**: assigned amount units in % of 1990 emissions computed taking into account the Bonn-Marrakesh agreements (using den Elzen and Both 2002) and 20% additional reduction; **AAU**: assigned amount units in million tonnes of CO_2 equivalent; **E2015**: projected emissions 2015 in million tonnes of CO_2 equivalent; **gE**: average annual growth rate emissions between 1990 and 2015 in %; **hot air**: difference between AAU and E2015 (only for regions for which AAU ≥ E2015) as % of E2015; **Y2015**: projected GDP 2015 in billion US\$$_{2000}$; **gY**: average annual growth rate GDP between 2003 and 2015 in %; γ : parameter marginal benefit of emission function.

E1990 was constructed from WRI-CAIT database and includes all six greenhouse gases covered by the 1997 Kyoto Protocol including emissions from land use changes. AAU and AAU% were computed by combining E1990 with the individual commitments in Annex-B of the 1997 Kyoto Protocol and taking into account the Bonn-Marrakesh agreements (as in den Elzen and Both 2002) plus and additional reduction of 20%. Hence, we assume that emission targets for the second commitment period 2013-2017 is 20 % lower than during the first commitment period. Notice that for this assumption; only Ukraine has some limited amount of "hot air"[14]. E2015, gE, Y2015 and gY were constructed using DoE IEO 2007 projections. The parameter γ_i was estimated with OLS on a dataset of simulation results from the GEM-E3 World model. All emission data are expressed in million tonnes of CO_2 equivalent and all GDP values are expressed in billion US\$ of 2000.

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[14] See footnote 12 for a definition of "hot air".

5.3. Results

In this section we compare the outcome for the following four scenarios:

1. Reference scenario. China does not participate. Competitive permit market.
2. China does not participate. Noncompetitive permit market.
3. China participates. Noncompetitive permit market.
4. China participates. Noncompetitive permit market. Bilateral agreement between China and EU.

Detailed tables of the outcomes of the different scenarios are given in appendix C. Table 3 summarizes permit prices and total compliance costs for the EU (= EU15 + EEU), the strategic permit sellers (Russia and Ukraine) and China, the rest of Annex-B countries, and the total cost in the four different scenarios.

Table 3:   Price (US$/tonne CO_2) and compliance cost (mill. US$) comparison between the four scenarios

	(1)	(2)	(3)	(4)
Price	33	41	28	20
EU (=EU15+EEU)	32,338	36,234	29,421	24,901
Russia+Ukraine	-24,218	-31,032	-15,721	-8,591
China	-	-	-17,491	-17,491
Rest Annex-B	31,903	37,718	28,237	21,308
Total	40,022	42,919	24,447	20,126

We observe, by comparing scenarios 1 and 2, the impact of non-competitive behavior by Russia and Ukraine in a situation without participation from China. As a result of their non-competitive behavior, Russia and Ukraine manage to drive up the equilibrium permit price to 41$ instead of 33$ per tonne of CO_2 in the competitive reference scenario (+25%). This raises the compliance costs for the EU member states (= EU15 + EEU) to 36,234 compared to 32,338 million US$ (+12%). Total compliance costs for the Kyoto group as a whole are raised by 7% (40,022 to 42,919 million US$). Together, Russia and Ukraine can raise their net result from trading from 24,218 to 31,032 million US$ (+28%) by behaving strategically instead of competitively.

If China opts in, there are three oligopolistic emission permit suppliers competing à la Cournot besides the competitive fringe (scenario 3). This would reduce the permit price from 41$ to 28$ per tonne of CO_2 and reduce compliance costs for the EU member states by 19% (compared to scenario 2). For the

permit sellers Russia and Ukraine, the opt in of China reduces their joint permit sales revenues from 31,032 - 15,721 = 15,311 million US$, i.e. a decrease by about 50%.

In column (4) we report results for the minimal sales contract between EU and China. Comparing Table 5 and Table 6 (see Appendix C), we see that the minimal sales contract requires China to sell about 11.83% of its BAU emissions in 2015 whereas it would sell only 6.63% if it were not constrained by the contract. The financial transfer required to keep China equally well off (China's total net benefit of emissions trading amount to 17,491 million US$, both in scenario (3) and (4)) values about 1,720 million US$. This absolute number might seem high but it amounts to only about 0.01% of EUs projected GDP in 2015. Note that instead of transferring money, the EU could equally well transfer an amount of emissions permits equal to about 3% of EUs initial permit allocation. The market value of those permits corresponds to the required financial transfer. Note that this is the transfer mechanism that used to calculate the numbers reported in Table 6 in Appendix C. EUs AAUs are down by about 3% whereas China's AAU are up by 0.77% compared to all other scenarios. Overall, EU and China together are allocated the same amount of CO_2 emissions permits all the scenarios.

By making a bilateral contract with China, EU is able to reduce its member states compliance cost strongly. The contract (minimal sales condition) solution yields compliance costs for the EU of about 24,901 million US$ versus 29,421 million US$ in the scenario that China opts in and behaves non-competitively. Compared to the scenario without China opting in and Russia and Ukraine behaving noncompetitively, the EU saves even 31% in compliance costs when comparing to (from 36,234 in scenario (2) to 24,901 million US$ in scenario (4)). Furthermore, the total compliance cost of the full post-Kyoto agreement is reduced by 53% (from 42,919 to 20,126 million US$ $). For the permit sellers Russia and Ukraine, the opt-in of China combined with the minimal sales condition makes them lose about 31,032 - 8,591 = 23,545 million US$, i.e. a decrease by 73% compared to the situation where Russia and Ukraine where the sole permit exporters in the Kyoto market. This might raise serious concerns about the cohesion of the original Kyoto club since it is very likely that Russia and Ukraine will claim compensation for the sales revenues forgone. However, they can not credibly threaten to quit the Kyoto club since this would yield them zero sales revenues.

6. Concluding remarks

In this paper, we have shown how a group of net buyers of permits (the EU countries) benefits from broader participation in a climate treaty, given that the new entrant is a net seller of permits. We have

shown that an appropriately designed bilateral agreement regarding a minimum amount of permit sales from potential new entrants can substantially decrease the cost of the group of net permit importers. In the paper we considered the case where the entrant became a large seller of permits, and would reasonably be expected to act strategically in the permit market. This assumption, however, is not crucial for our conclusion. Even if the developing country did not intend to act strategically in the permit market, the group of net buyers would benefit from offering the country a contract which induces it to alter its strategy compared to the scenario without the bilateral contract. We demonstrated that an optimal contract leads to a situation where the marginal benefit of emissions for the developing country deviates from the market permit price. Finally, we noted that there is even more potential gain for the EU countries if they make bilateral agreements with several small price taking developing countries that consider to join the post-Kyoto climate agreement by inducing them to increase their permits sales volume.

We have also assumed that at least one of the original members of the Kyoto club is a large seller of permits and exploit its market power in the permit market. However, neither this, nor the previous, assumption is crucial for our conclusion that it is profitable for EU to make a bilateral agreement with potential entrants. The driving force for the gain of bilateral agreements is that EU and the potential entrants jointly become a large trader of permits, and hence can benefit from acting strategically in the permit market.

We showed that the entrance of a large seller of permits (China) is detrimental for the incumbent strategic sellers of permits (Russia and Ukraine), as the permit price falls sharply from 41$ to 28$ per tonne of CO_2. But even though China's participation was costly for them, they were still better off participating in the permit market than leaving the agreement. Finally, our computations show that by offering a deal to China, EU can cut its net compliance costs by more than one third, even after accounting for the financial transfer needed to satisfy China's voluntary participation constraint.

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This appendix shows the derivation of (25) and (26).

We see from (7), (14), (18) and (23), that $e_F(\overline{e}_c)$, $e_{eu}(\overline{e}_c)$ and $e_S(\overline{e}_c)$, such that $p(\overline{e}_c)$. Hence, (24) can be rewritten as:

(A.1) $\max\limits_{\underline{e}_c} \quad W_{eu} = B_{eu}\left(e_{eu}\left(\overline{e}_c\right)\right) + p\left(\overline{e}_c\right) \cdot \left[\varepsilon_{eu} - e_{eu}\left(\overline{e}_c\right)\right] - T\left(\overline{e}_c\right)$

where the first order condition is given by:

(A.2) $B'_{eu} \cdot \dfrac{\partial e_{eu}}{\partial \overline{e}_c} + \dfrac{\partial p}{\partial \overline{e}_c} \cdot \left[\varepsilon_{eu} - e_{eu}\left(\overline{e}_c\right)\right] + p \cdot \left[-\dfrac{\partial e_{eu}}{\partial \overline{e}_c}\right] - \dfrac{\partial T}{\partial \overline{e}_c} = 0$

Rearranging and inserting from the first order condition for the EU countries' trade in the permit market, given by (5) for f =eu, gives

(A.3) $\dfrac{\partial p}{\partial \overline{e}_c} \cdot \left[\varepsilon_{eu} - e_{eu}\left(\overline{e}_c\right)\right] = \dfrac{\partial T}{\partial \overline{e}_c}$

(equation (A.3) is identical to equation (25))

We see from total differentiation (14) that $\dfrac{\partial e_F}{\partial \overline{e}_c} = -\left[1 + \dfrac{\partial e_S}{\partial \overline{e}_c}\right]$.

We find $\dfrac{\partial F}{\partial \overline{e}_c}$ from total differentiation of (21);

(A.4) $\dfrac{\partial T}{\partial \overline{e}_c} = p - B'_c - \dfrac{\partial p}{\partial \overline{e}_c}(\varepsilon_c - \overline{e}_c)$

Inserting from (A.4), we find that equation (A.3) (equation (25)) can be written as:

(A.5) $\dfrac{\partial p}{\partial \overline{e}_c} \cdot \left[\varepsilon_{eu} + \varepsilon_c - \left[e_{eu}\left(\overline{e}_c\right) + \overline{e}_c\right)\right]\right] = p - B'_c$

Equation (A.3) is identical to equation (26).

$\square$

Proof of proposition 1

It follows from (5) that $p = B'_{eu}$. When China's supply of permits is set in the first stage, by the determination of $\overline{e}_c$, the other large sellers become Stackelberg followers in the permit market in the second stage. By assumption, $-1 < \dfrac{\partial e_s}{\partial \overline{e}_c} < 0$ (see footnote 8). If EU and China jointly are net buyers (sellers) of permits, $\left[\varepsilon_c + \varepsilon_{eu} - [e_{eu} + \overline{e}_c] \right] < 0$ (>0), the left hand side of (26) is negative (positive), which implies that $(B'_{eu} - B'_c) < 0$ (>0).

<div align="right">□</div>

Proof of proposition 2

The first order condition for China's emissions under the optimal bilateral contract given by (26) can be rearranged to

$$(B.1) \qquad B'_c(\overline{e}_c) = p\left(\varepsilon_K^+ - \left[\sum_{s=1}^{S} e_s(\overline{e}_c) + \overline{e}_c \right] \right) + p' \cdot \left[1 + \frac{\partial \sum_{s=1}^{S} e_s(\overline{e}_c)}{\partial \overline{e}_c} \right] \cdot \left[\varepsilon_c + \varepsilon_{eu} - [e_{eu} + \overline{e}_c] \right]$$

In order to prove that the supply of permits from China is larger under bilateral contract than without, suppose that China's emission under both situations equals e_c^*, which is the emissions from China which satisfies (16) with equity. That implies that the emissions from the other large suppliers, $s \in S$, also are identical under both regimes as the solution for e_s from (23) equals the solution for e_s from (15) when the emission from China is identical. However, if e_c^* satisfies (16) with equity it cannot

satisfy (B.1) with equality as $p' \cdot \left[1 + \dfrac{\partial \sum_{s=1}^{S} e_s(\overline{e}_c)}{\partial e_c^*} \right] \cdot \left[\varepsilon_c + \varepsilon_{eu} - [e_{eu} + e_c^*] \right] > p' \cdot \left[\varepsilon_c - e_c^* \right]$ since

$0 < \left[1 + \dfrac{\partial \sum_{s=1}^{S} e_s(\overline{e}_c)}{\partial e_c^*} \right] < 1$ (see footnote 8), and $\left[\varepsilon_{eu} - e_{eu} \right] < 0$, as EU countries are assumed be net

buyer of permits.

This implies that the left hand side is smaller than the right hand side of (B.1) for $\overline{e}_c = e_c^*$. Hence, it follows from the second order condition that the emissions from China which satisfies (B.1) must be

larger than e_c^*. Furthermore since $0 < \left[1 + \dfrac{\partial \sum\limits_{s=1}^{S} e_s(\overline{e}_c)}{\partial \overline{e}_c} \right] < 1$, total supply of permits is larger under the

contract than without, which leads to lower equilibrium permit price.

$\square$

Simulation results:

Table 3:   Scenario 1. Reference Scenario. China does not participate. Competitive permit market.[15]

	AAU	E	R	EXP	MAC	AC	TRADE	TC	MUP
EU15	72.84	87.95	12.05	-16.14	33.08	8,310	22,748	31,058	–
CEU	81.30	70.75	29.25	10.55	33.08	5,457	-4,177	1,280	–
OEU	72.82	92.88	7.12	-20.06	33.08	134	762	896	–
RUS	98.97	60.11	39.89	38.86	33.08	14,952	-31,818	-16,866	–
UKR	111.31	60.11	39.89	51.20	33.08	4,076	-11,429	-7,352	–
JAP	67.61	87.73	12.27	-20.12	33.08	2,816	9,439	12,255	–
CAN	56.65	83.88	16.12	-27.23	33.08	2,495	8,684	11,179	–
AUS	58.15	84.74	15.26	-26.59	33.08	1,551	5,557	7,108	–
NZL	77.34	84.74	15.26	-7.40	33.08	233	232	465	–
CHN	100	100	0	0	0	0	0	0	–
USA	100	100	0	0	0	0	0	0	–
ROW	100	100	0	0	0	0	0	0	–
F	77.58	78.29	21.71	0	33.08	40,022	0	40,022	–
S	–	–	–	–	–	–	–	–	–
KYOTO	77.58	78.29	21.71	0	33.08	40,022	0	40,022	–
WORLD	96.10	96.10	3.90	0	4.84	40,022	0	40,022	–

price: 33.08 $/tonne CO_2

F = {EU15, CEU, OEU, RUS, UKR, JAP,CAN, AUS, NZL}

S = ∅

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[15] **AAU**: assigned amount units or initial emission permit allocation as % of projected 2015 emissions; **E**: remaining emissions in 2015 as % of projected 2015 emissions; **R**: emissions reduction as % of projected 2015 emissions; **EXP**: net export of emissions permits (**AAU-E**) as % of projected 2015 emissions; **MAC**: marginal emission reduction cost in US$_{2000} per tonne of CO_2; **AC**: emission abatement costs in million US$_{2000}; **TRADE**: market value of net emissions permits trade (-**p**.**EXP**) in million US$_{2000}; **TC**: total net cost (**AC+TRADE**) in million US$_{2000}; **mup**: markup or difference in percent between MAC and price relative to price ((**p-MAC**)/**p**).

Table 4: Scenario 2. China does not participate. Noncompetitive permit market

	AAU	E	R	EXP	MAC	AC	TRADE	TC	MUP
EU15	72.84	85.14	14.86	-13.32	41.46	12,775	23,539	36,314	–
CEU	81.30	64.81	35.19	16.49	41.46	8,100	-8,180	-80	–
OEU	72.82	91.16	8.84	-18.34	41.46	207	873	1,080	–
<u>RUS</u>	98.97	71.62	28.38	27.35	21.70	7,197	-28,066	-20,868	91.09
<u>UKR</u>	111.31	61.46	38.54	49.85	31.64	3,782	-13,946	-10,164	31.04
JAP	67.61	84.87	15.13	-17.26	41.46	4,327	10,148	14,475	–
CAN	56.65	80.23	19.77	-23.58	41.46	3,806	9,424	13,230	–
AUS	58.15	81.26	18.74	-23.11	41.46	2,370	6,053	8,423	–
NZL	77.34	81.26	18.74	-3.92	41.46	356	154	510	–
CHN	100	100	0	0	0	0	0	0	–
USA	100	100	0	0	0	0	0	0	–
ROW	100	100	0	0	0	0	0	0	–
F	68.86	81.50	18.50	-11.67	41.46	31,940	42,011	73,951	–
<u>**S**</u>	101.61	69.44	30.56	32.17	23.58	10,979	-42,011	-31,032	–
KYOTO	77.58	78.29	21.71	0	37.24	42,919	0	42,919	–
WORLD	96.10	96.10	3.90	0	5.45	42,919	0	42,919	–

price: 41.46 \$/tonne CO_2

F = {EU15, CEU, OEU, JAP,CAN, AUS,NZL}

<u>**S**</u> **= {RUS, UKR}**

Table 5: Scenario 3. China participates. Noncompetitive permit market

	AAU	E	R	EXP	MAC	AC	TRADE	TC	MUP
EU15	72.84	89.58	10.42	-17.76	28.36	6,180	21,465	27,645	–
CEU	81.30	74.33	25.67	6.97	28.36	4,140	-2,364	1,776	–
OEU	72.82	93.86	6.14	-21.05	28.36	99	685	784	–
<u>RUS</u>	98.97	79.23	20.77	19.74	15.13	3,738	-13,852	-10,114	87.41
<u>UKR</u>	111.31	72.16	27.84	39.14	21.21	1,884	-7,490	-5,606	33.73
JAP	67.61	89.39	10.61	-21.77	28.36	2,094	8,757	10,851	–
CAN	56.65	86.02	13.98	-29.36	28.36	1,864	8,027	9,891	–
AUS	58.15	86.77	13.23	-28.62	28.36	1,157	5,127	6,284	–
NZL	77.34	86.77	13.23	-9.43	28.36	174	254	427	–
<u>CHN</u>	100	93.37	6.63	6.63	8.68	3,118	-20,609	-17,491	226.72
USA	100	100	0	0	0	0	0	0	–
ROW	100	100	0	0	0	0	0	0	–
F	68.86	86.87	13.13	-17.04	28.36	15,707	41,951	57,658	–
<u>**S**</u>	100.96	89.87	10.13	10.49	10.16	8,739	-41,951	-33,212	–
KYOTO	88.73	88.73	11.27	0	16.95	24,447	0	24,447	–
WORLD	96.10	96.10	3.90	0	5.42	24,447	0	24,447	–

price: 28.36 \$/tonne CO_2

F = {EU15, CEU, OEU, JAP, CAN, AUS, NZL}

<u>**S**</u> **= {RUS, UKR, CHN}**

Table 6: **Scenario 4. China participates. Noncompetitive permit market. Bilateral agreement between China and EU (EU15+EEU).**

	AAU	E	R	EXP	MAC	AC	TRADE	TC	MUP
EU15	69.83	92.43	7.57	-22.60	20.28	3,228	19,536	22,764	–
CEU	81.30	80.88	19.12	0.42	20.28	2,238	-101	2,137	–
OEU	72.82	95.57	4.43	-22.76	20.28	51	530	581	–
<u>RUS</u>	98.97	84.44	15.56	14.53	10.99	2,057	-7,294	-5,236	84.49
<u>UKR</u>	111.31	79.67	20.33	31.63	14.77	975	-4,329	-3,355	37.33
JAP	67.61	92.29	7.71	-24.68	20.28	1,094	7,098	8,192	–
CAN	56.65	89.79	10.21	-33.13	20.28	981	6,478	7,459	–
AUS	58.15	90.35	9.65	-32.20	20.28	608	4,125	4,733	–
NZL	77.34	90.35	9.65	-13.01	20.28	91	250	342	–
CHN*	100.77	88.94	11.06	11.83	14.82	8,803	-26,294	-17,491	36.85
USA	100	100	0	0	0	0	0	0	–
ROW	100	100	0	0	0	0	0	0	–
F	68.86	90.39	9.61	-21.53	20.28	8,291	37,917	46,208	–
<u>**S**</u>	101.61	83.42	16.58	18.19	11.77	3,032	-11,623	-8,591	–
KYOTO	77.58	88.53	11.47	-10.96	18.15	11,323	26,294	37,617	–
WORLD	96.10	96.10	3.90	0	5.42	20,126	0	20,126	–

price: 20.28 \$/tonne CO_2

minimal sales constraint: EXP $\geq$ 11.83%

F = {EU15, CEU, OEU, JAP, CAN, AUS, NZL}

S = {RUS, UKR}

* participation constraint