The Clean Development Mechanism under the Kyoto Protocol and the 'low-hanging fruits' issue[1]

Bréchet[2], Th., M. Germain[3] and V. van Steenberghe[4]

CORE DISCUSSION PAPER 2004/81

July 2004

[1]This paper is part of the research project entitled "Le mécanisme pour un développement propre : conception d'outils et mise en oeuvre" financed by the Belgian Federal Science Policy (PADD II, contract CP/F5/261). The authors wish to thank Gilles Grandjean for discussions and suggestions and Eric Strobl for careful reading of an earlier version of this paper. It has also benefited from the comments of participants at the 13th annual conference of the European association of environmental and resource economists. The usual disclaimer applies.

[2]CORE, Université catholique de Louvain, 34 voie du Roman Pays, 1348 LOUVAIN-LA-NEUVE, Belgium. E-mail: brechet@core.ucl.ac.be

[3]CORE, Université catholique de Louvain, 34 voie du Roman Pays, 1348 LOUVAIN-LA-NEUVE, Belgium. E-mail: germain@core.ucl.ac.be

[4]Corresponding author. CORE, Université catholique de Louvain, 34 voie du Roman Pays, 1348 LOUVAIN-LA-NEUVE, Belgium. Tel. +32 10 47 43 29 E-mail: vansteen-berghe@core.ucl.ac.be

Abstract

The Kyoto Protocol has introduced the so-called Clean Development Mechanism (CDM) under which industrialized countries are allowed to fulfill part of their obligations through the use of emission credits generated by emission reduction projects undertaken in developing countries. Developing countries have been reluctant to participate in the CDM, fearing that the CDM will use up most of their cheap abatement options (the 'low-hanging fruits' problem). In this paper we show that developing countries should in general participate in the CDM, unless the credit prices are relatively low. Moreover, these countries always gain by participating in the CDM when banking of credits is allowed. Nevertheless, three effects that are likely to limit the extent of such a participation are identified. A case-study (South Africa) reveals that these effects may play a significant role.

1 Introduction

In Kyoto, December 1997, most industrialized countries decided to reduce or limit their emissions of greenhouse gases. In its Art. 17 the Kyoto protocol allows for the trading of emission permits among industrialized countries. The purpose of such a market for emission permits is to reduce world compliance costs by giving incentives to reduce emissions where abatement costs are lowest.

In the same spirit, the Kyoto Protocol has introduced the so-called 'Clean Development Mechanism' (CDM) (Art. 12). Under this mechanism, industrialized countries (more precisely, countries listed in Annex I of the United Nations Convention on Climate Change (UNFCCC), Annex I countries hereafter) are allowed to fulfill part of their obligations through the use of emission credits generated by emission reductions projects undertaken in developing countries (more precisely, non-Annex I countries). In addition to minimizing compliance costs, the CDM also shares the following purpose: "*... to assist Parties not included in Annex I in achieving sustainable development ...*" (The Kyoto Protocol, Art. 12, §2).

Despite these transfers of technologies, some developing countries have been reluctant to participate in the CDM. The main reason refers to the "low-hanging fruits" (LHF) problem: the CDM will use up most of their low-cost abatement options, leaving them with only expensive options in order to satisfy to their own emission reduction commitments in the future. Accordingly, their future abatement costs would be higher and would result in foregone opportunities to earn revenues on the international permits market.

The LHF problem has been widely addressed in the UNFCCC forums. However, according to Akita (2003), it has not been very much analyzed from a formal point of vue. To our knowledge, the only formal analyses of the problem have been done by Rose et al. (1999), Narain and van't Veld (2001) and Akita (2003). Rose et al. (1999)

study the LHF problem in an intertemporal continuous time framework where both Annex I and non-Annex I countries face a commitment to reduce their emissions at a certain future time T. The non-Annex I country can fulfill its commitment either by hosting CDM projects (financed by the Annex I country) or by abating on its own. The authors look for the optimal combination between CDM and other domestic abatement policies in order to satisfy the emission reduction commitment. Although they deal with some major apprehensions of developing countries to participate in the CDM, they do not offer any formal or explicit definition of the LHF problem.

Such an explicit definition of the LHF problem is provided in Akita (2003) and Narain and van't Veld (2001). In rather different theoretical frameworks, these contributions confirm the possible occurrence of the LHF problem. The discrete two-period, two-projects model of Akita (2003) introduces technology improvements in period 2 induced by the use of the CDM in period 1. An important consequence of that assumption is that the high-cost project (high hanging fruits) might be used before the low-cost project (low-hanging fruits).[1] In Akita's framework, the LHF problem occurs when it is optimal for the non-Annex I country to carry out the high-cost project through CDM in period 1 and to carry out the low-cost project by itself in period 2, which happens for intermediate values of (i) the Annex I country share of the credits generated via the CDM project and of (ii) the technology improvements on domestic technology due to CDM.

Using a continuous time model of foreign investment in a CDM project by an Annex I country in a non-Annex I country, Narain and van't Veld (2001) define the LHF problem as "any shortfall in the host country's compensation for the true opportunity cost of hosting a CDM project, namely the value of the foregone option to delay the project at least until graduation time" (i.e., the time at which this country is reducing

[1] This goes againts what is usually assumed in the literature (where gradually more expensive abatement measures are used to reduce emissions).

its own emissions). They show first that the standard LHF problem is mischaracterised, in particular because, once committed to reduce its emissions, the host country will not only be left with high cost abatement measures, but will also have the opportunity to buy permits on the tradable permits market. Assuming some form of myopia of the non-Annex I government due to its private –as opposed to social– interest in the CDM project and its impatience[2], they show that the LHF problem occurs either when (i) the Annex I investors have market power, or (ii) the credit price is increasing with time while the host country is unable to auction off contracts for the future rising return of the CDM project.

However, these three contributions leave aside several important features. First, all of them consider that the allocation of permits to developing (non-Annex I) countries is purely exogenous. Second, Rose et al. (1999) and Akita (2003) do not consider the case where the price of the credits generated by the CDM projects varies through time[3], while Narain and van't Veld (2001) only consider a constant or increasing price of the permits or credits. Third, although it is allowed by Art. 3.13 of the Kyoto Protocol, none of these authors discuss the possibility of banking credits. Fourth, all models are deterministic while huge uncertainties surround future prices of permits and credits. In a rather standard framework, our paper improves upon these issues by introducing (i) allocations of permits which may vary according to the amount of CDM projects undertaken in the non-Annex I country, (ii) variations in the permits prices, (iii) the possibility to bank permits or credits from one period to the other and (iv) uncertainty on the future prices of permits.

[2] They model impatience by assuming that non-Annex I country governments use a discount rate which is higher than the social discount rate.

[3] When Rose et al. (1999) analyze market power, the price of credits is considered as a decreasing function of the current abatement realised through CDM. It is therefore chosen by the host country. This is different with the case where the host country faces a price of credits which varies exogenously through time.

The paper is organized as follows. In section 2, we highlight the main features of the CDM, model those features and determine the decision rules of a developing country implementing CDM projects. Section 3 analyses the low-hanging fruits problem and highlights the conditions under which it may occur. In section 4, we extend the analysis to uncertainty on future permits prices. Then, in section 5, we give a numerical illustration of our results based on the situation of a non-Annex I country: South Africa. Finally, section 6 concludes.

2 Modeling CDM host country behavior

The CDM has some specific features. Below, we present these features before modelling the behavior of a developing country taking them into account. We also characterize its decision rules as far as CDM projects are concerned.

For the stake of simplicity we consider two periods. In the first period, the developing country[4] has no commitment to reduce its emissions of greenhouse gases.[5] During this first period the country is allowed to host CDM projects. In the second period we assume that the developing country commits to emission reductions or limitations. Hence, assigned amount units (permits) are negotiated and allocated to the non-Annex I country in this second period.

2.1 The key features of the CDM

Three important features of the CDM have to be taken into account. A first characteristic is that the CDM involves project-based investments. Projects that are eligible include the implementation of hydro power plants or other renewable energy sources, co-generation, gas capture or removal, improvement of refrigerators, catalytic com-

[4] Also called "non-Annex I country" ("NAI country") or "host country" hereafter. An "industrialized country" will also be called an "Annex I country" ("AI country") hereafter.

[5] We have in mind here the Kyoto committment period, i.e., 2008-2012.

bustion of methane, etc. Such investments last typically more than one commitment period. Therefore, the emission reductions generated from the implementation of such investments give rise to emission credits not only in the period during which the investment takes place, but also in subsequent ones. We model this feature by assuming that all emission reductions in the first period produce an equal amount of emission credits in both the first and the second periods.

The second feature of the CDM is that the credits will be fungible with the emission permits (Emissions Trading (Art. 17 of the Kyoto Protocol) and Joint Implementation activities (Art. 6)). Since emission permits will be traded on an international market, the price of the credits will be determined on this international market. Assuming that the country is 'not too big' (or, at least, does not act strategically on this market), it considers the price of the credits as given at each period.

The third feature of the mechanism is linked to the absence of commitment for the non-Annex I country in the first period, followed by emission reductions obligations in the second period. Consequently, as long as the commitment in the second period has not been negotiated before the beginning of the first period, there is a fear that any emission reduction taking place in the first period (no commitment) will be –at least partly– substracted from the assigned amount units allocated in the second period (commitment). To put things differently, the country representatives might have a lower power (in fact, a lower level of reference emissions) to negotiate a generous allocation of assigned amount units in the following period.[6]

We model below the behavior of a developing country which has to choose the amount of CDM projects it wishes to accept or to implement. The model is based on the three features just described.

[6] However, such a problem is avoided if the level of emissions on which the negotiation on the second period commitments takes place, is based on the emissions realized before the first period.

2.2 The model

We denote by E_t the emissions of the country at time t ($t = 1, 2$). E^{REF} are the baseline emissions, i.e., the level of emissions when the country does not abate (assumed to be constant over time). Hence, the level of abatement in the first period is given by $E^{REF} - E_1$. The amount of permits (called 'assigned amount units' in the Kyoto protocol) negotiated for the second period is given by

$$\overline{E}_2 = \widetilde{E}_2 - \alpha \left[E^{REF} - E_1 \right] \tag{1}$$

where $\widetilde{E}_2$ is any given reference emissions level and α is a positive exogenous parameter ($0 \leq \alpha \leq 1$). This parameter allows one to account of the third feature described just above. The problem of having a lower assigned amount units in period 2 due to abatement efforts made in period 1 does not exist when $\alpha = 0$. When $\alpha = 1$, all the reductions of the first period are substracted from the quotas allocated to the country in the second period. In the following, we will call the effect described by equation (1) the permit's "endowment effect".

An abatement cost function is made from a list of all possible investments leading to abatement of emissions. For each of these projects the cost of their implementation as well as the amount of emission reductions (with respect to the baseline emissions) are needed. The costs of the projects are considered as *annualized costs*. Then, following Narain and van't Veld (2001), a marginal abatement cost function is built by ranking, in decreasing order of costs, all the projects. Let $\gamma(E)$ be the marginal abatement cost corresponding to emission level E. We assume that $\gamma(E)$ is a continuous decreasing function on the interval $[0, E^{REF}]$, such that $\gamma(E^{REF}) = 0$ and $\lim_{E \to 0} \gamma(E) = +\infty$.[7] Then the (total) abatement costs can be written as follows:

$$C(E) = \int_E^{E^{REF}} \gamma(x) dx. \tag{2}$$

[7] This last condition ensures that the positivity constraint on the optimal emission levels is satisfied.

It is assumed that, in both periods, the developing country bears the abatement costs and benefits from the sales of the credits or permits. Indeed, on the one hand, the CDM projects may be financed by the non-Annex I (developing) country which receives all the credits and sells them to an Annex I country. On the other hand, the CDM projects may rather be financed by an Annex I country (or a private firm from such a country) and the credits generated are entirely given to that country (or firm).[8] In the first case, the non-Annex I country captures the seller surplus while the Annex I investor gets the buyer surplus. In the second case, the Annex I investor captures both surpluses, leaving no gains for the developing country. As suggested by CDM market participants, a situation in which non-Annex I countries abandon their surplus is very unlikely to occur or to persist when an international market for emission permits provides a clear price signal for emission reductions. Hence, the second case in not very realistic. In this paper, we choose the first assumption, which corresponds to the standard assumption when markets are analyzed, i.e., the seller surplus goes to the non-Annex I country, while the buyer surplus goes to the Annex I country. A discussion on the role of that assumption is provided in section 3.

Under this assumption, the problem of the host country can be written in the following way:

$$\min_{E_1, E_2} C(E_1) + p_1 \left[E_1 - E^{REF}\right] + \frac{1}{1+\theta} \left[C(E_2) + p_2 \left[E_2 - \overline{E}_2\right]\right] \tag{3}$$

subject to (1),

$$0 \leq E_2 \leq E_1 \quad \text{and} \tag{4}$$

$$0 \leq E_1 \leq E^{REF} \tag{5}$$

where p_t is the international price of the permits (and, according to the second feature, also the price of the CDM credits) at time t and θ is the discount rate. The purpose

[8] Note that intermediate situations may also occur.

of introducing constraint (1) has been explained just above. Constraint (4) aims at capturing the investment aspect of the CDM. Indeed, since we only consider long-lasting projects, a given amount of emission reductions in period 1 automatically leads to the same amount of reductions in period 2. Consequently, the emissions in the second period cannot be larger that those in the first period. From now on, this constraint will be called the "irreversibility constraint", which corresponds to the first feature. Finally, constraint (5) is a feasibility constraint which stipulates that the country cannot emit more than at its reference level.

In the first period, the country therefore minimizes abatement costs and the cost of the net purchase of credits, which is negative since the country sells credits (from constraint (5)). In the second period, the country minimizes the discounted abatement costs and the cost of the net purchase of permits, which is not necessarily negative and the level of which depends, among other things, on the assigned amount units $\overline{E}_2$.

Note that, although emission reductions via projects implemented in the first period are also present in the second period, the costs of such reductions must be borne in each period since we consider annualized costs.

Three regimes are defined according to the level of the first period permits price relative to the second period permits price. Indeed, the solution to problem (3) is characterized by (details of the computations are given in the appendix) :

- **Regime A** : If $0 \leq p_1 \leq p_2 \frac{\alpha}{1+\theta}$, then $E_2^* < E_1^* = E^{REF}$ and

$$\begin{aligned} \gamma\left(E_1^*\right) &= \gamma\left(E^{REF}\right) = 0 \\ \gamma\left(E_2^*\right) &= p_2 \end{aligned} \tag{6}$$

- **Regime B** : If $p_2 \frac{\alpha}{1+\theta} < p_1 < p_2 \left[1 + \frac{\alpha}{1+\theta}\right]$, then $E_2^* < E_1^* < E^{REF}$ and

$$\begin{aligned} \gamma\left(E_1^*\right) &= p_1 - p_2 \frac{\alpha}{1+\theta} \\ \gamma\left(E_2^*\right) &= p_2 \end{aligned} \tag{7}$$

- **Regime C** : If $p_1 \geq p_2 \left[1 + \frac{\alpha}{1+\theta}\right]$, then $E_2^* = E_1^* < E^{REF}$ and

$$\gamma(E_1^*) = p_1 \frac{1+\theta}{2+\theta} + p_2 \frac{[1-\alpha]}{2+\theta} = \gamma(E_2^*) \tag{8}$$

See figure 1 (see section 10)

2.3 Interpretation of the results

Three regimes are defined according to the level of the price of the permits or credits.[9] The two bounds delimiting the regimes are decreasing with the discount rate (θ) and are increasing with (i) the price of permits in period 2 and (ii) the extent to which emission reductions in the first period are likely to affect the amount of permits allocated to the country in the second period (α, i.e., the endowment effect). The three regimes are illustrated in Figure 1 in function of p_1.

Regime A is observed for low levels of the credit price in period 1 and is characterized by no emission reductions. It is worthwhile noting that it is in the interest of the developing country not to participate in the CDM even for positive (though low) levels of the price of the credits. This is due to the permits "endowment effect" (see just below).

Regime B is characterized by increasing optimal abatement rates, i.e., $E_1^* > E_2^*$. The country implements new abatement projects in the second period. In period 2, the country has the incentive to reduce its emissions as long as the marginal abatement

[9] Note that, in the particular case of $p_1 = 0$, no CDM projects are undertaken. Indeed, this situation falls under Regime A and no abatement measures are undertaken in period 1. The fact that there are no reductions in the absence of the CDM guarantees that all projects implemented through the CDM satisfy the additionality condition (see UNFCCC, 1997).

cost ($\gamma(E_2)$) is lower than p_2, which corresponds to the usual (static) decision rule in the presence of tradable emission permits. On the contrary, the behavior in the first period consists of choosing a level of emissions such that the marginal abatement costs are below the first period permit's price. Indeed, due to the "permit's endowment effect" (cfr. (1)), reducing the emissions by one more unit in the first period leads to a loss of permits sales in the second period, which amounts to $\alpha p_2/[1+\theta]$.

In regime C, however, no additional abatement is undertaken in the second period since $E_1^* = E_2^*$. In this case, the irreversibility constraint (4) is binding. The marginal abatement costs are equalized across periods. In order to interpret more easily condition (8), let us rewrite it as:

$$\frac{\gamma(E_t)\left[1+\frac{1}{1+\theta}\right]}{2} = \frac{p_1 + \frac{1}{1+\theta}p_2[1-\alpha]}{2},\ t = 1, 2 \tag{9}$$

It appears that in Regime C the average of the discounted marginal abatement costs (LHS of equation (9)) is equal to the average of the discounted marginal benefit of the abatement (RHS of equation (9)).

Consider now the benchmark case characterized by the absence of the "endowment effect" ($\alpha = 0$). Then, Regime A disappears, Regime B corresponds to $p_1 < p_2$ and Regime B to $p_1 > p_2$. In Regime B, the host country abates in each period up to the equalization of the marginal abatement costs and the permits price ($\gamma(E_t) = p_t$, $t = 1, 2$). In Regime C, the average of discounted marginal abatement costs are equal to the average of the discounted prices of permits.

3 A problem of low-hanging fruits ?

3.1 An explanation of the problem at stake

The literature on the CDM reports that there is a fear that all low cost abatement projects –the so-called low-hanging fruits– are wiped out by investors from developed countries, leaving only high cost projects for developing countries when these are themselves committed to emission reductions.

Of course, if the developing country behaves in a farsighted way, no 'low-hanging fruits' problem occurs. In order to analyze the extent of the LHF problem and to determine the conditions of its occurrence, one must compare the consequences of a farsighted behavior with those of a myopic acceptance or implementation of CDM projects. Such a myopic behavior could indeed occur. As argued by Narain and van't Veld (2001), political and institutional realities in developing countries (such as corruption, political instability, lack of human capital and of legal infrastructure, lack of knowledge in order to successfully bargain with the foreign investors) could explain a suboptimal behavior of the host decision makers, which might give rise to the low-hanging fruits (LHF hereafter) problem.

Assuming that both the seller surplus and the buyer surplus go to the Annex I country, Narain and van't Veld (2001) show that developing countries should not accept any CDM projects in the first period.[10] Indeed, developing countries would loose their low cost abatement measures and would have to use higher cost measures or purchase permits on the international market in order to fullfil their future commitments. Hence, the LHF problem occurs. Although we have chosen the alternative assumption, our framework may be modified in order to introduce the same assumption as in Narain and van't Veld (2001) on the surplus sharing.[11] In doing so we obtain the same results

[10] Unless, of course, they are compensated for their losses.

[11] The problem writes:

$$\min_{0 \leq E_2 \leq E_1 \leq E^{REF}} C(E_2) - C(E_1) + p_2 \left[E_2 - \widetilde{E}_2 - \left[E^{REF} - E_1 \right] \right].$$

Indeed, abatement costs for the CDM projects undertaken in the first period are not borne by the developing country (neither in the first period, nor in the second one). Moreover, in the second period, the developing country can only sell emission reductions above those that undertaken via the CDM projects implemented in the first period.

as theirs.

However, as motivated in section 2.1, we do believe that it is more natural to consider that the seller surplus goes to the NAI country and the buyer surplus goes to the AI country. As argued above in section 2.2, this is also more appropriate given the actual development of international markets for emission permits. Hence, our purpose is to analyze the extent of such a problem and to determine the conditions of its occurrence in such a context. Accordingly, we compare the farsighted behavior, as modelled in section 2, with a myopic one. However, in order to keep the model simple, we do not explicitly model the possible causes of myopia.[12] Rather, we concentrate on their implications.

Formally the myopic developing country is supposed to solve the following problem:

$$\min_{0 \leq E_1} C(E_1) + p_1 \left[E_1 - E_1^{REF}\right] \tag{10}$$

which leads to the following first order condition[13] :

$$\gamma(\widehat{E}_1) = p_1. \tag{11}$$

This condition corresponds to the usual rule of 'marginal abatement cost equals the price in the current period'. By applying this rule, the host country ignores (i) the presence of future constraints on emissions or, in other words, the irreversibility aspect of the investment and (ii) its possible impact on the future allocation of assigned amount units (the permits "endowment effect").

3.2 Conditions for the 'low-hanging fruits' problem to occur

Proposition 1 *Developing countries should not accept CDM projects on the basis of "marginal abatement costs equal the permit's price" rule, unless* $\alpha = 0$ *and* $p_1 \leq p_2$.

[12]Narain and van't Veld (2001) model myopia of the host country by a mix of corruption (the host government has private interest in the CDM) and political instability (the government fears to be overthrown and thus discounts at a higher rate than the social discount rate).

[13]We may ignore constraint (5) as it will never be stricly binding for $p_1 \geq 0$.

According to the explanation given in the above section, the LHF problem occurs when the farsighted solution characterized by (6)-(8) does not coincide with the myopic solution characterized by (11). Figure 2 shows the shape of the marginal abatement costs under the farsighted and myopic behaviors in function of p_1 ($\gamma(\widehat{E}_1)$ and $\gamma(E_1^*)$ respectively). Under general conditions, the LHF problem exists in all regimes. The myopic country tends to reduce too much its emissions in period 1, i.e., to accept too much CDM projects in all regimes.[14]

The magnitude of the problem depends on both the permit's endowment effect and the irreversibility effect. Figure 2 is helpful in disentangling these effects. The extent of the LHF problem (as measured by the difference $\gamma(\widehat{E}_1) - \gamma(E_1^*)$) is first increasing with p_1 under Regime A, then constant under Regime B, and then again increasing under Regime C. This last increase is due to the irreversibility constraint (4). This constraint is only binding under Regime C, while the permits endowment effect described by (1) is present in all regimes.

See Figure 2

When $\alpha = 0$, i.e., when the CDM has no impact on the future allocation of assigned amount units, the picture changes. Regime A disappears and the bound delimiting Regimes B and C becomes p_2. Then, the comparison of (7) and (8) with (11) shows that the LHF problem remains only in Regime C, namely for $p_1 > p_2$. In Regime B (i.e. $p_1 \leq p_2$), the irreversibility constraint $E_1^* \leq E_2^*$ does not bind, so that the solutions under the myopic and farsighted behaviors coincide.[15]

[14] Formally, looking at (6) and (7), it appears immediately that $\gamma(E_1^*) < p_1$ in Regime A and B, which implies that $E_1^* > \widehat{E}_1$. This is also the case in Regime C. Indeed, comparing (8) and (11), one has $E_1^* > \widehat{E}_1$ if $p_1 \frac{1+\theta}{2+\theta} + p_2 \frac{[1-\alpha]}{2+\theta} < p_1$. This inequality reduces to $p_2[1-\alpha] < p_1$, which is always true because Regime B is characterised by $p_2 \left[1 + \frac{\alpha}{1+\theta}\right] \leq p_1$.

[15] Note that Akita (2003) also obtains that, *even* if the NAI country's behaviour is not optimal, it is

3.3 The impact of banking

Banking of permits across commitment periods is allowed by Article 3.13 of the Kyoto Protocol. The literature on permits banking is well developed (see, among others, Yates and Cronshaw (2001)). According to this literature, the first period permit's price cannot drop below the discounted second period price, namely $\frac{1}{1+\theta}p_2 \leq p_1$. By $0 \leq \alpha \leq 1$, one has $\frac{\alpha}{1+\theta}p_2 \leq \frac{1}{1+\theta}p_2$. Then, as illustrated in Figure 1, Regime A disappears and Regime B is reduced by the interval $\left[\frac{\alpha}{1+\theta}p_2, \frac{1}{1+\theta}p_2\right[$. Accordingly:

Proposition 2 *Under the possibility of banking, the low-hanging fruits problem still occurs. However, its occurrence is reduced.*

4 Uncertainty on future prices

In this section, we modify the above framework in order to analyze how uncertainty on the future permits prices is likely to affect the LHF problem. The price of the permits in period 2 is now a random variable with two possible values p_2^H and p_2^L with probabilities π and $1-\pi$ (such that $p_2^L < p_2^H$ and $0 < \pi < 1$). It is assumed that the host country observes the actual price of the permits at the beginning of period 2 (p_2), so that this information is taken into account when computing the optimal abatement measures in period 2. Thus, the problem reads as a two stage decision problem that can be solved by backward induction, starting with the last period.

In period 2, the host country solves :

$$\min_{E_2} C(E_2) + p_2 \left[E_2 - \overline{E}_2\right] \tag{12}$$

subject to (1) and (4) where p_2 and E_1 are given. Let

$$V(E_1, p_2) = \min_{E_2} \left\{C(E_2) + p_2 \left[E_2 - \overline{E}_2\right]\right\} \tag{13}$$

still possible that the LHF problem will not occur.

be the solution of the above problem and E_2^H and E_2^L be the optimal emission levels corresponding to the two permit's price levels p_2^L and p_2^H.

Then the host country problem in period 1 is :

$$\min_{E_1} - = C(E_1) + p_1 \left[E_1 - E^{REF}\right] + \frac{1}{1+\theta}\left[\pi V(E_1, p_2^H) + [1-\pi] V(E_1, p_2^L)\right] \quad (14)$$

subject to (5). When $p_2^L = p_2^H$, this problem reduces to (3). Let $\widetilde{p}_2 = \pi p_2^H + [1-\pi] p_2^L$ be the mathematical expectation of p_2. Then, the solution of problem (14) is characterized by (the details of the computations are provided in appendix) :

- Regime A : If $0 \le p_1 \le \widetilde{p}_2 \frac{\alpha}{1+\theta}$, then $E_2^H < E_2^L < E_1^* = E^{REF}$ and

$$\begin{aligned} \gamma(E_1^*) &= \gamma\left(E^{REF}\right) = 0 \\ \gamma(E_2^x) &= p_2^x, \ x = H, L \end{aligned} \quad (15)$$

- **Regime B.1** : If $\widetilde{p}_2 \frac{\alpha}{1+\theta} < p_1 < p_2^L + \widetilde{p}_2 \frac{\alpha}{1+\theta}$, then $E_2^H < E_2^L < E_1^* < E^{REF}$ and

$$\begin{aligned} \gamma(E_1^*) &= p_1 - \widetilde{p}_2 \tfrac{\alpha}{1+\theta} \\ \gamma(E_2^x) &= p_2^x, \ x = H, L \end{aligned} \quad (16)$$

- **Regime B.2** : If $p_2^L + \widetilde{p}_2 \frac{\alpha}{1+\theta} \le p_1 < p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{[1-\alpha]}{1+\theta}$, then $E_2^H < E_2^L = E_1^* < E^{REF}$ and

$$\begin{aligned} \gamma(E_1^*) &= \frac{[1-\pi] p_2^L - \alpha \widetilde{p}_2}{2+\theta-\pi} + p_1 \frac{1+\theta}{2+\theta-\pi} = \gamma\left(E_2^L\right) \\ \gamma\left(E_2^H\right) &= p_2^H \end{aligned} \quad (17)$$

- Regime C : If $p_1 \ge p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{[1-\alpha]}{1+\theta}$, then $E_2^H = E_2^L = E_1^* < E^{REF}$ and

$$\gamma(E_1^*) = p_1 \frac{1+\theta}{2+\theta} + \widetilde{p}_2 \frac{[1-\alpha]}{2+\theta} = \gamma\left(E_2^H\right) = \gamma\left(E_2^L\right). \quad (18)$$

4.1 Interpretation of the results

Four regimes prevail according to the level of the price of the permits or credits in the first period. These regimes are illustrated in Figure 3 as a function of p_1.

See Figure 3

As in the deterministic case, Regime A is observed for low levels of the price of credits in period 1 and is characterized by the absence of any reduction of emissions in $t = 1$.

Regime B.1 is characterized by increasing optimal abatement rates in each state of the world, i.e., $E_1^* > E_2^x,\ x = H, L$. In period 2, the NAI country has, in both states, the incentive to reduce its emissions as long as the marginal abatement cost $(\gamma (E_2))$ is lower than p_2^x. Accordingly, more reductions are undertaken when the price of the permits is high. As in the deterministic case, the behavior in the first period consists of choosing a level of emissions such that the marginal abatement costs are below the first period permits price, because of the loss of the permits sales in the second period induced by the abatement of emissions in period 1.

In Regime B.2, additional abatement is undertaken in the second period only when the price of permits in that period is high, i.e., for $x = H$. On the contrary, the irreversibility constraint (4) is binding for $x = L$.

In Regime C, no additional abatement is undertaken in $t = 2$ in either state of the world since $E_2^H = E_2^L = E_1^*$. The irreversibility constraint is binding in both states and the marginal abatement costs are equalized across periods *and* across states.

The fundamental difference with the deterministic case is that, when p_2 is random, the irreversibility constraint may be binding in some states of the world (when p_2 is low) and not binding in the others (when p_2 is high). This is precisely what happens in Regime B.2, the new regime that appears when p_2 is random. It is easy to check that, when $p_2^L = p_2^H$, the two bounds delimiting Regime B.2 are equal, so that this regime disappears. Regimes A, B.1 and C reduce then to Regimes A, B, C characterizing the deterministic framework.

In the benchmark case characterized by $\alpha = 0$ (i.e., no endowment effect), Regime A disappears, Regime B.1 corresponds to $0 \leq p_1 < p_2^L$, Regime B.2 to $p_2^L \leq p_1 \leq p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{1}{1+\theta}$ and Regime C to $p_1 > p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{1}{1+\theta}$.

4.2 The LHF problem under uncertainty

Proposition 3 *Even in the absence of risk aversion, uncertainty on the future permits' prices exacerbates the LHF problem for intermediate values of* p_1.

Figure 4 shows the shape of the marginal abatement costs under the farsighted and myopic behavior in function of p_1. The LHF problem occurs in all regimes. The difference in marginal abatement costs under myopia and farsightedness $(\gamma(\widehat{E}_1) - \gamma(E_1^*))$ is increasing with p_1 under Regime A, constant under Regime B.1 and then increasing again under Regimes B.2 and C. The increase under these last two regimes is due to the irreversibility constraint (3), at least partly under Regime B.2 (see Figure 4).

See Figure 4

4.3 The LHF problem under uncertainty and banking

Proposition 4 *Under banking and uncertainty on future permits price, developing countries should not accept CDM projects on the basis of "marginal abatement costs equal the permits' price", unless* $\alpha = 0$ *and* $p_1 \leq p_2^L$.

If banking of permits across commitment periods is allowed, then the first period permits price cannot drop below the discounted mathematical expectation of the second period price, i.e. $\frac{1}{1+\theta}\widetilde{p}_2 \leq p_1$. Since $0 \leq \alpha \leq 1$, Regime A disappears as it is illustrated in Figure 3. Regime B.1 will be reduced or will even disappear, depending of the size of p_2^H/p_2^L, while the two other regimes remain[16]. Now, the LHF problem is likely to occur only in Regime B.1, so that the preceding analysis remains valid.

5 An application

In this section, we evaluate the potential extent of the low-hanging fruits problem by means of a simple application based on the actual situation of a NAI country. Deep and detailed analyses of the potential for CDM investments in various developing countries have been performed by The World Bank.[17] These studies evaluate all the potential technologies aimed at reducing greenhouse gas emissions, as well as their cost. Among the various available studies, we choose a recent analysis of the potential for CDM in South Africa (see The World Bank (2002)).[18]

In order to stick to the current state of international negotiations on climate change, we model commitment periods of 5 years each. Since the investments considered in the application are of 30 years length, we need to deal with 6 commitment periods. In order to simplify the reasoning, several assumptions are made. Developing countries have no emission reductions obligations during the first commitment period (2008-2012). From then onwards it is assumed that these countries commit to emission reductions and receive the same assigned amount units during each of the five last periods. Moreover,

[16] A sufficient condition for Regime B.1 to disappear is $\frac{1}{1+\theta}\widetilde{p}_2 \geq p_2^L + \widetilde{p}_2\frac{\alpha}{1+\theta}$, which leads to $\frac{p_2^H}{p_2^L} \geq \frac{1}{\pi}\left[\frac{1+\theta}{1-\alpha} - 1 + \pi\right]$. This is more likely to happen when θ and α are low and when π is high. In particular it never happens if $\alpha = 1$. Moreover, because $\frac{1}{1+\theta}\widetilde{p}_2$ is always lower than the upper bound of Regime B.2, this regime never disappears.

[17] These analyses are part of the National CDM/JI Strategy Studies (NSS) of the World Bank. They are available at http://www.worldbank.org.

[18] South Africa is among the African countries which offer the largest emission reductions potential. It is also a country where risks in investments have significantly decreased recently, what makes investments in emission reduction credits even more attractive.

we assume that the price of the permits on the international market keeps the same from the second to the last period.[19] The model is adapted to such a framework.

The authors of the World Bank report list a series of technologies –like catalytic combustion of methane in the coal mining sector, manure management of land use or the use of hybrid solar water heaters in the residential sector– and their corresponding costs. Leaving aside the technologies whose implementation is not likely to be eligible as CDM projects –like the implementation of nuclear power stations–, the marginal technological abatement cost curve is the following one (see The World Bank (2002, p. 47)):

See Figure 5

Estimated reference emissions in 2010 amount to about 675 $MtCO_2$-eq (see The World Bank). For simplicity, we assume that $\widetilde{E}_2 = \widetilde{E}_3 = ... = \widetilde{E}_6 = 650$ $MtCO_2$-eq. If $\alpha = 0$, this corresponds to the assigned amount units allocated to the country. However, assigned amount units are lower than 650 $MtCO_2$-eq when the permits endowment effect is present ($\alpha > 0$).

Four scenarios are considered, according to whether the endowment effect is present or not and according to whether uncertainty is present or not:

(a) a base case scenario under certainty on the future permits price ($p_2 = 10$) and where any endowment effect is absent ($\alpha = 0$);

(b) a scenario under certainty ($p_2 = 10$) where the endowment effect does play a role

[19] Indeed, we do not know if permits prices are going to rise in the future or, on the contrary, to drop down; our assumption may be seen as an intermediary case which simplifies the notation and the reasoning.

$(\alpha = 0,3)$;

(c) a scenario under uncertainty on future permits prices $(p_2^L = 5, p_2^H = 20, \widetilde{p}_2 = 10)$ and where the endowment effect is absent $(\alpha = 0)$ and

(d) a scenario under uncertainty $(p_2^L = 5, p_2^H = 20, \widetilde{p}_2 = 10)$ where the endowment effect is present $(\alpha = 0,3)$.

Assuming a constant permits price for periods 2 to 6 (p_2), we select alternative first period permits prices (p_1) associated with alternative Regimes. Since, in accordance with Art. 3.13 of the Kyoto Protocol, we assume that banking of permits is allowed, Regime A never exists.

Then, at each of these points and for a given level of the second period permits prices $(p_2 = 10$, or $p_2^L = 5, p_2^H = 20, \widetilde{p}_2 = 10$ under uncertainty), Table 1 presents for each scenario: *(i)* the first period permits' price (p_1) which corresponds to the marginal abatement costs under the myopic behavior $(\gamma\left(\widehat{E}_1\right))$, *(ii)* the corresponding marginal abatement cost in period 1 under the farsighted behavior $(\gamma\left(E_1^*\right))$, *(iii)* the emission reductions in the first period under the myopic behavior $(E_1^{REF} - \widehat{E}_1)$, *(iv)* the emission reductions in the first period under the farsighted behavior $(E_1^{REF} - E_1^*)$, *(v)* the total costs –abatement costs and permits purchase costs– under the myopic behavior, *(vi)* the total costs –abatement costs and permits purchase costs– under the farsighted behavior and *(vii)* the relative difference between the total costs under the myopic behavior and the total costs under the farsighted behavior.

Note that a discount rate of 5% per year is used in the computations.[20]

[20] Ellerman (2002) has shown that participants to the U.S. Acid Rain Program –aimed at limiting the emissions of sulfur dyoxide via a tradable emission permits system– have used an annual discount rate of around 6% per year. Moreover, he states that the current rate is probably slighly below 6%, possibly at 4.5%. Therefore, by analogy to this system, we use a discount rate that we set at 5%.

See Table 1

In the base case (scenario (a)), myopic and farsighted behaviors coincide in Regime B as well at the intersection of Regimes B and C. When the first period permits price is equal to 7,8 \$/ton of CO_2, the emission reductions under both behaviors amount to 20,7 MtCO_2-eq. In Regime C, however, the *irreversibility* aspect of the investment plays a role: the farsighted behavior leads to a lower level of the first period marginal abatement cost (11,4 \$) than the myopic one (15,0 \$). Consequently, slightly fewer emission reductions are undertaken under the farsighted behavior than under the myopic one. As far as total costs differences are concerned, negative figures correspond to situations where both farsighted and myopic behaviors lead to negative total costs, i.e., to net gains. Hence, negative figures correspond to the relative decrease of total gains (in percentage) caused a myopic behavior[21]. As expected, total costs under the farsighted behavior are always lower than those under the myopic behavior. In the base case, the relative difference is significant and amounts to about 15%.

In the case where the endowment effect is present (scenario (b)), figures change dramatically under all Regimes. In Regime B, for the same level of the first period permits price ($p_1 = 7,8$), almost no emission reductions are undertaken under the farsighted behavior. The *endowment effect* is so important that the country should implement almost no CDM projects. Then, the relative difference in total costs amounts to more than 19%. The same comments apply to the other Regimes, except that significant emission reductions are undertaken also under the farsighted behavior. However, the difference in emission reductions decreases with the first period permits price, even if, in Regime C, the irreversibility effect also reinforces the endowment effect.

[21] The negative sign of the relative difference is always due to the negative sign of the denominator.

In a scenario under uncertainty (scenario (c)), a difference in emission reductions and total costs is observed in Regime B2. If the first period permits price is equal to 10$/ton, the farsighted marginal abatement costs amount to only 6,9$. Consequently, emission reductions are lower under the farsighted behavior and total cost difference reaches almost 30%. At the intersection of Regimes B1 and B2, both myopic and farsighted behaviors coincide since the endowment effect is absent. In Regime C and at the intersection between Regimes B2 and C, uncertainty does not play any role. However, the irreversibility effect causes slight differences in marginal abatement costs, emission reductions and total costs under both behaviors.

Finally, when both the endowment and the uncertainty effects are combined (scenario (d)), the total costs difference may rise up to 270%. Lower impacts for larger first period permits price may be explained by the shape of the marginal abatement cost curve which is almost vertical above 20 $ per ton of CO_2.

6 Conclusion

The "low-hanging fruits" problem has been put as a main cause for the reluctance of developing countries to participate in the CDM: through the CDM industrialized countries would use up most of developing countries low-cost abatement options, leaving them with only expensive options in order to satisfy their own emission reduction commitments in the future. Accordingly, their future abatement costs would be higher and would result in foregone opportunities to earn revenues on the international permits market.

The extend of the participation of the developing countries to the CDM is limited by three effects: (i) an irreversibility effect, since investments projects last typically more than one commitment period, (ii) a permits endowment effect, when future commitments are negatively affected by the CDM projects undergone within the country, and (iii) an uncertainty effect, related to the permits price in the second period.

Indeed, when assuming that both the seller surplus and the buyer surplus go to the Annex I country, it has been shown in the literature that developing countries should not accept any CDM projects (unless they are compensated for their losses). Under the more natural assumption that the developing country captures the seller surplus, we show that the country would gain by participating in the CDM, except when (i) the permits price is low during the first period relatively to the second period and, simultaneously, (ii) the future permits allocation to the developing country is negatively affected by its participation to the CDM (the so-called ‘endowment effect’).

Important policy implications stem from these results. First, although it does not solve the LHF problem, banking of permits between commitment periods reduces its occurrence. Second, reducing the risk of LHF diversion when designing the procedures for projects validation clearly falls within the competence of the CDM Executive Committee under the UN Framwork Convention on Climate Change. Problems related to the capture of the surplus and the endowment effect could be overcome by ensuring fair bargaining conditions between the host country and the Annex I country.

A simple numerical application to South Africa reveals that, by ignoring these effects, the country would bear significant additional costs (or significant lower gains). When all these effects are combined, reasonable values of the parameters lead to total cost differences exceeding 50%.

From a broader perspective, empirical evaluations of the contribution of the CDM to world emission reductions neglect these effects. Our results suggest that this contribution is usually overestimated.

7 References

Akita, J. (2003), "A simple model of CDM low-hanging fruits", in Sawa, T. (ed.), *International frameworks and technological strategies to prevent climate change*, Springer, Tokyo, Japan.

Ellerman, D. (2002), "Analysis of the Bush Proposal to Reduce the SO2 Cap", Working Paper 02-002, Center for Energy and Environmental Policy Research, Massachusetts Institute of Technology, February 2002.

Narain, U. and K. van't Veld (2001), "Long-term risks to developing countries from participating in the clean development mechanism", mimeo.

Rose, A., E. Bulte and H. Folmer (1999), "Long-run implications for developing countries of joint implementation of greenhouse gas mitigation", *Environmental and Resource Economics* **14**: 19-31.

World Bank (2002), *South African national strategy study on the clean development mechanism*, Program of the National CDM/JI Strategy Studies, Washington, USA (available at http://www.worldbank.org).

Yates, A. and M. Cronshaw (2001), "Pollution permit markets with intertemporal trading and asymetric information", *Journal of Environmental Economics and Management* **42**: 104-118.

8 Appendix : the problem under uncertainty

In this appendix, we solve the NAI country's problem under the assumption of far-sighted behavior and uncertainty. The deterministic case in solved afterwards.

The price of permits in period 2, p_2, is a random variable taking two possible values, p_2^L and p_2^H, with probabilities $1 - \pi$ and π (such that $p_2^L < p_2^H$ and $0 < \pi < 1$). The host country observes the actual price of permits at the beginning of period 2 (p_2) so that it can take account of this information when computing the optimal abatement measures of period 2. The problem reads as a two stage decision problem and is solved by backward induction, starting with the last period.

The first order condition of problem (12) reads :

$$\gamma\left(E_2^x\right) = p_2 \text{ if } p_2 \leq \gamma\left(E_1\right) \quad (19)$$

$$E_2^x = E_1 \text{ if } p_2 > \gamma\left(E_1\right) \quad (20)$$

Let $V(E_1, p_2)$ be the solution of the above problem. Then

$$V(E_1, p_2) = C\left(E_2^x\right) + p_2\left[E_2^x - \widetilde{E}_2 + \alpha\left[E^{REF} - E_1\right]\right] \text{ if } p_2 \leq \gamma\left(E_1\right) \quad (21)$$

$$= C\left(E_1\right) + p_2\left[E_1 - \widetilde{E}_2 + \alpha\left[E^{REF} - E_1\right]\right] \text{ if } p_2 > \gamma\left(E_1\right) \quad (22)$$

From (21) and (22), one has

$$\frac{\partial V}{\partial E_1}(E_1, p_2^x) = -\alpha p_2^x \text{ if } p_2^x \leq \gamma\left(E_1\right) \quad (23)$$

$$= -\gamma\left(E_1\right) + [1-\alpha] p_2^x \text{ if } p_2 > \gamma\left(E_1\right) \quad (24)$$

where $x = H, L$. Let $\widetilde{p}_2 = \pi p_2^H + [1-\pi] p_2^L$ be the mathematical expectation of p_2. Given (23) and (24), the first order condition of problem (14) can be written as follows:

$$\frac{\partial -}{\partial E_1} = -\frac{2+\theta}{1+\theta}\gamma\left(E_1\right) + p_1 + \widetilde{p}_2\frac{1-\alpha}{1+\theta} \text{ if } \gamma\left(E_1\right) > p_2^H \quad (25)$$

$$= -\frac{2+\theta-\pi}{1+\theta}\gamma\left(E_1\right) + p_1 + \frac{[1-\pi]p_2^L - \alpha\widetilde{p}_2}{1+\theta} \text{ if } p_2^H \geq \gamma\left(E_1\right) > p_2^L \quad (26)$$

$$= -\gamma\left(E_1\right) + p_1 - \widetilde{p}_2\frac{\alpha}{1+\theta} \text{ if } p_2^L \geq \gamma\left(E_1\right) > 0 \quad (27)$$

Although they are not analytical functions, $V(E_1, p_2^H)$ and $V(E_1, p_2^L)$ are continuous, differentiable and convex functions of E_1. Given (14), this is also true for - . Hence - admits a unique minimum. Three regimes must be distinguished according to whether the optimal condition $\partial - /\partial E_1 = 0$ is satisfied for some abatement cost $\gamma\left(E_1^*\right)$ higher than p_2^H, between p_2^H and p_2^L or lower than p_2^L. Regime B is characterized by $\gamma\left(E_1^*\right) > p_2^H$, so that by (25), $\gamma\left(E_1^*\right) = p_1\frac{1+\theta}{2+\theta} + \widetilde{p}_2\frac{[1-\alpha]}{2+\theta}$. These two relations imply that this regime will occur if $p_1 \geq p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{[1-\alpha]}{1+\theta}$. Regime A.2 is characterized by $p_2^H \geq \gamma(E_1) > p_2^L$, so that by (26), $\gamma(E_1^*) = \frac{[1-\pi]p_2^L - \alpha\widetilde{p}_2}{2+\theta-\pi} + p_1 \frac{1-\alpha}{2+\theta-\pi}$. These relations imply that this regime will occur if $p_2^L + \widetilde{p}_2 \frac{\alpha}{1+\theta} \leq p_1 < p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{[1-\alpha]}{1+\theta}$. Regime A.1 is characterized by $p_2^L \geq \gamma(E_1) > 0$, so that by (27), $\gamma(E_1^*) = \frac{[1-\pi]p_2^L - \alpha\widetilde{p}_2}{2+\theta-\pi} + p_1 \frac{1-\alpha}{2+\theta-\pi}$. These relations imply that this regime will occur if $\widetilde{p}_2 \frac{\alpha}{1+\theta} < p_1 < p_2^L + \widetilde{p}_2 \frac{\alpha}{1+\theta}$. Finally, a fourth regime (Regime C) occurs if $\partial\text{-} / \partial E_1 < 0, \forall E_1 \in [0, E^{REF}]$. Then $E_1^* = E^{REF}$, which happens if $0 \leq p_1 \leq \widetilde{p}_2 \frac{\alpha}{1+\theta}$.

The deterministic case analyzed in section 2 corresponds to the particular case where $p_2^H = p_2^L = \widetilde{p}_2$. Hence one can check that $p_2^L + \widetilde{p}_2 \frac{\alpha}{1+\theta} = p_2^H \frac{2+\theta}{1+\theta} - \widetilde{p}_2 \frac{[1-\alpha]}{1+\theta}$, so that Regime A.2 disappears and Regimes A.1, B, C reduce to Regimes A, B, C described by (7) to (6).

9 Figures and table

Figure 1

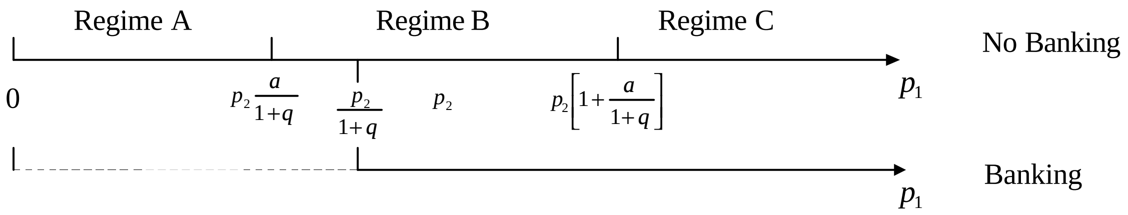


Figure 2

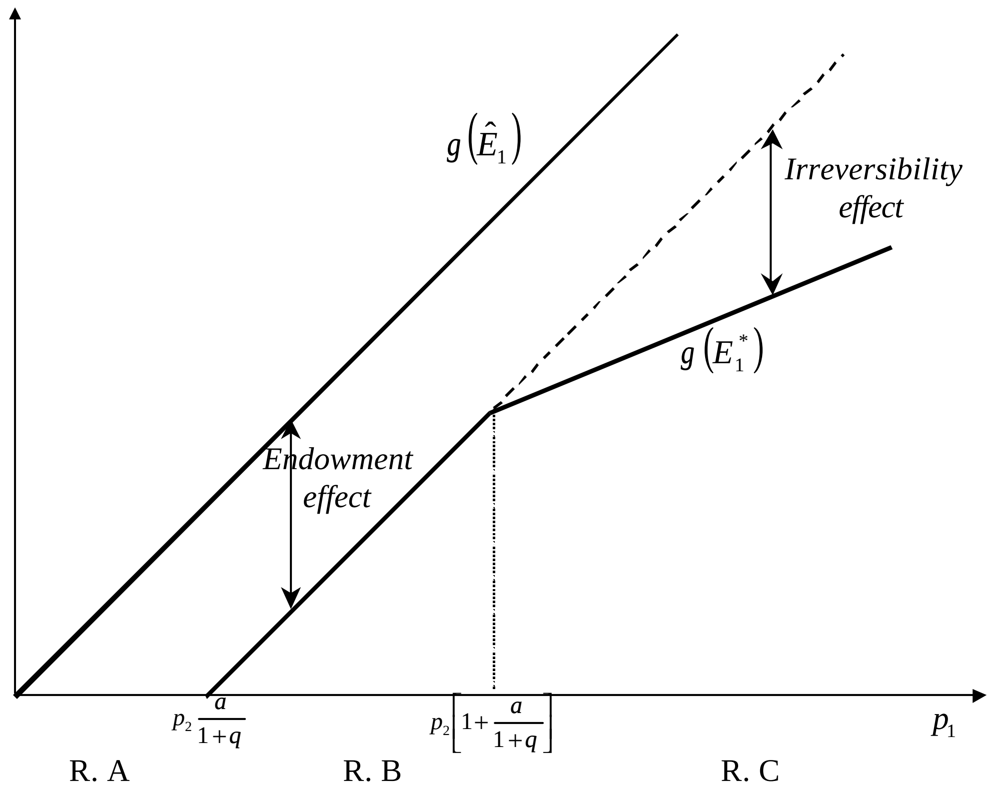


Figure 3

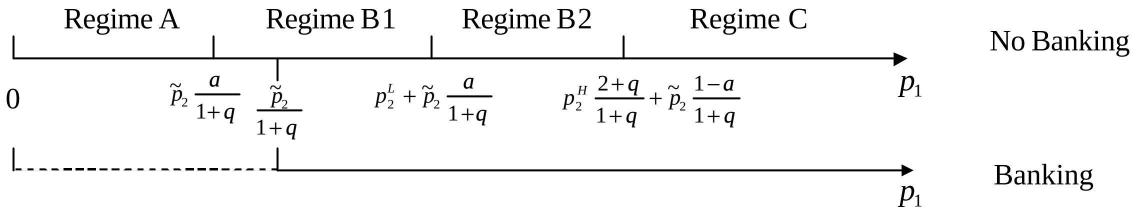


Figure 4

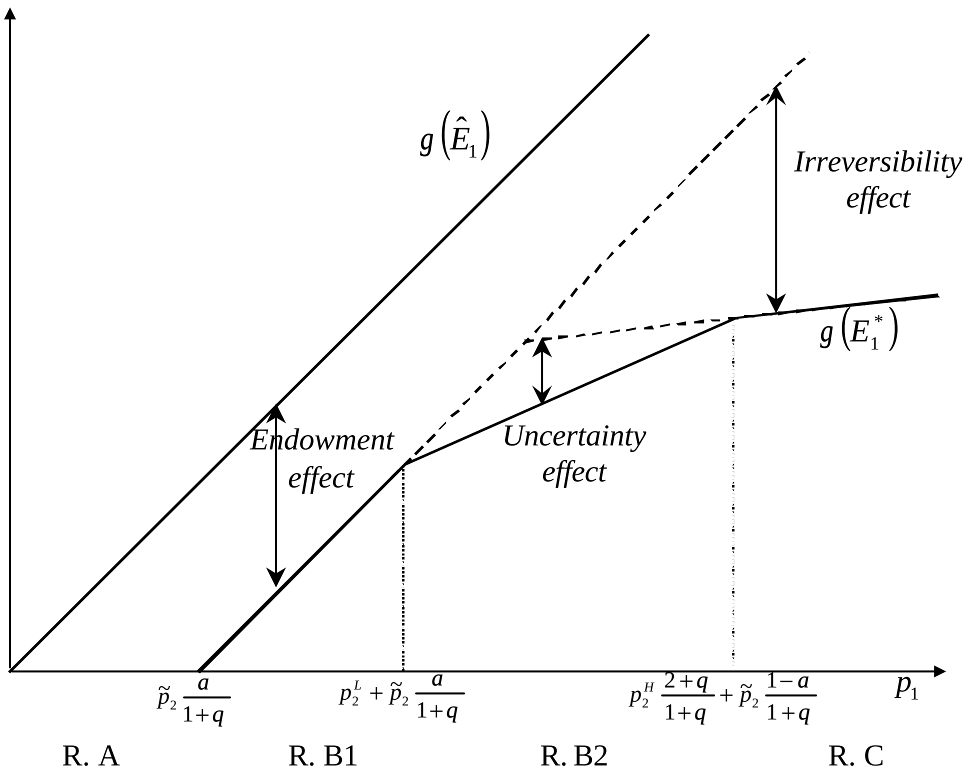
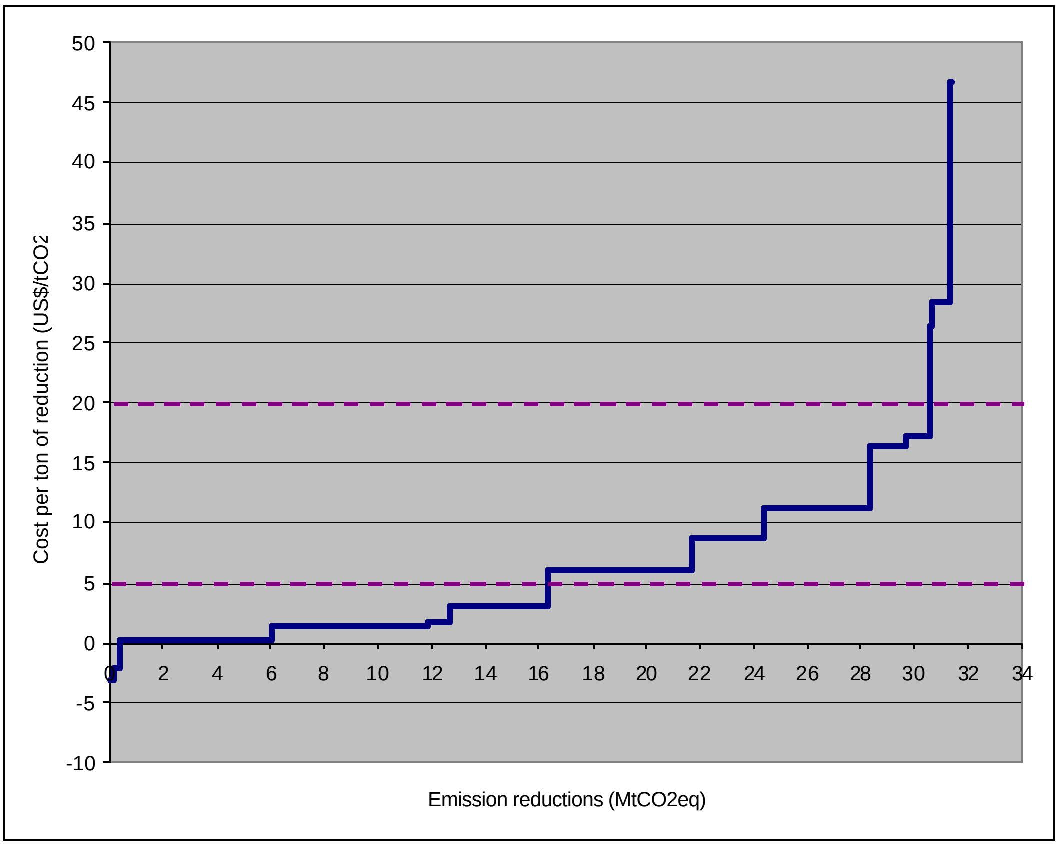


Figure 5



Cost per ton of reduction (US$/tCO2
50
45
40
35
30
25
20
15
10
5
0
-5
-10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
Emission reductions (MtCO2eq)

Table 1

(a) Base case: p2=10 ; Teta=0,05/year ; alpha=0

Regime	*B*	*B/C*	*C*
Price in period 1 or MAC in period 1 : Myopic	7,8	10,0	15,0
MAC in period 1 : Farsighted	7,8	10,0	11,4
Emission reductions : Myopic (MtCO2eq)	20,7	22,4	25,7
Emission reductions : Farsighted (MtCO2eq)	20,7	22,4	25,3
Total costs : Myopic (x1000 $)	108,9	61,9	-44,5
Total costs : Farsighted (x1000 $)	108,9	61,9	-52,1
Total costs difference (%)	0,0	0,0	*-14,6*

(b) Endowment effect: p2=10 ; Teta=0,05/year ; alpha=0,3

Regime	*B*	*B*	*B/C*	*C*
Price in period 1 or MAC in period 1 : Myopic	7,8	10,0	17,7	26,5
MAC in period 1 : Farsighted	0,2	2,3	10,0	12,5
Emission reductions : Myopic (MtCO2eq)	20,7	22,4	26,6	26,6
Emission reductions : Farsighted (MtCO2eq)	0,0	12,7	22,4	25,3
Total costs : Myopic (x1000 $)	267,4	233,1	105,5	-125,4
Total costs : Farsighted (x1000 $)	224,1	203,9	61,9	-148,9
Total costs difference (%)	19,3	14,3	70,5	*-15,8*

(c) Uncertainty effect: p2L=5 ; p2H=20 ; pi=1/3 ; Teta=0,05/year ; alpha=0

Regime	*B1/B2*	*B2*	*B2/C*	*C*
Price in period 1 or MAC in period 1 : Myopic	5,0	10,0	45,5	68,3
MAC in period 1 : Farsighted	5,0	6,9	20,0	26,4
Emission reductions : Myopic (MtCO2eq)	16,3	22,4	27,4	27,4
Emission reductions : Farsighted (MtCO2eq)	16,3	20,7	26,6	26,6
Total costs : Myopic (x1000 $)	120,2	36,7	-814,1	-1431,6
Total costs : Farsighted (x1000 $)	120,2	28,5	-837,5	-1441,8
Total costs difference (%)	0,0	29,1	*-2,8*	*-0,7*

(d) Endow. and uncert. effects: p2L=5; p2H=20; pi=1/3; Teta=0,05/yr; al=0,3

Regime	*B1/B2*	*B2*	*B2/C*	*C*
Price in period 1 or MAC in period 1 : Myopic	12,7	17,7	53,2	79,7
MAC in period 1 : Farsighted	5,0	6,9	20,0	27,5
Emission reductions : Myopic (MtCO2eq)	25,3	26,6	27,4	27,4
Emission reductions : Farsighted (MtCO2eq)	16,3	20,7	26,6	26,6
Total costs : Myopic (x1000 $)	197,6	105,5	-807,5	-1536,5
Total costs : Farsighted (x1000 $)	120,2	28,5	-837,5	-1543,7
Total costs difference (%)	64,4	270,9	*-3,6*	*-0,5*