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CO_2 abatement costs and permits price: Exploring the impact of banking and the role of future commitments

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December 2003

ENVIRONMENTAL
ECONOMICS & MANAGEMENT
MEMORANDUM

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CO_2 abatement costs and permits price: Exploring the impact of banking and the role of future commitments[1]

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[1]The author whishes to thank Johan Eyckmans, Emmanuel Martinez and Henry Tulkens for their numerous comments and suggestions. This paper has also benefited from discussions with Patrick Criqui, Daniel Delalande, Sylviane Gastaldo, Sandrine Rocard, Eve Roumiguières, as well as with the participants of the third CATEP (Concerted Action on Tradable Emission Permits) workshop in Kiel, October 2002. Financial support from SSTC (Services fédéraux des Affaires scientifiques, techniques et culturelles, Brussels, Belgium) and MEDD (Ministère de l'Ecologie et du Développement Durable, Paris, France) is gratefully acknowledged.

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Abstract

Since the signing of the Kyoto Protocol in December 1997, several authors have computed the costs of reducing greenhouse gas emissions by the amount specified in the Protocol, while accounting for the possibility to use the flexible mechanisms of the Protocol (internationally tradable emission permits). A number of such studies have recently shown that, following the US withdrawal and the Bonn and Marrakesh agreements, these abatement costs will be very low and the price of the permits could reach zero. However, these analyses usually take only the first commitment period (2008-2012) into account and do not explicitly consider the possibility of banking permits from one commitment period to the other (Art. 3.13 of the Protocol).

The simple dynamic model that we develop here introduces this possibility. It allows one to analyze the impact of alternative future commitments (post 2012) for the US and the non-Annex B countries on world emissions, abatement costs and the permits price.

We find that, provided ambituous post-Kyoto commitments are negotiated: (i) in 2008-2012, the amount of banked permits will largely exceed the amount of hot air and permits prices will be much higher than predicted by most other studies, (ii) the banking provision significantly reduces world total costs but increases total costs for all permit-importing Annex B countries (i.e. all Annex B countries except countries of eastern Europe) via a rise in the permits price in 2008-2017 and (iii) the issue of market power on hot air is not likely to be a relevant one.

Keywords: Kyoto protocol, flexible mechanisms, banking, future commitments

Contents

1 Introduction

Since 1998, several studies have been devoted to the estimation of the abatement costs caused by the greenhouse gas emissions reduction policy negotiated in Kyoto on December 1997. The flexible mechanisms defined in Articles 6, 12 and 17 of the Kyoto Protocol –i.e. the possibility to trade emission permits– play a key role in these analyses since they allow to lower total abatement costs considerably by inducing countries to locate emission reductions where they are cheapest. Following the US president declaration not to ratify the Kyoto Protocol in June 2001, a couple of new studies have estimated the abatement costs and the permits price while taking into account the outcome of the Bonn and Marrakesh negotiations in July and November 2001 (see UNFCCC (2001a,b)). All these authors (see Blanchard, Criqui, Trommetter and Viguier (2002), Böhringer (2001), Buchner, Carraro and Cersosimo (2001), den Elzen and de Moor (2001a,b), Eyckmans, Van Regemorter and van Steenberghe (2001), Hagem and Holtsmark (2001), Hourcade and Ghersi (2002), Löshel and Zhang (2002) and Manne and Richels (2001)) show that the US withdrawal together with the Bonn and Marrakesh accords drive down the abatement costs and the permits price, the latter being close to –or even equal to– zero.

However, these analyses do not explicitly take into account Article 3.13 of the Kyoto Protocol, i.e. the possibility of banking emission permits from one commitment period to the other (see UNFCCC (1998), p. 11) :

> "If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount of that Party for subsequent commitment periods."

This provision may be seen as an intertemporal flexibility mechanism, which allows countries to make emission reductions when –rather than where– they are cheapest. Full intertemporal flexibility is nevertheless not permitted since borrowing of permits has been forbidden.

den Elzen and de Moor (2001a,b) as well as Manne and Richels (2001) look at the effect of banking on the permits price in 2008-2012, but the banking behavior is not explicitly modeled and the amount of banked permits is limited to the hot air, which is mainly hold by Russia and Ukraine. However, provided that ambitious future commitments are negotiated, the amount of banking might be very large, well above hot air, and might drive up abatement costs and permits price in 2008-2012. The amount of banked permits and the impact of banking depend on several elements, among which are the tightness of the future world emissions reduction objectives, the number of committed countries and the allocation of the commitments among the participants. Given the considerable uncertainty surrounding these issues, it is necessary to set up a simple and flexible tool aimed at estimating world emissions, abatement costs and permits price while allowing for a large panel of scenarios.

The world partial equilibrium model developed here, called *MacBank*, is based on a set of marginal abatement cost curves for CO_2 fossil fuel energy. Its main peculiarity is that it allows for a flexible participation structure: the set of countries participating to an international agreement or to the market for permits need not be the same at each period. This feature is essential since we are interested in the participation of USA and developing countries to post-Kyoto agreements.

Since the dynamics of the model relies only on the banking mechanism, this approach is similar to the one of Ellerman (2002) who analyzes the impact of a decrease in the allocation of sulfur dioxide (SO_2) emission permits in the context of the US Acid Rain Program. Our description of the permits market distinguishes Emissions Trading (ET, Art. 17 of the Kyoto Protocol) and Joint Implementation (JI, Art. 6) from the Clean Development Mechanism (CDM, Art. 12), and allows for the inclusion of carbon sinks (see Art. 3.3 and 3.4). Restrictions on permits trades –of hot air for instance– may also be introduced. Finally, one can use the permits allocation rules the most often referred to in the literature.

The paper is organized as follows. Section 2 introduces the model and provides a simple algorithm which computes a unique market equilibrium with banking. The main parameters of the model and their reference values are presented in section 3 which also sets up the alternative choices driving the scenarios, i.e. (i) the countries committed to emissions reductions, (ii) the global target and (iii) its distribution. Section 4 describes in detail the results of our base case scenarios. Then, in section 5, alternative scenarios based on different participation structures and on different permits allocation rules are tested. The issue of hot air restriction is discussed in section 6 while the last section summarizes the results and concludes.

2 A model of banking with flexible participation structure

The model is initially based on the MacGEM model developed by Eyckmans, Van Regemorter and van Steenberghe (2001). The purpose of MacGEM is to estimate the CO_2 emission reductions, their costs and the equilibrium permits price for the first commitment period specified in the Kyoto Protocol, 2008-2012. This model divides the world into 15 regions or countries. It is based on a set of marginal abatement cost curves for fossil fuel energy CO_2 emissions computed from the general equilibrium model GEM-E3-World (see Capros, Georgakopoulos, Van Regemorter, Proost, Schmidt, Koschel, Conrad and Vouyoukas (1999)).

In this paper, we extend MacGEM to the subsequent commitment periods which are assumed to be of the same length as the first one, i.e. five years. The main difficulty consists in modelling and computing the banking behavior. Most authors, like Yates and Cronshaw (2001), Hagem and Westskog (1998) and King and Rubin (1997), consider not only banking but also borrowing of permits. This allows full intertemporal flexibility which considerably simplifies the analysis since it avoids dealing with constraints on intertemporal trades, i.e. with non-linearities. Among those who deal only with banking, Cronshaw and Kruse (1996) work in a discrete time multiperiod framework, which corresponds to ours[1]. We therefore adapt their model dealing with banking behavior of firms under profit regulation to our context.

We use the following notations borrowed from Eyckmans, Van Regemorter and van Steenberghe (2001):

GDP_{it}^{BAU} : GDP of country i at time t under business-as-usual (no emission reduction) policy

POP_{it} : population of country i at time t

AAU_{it} : assigned amount units (permits) allocated to country i at time t

[1]For other studies on banking only, see Schennach (2000) and Rubin (1996) who use continuous time models.

E_{it}^{BAU} : fossil fuel CO_2 emissions of country i at time t under no emission reduction policy

R_{it} : emission reductions of country i at time t $(0 \leq R_{it} < E_{it}^{BAU})$

$E_{it} = E_{it}^{BAU} - R_{it}$: actual emissions of country i at time t

with $i \in [1, ..., I]$, the set of countries, and $t \in [1, ..., T]$, the set of commitment periods.

During the first commitment period(s), only a subset of countries are likely to commit to emission reductions and, consequently, to participate to the permits market. Accordingly, we define a participation structure as a family $S = \{S_1, ..., S_T\}$ of coalitions of countries. We assume that, once it commits to emission reductions, a country keeps participating to reductions for the rest of the time, i.e. $S_t \subseteq S_{t+1}$ $\forall t$.

We further assume that the total amount of permits allocated in each period to the participating countries is strictly lower than the sum of their business-as-usual emissions[2], i.e.

$$\sum_{i \in S_t} AAU_{it} < \sum_{i \in S_t} E_{it}^{BAU} \forall t. \tag{1}$$

2.1 Countries

In each period t, any country $i \in S_t$ committed to reduce or limit its emissions receives an amount AAU_{it} of tradable permits and is not allowed to emit more CO_2 than specified by the amount of permits in its possession. Each country then maximizes its GDP while choosing, in each period, an amount of emission reductions R_{it} $(0 \leq R_{it} < E_{it}^{BAU})$, an amount XS_{it} of permits to sell $(XS_{it} > 0)$ or to purchase $(XS_{it} < 0)$ on the international market and the level of its account of unused –i.e. banked– permits CB_{it}.

Consider a country i which starts trading permits in the first commitment period, that is, $i \in S_1$ ([3]). Its behaviour is described by the solution of the following problem:

[2] This assumption does not prevent some countries, like Russia for instance, to enjoy 'hot air' ($AAU_{it} > E_{it}^{BAU}$ for some i, t). However, global hot air is ruled out under this assumption. Given our data set (see below), reference emissions are well strictly above the Kyoto target of participating countries (Annex B countries excluding the US). Hence, assumption (1) is satisfied. Note that removing this assumption is technically feasible, although this would make the exposition much more heavy.

[3] The analysis extends directly to the case of countries which do not participate in the very first period by noting that $CB_{it} = 0$ $\forall i \notin S_{t-1}$, $\forall t$.

$$Max_{\{(R_{it},CB_{it+1},XS_{it})_{t=1,...,T}\}} \sum_{t=1}^{T} \alpha^{t-1} GDP_{it} = \sum_{t=1}^{T} \alpha^{t-1} \left[GDP_{it}^{BAU} - C_{it}(R_{it}) + p_t XS_{it} \right] \tag{2}$$

subject to

$$CB_{it+1} = CB_{it} + AAU_{it} - \left[E_{it}^{BAU} - R_{it} \right] - XS_{it} \quad \forall t \qquad (\lambda_{it}) \tag{3}$$

$$CB_{it} \geq 0 \quad \text{for} \quad t = 2, ..., T \qquad (\mu_{it}) \tag{4}$$

$$CB_{it} = 0 \ \text{(a constant)} \quad \text{for} \quad t = 1 \tag{5}$$

where $p = [p_1, ..., p_T]$ is the vector of the permits price on the international market, assumed such that $p_t > 0 \ \forall t$ ([4]), and where λ_{it} and μ_{it} are the multipliers of the Lagrangian associated to this problem. $C_{it}(R_{it})$ is the abatement cost function of country i at time t, defined on $0 \leq R_{it} < E_{it}^{BAU}$. This function is assumed to be continuous, twice differentiable, strictly increasing ($C_{it}^{'} > 0$ for $R_{it} > 0$) and strictly convex ($C_{it}^{''} > 0$), with $C_{it}(0) = 0$, $C_{it}'(0) = 0$ and $\lim_{R_{it} \to E_{it}^{BAU}} C_{it}'(R_{it}) = +\infty$.

Equation (3) describes the evolution of the banked permits account. It increases with the difference between the allocation of permits (AAU_{it}) and actual emissions ($E_{it}^{BAU} - R_{it}$) and decreases with the net sales of permits. Since borrowing of permits is not allowed, the account must be positive (condition (4)) and its initial level is null (condition (5)).

The solution of problem (2)-(5) is a $3 \times T$ dimensional vector $\left[\left(R_{it}^{\circ}, CB_{it}^{\circ}, XS_{it}^{\circ} \right)_{t=1,...,T} \right]$. At each period, this vector depends on the prices at all periods (the vector p) as well as on its assigned amount units (AAU_{it}) and its business-as-usual emissions (E_{it}^{BAU}). We shall however drop the AAU_{it} and E_{it}^{BAU} arguments when they play no role in the developments and write $\left[\left(R_{it}^{\circ}(p,), CB_{it}^{\circ}(p,), XS_{it}^{\circ}(p,) \right)_{t=1,...,T} \right]$ with the symbol $\cdot$ referring to these dropped arguments. We characterize now this solution.

Using the multipliers associated to constraints (3) and (4) in period t, Kuhn-Tucker first order conditions with respect to the three variables R_{it}, CB_{it} and XS_{it} are:

[4] We shall show later that the equilibrium prices are strictly positive under assumption (1).

$$\alpha^{t-1}C'_{it} + \lambda_{it} = 0, \ \forall t \tag{6}$$

$$\lambda_{it-1} - \lambda_{it} + \mu_{it} = 0 \ \text{ for } t \geq 2 \tag{7}$$

$$\alpha^{t-1}p_t + \lambda_{it} = 0, \ \forall t. \tag{8}$$

From Kuhn-Tucker theorems, this solution also has the property that

$$\mu_{it} \geq 0, \ \text{ for } t \geq 2 \tag{9}$$

$$\text{and } \ CB_{it+1}(p, \cdot) . \mu_{it} = 0, \ \text{ for } t \geq 2. \tag{10}$$

By combining conditions (6) and (8), and ignoring the corner solution $\overset{\circ}{R}_{it}(p,) = 0$ ([5]), we obtain:

$$p_t = C'_{it}\left(\overset{\circ}{R}_{it}\right) \tag{11}$$

that is, each country abates in such a way that its marginal abatement cost equals the current permits price. We may also write:

$$\overset{\circ}{R}_{it} = C'^{-1}_{it}(p_t). \tag{12}$$

Net sales of permits by country i in period t, $X\overset{\circ}{S}_{it}(p,)$, are given by equation (3). Using expression (12), we obtain

$$X\overset{\circ}{S}_{it}(p, \cdot) = AAU_{it} - \left[E^{BAU}_{it} - C'^{-1}_{it}(p_t)\right] - \left[C\overset{\circ}{B}_{it+1}(p, \cdot) - C\overset{\circ}{B}_{it}(p, \cdot)\right]. \tag{13}$$

Net sales correspond to the initial allocation of the current period less (i) the actual emissions of that period and (ii) the net increase in the permits account.

As to banking, by combination of conditions (7) to (10), we also have

$$C\overset{\circ}{B}_{it+1}(p, \cdot) = 0 \Leftarrow p_t > \alpha p_{t+1} \tag{14}$$

$$C\overset{\circ}{B}_{it+1}(p, \cdot) > 0 \Rightarrow p_t = \alpha p_{t+1}. \tag{15}$$

[5]We may safely ignore this corner solution because $R^{b0}_{it}(p, \text{b7}) = 0$ would imply $C'_{it}\left(R^{b0}_{it}(p, \text{b7})\right) = 0$ which leads to a contradiction of (11) since $p_t > 0$ by assumption.

(14) shows that each country empties its account of permits when the discounted price is strictly greater than the one of the following period. It is indeed profitable to sell now rather than in the next period. (15) shows that non empty accounts imply discounted price equalization.

Finally, first order conditions only have a solution if discounted prices are non-increasing over time. Indeed, by conditions (7)-(9), we have

$$p_t \geq \alpha p_{t+1}. \tag{16}$$

If this relation does not hold, a country increases its GDP by buying permits early and selling them later. However, this would lead to an unboudedly large demand for early permits, which could not occur in equilibrium (see Cronshaw and Kruse (1996), p.184).

Note also that it is assumed that any country j which does not commit to emission reductions at period t ($j \notin S_t$) realizes its BAU emissions ($R_{jt} = 0$) or may engage in an autarkic emission reduction policy ($0 < R_{jt} < E_{jt}^{BAU}$). However, such country is not allowed to trade permits on the international market.

2.2 Market

A market clearing price for the set of periods $[1, ..., T]$ and the participation structure S is given by a vector of prices $p = [p_1, ..., p_T]$ with $p_t > 0$ $\forall t \in [1, ..., T]$ for which total excess supply equals zero, $\sum_{i \in S_t} XS_{it}^{\circ}(p,) = 0$, at each time t, i.e.

$$\sum_{i \in S_t} \left[AAU_{it} - E_{it}^{BAU} + C_{it}^{\prime -1}(p_t)\right] = \sum_{i \in S_{t+1}} CB_{it+1}^{\circ}(p, \cdot) - \sum_{i \in S_t} CB_{it}^{\circ}(p, \cdot) \;\; \forall t. \tag{17}$$

Market clearing conditions are nested when –and only when– banking takes place. For the sake of simplicity, we drop from now on the argument $(p,)$ of the countries' decisions variables.

Condition (15) shows that $p_t = \alpha p_{t+1}$ when banking takes place between periods t and $t+1$ ($CB_{it+1}^{\circ} > 0$ for at least one i). In that case, any country is indifferent between selling a permit at price p_t in period t and banking this permit in order to sell it at price p_{t+1} in period $t+1$. Banking a permit can be seen as a forward sale. As a result, an infinity of vectors $\left[CB_{1t}^{\circ}, ..., CB_{It}^{\circ}\right]$ and $\left[XS_{1t}^{\circ}, ..., XS_{It}^{\circ}\right]$ satisfy the market clearing condition in period t. Indeed, from equations (17), it is clear that the impact of banking on the permits price comes from the aggregate level of banking, no matter which countries do actually bank the permits.

In order to avoid this indeterminacy, we do not distinguish permits that are sold in a given period from permits that are banked in that given period and sold in a subsequent one. Accordingly, we define PS_{it}° as the 'present net supply' of permits of country i at time t, that is

$$PS_{it}^{\circ} \underset{def}{=} XS_{it}^{\circ} + \left[CB_{it+1}^{\circ} - CB_{it}^{\circ}\right]$$

which, by relation (13), also reads

$$PS_{it}^{\circ} = AAU_{it} - E_{it}^{BAU} + C_{it}^{\prime -1}(p_t).$$

If banking takes place, a 'present supply' permit sold by country i at period t ($PS_{it}^{\circ} > 0$) is purchased either at the same period t (by another country) or at a subsequent one (by country i or by another country). Similarly, a 'present supply' permit purchased by country i at period t ($PS_{it}^{\circ} < 0$) is a permit that is sold either at the same period t (by another country) or at a previous one (by country i or by another country).

Consequently, only the aggregate amount of permits banked is determined at each period. Because $\sum_{i \in S_t} XS_{it}^{\circ} = 0$ at the market clearing price, the total amount of permits banked in period t is given by

$$\sum_{i \in S_{t+1}} CB_{it+1}^{\circ} - \sum_{i \in S_t} CB_{it}^{\circ} = \sum_{i \in S_t} PS_{it}^{\circ}.$$

Finally, let us denote the total permits account by $CB_t^{\circ} = \sum_{i \in S_t} CB_{it}^{\circ}$. Therefore, the market clearing conditions (17) read

$$\sum_{i \in S_t} \left[AAU_{it} - E_{it}^{BAU} + C_{it}^{\prime -1}(p_t)\right] = CB_{t+1}^{\circ} - CB_t^{\circ} \ \forall t. \tag{18}$$

A permit market equilibrium is then defined as a $1 \times T$ vector of prices p^*, a $I \times T$ matrix of emission reductions R^* and a $I \times T$ matrix of present net supply PS^* which solve (18).

The computation of such an equilibrium is not straightforward since, as mentioned above, equations (18) are nested when banking takes place. As suggested by Ellerman

(2002), this problem is relatively close to the one of inventory models. These models which deal with uncertainty are usually solved by dynamic programming techniques. In our simpler framework, we develop a simple algorithm leading to unique market clearing prices. The algorithm is presented in appendix 1 [6].

3 Parameters of the model and characterization of the scenarios

The model is divided into 15 countries or regions (see the details in appendix 2). It runs over 5 periods of 5 years, the first one being 2008-2012 (2010 hereafter). Since the purpose of the analysis is to estimate the impact of flexible mechanisms, banking and future commitments on the short to medium run, we focus on the first three periods, that is up to 2022. Two other periods are introduced for two reasons. Firstly, we want to be able to model late commitment of USA and, more particularly, of non-Annex B countries. Secondly, the last two periods are also aimed at capturing a possible long term effect of banking and at avoiding as much as possible any border effect. In particular, limiting the model to only three periods implies that all banked permits, if any, will be used in the third period during which non-Annex B countries are likely to start committing to emissions reductions. This would certainly alter the analysis of the issue of their participation.

We now deal in turn with the main parameters of the model –on which sensitivity analyses will be performed– and with the main determinants of the scenarios, that is the choices of the participating countries, the global emissions reductions and the allocation of permits.

3.1 Parameters

The main parameters are related to (i) marginal abatement costs, (ii) reference emissions, population and GDP, (iii) the discount rate, (iv) the Clean Development Mech-

[6] The algorithm sequentially considers groups of periods. For each group of periods, prices are computed under the assumption that no banking takes place and this assumption is tested by checking relation (16). If the relation is not satisfied, banking necessarily takes place and new prices are computed for all periods under consideration.

anism and (v) the sinks.

Marginal abatement costs

As mentioned above, marginal abatement cost curves for fossil fuel CO_2 emissions have been computed for the first commitment period, 2008-2012, from the general equilibrium model GEM-E3-World. A description of these curves is provided in Eyckmans, Van Regemorter and van Steenberghe (2001).

A first important parameter is the rate of technological progress. The marginal abatement cost curves computed for 2008-2012 are extended to the subsequent periods by introducing for each country a degree of technological progress γ_i per period of 5 years. It directly bears on the marginal *absolute* abatement cost[7]: $C'_{i,t+1} = (1 - \gamma_i)C'_{i,t}$. As depicted in figure 1, this parameter modifies only the slope of the marginal abatement cost curve. The change in energy intensity over time is captured by the change in baseline emissions.

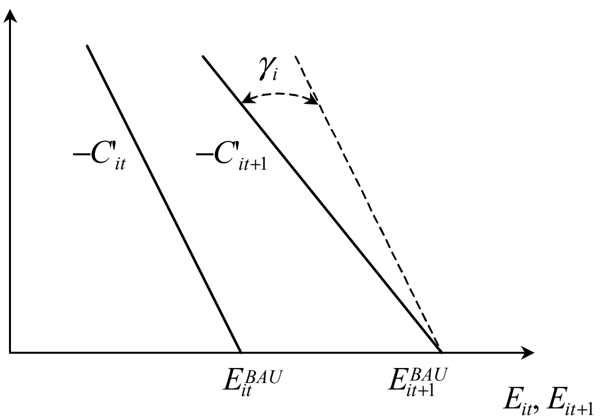

Fig. 1: Role of γ_i and baseline emissions on marginal abatement cost curves

The idea is to select higher rates of technological progress for countries characterized by higher emission growth rates. We use here a degree of technological progress of (i) 2% ($RTP_{\min}$) for the country whose reference emissions growth is the lowest between 2010 (2008-2012) and 2030 (2028-2032) and (ii) 35% ($RTP_{\max}$) for the country whose reference emissions growth is the largest over the same period. The rate assigned to the other countries then lies between these two values and depends on their

[7]As opposed to abatement relative to the baseline emissions.

reference emissions growth[8]. These values are such that marginal relative abatement costs slightly decrease in industrialized countries while slowly increasing in developing ones due to their much larger growth of reference emissions[9].

A second important parameter related to marginal abatement cost curves concerns the efficiency of domestic abatement policies. Two sets of curves have been computed from GEM-E3-World. A first set assumes that, *within each country*, the abatement effort is allocated among sectors in such a way that marginal abatement costs equalize between these sectors. This approach, which is followed by all the other models using marginal abatement cost curves, considers that domestic policies are fully efficient. A second set is based on the assumption of a uniform abatement effort (same percentage of abatement) for all sectors within a country. Needless to say, marginal abatement costs are higher in the second set than in the first one. In practice, countries are not likely to directly implement fully efficient domestic policies, like a tax or a domestic market for emission permits covering all sectors of the economy. Hence, a factor of domestic policies efficiency is introduced. For instance, a factor of 50% produces a marginal abatement cost curve which lies strictly between those computed under the extreme assumptions just explained above. In our base case, we use the same factor of efficiency for all countries[10] which ranges from 75% in 2010 to 95% in 2030. This captures an increasing ability to set up efficient domestic policies.

Discount rate

The level of the discount rate plays a key role on the results of such a medium run model. It impacts considerably on the level of future prices and therefore on the amount of banked permits in each period. A high discount rate decreases the discounted value

[8]The rate of technological progress attibuted to country i, RTP_i, is given by the following formula:

$$RTP_i = RTP_{\min} + \frac{RateBAU_i - RateBAU_{Min}}{RateBAU_{Max} - RateBAU_{Min}}(RTP_{\max} - RTP_{\min})$$

where $RateBAU_i$ is the reference (BAU) emissions growth rate of country i between 2010 and 2030, $RateBAU_{Min}$ is the lowest of these rates among all countries and $RateBAU_{Max}$ is the highest of them.

[9]The rates $RTP_{\min}$ and $RTP_{\max}$ have been calibrated on marginal abatement cost curves computed from the POLES model for 2010 and 2030 (see Blanchard, Criqui and Kitous (2002)).

[10]Note however that this factor is not applied to countries hosting CDM projects since they do not implement actual domestic policies and since the accessibility factor and transaction costs allready account for the inefficiency of the CDM.

of future permits which provides less incentives to abate more than required in the present in order to bank permits for the future.

What level of discount rate should then one choose ? We propose to get some insights from the US markets for SO_2 and NO_x emission permits. Ellerman (2002) states that, under the Acid Rain Program, firms have based their SO_2 permits banking behavior on an annual discount rate of 6% between 1995 and 2000. He then suggests that more recent rates should rather lie at around 4.5%. These rates might seem low relative to those usually employed for industrial projects for instance. However, we argue that the characteristics of emission permits make them rather close to financial assets (which can be traded on stock exchanges and on which derivatives can be developed) for which relatively low discount rates are used. It is already the case for SO_2 emissions permits and many recent initiatives[11] tend to indicate that CO_2 emission permits will follow the same route. Accordingly, we choose a discount rate of 5% for our base case.

Reference emissions, population and GDP

Reference emissions, population and GDP are based on the special report on emissions scenarios of the IPCC (2000). A short description of the main assumptions surrounding the six main IPCC scenarios is provided in appendix 3 [12]. Our base case reference emissions, population and GDP will use the A1 FI scenario. Since several authors like Ciorba et al. (2001), den Elzen and de Moor (2001a,b), Eyckmans and Cornilie (2000) and Eyckmans, Van Regemorter and van Steenberghe (2001) emphasize the crucial role of reference emissions on their results, a parameter for a change in reference emissions is introduced.

Clean Development Mechanism (CDM)

The CDM is used between non-Annex B countries and the other participating countries as long as the former ones do not commit to emission reductions. It is

[11] From US brokers like *Natsource* or *Cantor Fitzgerald*, from international stock exchanges like the *Sidney Futures and Options Exchange*, the *Chicago Board of Trades* or the *International Petroleum Exchange*, as well as consulting firms like *PriceWatherhouseCoopers*.

[12] Our reference emissions, population and GDP growth rates are borrowed from IMAGE2 (see e.g. den Elzen and de Moor (2001a,b)).

modelled by introducing an accessibility and a transaction costs factors in the present net supply of host countries in the following way:

$$PS_{it} = AAU_{it} - E_{it}^{BAU} + \phi_t C_{it}^{\prime -1}([1-\varphi_t]\, p_t)$$

where ϕ_t ($0 \leq \phi_t \leq 1$) is the accessibility factor and φ_t ($0 \leq \varphi_t \leq 1$) is the transaction cost factor. This approach is now rather standard in the literature[13]. The limited accessibility of CDM means that only a fraction of all the projects eligible for CDM and which would have been realised given the international permit/credit price, are actually carried out because of practical, legal and administrative reasons. The transaction costs, which complement this limited accessibility, are a cost for the host countries. We choose an accessibility factor which increases progressively from 30% (in 2010) to 50% (from 2020 onwards) and a transaction costs factor decreasing from 20% (in 2010) to 10% (from 2020 onwards), reflecting the growing efficiency of the CDM.

Carbon sinks

For the first commitment period, we follow the same approach as Eyckmans, Van Regemorter and van Steenberghe (2001). It is assumed that sinks enhancement activities are free and limited by the amounts specified by the Bonn and Marrakesh agreements. The model also allows for the introduction of sinks in the subsequent periods. However, due to the huge uncertainties surrounding this issue, no sinks are taken into account in our base case after 2012.

Summary

Table 1 gathers all the main parameters described above. A sensitivity analysis on each of them except the sinks will be performed in appendix 3.

Parameter values

1	*Technological progress*	From 2% to 35% (same each period)
2	*Efficiency of domestic policies*	From 75% (2010) to 95% (2030)
3	*Discount rate*	5% per year
4	*Baselines*	SRES A1FI
5	*CDM access*	30% (2010), 40% (2015), 50% (2020-2030)
	CDM transaction costs	20% (2010), 15% (2015), 10% (2020-2030)
6	*Sinks*	No sinks after 2012

Table 1

[13] See mainly Blanchard, Criqui and Kitous (2002) for more details on this issue.

3.2 Scenarios

A scenario consists of the specification of (i) the countries taking part in the emissions reductions, (ii) the world emissions reductions objective and (iii) the allocation of this objective among countries. Let's specify these elements.

Participation structure

A key characteristic of our model is the complete flexibility in the choice of the countries taking part in emission reduction policies. Practically, one can consider the participation of non-Annex B countries (*choice 1.a*) at any period. When one of them does so, it receives a certain amount of emission permits AAU_{it} that can be traded. CDM projects can then not be hosted anymore by this country.

Another choice to be made concerns the participation of Annex B countries (*choice 1.b*) and the level of a possible autarkic reduction policy (*choice 1.c*) in case of non-participation. We have in mind the position of the USA whose president announced his intention not to ratify the Kyoto Protocol and to set up a domestic policy. In our model, such an autarkic policy is formulated in terms of a level of abatement with respect to reference emissions. The reductions are assumed to be made domestically and cannot give rise to international emission permits.

World emissions (reductions) objectives

The world emissions objective for the first commitment period (2008-2012) is implicitly determined by the Kyoto Protocol. World emissions will –in case of compliance– correspond to the amount of permits allocated to participating Annex B countries plus reference emissions of non-Annex B countries and of non-participating Annex B countries (USA) less the emissions reduced via autarkic policies.

World emissions objectives (*choice 2*) must then be introduced for the last two periods (2025 and 2030). World objectives in periods 2 (2015) and 3 (2020) are then determined in such a way that they stand on a linear trajectory of world emissions objectives between the first (Kyoto) and the fourth (2025) periods.

Allocation of permits

How are these emissions objectives allocated in periods 2 to 5 and how do they relate to the allocation of permits ? We assume that, in each period, the world emissions objective is defined in terms of an amount of permits. These permits are allocated to all countries according to a certain allocation rule (see below), whatever the participation structure. Then, the countries not taking part to the world emissions reductions policy simply ignore the permits that they have received. This way of proceeding ensures that participating countries receive a certain amount of permits independently of the participation structure. However, this implies that actual world emissions will not necessarily correspond to world emissions objective and will vary slightly according to the allocation rule.

Any possible allocation rule (*choice 3*) may be used for the allocation of the permits. Several authors have analyzed various proposals corresponding to a certain perception of equity. Following Rose (1992), Edmonds, Wise and Barns (1995), Kverndokk (1995), IPCC (1996), Rose and Knverndokk (1998), Rose, Stevens, Edmonds and Wise (1998), Torvanger and Godal (1999), Blanchard, Criqui, Trommetter and Viguier (2000) and Cazorla and Toman (2000), we detail the main allocation rules in Table 2. The name of each allocation rule, its definition, the criterion on which it is based and the corresponding conception of equity are presented[14] [15].

Allocation rules	*Definition: permits allocated in proportion of*	*Criteria*	*Equity principle*
Kyoto	emissions objectives negotiatied in Kyoto (2010 reference emissions for non-Annex B countries)	-	Negotiation / Consensus
Egalitarian	inhabitants	Population	Egalitarianism
Grandfathering 1990	1990 emissions	Historical emissions (1990)	Sovereignty
Responsibility	cumulative emissions or responsibility in global warming	Cumulative emissions or responsibility in global warming	Polluters pay
Ability to pay	the inverse of the GDP per capita	GDP per capita	Ability to pay
Energy intensity	energy intensity	Emissions per unit of GDP	Merit

Table 2

The Kyoto rule deserves an explanation. Under this rule, a country receives a share of the world emissions objective (total amount of permits). For a Annex B country, this share is the amount of permits received in the Kyoto period divided by the world emissions objective of the Kyoto period (see above) while for a non-Annex B country,

[14]Note that according to Rose, Stevens, Edmonds and Wise (1998) terminology, we consider here allocation-based rules, but not outcome-based ones.

[15]The Kyoto rule is derived from the Kyoto negotiations.

it is the amount of its reference emissions during the Kyoto period divided by the world emissions objective of the Kyoto period. These shares are the following ones :

An.-B		**non An.-B**	
USA	18.3%	MED	2.0%
CAN	1.6%	MEA	4.5%
EU15	11.9%	AFR	2.6%
OEU	0.3%	CHI	15.7%
CEU	17.9%	IND	4.1%
AUZ	1.1%	ASI	6.6%
JPN	4.0%	SAM	6.1%
		ROW	3.3%
		TOTAL	**100%**

Many Parties to the Framework Convention on Climate Change have also proposed rules mixing those presented in Table 2. We will devote some attention to some of them.

4 Base case scenarios

4.1 Description

Our base case scenarios assume the following participation structure. USA do not participate to the first commitment period (2010) but implement an almost insignificant autarkic emissions reductions policy corresponding to a 2% reduction with respect to their reference emissions. Indeed, the recently released climate change policy of the Bush administration should still lead to a large increase in absolute emissions, that is to a very low reduction relative to the reference emissions given the predicted GDP and reference emissions growth rates[16]. Then, USA join the other Annex B countries in the second commitment period (2015). As far as non-Annex B countries are concerned, they have shown a strong cohesion within the G77 during all Conferences Of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). Accordingly, they are likely to start committing to emission reductions at the same time, although their level of commitment might be very different. Base case

[16]The policy mainly aims at reducing GHG intensity by 18% over the next 10 years. For an evalution of the US climate change policy, see Viguier (2002).

scenarios therefore assume that all non-Annex B countries join the Annex B ones at the same time, in the third commitment period (2020).

Two world emissions objectives are considered. The *weak objective* roughly puts the world on a trajectory of CO_2 emissions leading to a stabilization of their concentration at around 550 ppmv [17] in 2100. It sets world annual emissions at the level of 34.0 $GtCO_2$ in the fourth commitment period (2025) and 35.0 $GtCO_2$ in the fifth one (2030). The *strong objective* should rather lead to a stabilization of the concentration at around 450 ppmv by setting world emissions objectives of 25.5 and 24.5 $GtCO_2$ in, respectively, the fourth and the fifth commitment periods. Needless to say that these numbers do not necessarily lead to the suggested concentration target since (i) world emissions slightly change according to the participation structure and (ii) other trajectories, leading to e.g. more emissions during the first five commitment periods but fewer than assumed during the following ones, could be considered. They should only be seen as indicative numbers.

The distribution of the world emissions objectives follows a "Kyoto towards Egalitarian" rule. The allocation rule is assumed to progressively move from the Kyoto rule to the Egalitarian one. The convergence to the latter is linear and takes place in 2080 [18].

The base case scenarios can thus be summarized as follows (see Table 3):

Base case scenarios

1 Participation	*a*	*non-Annex B commitment*	All non-Annex B countries in period 3 (2020)
	b	*Annex B participation*	USA in period 2 (2015)
	c	*Autarkic policy*	USA: -2% in period 1 (2010)
2 Objectives		*World emissions: WEAK*	34,0 GtCO2 in 2025 - 35,0 GtCO2 in 2030
		World emissions: STRONG	25,5 GtCO2 in 2025 - 24,5 GtCO2 in 2030
3 Allocation		*Allocation rule*	Kyoto with convergence in 2080

Table 3

[17] Parts per million volume.

[18] In order to guarantee that, as it is likely to be the case, Countries of Eastern Europe (CEU, i.e. mainly Russia and Ukraine) do not receive any hot air from the second commitment period onwards, the Kyoto rule is adapted. It is built as explained above (section 3.2.3) but reference emissions in 2008-2012 –rather than assigned amount units negotiated in Kyoto– are used for CEU.

4.2 Results: weak objective

The allocation of the weak world emissions objectives under the "Kyoto towards Egalitarian" rule is such that the amount of permits allocated per head are still very unequal in the last period under consideration (2030): The USA receive 19 permits per head while India only gets 2. The amount of hot air received by CEU in the first period amounts to about 0.540 $GtCO_2$. It is however not the only region to benefit from an allocation of permits which is greater than its reference emissions: AFR also receives some hot air which ranges from 0.247 $GtCO_2$ in 2020 to 0.403 $GtCO_2$ in 2030.

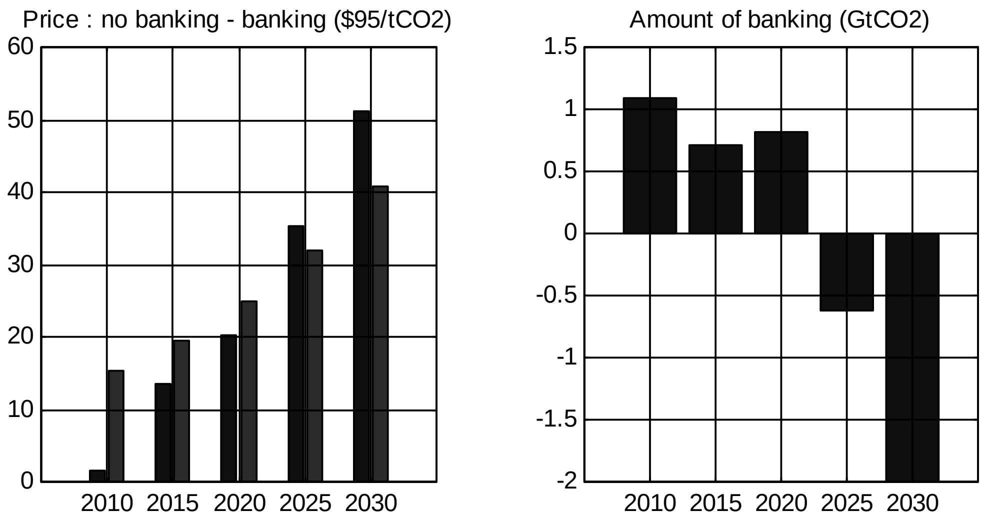

Fig. 2.a and 2.b

What is the impact of such an allocation rule and participation structure on the market for permits ? Fig. 2.a shows that under no banking, the permits price is much lower in the first period (1.7 $\$_{95}$ in 2010) than in the second one (13.4 $\$_{95}$ in 2015). The discounted prices (not shown in Fig. 2) are even strictly increasing over the five periods under consideration. Banking therefore takes place and discounted prices equalize. A **first important result** of this scenario is the significant impact of banking on the permits price which rises from 1.7 to 15.4 $\$_{95}$ in the Kyoto (first) commitment period.

The high level of banking in the first three periods and the non linear evolution of the permits account constitute a **second main result** of the analysis. Fig. 2.b shows the change in the permits account in each period : $CB_t - CB_{t-1}$ $\forall t$ [19]. In the first period, the amount of banking reaches 1.094 $GtCO_2$ and largely exceeds CEUs' hot

[19] All bars in Fig. 2.b sum up to 0.

air (0.540 Gt) although only a relatively weak emissions objective is considered here. This result suggests that, by ignoring the mechanism of banking or by limiting it to the amount of hot air, most recent studies underestimate the permits price and the abatement costs in the Kyoto commitment period.

The evolution of the banking behavior, as shown in Fig. 2.b, also gives interesting insights. Rather than regularly decreasing, the amount of banking increases from the second to the third period. This is clearly due to the participation structure. In the second period, the participation of the USA makes the emissions reductions objective relatively costly. In the third period, two effects play in opposite directions. On the one hand, the world emissions reductions target is tighter, partly due to the commitment of the non-Annex countries; this tends to increase total and marginal abatement costs. On the other hand, since non-Annex B countries start committing, trade of permits between them and the Annex-B countries takes place via Emissions Trading rather than via CDM; since the former is much more efficient than the latter, costs tend to decline. When costs are discounted, the second effect dominates the first one. It is therefore profitable to abate relatively more in the third period than in the second one in order to bank permits[20].

As far as trades are concerned, we cannot distinguish between sold and banked permits (see section 2.2). Fig. 3 shows that most present sales (75%) come from CEU in the first period while the rest of the permits comes from the CDM. In the second period, CEUs' share of sales drops to 35% as a result of two effects. First, they do not receive hot air in that period. Second, sales via the CDM expand since its efficiency increases with the higher accessibility and lower transaction costs. As non-Annex B countries commit to emissions reductions in the third period, they now make use of Emissions Trading. This leads AFR, CHI and IND to be the main sellers. While several non-Annex B countries must import permits, they together export 7% of their Assigned Amount Units.

[20]These effects might be such that the amount of banked permits is negative in the second period. Part of the –or even all– permits which are banked in the first period are then used in the second one. This is for instance the case if the allocation rule converges to the Egalitarian one in 2030 rather than in 2080 under the weak objective.

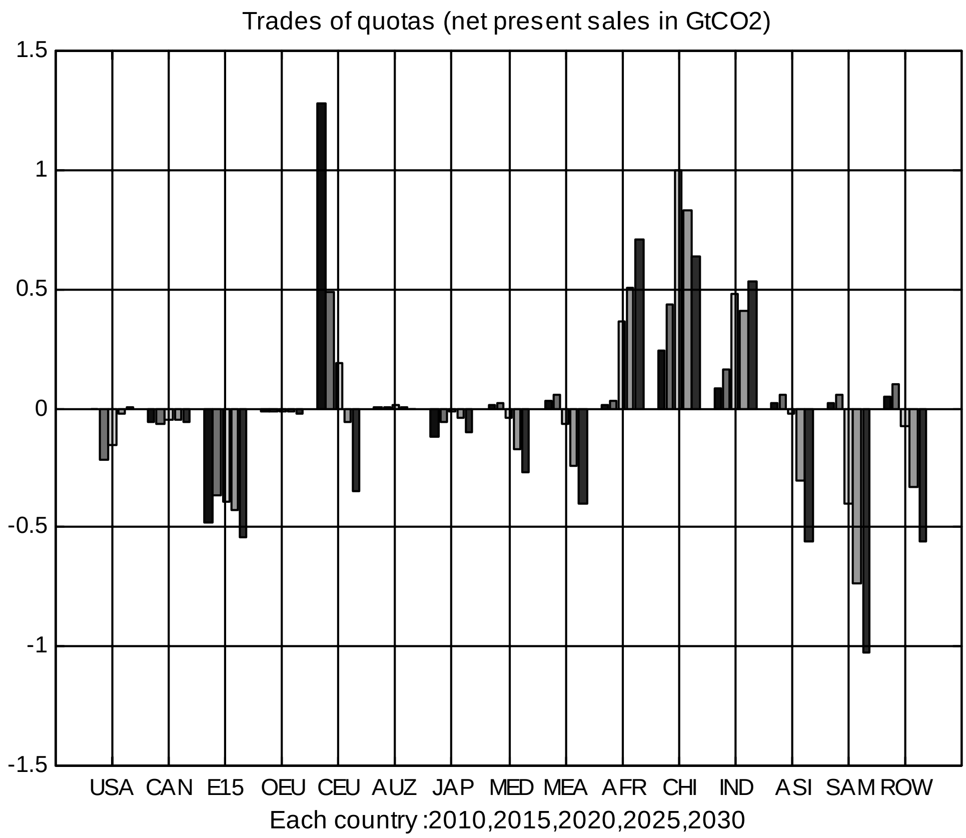

Fig. 3

Total costs, including both abatement costs and costs of net purchase of permits, are fairly low in all regions. In the first period, the autarkic policy of the USA generates costs of less than 0.001% of their GDP in the same period. Their participation from the second period onwards makes them bear costs of 0.089% and 0.107% of their current GDP in the second and third periods respectively (see Fig. 4 below). The large sales of CEU in 2010 allow them to gain 1.006% of their GDP during that period. However, this gain declines considerably in the second period and becomes a net cost of 0.174% GDP in the third one. The other Annex B countries bear costs ranging from 0.015% of GDP for JPN in the third period to 0.210% for CAN in the same period. As regards to non-Annex B countries, they all enjoy some limited gains during the first two commitment periods since they do not commit to emission reductions and sell permits via the CDM in those periods. In the third period, the gains of AFR, CHI and IND are relatively large, reaching respectively 0.572%, 0.250% and 0.339% of their GDP, while the other regions bear significant costs. As a whole, the costs of non-Annex B countries do not exceed 0.010% of their GDP.

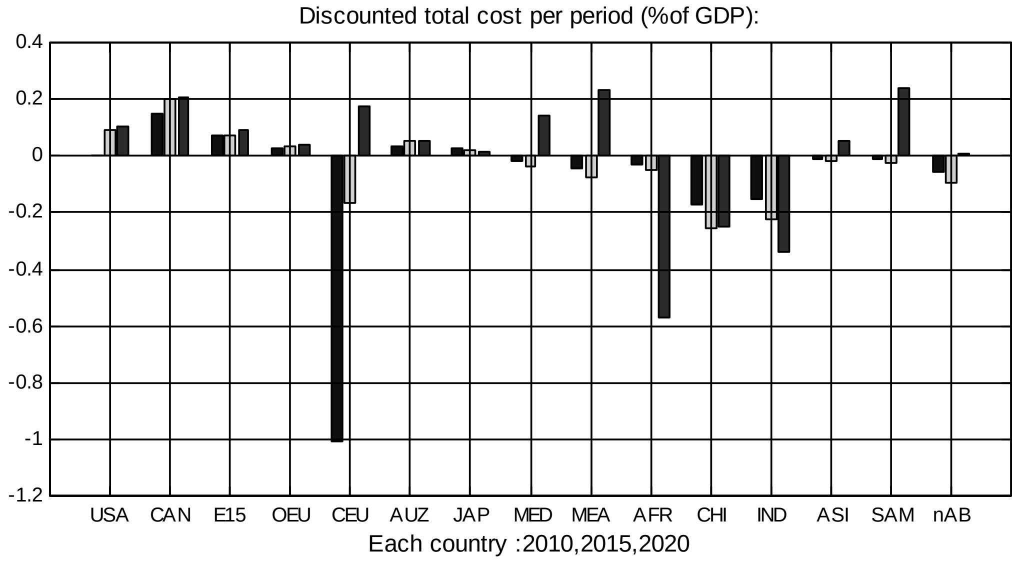

Fig. 4

The weakness of the emissions reductions objective is the main cause of the low level of total costs. Nevertheless, the banking mechanism is also partly responsible for this observation. It allows to decrease total discounted costs of all regions by 10.5% between 2008 and 2032. Hence, as a **third important result**, we observe that the mechanism of banking significantly decreases total discounted costs.

The analysis of the impact of banking by region leads to a **fourth and more surprising result**: All Annex B countries except CEU bear larger total discounted costs when the banking mechanism operates. The increase in total discounted costs goes from 8% for USA to 30% for JPN (21% for EU15). The main beneficiary of the banking mechanism is CEU whose total costs decrease by 65%. Indeed, the banking provision avoids them to sacrifice their generous 2008-2012 allocation of permits – including hot air– at a very low price (1.7 $\$_{95}$, see above) and allows to increase the permits price up to 15.4 $\$_{95}$ in the first period, during which they are the main sellers. Although they do not benefit from hot air in the second period, the same argument holds for the second period, CEU still being important sellers. Furthermore, the banking provision induces the permits price to decrease in the fourth and fifth periods, during which CEU are importers of permits. While all these elements benefit CEU, they play opposingly for the other Annex B countries by increasing the permits price when they are large importers (first two periods) and decreasing it when they import fewer of them or even export them (fourth and fifth periods). For non-Annex B countries as a whole, banking decreases their total discounted costs by 20%. All of them benefit from the price increase in the first two periods since they all then sell permits via the CDM. Those who purchase permits in the fourth and fifth periods also enjoy the price cut in those periods.

Let's now check if those results still hold under a strong world emissions reductions objective.

4.3 Results: strong objective

Under the strong objective, world emissions over the five commitment periods amount to 672.383 $GtCO_2$, to be compared with the 802.480 $GtCO_2$ under the weak objective. Permits prices also equalize over the five periods and reach 37.3 $\$_{95}$ instead of 15.4 $\$_{95}$ due to the much more ambitious objective. The amount of banked permits in the first two periods becomes very large: 2.282 $GtCO_2$ and 1.944 $GtCO_2$ respectively, that is 8.6% and 7% of the world emissions in those periods.

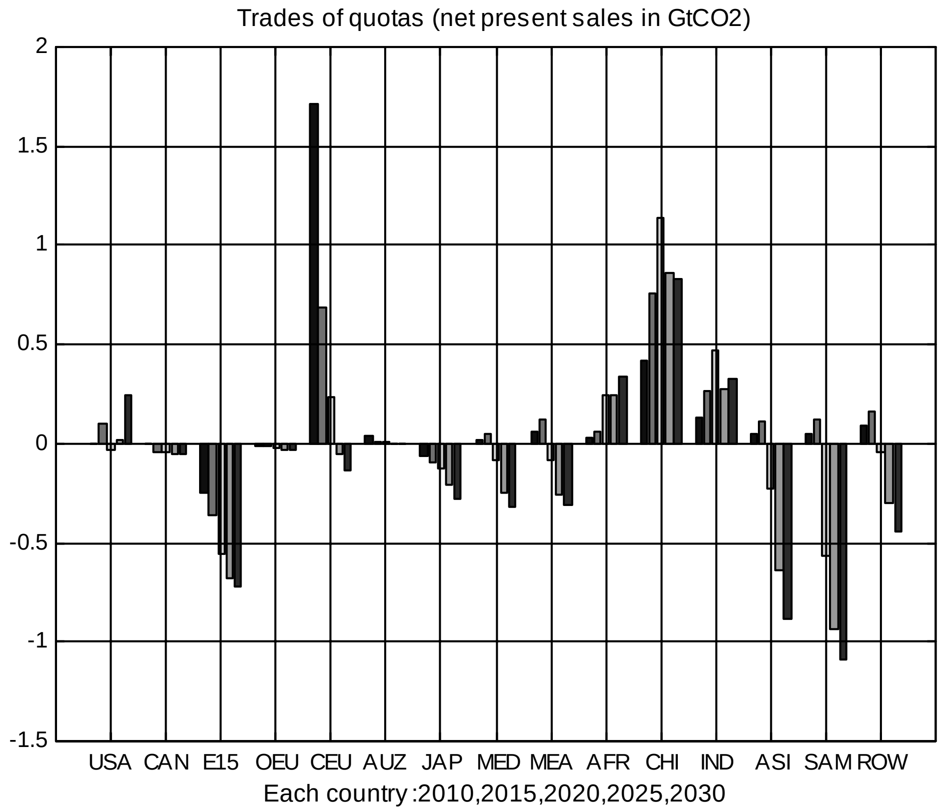

Fig. 5

Regarding trades, we observe (see Fig. 5) that USA sell (and/or bank) permits when they start participating to the global policy in the second period, as well as during the fourth and the fifth periods. These sales amount to 2.2% of their assigned amount units in 2015. Indeed, marginal abatement costs are lower in the USA than in any other Annex B region but CEU. Nevertheless, other Annex B countries (except CEU) purchase much fewer permits than under the weak objective.

Compared to the weak scenario, total costs over the five periods are multiplied by a factor of 2 to 3 for Annex B regions. Non-Annex B regions' total costs become now significant, reaching 0.540% of their GDP over the five periods. Again, banking decreases world total costs by an important amount (11.9%) and do not benefit Annex B regions except CEU.

Hence, all results obtained under the weak objective still hold and are even reinforced under the strong objective.

5 The role of the participation structure and the allocation rule

5.1 Earlier participation of non-Annex B countries and later participation of USA

This section analyses the impact of earlier commitments for non-Annex B countries and/or a later participation of the USA. As mentioned above (see section 3.2), participating countries receive the same amount of permits whatever the participation structure. As a consequence, world emissions may vary with the participation structure since the emissions of non participating countries are not compensated by participating ones. Three participation structures are considered for both the weak and the strong emissions objectives : (1) participation of USA and non-Annex B countries from the second commitment period (2015) onwards, (2) participation of USA in the second period (2015) and of non-Annex B in the third period (2020) (base case scenario) and (3) participation of USA and non-Annex B countries from the third period (2020) onwards.

Scenario:	**1**	*2015 or 2020 (all): see below*
		USA in 2015 or 2020 : see below
		USA: -2% when no participation
	2	*Weak and Strong (No)*
	3	*Kyoto towards Egal (2080)*

Participation structure		USA: 2015 ; nAB: 2015	*% var <---*	USA: 2015 ; nAB: 2020	*% var --->*	USA: 2020 ; nAB: 2020
Weak	*Price bank, (disc) ($95/tCO2)*	14.8	*-3.9*	15.4	*-1.3*	15.2
	World emissions (GtCO2)	799.055	*-0.4*	802.48	*0.6*	807.455
	Banking in 2010 (GtCO2)	1.06	*-3.1*	1.094	*-0.9*	1.084
	in 2015 (GtCO2)	1.369	*95.6*	0.7	*29.6*	0.907
	in 2020 (GtCO2)	0.675	*-17.8*	0.821	*-5.4*	0.777
	Total costs USA (% GDP)	0.089	*0.0*	0.089	*-22.5*	0.069
	Total costs EU15 (% GDP)	0.098	*-2.0*	0.1	*0.0*	0.1
	Total costs n-A B (% GDP)	0.099	*4.2*	0.095	*1.1*	0.096
Strong	*Price bank, (disc) ($95/tCO2)*	36.9	*-1.1*	37.3	*0.3*	37.4
	World emissions (GtCO2)	661.556	*-1.6*	672.383	*1.1*	679.672
	Banking in 2010 (GtCO2)	2.263	*-0.8*	2.282	*0.2*	2.286
	in 2015 (GtCO2)	2.312	*18.9*	1.944	*-4.6*	1.855
	in 2020 (GtCO2)	0.213	*-27.8*	0.295	*6.4*	0.314
	Total costs USA (% GDP)	0.317	*0.0*	0.317	*-15.8*	0.267
	Total costs EU15 (% GDP)	0.349	*-0.6*	0.351	*0.0*	0.351
	Total costs n-A B (% GDP)	0.599	*10.9*	0.54	*0.0*	0.54

Table 4

Table 4 presents the main results. Given the allocation rule, participation of non-Annex B countries in the second commitment period would only slightly reduce world emissions over the five periods. We then observe that, although emissions decrease, permits prices are also driven down, by 3.9% under the weak objective and by 1.1% under the strong one. Indeed, the CDM is left aside and permits' trades between Annex B and non-Annex B countries take place via ET as early as 2013, which tends to compress total abatement costs. This effect dominates the stronger constraint on emissions in the second period. However, non-Annex B countries as a whole do not benefit from this earlier participation: Their total discounted costs over the five periods increase by 4% to 11% depending on the world emissions objective. On the contrary, the slight decline of the permits price benefits all Annex B countries, except the USA whose total costs are stable. Finally, early commitments for non-Annex B countries cause the amount of banked permits to increase a lot in the second period and to decrease in the following periods.

On the contrary, a later participation of the USA is responsible for a rise in the world emissions. Under both emissions objectives, this induces (i) an increase of the amount of banking in the second period since the demand for permits is lower and

(ii) a slight decrease of Annex B total costs due to the lower permits price. Being free of commitments in the second period, the USA now bear much lower total costs (-23% under the the weak objective and -16% under the strong one) while non-Annex B countries are not significantly affected.

5.2 Other allocation rules

Let's now analyze the impact of other allocation rules on the results while assuming a strong emissions reductions objective. Several rules are considered in turn: (i) the main rules presented in section 3.2, (ii) a rule aimed at favouring non-Annex B countries in their first period of commitment ('soft entry' rule), (iii) the base case rule with changes in the year of convergence. Note that actual world emissions will vary slightly according to the allocation rule as explained in section 3.2.

Simulations with the main allocation rules[21] (see Table 2, section 3.2) confirm the results of the literature on this issue (see for instance Rose, Stevens, Edmonds and Wise (1998)). Compared to the base case "Kyoto towards Egalitarian" rule, the three pure rules, namely Kyoto, Grandfathering and Energy Intensity, favour Annex B countries. The Grandfathering rule even leads to gains for all Annex B countries except OEU over the five periods but causes non-Annex B countries' total costs to increase by more than 150% as a whole compared to the base case rule. On the contrary, the Egalitarian rule provides large gains for all non-Annex B regions, reaching almost 7% of GDP for AFR, while Annex B countries' total costs rise significantly. The Ability to Pay rule leads to similar effects as far as the Annex B and non-Annex B groups are concerned, but differences appear within each of these groups. For instance, within Annex B countries total costs rise sharply for USA and CAN while OEU and JPN enjoy gains over the five periods.

We also model a rule which we call 'soft entry' for non-Annex B countries. The idea is to give these countries incentives to commit to emissions reductions –or limitations– by distributing them, in their first commitment period (2020), an amount of permits corresponding to their reference emissions in that period. The base case rule (Kyoto towards Egalitarian) is then applied from the next commitment period (2025) onwards.

[21] The allocation rule 'Responsibility' as not been modeled since it requires a more sophisticated model including a climatic component. For an analysis of this rule, see den Elzen et al. (1999).

It is also used for all Annex B countries. Two results emerge from the soft entry rule. Firstly, since more permits are allocated to non-Annex B countries than under the base case rule, the amount of permits banked in the third period explodes and reaches 4.518 $GtCO_2$ (instead of 0.295 $GtCO_2$) (see Fig. 6.b). Secondly, banking decreases world total costs by 22.5% over the five periods (instead of 11.9%). Indeed, the mechanism of banking is crucial here in order to take advantage of the very weak constraint on world emissions in the third period, as suggested by the low price under no banking reported in Fig. 6.a.

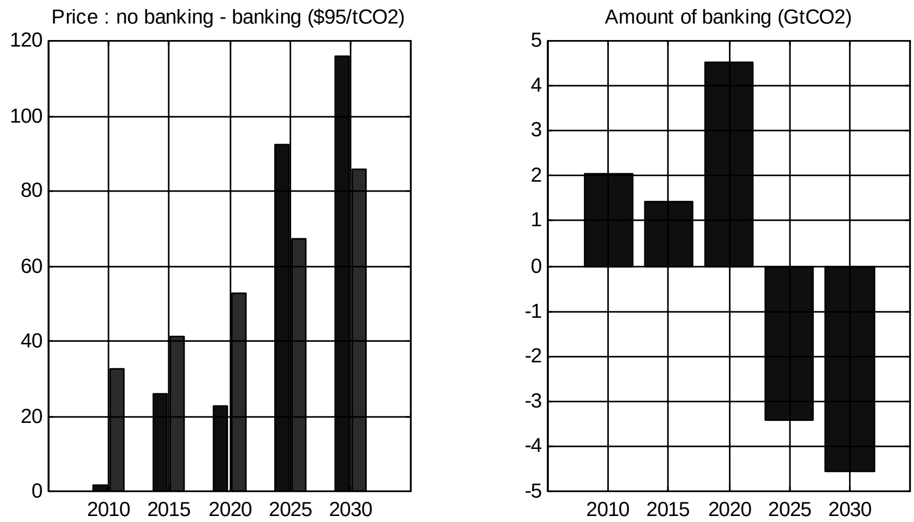

Fig. 6.a and 6.b

Using a closer convergence year than under the base case rule implies a transfer of costs from the non-Annex B countries to the Annex B ones and mainly to CEU. For instance, if the convergence takes place in 2030 rather than in 2080, CEUs' total costs over the five periods are multiplied by 4, reaching 2.437% of their GDP, while non-Annex B countries start enjoying substantial gains.

6 The issue of market power on hot air

The issue of hot air has received much attention in the recent studies evaluating the costs of the Kyoto commitments. Indeed, the generous allocation of CEU in 2008-2012 makes them the dominant seller on the market for permits in that period as long as they can coordinate in order to form a cartel. All studies mentioned above (see section

1) conclude that, in these circumstances, CEU would increase their gains –or decrease their costs– by restricting their supply of permits to at least part of the hot air and banking them for use in subsequent periods.

Although our model does not explicitly address strategic behavior, we argue that the issue of market power *on hot air* is not likely to be a relevant one. Firstly, the present analysis shows that, when the banking provision is properly modelled, the total amount of banked permits in the first period is much larger than the amount of hot air. This holds for all scenarios described above. Therefore, restriction and banking of hot air are not the outcomes of a strategic behavior of a cartel but simply result from a competitive behavior.

Secondly, one may object that CEU could act strategically by choosing a particular period to sell the banked hot air. This issue cannot be explicitly analyzed with the present model. However, this strategy means that CEU governments should be able to commit in advance not to make use of such a valuable amount of permits before a certain date, which, we believe, is not likely to occur. Furthermore, in all scenarios considered up to now, the total amount of banked permits is strictly positive and greater than the amount of hot air in each period –but the last one. Hence, such a strategy will be completely crowded out by the banking behavior of the other countries[22].

Thirdly, another strategic behavior could consist in withdrawing and deleting (rather than banking) a certain amount of hot air in order to increase further the permits price. Such a potential behavior is realistic since, given the current state of the negotiations, a refusal to use (part of) the hot air would be very welcome by the other Parties. However, Fig. 7 shows that this does not benefit CEU when the banking provision is taken into account. If banking is not modelled, total costs over the five periods are minimized for CEU when they restrict 75% to 100% of their hot air. However, when the banking provision is introduced, total costs always increase for such a restriction. Indeed, the banking provision extends the market by making it intertemporal. On such a large market, CEU are not likely to be able to exert market power anymore.

[22]This argument does nevertheless not hold if the total amount of banked permits is lower than the amount of hot air in some periods but the last one, which could in principle occur for some other scenarios and parameter values than those analysed up to now.

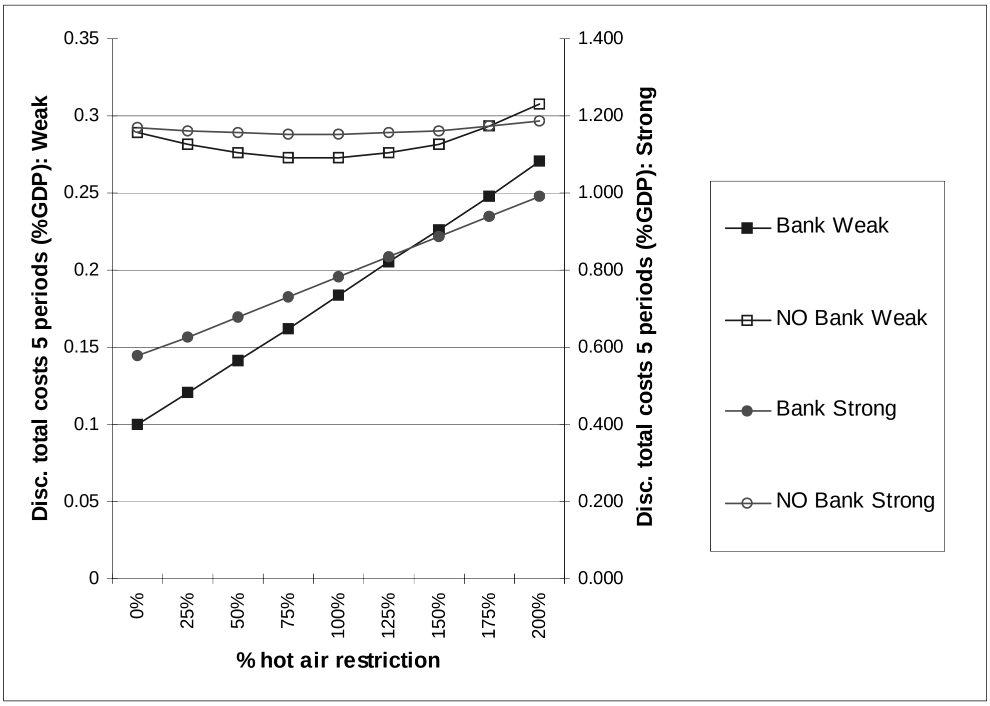

Fig. 7

7 Conclusion

Most recent studies on the costs of the Kyoto emissions reductions policy ignore or do not explicitly take into account the possibility to bank emission permits from one commitment period to the other. This important limitation must be addressed in conjunction with the issues of future commitments and participation of USA and non-Annex B countries. The present analysis aims at exploring these questions by setting up a simple dynamic partial equilibrium model based on a set of marginal abatement cost curves for CO_2 fossil fuel energy. The simplicity of the model is motivated by the requirement of flexible participation structures and by the willingness to model all the main characteristics of the permits market like, for instance, the use the Clean Development Mechanism, possible restrictions on permits' trades and inclusion of carbon sinks. The robustness of our results is tested by sensitivity analyses.

Six important results emerge.

1) In 2008-2012, permits prices are likely to be much higher than predicted by most recent studies and the amount of banked permits might largely exceed the amount of hot air.

2) The banking provision significantly reduces world total costs but increases total costs of all Annex B countries except countries of eastern Europe, via a rise in the permits price in the first two periods.

3) The issue of market power on hot air is not a relevant one, at least according to our base case scenarios. The reason is that the banking provision enlarges the market by making it intertemporal and therefore prevents countries of eastern Europe to act as dominant players.

4) Total costs are not huge and the permits allocation rule strongly influences the distribution of the costs among countries and may lead some of them to enjoy considerable net gains.

5) The participation structure affects the evolution of banking. The amount of banked permits tends to decrease in the period during which the USA start participating, but tends to increase in the period during which non-Annex B countries start committing since more efficient trading –than via the CDM– can then take place

6) Most parameters, especially reference emissions, have a crucial impact on the level of the permits price and the abatement costs.

From these findings, we derive three recommendations. Firstly, the banking provision, future commitments and alternative participation structures should together be taken into account when evaluating the costs of GHG emissions abatement policies. The transposition of our approach to more sophisticated models including endogenous investment would bring more accuracy in the predicted prices and abatement costs. However, this might require rather complex dynamic programming techniques. Furthermore, models should anyway be cautious in providing precise numbers since all variables are very sensitive to most parameters, especially to reference emissions.

Secondly, countries should right now prepare to engage, during the first commitment period (2008-2012), in much more emissions abatements than what have suggested static models with no banking. The indicative prices driving decisions on domestic and international abatement projects and policies might indeed be higher than those that have been circulated.

Thirdly, a crucial issue is the uncertainty on the level, and even on the existence, of future commitments. If this uncertainty persists, opportunities to significantly reduce world abatement costs via the mechanism of banking will be missed. Even if Annex B countries –except countries of eastern Europe– bear higher total costs when banking takes place, we believe that the world economic surplus created by this mechanism could somehow be redistributed to all countries via, for instance, a slight change in the allocation rule. Hence, discussions on future commitments should start as early as possible in order to provide clear signals to the concerned economic agents.

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9 Appendix

9.1 Appendix 1: Algorithm

Algorithm 1:

Step 1: Compute the price of the permits in each period by assuming that no banking takes place and call this price p_t^{NB} in period t. This amounts to solving equations (18) $\forall t$ assuming that $CB_t = 0\ \forall t$, that is

$$\sum_{i \in S_t} \left[AAU_{it} - E_{it}^{BAU} + C_{it}^{\prime -1}(p_t) \right] = 0\ \forall t. \tag{19}$$

Step 2: Set $p_t = p_t^{NB}\ \forall t$.

While $p_t < \alpha p_{t+1}$ for at least one t, **do**

- select all adjacent periods with increasing discounted price;

- **For** each group of adjacent periods with increasing discounted price $[\theta, ..., \theta + N]$, **do**

solve equations (18) by setting $p_\theta = \alpha p_{\theta+1} = ... = \alpha^N p_{\theta+N}$ (equalization of discounted prices) and $CB_{\theta-1} = 0 = CB_{\theta+N}$ (the total permits accounts are empty before the first period under consideration and at the end of the last period under consideration), that is

$$\sum_{i \in S_\theta} \left[AAU_{i\theta} - E_{i\theta}^{BAU} + C_{i\theta}^{\prime -1}(p_\theta) \right] + ... + \sum_{i \in S_{\theta+N}} \left[AAU_{i,\theta+N} - E_{i,\theta+N}^{BAU} + C_{i,\theta+N}^{\prime -1}\left(\frac{p_\theta}{\alpha^N}\right) \right] = 0. \tag{20}$$

■

Proposition 1 *Under assumption (1), i.e.* $\sum_{i \in S_t} AAU_{it} < \sum_{i \in S_t} E_{it}^{BAU}\ \forall t$, *algorithm 1 leads to strictly positive market clearing prices which are unique*[23].

[23]The proof is available from the author upon request.

9.2 Appendix 2: Details of the regions

label	name	Composition
EU15	European Union	
OEU	other Europe	Iceland, Norway, Switzerland
CEU	Eastern Europe and former Soviet Union	Bulgaria, Czech-Rep, Hungary, Poland, Romania, Slovak-Rep, Slovenia, former Soviet Union
AUZ	Australazia	Australia, New Zealand
JAP	Japan	
CAN	Canada	
USA	USA	
MED	Mediterranian	Turkey, Morocco, Algeria, Egypt, Libya, Tunisia
MEA	Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen
AFR	Africa	Angola, Benin, Botswana, Burkina-Fasso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Republic of Congo, Djibouti, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Ivory Coast, Kenya, Leshoto, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Seychelles, Sierra-Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
CHI	China	China, Hong Kong
IND	India	
ASIA	Asia	South Korea, Indonesia, Malaysia, Philippine, Singapore, Thailand, Vietnam, Taiwan, Sri-Lanka, Bangladesh, Nepal, Pakistan
SAM	South America	Costa-Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Antilles, Nicaragua, Panama, Trinidad-Tobago, Venezuela, Colombia, Bolivia, Ecuador, Peru, Argentina, Brazil, Chile, Uruguay, Paraguay
ROW	rest of world	

9.3 Appendix 3: Data

	Emissions		AAU	Sinks	Reference Emissions (EBAU) (A1 FI)					MAC coef.	
	1990	2000	2010	2010	2010	2015	2020	2025	2030	a	b
USA	4.908	5.5582	5.730	0	5.847	6.045	6.242	6.364	6.487	373.61	1.22
CAN	0.431	0.5006	0.405	44	0.574	0.582	0.590	0.611	0.632	251.33	1.538
EU15	3.218	3.3714	2.961	29.23	3.730	3.926	4.122	4.290	4.458	241.28	1.426
OEU	0.078	0.0846	0.075	3.45	0.094	0.099	0.104	0.108	0.112	291.83	1.426
CEU	4.513	3.1646	4.450	141.5	3.912	4.524	5.136	5.737	6.338	694.56	1.1
AUZ	0.29	0.3284	0.310	29	0.376	0.382	0.387	0.401	0.415	423.33	1.206
JAP	1.065	1.2017	1.001	47.67	1.219	1.214	1.210	1.255	1.300	290.22	1.251
Annex B	**14.503**	**14.210**	**14.931**	**294.85**	**15.751**	**16.771**	**17.791**	**18.766**	**19.740**		
MED	0.35	0.4231			0.626	0.807	0.987	1.305	1.622	432.42	1.296
MEA	0.652	0.8733			1.248	1.503	1.758	2.094	2.429	269.22	1.279
AFR	0.412	0.4805			0.711	0.916	1.121	1.482	1.842	525.05	1.097
CHI	2.411	3.1851			4.440	5.208	5.976	6.929	7.883	199.02	1.634
IND	0.602	0.831			1.379	1.883	2.387	3.328	4.269	235.5	1.846
ASIA	0.833	1.3014			1.923	2.392	2.861	3.594	4.326	496.16	1.18
SAM	0.974	1.1785			1.914	2.474	3.034	3.684	4.333	523.79	1.209
ROW	0.818	0.6286			0.981	1.273	1.564	2.028	2.492	258.49	1.771
non Annex B	**7.052**	**8.9015**		**0**	**13.222**	**16.456**	**19.689**	**24.442**	**29.195**		
World	**21.555**	**23.111**		**294.85**	**28.973**	**33.226**	**37.480**	**43.208**	**48.935**		
	$GtCO_2$		$GtCO_2$	$MtCO_2$	$GtCO_2$						

	POP					GDP				
	2010	2015	2020	2025	2030	2010	2015	2020	2025	2030
USA	0.299	0.311	0.323	0.282	0.242	11257	12924	14590	16405	18221
CAN	0.034	0.035	0.036	0.032	0.028	848	959	1070	1220	1371
EU15	0.395	0.400	0.405	0.360	0.315	12247	14022	15796	17817	19838
OEU	0.013	0.013	0.013	0.012	0.010	716	819	923	1041	1159
CEU	0.404	0.406	0.408	0.385	0.362	1598	2317	3037	4348	5660
AUZ	0.024	0.025	0.026	0.023	0.020	617	698	779	888	998
JAP	0.135	0.136	0.137	0.121	0.104	7089	7680	8271	9023	9774
Annex B	**1.304**	**1.326**	**1.348**	**1.214**	**1.081**	**34372**	**39419**	**44466**	**50742**	**57021**
MED	0.273	0.304	0.336	0.375	0.413	705	1058	1412	2137	2862
MEA	0.216	0.238	0.261	0.263	0.265	1002	1422	1841	2616	3391
AFR	0.850	0.948	1.046	1.166	1.287	685	1029	1373	2078	2782
CHI	1.352	1.379	1.405	1.377	1.349	2048	3108	4167	5949	7730
IND	1.193	1.272	1.351	1.559	1.767	806	1355	1904	3104	4304
ASIA	0.941	0.983	1.026	1.076	1.125	3093	4499	5905	8505	11105
SAM	0.589	0.622	0.654	0.664	0.673	3094	4217	5340	7275	9209
ROW	0.173	0.185	0.197	0.214	0.230	543	815	1087	1615	2144
non Annex B	**5.587**	**5.931**	**6.275**	**6.692**	**7.109**	**11976**	**17503**	**23029**	**33279**	**43527**
World	**6.891**	**7.257**	**7.623**	**7.907**	**8.190**	**46348**	**56922**	**67495**	**84021**	**100548**
	billion					billion $ 1995				

9.4 Appendix 4: Sensitivity analyses

Sensitivity analyses are performed on the main parameters detailed in section 3.1: (i) the discount rate, (ii) the reference emissions, (iii) the degree of technological progress, (iv) the efficiency of domestic policies and (v) the efficiency of the CDM[24].

As expected, a change in the discount rate affects considerably the permits price and the level of banking. A lower discount rate strengthens the incentives to abate more in the present in order to bank and use permits in the future. For instance, a 2% annual discount rate (instead of 5%) drives up the permits price by almost 50% and rises the first period amount of banking by 40% under both objectives. However, the evolution of the bank account does not change: The amount of permits banked is still larger in the third than in the second period.

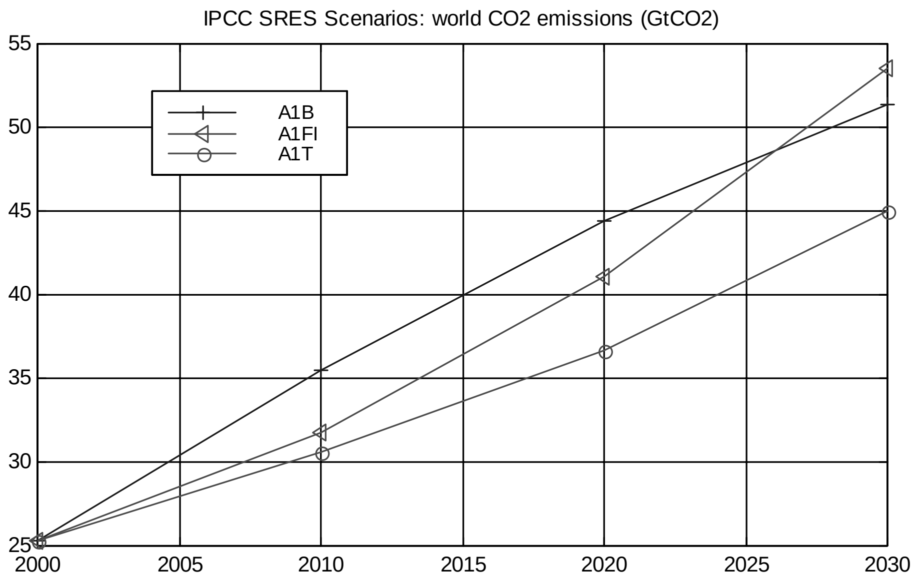

Fig. 8

Reference emissions also play a crucial role. We analyze here the effect of two alternative references from the IPCC (2000). As shown in Fig. 8, one of them (A1 B) leads to a world emissions trajectory lying above the base case one except in the last period, while the other (A1 T) lies below it in all periods. Under the A1 B reference, permits price increases slightly, but banking is lower in the first period and part of these banked permits are used in the second or in the third period. This is due to the lower

[24] Due to the overwhelming uncertainty on the use of sinks after the Kyoto commitment period, we do not consider any alternative to the non-use of sinks in those periods.

reference emissions in the last period which decreases the incentive to bank permits in earlier periods. At the same time, abatement costs are higher for Annex B countries but lower for non-Annex B counties since these commit later to emissions reductions and benefit from the increase in the permits price in the first two periods. Under the A1 T reference, however, permits price, banking and costs decrease considerably –especially under the weak objective– but uniformly.

Changes in the degree of technological progress and in the efficiency of domestic policies have significant impact on the variables but do not change the nature of the results.

On the contrary, a variation of the CDM efficiency modifies the evolution of banking. For instance, a higher efficiency –higher accessibility and lower transaction costs– leads banking to increase when the CDM is used (i.e. during the first two periods). At its turn, this allows for a reduction of banking in the third period. Furthermore, this drives down non-Annex B total costs while keeping Annex-B countries' costs relatively stable, except for CEU that suffer from the larger sales of non-Annex B countries in the first two periods.

Environmental Economics & Management Memorandum

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