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Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues[1]

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Abstract

Under the Kyoto Protocol, industrialized countries committed to emission reductions may fullfil part of their obligations by implementing emission reduction projects in developing countries. In doing so, they make use of the so-called Clean Development Mechanism (CDM). Two important issues surround the implementation of the CDM. First, if the cheapest abatement measures are implemented for CDM projects, developing countries may be left with only more expensive measures when they have to meet their own commitments in the future (the so-called low-hanging fruits issue). Second, a choice must be made on the type of baseline against which emission reductions are measured: an absolute baseline or a relative (to output) one (the baseline issue). The purpose of this paper is to study the interactions between these two issues from the point of view of the developing country. Two major results are obtained. First, when possible future commitments for developing countries and irreversibility of abatement measures are taken into account, we show that the industry where CDM projects are implemented enjoys larger profits under an absolute baseline than under a relative one. Second, concerning the low-hanging fruits problem, the financial compensation required by the developing country for implementing 'too many' CDM projects is larger under the relative baseline.

1 Introduction

In Kyoto, December 1997, industrialized countries agreed on greenhouse gas emission limitations for the period 2008-2012. The Kyoto Protocol allows for the use of several so-called flexible mechanisms, among which are (i) the trade of emission quotas between industrialized countries (Emissions Trading, Art. 17) and (ii) the possibility for industrialized countries to fullfil part of their obligations by reducing emissions in developing countries (not committed to emission limitations or reductions) via the implementation of specific projects (Clean Development Mechanism, Art. 6). Our focus here is on the second mechanism, the Clean Development Mechanism (CDM). On the one hand, the CDM should help industrialized countries to reduce their emissions at a lower cost than if they were not allowed to have access to the cheap reductions that can be found in developing countries. On the other hand, the CDM also shares the purpose of helping developing countries hosting emission reduction projects to develop in a sustainable way through the implementation of new and more efficient technologies.

When deciding on the amount of CDM projects to be implemented, developing countries must be aware that they may be facing own emission reduction commitments in the future. Since most emission abatement measures are irreversible, ignoring possible future commitments could lead to a problem that is very much debated in the forums of the Framework Convention on Climate Change of the United Nations, the so-called 'low-hanging fruits' (or cream-skimming) issue: the cheapest abatement measures will be implemented for CDM projects, leaving the developing countries with only more expensive measures when they have to meet their own commitments in the future.

Another issue which is much debated is the choice of the type of baseline against which emission reductions generated via the implementation of a CDM project are evaluated. Baselines may be either absolute or relative. Under *absolute* baselines, emission reductions are defined as the difference between estimated business-as-usual emissions and actual emissions. Under *relative* baselines, emission reductions are defined as the difference between the emissions rate (emissions per unit of output) under an estimated business-as-usual situation and the actual emissions rate, multiplied by the actual level of output.[1] [2]

The purpose of this paper is to analyze, from the point of view of a developing country, the interactions between the 'low-hanging fruits' (LHF) issue and the alternative types of baselines. The (sparse) literature on LHF considers only absolute baselines, while the literature on baseline types is mainly based on static models and therefore ignores the LHF issue. However, as it will be shown in this paper, both issues are related. Let us describe the results of the literature on each of these aspects before explaining the methodology of our analysis.

On the LHF issue, formal analyses are rather scarce. In an optimal control framework analogous to the Hotelling model of exhaustible natural resources, Rose et al. (1999) show the conditions under which the LHF problem may arise. In particular, developing countries would loose their low cost abatement options when cumulative abatement effects are present, as well as under market power and some forms of technological change. Akita (2001) –using a particular framework characterized by two types of projects (high-cost and low-cost projects, i.e., high-hanging fruits and low-hanging fruits)– shows that when the implementation of CDM projects leads to future domestic technological improvements, the developing country should, under certain conditions, implement high-cost projects first. If such conditions, bearing on the size of the technological improvement and on the amount of credits generated by the project, are met, then the LHF problem occurs when the low-cost projects are implemented first. Narain and van't Veldt (2001) indicate that the LHF issue is mischaracterized given that developing countries facing emission reduction commitments will also have access to the international permits market and will therefore not necessarily have to implement high-cost measures in the future. In their setting, the LHF problem shows up when project investors have market power as well as when the price of emission credits increases through time and, at the same time, the developing country is not able to auction off contracts for the future rising returns of the CDM projects. Bréchet et al. (2004) show that developing countries should in general participate to the CDM. They

[1] Various *methodologies* may be used to determine baselines. Fischer (2002) points out three of them: historical emissions, an average emissions standard for the industry and expected emissions. All three can be applied to both absolute and relative baseline types.

[2] Note that an important strand of the literature on the CDM (and related mechanisms) addresses the crucial issue of the incentives to overstate emission reductions (see e.g. Millock, 2002, and Fischer, 2002). Such incentives rest upon the difficulty to observe actual emission reductions. In this paper, we leave this issue aside and assume that the additionality condition of emission reductions is verified.

identify three effects that however limit the extent of such a participation: the fact that future allocations of permits to the developing country may vary according to the amount of CDM projects implemented, the change in permits prices through time and the uncertainty on future permits prices.

In fact, Rose et al. (1999), Narain and van't Veld (2001) and Bréchet et al. (2004) suggest that the LHF issue is no longer a problem if developing countries can be compensated for implementing or accepting the implementation of 'too many' CDM projects.[3] The level of this (financial) compensation is affected by the magnitude of the various effects –as identified in the different papers– that are responsible for the LHF problem. While these authors concentrate on absolute baselines, we will analyze how the level of such a compensation must be modified when relative baselines are used instead of absolute ones. This is of crucial concern since limits to the use of absolute baselines have been set at the seventh conference of the Parties to the Kyoto Protocol in Marrakesh (UNFCCC, 2001) and since relative baseline are used in methodologies for computing baseline emissions of small CDM projects while they are becoming increasingly important in all kinds of projects (see Executive Board of the CDM, 2003).

On the baseline issue (absolute versus relative), a few more analyses have been done. Janssen (2001) shows that investment projects are less risky under an absolute baseline than under a relative one. However, Laurikka (2002) shows that the relative baseline leads to more conservative emissions predictions while providing more appropriate investment incentives than an absolute baseline. Fischer (2001) points out that a relative baseline leads to a subsidy to production since the amount of emission credits generated are proportional to actual output. In that case, the total amount of reductions may be negatively affected because the relative baseline encourages a decrease in the emissions rate, not in the emissions themselves. However, other authors (see for instance Winkler and Thorne, 2002) state that such a subsidy effect is beneficial to sustainable development in some situations, including those where the project leads to the provision of goods (energy for instance) that would otherwise not be provided. Such analyses suggest that absolute baselines favor the environment (emission reductions) while relative baselines favor development (production).

However, these papers are not based on dynamic models including the fact that the developing county may later commit to emission reductions and that abatement

[3] This is also suggested in Millock (2002) who does not specifically analyse the LHF issue.

measures are usually irreversible. Moreover, their authors use various criteria in order to evaluate the relative performance of the two alternative types of baselines. Our purpose is to focus on the effect of the baselines on the situation of the developing country only, instead of deriving general recommendations on which baseline should be used.

In terms of methodology, we integrate both LHF and baseline issues by modelling absolute and relative CDM baselines in a dynamic framework which takes into account developing countries future commitments and the irreversibility of abatement measures. In order to account for relative baselines, a framework endogenizing production is needed. Moreover, due to the large uncertainties on post-Kyoto commitments, future permits prices are very uncertain. Our approach also takes this feature into account.

In the main part of the paper, we assume that the CDM projects are implemented following an unilateral approach as opposed to bi- or multilateral approach. Under an unilateral approach, the developing country (or an economic agent in this country) implements the CDM projects and sells itself the emission reduction credits to an Annex-I country (or an economic agent in this country). Under a bi- or multilateral approach, the projects are implemented by the Annex-I country (or a group of Annex-I countries) who bears the costs of such projects while receiving the emission reduction credits. Hence, the developing country keeps passive. We focus on the unilateral approach for two reasons. First, it is more realistic since we believe that, once a world market price emerges for emission permits and credits, developing countries will no longer keep passive. Second, this approach corresponds to the standard assumption in economics when markets are analyzed, that is, the trade surplus is shared among the participating agents. However, we will test the robustness of our results –obtained under the unilateral approach– under the bi- or multilateral approach.

The paper is organized as follows. In Section 2, we present the dynamic framework and model the behavior of a developing country hosting CDM projects when absolute baselines are used. The case of relative baselines is analyzed and compared to the absolute baselines one in Section 3. The issue of the low-hanging fruits is then discussed in Section 4. In these sections, it is assumed that CDM projects are implemented under an unilateral approach. The bi- or multilateral approach is then analyzed in Section 5. Finally, Section 6 summarizes the results and concludes.

2 Model

We consider two periods indexed by t ($t = 1, 2$). In the first period, the developing country has no commitment to reduce its emissions but is allowed to implement or host CDM projects. In the second period, the country faces an emissions constraint. Before describing the objective function of the developing country, we define its production function and describe some preliminary issues. These issues are related to (i) the baseline against which emission reductions via CDM projects are evaluated, (ii) the future commitments of the country –its future permits endowments–, (iii) the uncertainty on future permits prices and (iv) the irreversibility aspect of emission reductions.

2.1 Preliminaries

Since we want to model alternative baselines, we need a framework where production is endogenous. We therefore consider a representative industry of the host country whose production technology is described by a Cobb-Douglas function with decreasing returns to scale :

$$y_t = e_t^{\alpha} k_t^{\beta} \tag{1}$$

where y_t denotes output, e_t energy and k_t capital at time t, with α and β being strictly positive parameters ($0 < \alpha, \beta$ with $\alpha + \beta < 1$). We assume that the use of a certain amount of energy leads to the same amount of emissions of greenhouse gases.

To reduce its emissions, the industry may reduce its output or increase its energy efficiency, i.e., increase the capital-energy ratio (k/e). Since this ratio plays a key role in the analysis, we rewrite the production function in the following way

$$y_t = e_t^{\gamma} \lambda_t^{\beta} \tag{2}$$

where $\gamma = \alpha + \beta$ and

$$\lambda_t = k_t / e_t. \tag{3}$$

In our framework, CDM projects are considered as abatement measures that increase energy efficiency. The larger the amount of accepted CDM projects, the larger the energy efficiency (i.e., the larger the λ_t). Moreover, for a given level of output, the cost of increasing energy efficiency is increasing (marginal costs are increasing).

(i) CDM baseline - In the first period, the emission reductions generated via a CDM project are evaluated against either an absolute baseline or a relative baseline.

Under an absolute baseline, emission reductions are defined as the difference between estimated business-as-usual emissions and actual emissions. Formally, the total amount of credits generated are given by $e_1^{BAU} - e_1$ where e_1^{BAU} is the level of emissions when no reductions are undertaken, i.e., in the absence of the CDM (to be defined explicitly below). Under a relative baseline, emission reductions are defined as the difference between the emissions rate (emissions per unit of output) under an estimated business-as-usual situation and the actual emissions rate, multiplied by the actual level of output. Formally, the emission credits are given by $\left[\frac{e_1^{BAU}}{y_1^{BAU}} - \frac{e_1}{y_1}\right] y_1$ where y_1^{BAU} is the level of the output when no reductions are undertaken (to be defined explicitly below).

(ii) Permits endowment - In the second period, the developing country commits to emission reductions and receives an amount of emission permits $\overline{e}_2$ such that

$$\overline{e}_2 = \widetilde{e}_2 - \delta \left[e_1^{BAU} - e_1\right] \tag{4}$$

where $\widetilde{e}_2$ is an exogenous amount of emission permits and δ is a positive parameter ($0 \leq \delta \leq 1$). δ denotes the extent to which emission reductions undertaken in a developing country (via CDM) before its commitment may affect its future endowment of permits. Indeed, since post-Kyoto commitments for developing countries are not yet defined, there is a risk that earlier reductions (i.e., Kyoto period reductions) affect the reference level of emissions on which negotiations will be based.[4] The lower the δ, the higher the negotiation power of the developing country.

(iii) Uncertainty on permits prices - The emission credits generated via the CDM are fungible with the permits allocated to the countries committed to emission reductions. Therefore, we denote by τ_t the price of the permits/credits at period t. Since future permits prices are very uncertain, we assume that the agents only know the density function of the permits price in the second period, $f(\tau_2)$, with $\tau_2 \in [\tau_{\min}, \tau_{\max}]$, $0 < \tau_{\min} < \tau_{\max}$.

(iv) Irreversibility - There is some irreversibility in the decision to reduce emissions because, once implemented, the projects typically last more than one commitment period. Accordingly, if further emission reductions are to be taken subsequently, such reductions will be more costly than the former ones. As suggested by Rose et al. (1999),

[4] This problem is not specific to the CDM. In the context of a private polluting firm that must negotiate on a level of commitment with its authority, the issue of the recognition of 'early reductions' is a similar problem.

such an issue of irreversibility is best addressed in a vintage capital model. Since such models are heavy to handle, these authors rather use, in a continuous time framework, a general abatement cost function that depends on total cumulative abatement. Once low cost abatement measures have been undertaken, further reductions are necessarily more expensive. In a discrete time context, Narain and van't Veld (2001) and Bréchet et al. (2004) use a marginal abatement cost function that is truncated from one period to the other in order to reflect the irreversibility of the decisions over two periods and the fact that additional abatement measures in the future necessarily lead to larger marginal abatement costs.[5]

In order to take the irreversibility aspect into account, we assume that the energy efficiency indicator (the capital-energy ratio λ_t) cannot decrease through time. Once a cleaner technology has been implemented –with the purpose of reducing emissions–, it is not possible to go back and replace that technology by a dirtier one. Such an indirect interpretation of the irreversibility constraint stands well in line with the concept of 'clean development'. Formally, the irreversibility constraint reads as follows:

$$\lambda_2 \geq \lambda_1. \tag{5}$$

2.2 Objective function with an absolute baseline

Let us denote by p_e and p_k the price of, respectively, energy and capital, expressed in output units. All prices are deflated by the output price and, for simplicity, are assumed to be constant over time. In this context, the problem of the representative industry –which is assumed to be price-taker– reads as follows:

$$\max_{\{e_1 \geq 0, k_1 \geq 0\}} y_1 - [p_e e_1 + p_k k_1] + T_1 + \rho \int_{\tau_{\min}}^{\tau_{\max}} f(\tau_2) \, \Pi_2^* (e_1, k_1, \tau_2) \, d\tau_2 \tag{6}$$

subject to (1), (4) and (5) where T_1 is defined just below, ρ $(0 \leq \rho \leq 1)$ is the discount factor and

$$\Pi_2^* (e_1, k_1, \tau_2) = \max_{\{e_2 \geq 0, k_2 \geq 0\}} y_2 - [p_e e_2 + p_k k_2] + \tau_2 [\bar{e}_2 - e_2]. \tag{7}$$

The last term of (7), $\tau_2 [\bar{e}_2 - e_2]$, is the net sales of emission permits.

T_1 is the sales of CDM credits with

$$T_1 = \tau_1 \left[e_1^{BAU} - e_1 \right] \tag{8}$$

[5] As mentionned above, Akita (2003) uses a model with only two types of projects, a low cost and a high cost type projects, but he accounts for possible technological improvements.

where e_1^{BAU} is the value of e_1 solving problem (6) with $T_1 = 0$ (i.e., in the absence of the CDM). Under this formulation, CDM credits are generated with respect to an absolute baseline. We start the analysis with this standard approach. The case of a relative baseline is analyzed in section 3. Subscripts a and r will denote the value of a variable under, respectively, the absolute and the relative baseline assumptions.

Recalling (2), (3) and (8), we may rewrite problem (6) in the following way:

$$\begin{aligned} \max_{\{e_{a1}\geq 0, \lambda_{a1}\geq 0\}} \Pi_1 (e_{a1}, \lambda_{a1}, \tau_1) &= e_{a1}^{\gamma} \lambda_{a1}^{\beta} - [p_e + p_k \lambda_{a1}] e_{a1} + \tau_1 \left[e_1^{BAU} - e_{a1} \right] \\ &+ \rho \int_{\tau_{\min}}^{\tau_{\max}} f(\tau_2) \Pi_2^* (\lambda_{a1}, \tau_2) d\tau_2 \end{aligned} \quad (9)$$

subject to (4)-(5) where $\gamma = \alpha + \beta$ and

$$\Pi_2^* (\lambda_{a1}, \tau_2) = \max_{\{e_{a2}\geq 0, \lambda_{a2}\geq 0\}} e_{a2}^{\gamma} \lambda_{a2}^{\beta} - [p_e + p_k \lambda_{a2}] e_{a2} + \tau_2 [\bar{e}_2 - e_{a2}] . \quad (10)$$

Note that e_1^{BAU} and $\bar{e}_2$ are not indexed by a since $\bar{e}_{a2} = \bar{e}_{r2}$ and $e_{a1}^{BAU} = e_{r1}^{BAU}$. This problem is solved by backward induction, starting with the second period.

2.3 Behavior in the second period

The solution of problem (10) leads to two solution regimes according to whether the irreversibility constraint (5) is binding or not.

Proposition 1 The solution of problem (10) is characterized by

$$\begin{aligned} \lambda_{a2} &= \max \left\{ \lambda_{a1}, \frac{[p_e + \tau_2] / \alpha}{p_k / \beta} \right\} \\ e_{a2} &= \left[\frac{(\lambda_{a2}^*)^{\beta} \gamma}{p_k \lambda_{a2}^* + p_e + \tau_2} \right]^{\frac{1}{1-\gamma}} \end{aligned}$$

Proof *Straightforward.* ■

The irreversibility constraint corresponds to $\frac{[p_e+\tau_2]/\alpha}{p_k/\beta} \geq \lambda_{a1}$. It is more likely to be binding when the price of the energy in the second period, including the permits price, is relatively low. This means that it would be more interesting to substitute energy (and therefore emissions) to capital, which is not possible given the constraint. In that case, the welfare in the second period decreases with respect to an unconstrained situation.

When the irreversibility constraint is not binding, the situation is standard: the levels of emissions and capital are directly determined by their prices, i.e., the price for the use of energy (p_e), the price of an emission permit in the second period (τ_2) and the price of the capital (p_k).

When the irreversibility constraint is binding, the technology is characterized by the same capital-energy ratio as in the first period. Then, the levels of the inputs also depend on the capital-energy ratio of the previous period (λ_{a1}). However, these levels need not be the same as in period 1. They may be both either larger or smaller.

2.4 Behavior in the first period

When the irreversibility constraint is not binding, the value of (10), $\Pi_2(\cdot)$, does not depend on the first period decisions. Otherwise, $\Pi_2(\cdot)$ decreases with the strength of the irreversibility constraint. We now state the existence and the unicity of the solution of problem (9) and we characterize this solution.

Proposition 2.a **(i)** A solution to problem (9) exists.
(ii) A sufficient condition for the solution to be unique is that (a) either the returns to scale are sufficiently decreasing for given relative permits prices (τ_1/p_e) or (b) the relative permits price is sufficiently low for given returns to scale.
(iii) Then, the solution of problem (9), is characterized by

$$\lambda_{a1} = \frac{[p_e + \tau_1 - \rho\delta\widetilde{\tau}_2]/\alpha}{p_k/\beta} \quad \text{if} \quad 0 \leq \tau_1 \leq \tau_{2\min} + \rho\delta\widetilde{\tau}_2 \tag{11}$$

$$\lambda_{a1} < \frac{[p_e + \tau_1 - \rho\delta\widetilde{\tau}_2]/\alpha}{p_k/\beta} \quad \text{if} \quad \tau_{2\min} + \rho\delta\widetilde{\tau}_2 < \tau_1 \tag{12}$$

Proof *See appendix (Sections 1 and 2.a).* ■

The sufficient condition for unicity (formally established in the Appendix) is in fact satisfied for all reasonable values of the parameters.[6] Moreover, it must be emphasized that it is a sufficient condition, not a necessary one.

The shape of the capital-energy ratio, λ_{a1}, is illustrated in Figure 1. The effects of the following three components are highlighted: the endowment, the irreversibility constraint and the uncertainty on the future permits price. Let us first assume that, at the same time, emission reductions have no impact on future endowments ($\delta = 0$), the irreversibility constraint is not taken into account and there is no uncertainty. Then,

[6] Consider for instance the following parameter values: $\alpha = .2$, $\beta = .7$, $\rho = .9$, $\delta = .5$, $p_e = 1$, $p_k = .25$, $\tau_{2\min} = .1$ and $\tau_{2\max} = .9$ with a uniform density function. Then, the sufficient condition is satisfied $\forall\gamma \leq 0.94$.

the solution is characterized by S0 (S0$\equiv$ $\lambda_{a1} = \beta\,[p_e + \tau_1]\,/\,[\alpha p_k]$). The optimal value of the capital-energy ratio is linear in the first period permits price.

Let us now introduce successively each of the components described above and analyse how they affect the capital/energy ratio.

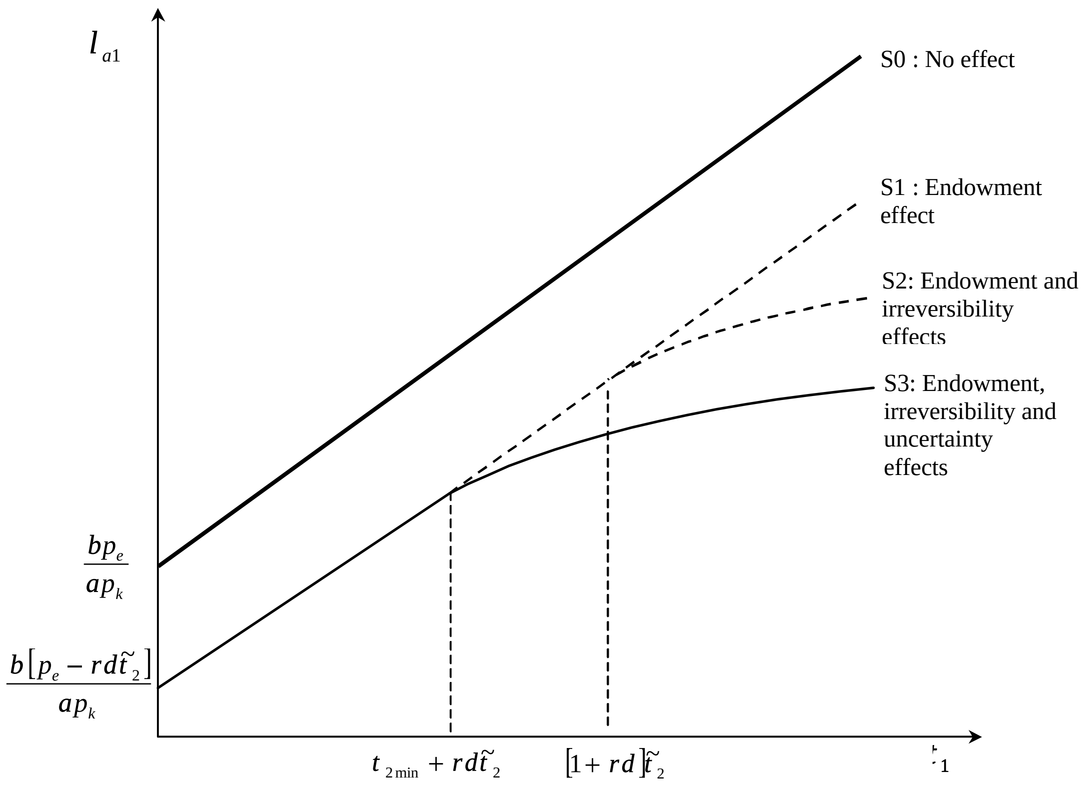

Figure 1: The capital-energy ratio as a function of the permits price

S1 is the locus of solutions when only the endowment effect is present (i.e., $\delta > 0$) (S1$\equiv$ $\lambda_{a1} = \beta\,[p_e + \tau_1 - \rho\delta\widetilde{\tau}_2]\,/\,[\alpha p_k]$). Indeed, in that case the country anticipates the fact that emission reductions in the first period lead to a loss in the second period permits endowments, which are valued at the expected price $\widetilde{\tau}_2$. Therefore, such an effect discourages emission reductions (i.e., implementation of CDM projects) in the first period.

S2 is the locus of solutions for the capital-energy ratio when both the endowment and the irreversibility effects are taken into account (i.e., $\delta > 0$ and $\lambda_1 \leq \lambda_2$). In such a situation, the irreversibility constraint is *not* binding when and only when $\tau_1 \leq [1 + \rho\delta]\,\widetilde{\tau}_2$. Indeed, if the permits price increases from $t = 1$ to $t = 2$, the country substitutes capital to energy since their relative prices change. However, if the permits price decreases, a substitution of energy to capital is not feasible due to the irreversibility constraint and the energy efficiency is too large given the level of the second period permits price. Therefore the irreversibility constraint will be binding in the second period, which is anticipated by the choice of a lower level of the capital-energy ratio in the first period (S2 is below S1 for all $\tau_1 > [1+\rho\delta]\,\widetilde{\tau}_2$).

Finally, S3 is the locus of solutions when there is also uncertainty on future permits prices. In that case, there is a probability that the irreversibility constraint becomes binding if the first period permits price is larger than the lowest possible value of the second period permits price, $\tau_{2\min}$ (see the horizontal axis of Figure 1). This is taken into account in the first period by the choice of a lower capital-energy ratio w.r.t. the situation without uncertainty: S3 departs from S1 earlier than S2 and, for all τ_1, S3 is below S2.

The above considerations on λ_{a1} are only related to the input substitution effect due to a change in factor prices. However, the absolute levels of the inputs, and therefore of the production, are also determined by a production contraction effect. We have the following proposition:

Proposition 2.b Optimal emissions (e_{a1}) are a decreasing function of τ_1 whereas optimal production (y_{a1}) and capital (k_{a1}) are bounded by decreasing functions of τ_1.

Proof *See appendix (Section 2.b).* ■

Hence, we are able to prove that, as a trend, y_{a1} and k_{a1} decrease with τ_1. Moreover, numerical simulations show that these decision variables are indeed monotonically decreasing in τ_1.

As expected, the increase in the price of an input leads to a decrease of both inputs, and consequently, to a decrease in the output level. This is a rather standard result. However, we show below that this need not be the case when the CDM baseline is a relative one.

3 Relative instead of absolute CDM baseline

Under a relative baseline, CDM credits are generated in proportion to output when the emissions-output ratio decreases. Hence,

$$T_{1r} = \tau_1 \left[\frac{e_1^{BAU}}{y_1^{BAU}} - \frac{e_1}{y_1} \right] y_1 \tag{13}$$

where e_1^{BAU} and y_1^{BAU} are the values of, respectively, e_1 and y_1 solving problem (6) with $T_1 = 0$ (i.e., in the absence of the CDM).[7] Then, under a relative baseline, (9) becomes:

$$\max_{\{e_1 \geq 0, \lambda_1 \geq 0\}} \left[1 + \tau_1 \frac{e_1^{BAU}}{y_1^{BAU}}\right] e_1^{\gamma} \lambda_1^{\beta} - [p_e + p_k \lambda_1 + \tau_1] e_1 + \rho \int_{\tau_{\min}}^{\tau_{\max}} f(\tau_2) \Pi_2^* (\lambda_1, \tau_2) d\tau_2 \tag{14}$$

subject to (4)-(5) where

$$\Pi_2^* (\lambda_1, \tau_2) = \max_{\{e_2 \geq 0, \lambda_2 \geq 0\}} e_2^{\gamma} \lambda_2^{\beta} - [p_e + p_k \lambda_2] e_2 + \tau_2 [\overline{e}_2 - e_2] \tag{15}$$

subject to (4)-(5).

The objective is thus similar to the one under absolute baselines. However, as mentioned in earlier studies (see e.g. Fischer 2001, 2002), such a relative baseline leads to an implicit subsidy to production. The value of this subsidy depends on the permits price (τ_1) and on the reference emissions-output ratio. It is equal to $\tau_1 \frac{e_1^{BAU}}{y_1^{BAU}}$ per unit of output.

Proposition 3.a (i) A solution to problem (14) exists.
(ii) A sufficient condition for the solution to be unique is that (a) either the returns to scale are sufficiently decreasing for given relative permits prices (τ_1/p_e) or (b) the relative permits price is sufficiently low for given returns to scale.
(iii) Then, the solution is characterized by

$$\lambda_{r1} = \lambda_{a1} = \frac{[p_e + \tau_1 - \rho\delta\widetilde{\tau}_2]/\alpha}{p_k/\beta} \quad \text{if} \quad 0 \leq \tau_1 \leq \tau_{2\min} + \rho\delta\widetilde{\tau}_2 \tag{16}$$

$$\lambda_{a1} < \lambda_{r1} < \frac{[p_e + \tau_1 - \rho\delta\widetilde{\tau}_2]/\alpha}{p_k/\beta} \quad \text{if} \quad \tau_{2\min} + \rho\delta\widetilde{\tau}_2 < \tau_1 \tag{17}$$

Proof *See appendix (Section 3.a).* ■

The sufficient condition for unicity is the same as the one presented above in proposition 2.a, related to the absolute baseline case.

[7] In this respect, we follow the approach of Laurikka (2002).

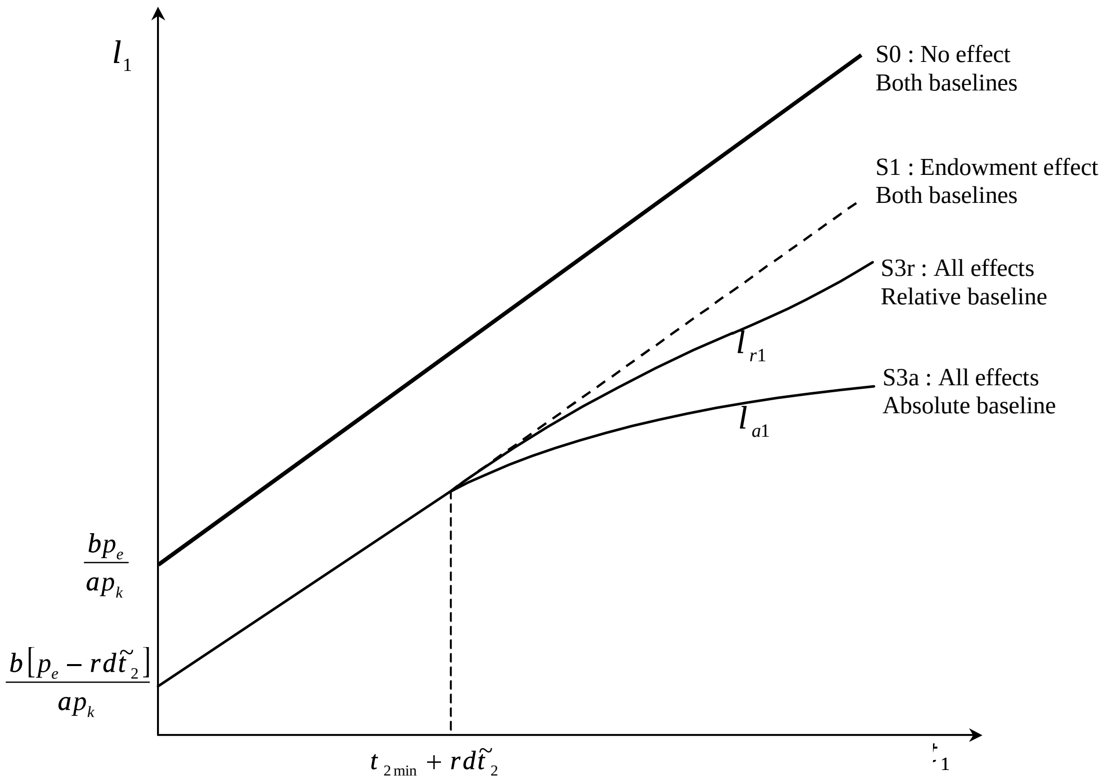

Figure 2. The capital-energy ratio under both baselines

Figure 2 illustrates the comparison of the capital-energy ratios under both baselines. The following observations can be made. First, when no effects are present, it is not surprising to observe the same substitution effect under both baselines (i.e., $\lambda_{r1} = \lambda_{a1}$, see S0) since relative input prices are exogenous and do not change with the baseline. Second, the endowment effect plays in the same way for both baselines (see S1). Third, the other elements (irreversibility and uncertainty) start to have an impact on the solution at the same level of τ_1 (at $\tau_{2\min} + \rho\delta\widetilde{\tau}_2$ precisely). Moreover, when the irreversibility constraint is binding, the irreversibility and uncertainty effects are stronger under the absolute baseline than under the relative one ($\lambda_{a1} < \lambda_{r1}$, see S3a and S3r). Indeed, the gains in the first period, relative to those in the second period, are larger under the relative baseline due to the subsidy effect identified above. Therefore, the cost of being left with too efficient equipments in the second period (the irreversibility constraint binding) is relatively lower than under the absolute baseline. Accordingly, it is in the interest of the country to go further in the substitution of inputs with respect to the absolute baseline case.

As far as production and emissions are concerned, we state the following result:

Result 3.b Optimal production and emissions (y_{r1} and e_{r1}) are decreasing and then increasing (U-shaped) w.r.t. τ_1, with argmin $y_{r1}(\tau_1) <$ argmin $e_{r1}(\tau_1)$. Optimal capital (k_{r1}) is increasing w.r.t. τ_1. ■

This result is rigorously proven for low and high values of τ_1 (see the appendix, section 3.b). Numerical simulations confirm it for all values of τ_1. Moreover:

Proposition 3.c

$$\begin{aligned} y_{r1} &\geq y_{a1} \\ k_{r1} &\geq k_{a1} \end{aligned}$$

Proof *See appendix (Section 3.c).* ■

We also observe numerically that $e_{r1} \geq e_{a1}$, which is not surprising since $y_{r1} \geq y_{a1}$.[8] Hence, the production subsidy always leads to higher levels of output, and therefore of inputs.

The absolute values of the inputs, and therefore of the output, need not be the same, even if the constraint is not binding ($\lambda_{r1} = \lambda_{a1}$). Figure 3 illustrates the shape of emissions and production under absolute and relative baselines (see ea, ya and er, yr respectively).[9] Under the absolute baseline, the rise in the permits price leads to the usual inputs substitution and output contraction effects (see Proposition 2.b). These effects tend to decrease the levels of both emissions and production. Under the relative baseline, the subsidy effect plays in the other direction. This effect tends to increase production, and therefore emissions. The subsidy is equal to $\tau_1 \frac{e_1^{BAU}}{y_1^{BAU}}$ per unit of output (recall (14)) and is thus a linear function of the permits price τ_1. Figure 3 shows that if τ_1 is sufficiently high, the subsidy effect overcomes the output contraction effect due to the increase in the total energy price, so that output increases through the

[8] Note that in the case of the absolute baseline, the implementation of CDM projects does not lead to changes in world emissions. However, under relative baselines, world total emissions either decrease (for low values of τ_1) or increase (for high values of τ_1) throught the implemention of CDM projects. Indeed, supplementary emissions by industrialized countries amount to $\overline{e}_1 [y_{1r}/\overline{y}_1] - e^*_{r1}$ while emission reductions by the developing country are $\overline{e}_1 - e^*_{r1}$. Therefore, total world emissions change by the following amount: $\overline{e}_1 [[y_{1r}/\overline{y}_1] - 1]$. This change is negative if $y_{1r} < \overline{y}_1$, which occurs when τ_1 is low (see Result 3 b), and positive if $y_{1r} > \overline{y}$, which occurs when τ_1 is high.

[9] This figure corresponds to the following parameter values: $\alpha = .2$, $\beta = .7$, $\rho = .9$, $\delta = .5$, $p_e = 1$, $p_k = .25$, $\tau_{2\min} = .1$ and $\tau_{2\max} = .9$ with a uniform density function. For comparison purposes, the figure also shows emissions and production under an absolute baseline.

implementation of CDM projects. For even larger values of τ_1, this increase of output overcomes the substitution of capital to energy effect due to the change in factor prices, so that emissions grow with τ_1.

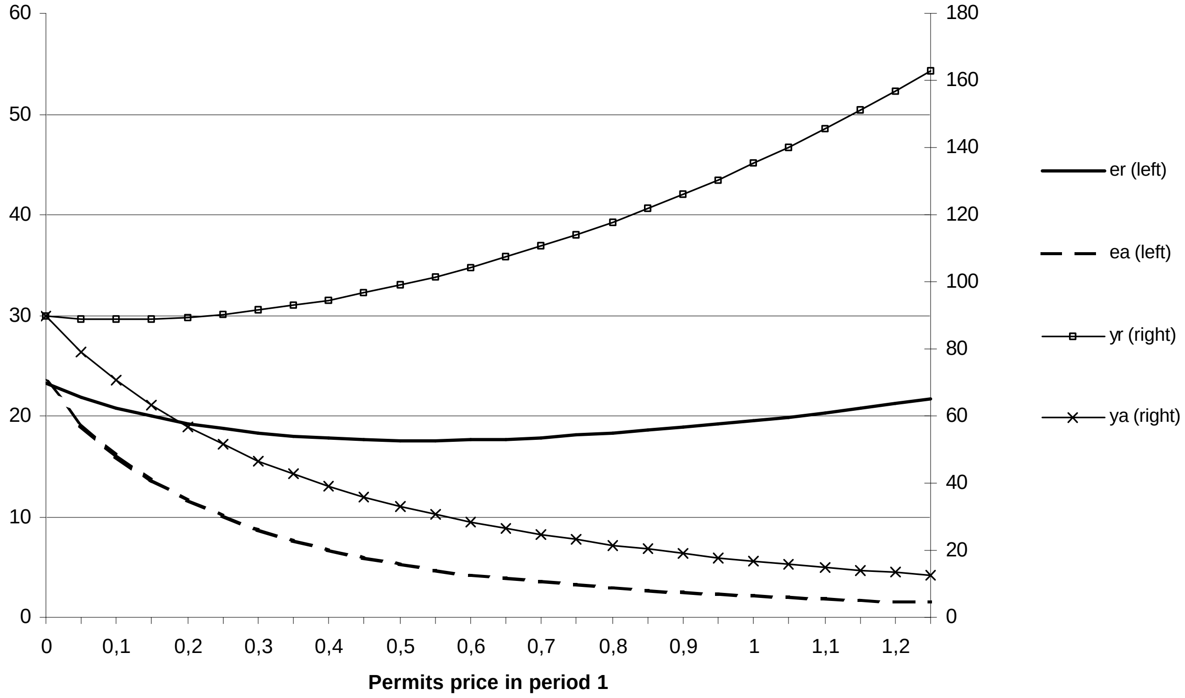

Figure 3 - Emissions and output under absolute and relative baselines

Figure 3 also suggests that, at least for some ranges of the price of permits in period 1, it is possible to find situations where emissions are reduced and output is increased under a relative baseline. Such situations seem to fit very well with the purpose of the CDM: allowing for both emission reductions and development (i.e., increasing production) at the same time.

The comparison of the profits under both baselines leads to the following important result:

Proposition 3.d

$$\Pi^*_{r1} \leq \Pi^*_{a1}$$

where Π^*_{a1} and Π^*_{r1} are the solution of respectively problem (9) and problem (14), if either (a) the returns to scale are sufficiently decreasing for given relative permits prices (τ_1/p_e) or (b) the relative permits price is sufficiently low for given returns to scale.

Proof *See appendix (Section 3.c).* ■

Proposition 3.c provides a sufficient (but not necessary) condition for this result to hold. This condition is satisfied for all reasonable values of the parameters.

Surprisingly, profits are larger under the absolute baseline than under the relative one. One could have indeed expected that the subsidy, by increasing the level of output, also leads to larger profits. Let us give a tentative description of this result by decomposing the profit under both baselines into four components: (i) the first period current profit without the revenues from CDM credits sales (call it $\widetilde{\pi}_{i1}$), (ii) the first period revenue from the sales of CDM credits (T_{i1}), (iii) the second period current expected profit without the net sales of permits ($E\left(\widetilde{\pi}_{i2}\right)$) and (iv) the second period expected revenue (spending) from the net sales (purchases) of permits ($E\left(T_{i2}\right)$).

From such a decomposition, one can make the following observations. In $t = 1$, both $\widetilde{\pi}_{i1}$ and T_{i1} are much larger under the absolute baseline. In $t = 2$, $E\left(T_{i2}\right)$ is larger under the relative one while $E\left(\widetilde{\pi}_{i2}\right)$ have almost the same value under both baselines.

In the first period, for any τ_1, the subsidy effect under the relative baseline leads to a level of production that is beyond the one selected under the absolute baseline. The choice is somehow 'distorted' by the presence of the subsidy. Hence, the first period current profit $\widetilde{\pi}_{i1}$ (which does not take the CDM revenues into account) is necessarily lower under the relative baseline than under the absolute one. Moreover, the CDM revenues are larger under the absolute baseline. In fact, the absolute baseline is more generous than the relative one in period 1.

In the second period, the difference between the current profit $E\left(\widetilde{\pi}_{i2}\right)$ under both baselines can only come from the irreversibility constraint. Since this constraint is more stringent under the relative baseline ($\lambda_{a1} \leq \lambda_{r1}$), $E\left(\widetilde{\pi}_{i2}\right)$ tends to be larger under the absolute baseline. However, we observe that the constraint plays a minor role in that respect. On the contrary, $E\left(T_{i2}\right)$ is significantly larger under the relative baseline. This is only due to the permits endowment effect: under the relative baseline, fewer reductions take place in the first period, which tends to attenuate the permits endowment effect, that is, to increase the initial allocation of permits w.r.t. the absolute baseline situation.

Thus, as a whole, we observe that the effects favoring the absolute baseline dominate those favoring the relative one.

4 The 'low-hanging fruits' issue

Despite the transfers of clean technologies associated with the implementation of CDM projects, developing countries have been somewhat reluctant to participate in the CDM. Such a reluctance is often said to be based on the 'low-hanging fruits' (LHF) issue: the cheapest abatement measures will be implemented for CDM projects, leaving the developing countries with only more expensive measures when they have to meet their own emission reduction commitments in the future.

Analyses in the previous sections have implicitly tackled this issue and suggest that the LHF problem is unfounded. First, recall that, in the present context, the implementation of CDM projects corresponds to an increase in the capital-energy ratio (λ). We have shown that it is always optimal for the developing country to implement CDM projects for every strictly positive permits price ($\lambda_{i1}(\tau_1) > \lambda_{i1}(0), \forall \tau_1 > 0, i = a, r$). Hence, developing countries should always participate in the CDM and implement at least some projects.

Second, low cost abatement projects are always implemented first (since the capital energy ratio is increasing with the permits price). Therefore, it would never be optimal for a developing country to keep its low-hanging fruits (low cost projects) for future use and implement its high cost projects first. This suggests that, at least in our context, the terminology 'low-hanging' is inappropriate.

Third, the above analyzes have shown that the developing country should accept the implementation of all CDM projects up to a certain threshold determined by the optimal capital-energy ratio $\lambda_1(\tau_1)$. The developing country should not accept the implementation of supplementary projects *unless* it receives the appropriate financial compensation.

We study now how the extent of this compensation varies with the context under consideration, more particularly the type of baseline and the level of the permits price. Figure 4 illustrates the compensation as a function of the capital energy ratio, λ_1. For each λ_1, the figure shows $\Pi_{i1}(\lambda_{i1}) - \Pi_{i1}(\lambda_1)$, $(i = a, r)$, for three alternative values of τ_1, where λ_{i1} is the optimal value of the ratio for the corresponding baseline (and permits price). [10] [11]

[10] As mentionned on the figure, the three alternative prices are 0.25, 0.7 and 1.15. The other parameter values are the same as those used in Figure 2: $\alpha = .2$, $\beta = .7$, $\rho = .9$, $\delta = .5$, $p_e = 1$, $p_k = .25$, $\tau_{2\,\min} = .1$ and $\tau_{2\,\max} = .9$ with a uniform density function.

[11] All lines start with a compensation that is equal to zero since we start with very small (always

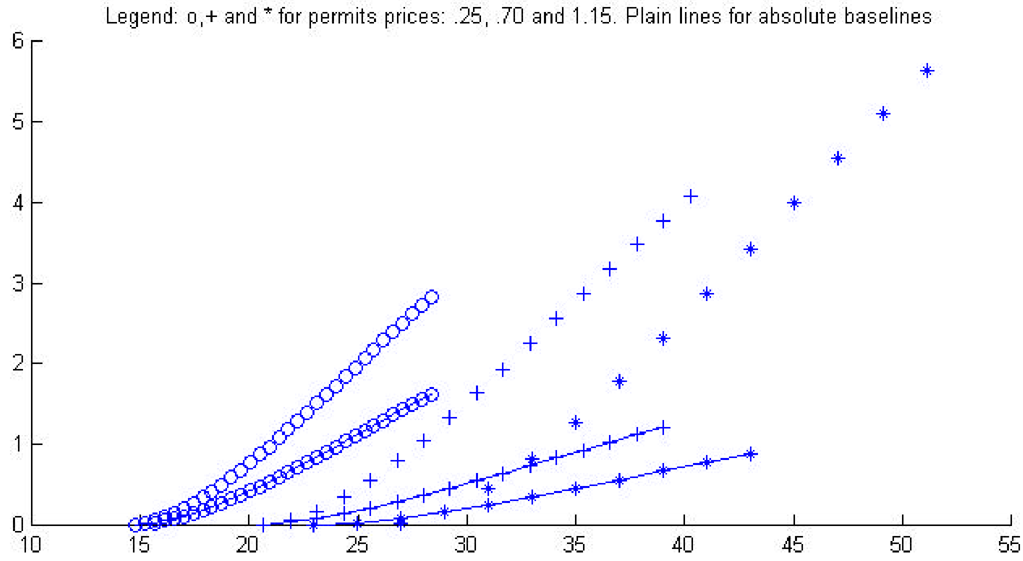

Figure 4 - Compensation (vert. axis) as a function of the capital-energy ratio (horiz. axis)

Such an analysis leads to the following three observations.[12] (i) For a given τ_1 and for a given baseline, the compensation increases with the amount of CDM projects implemented beyond the optimal level. This is fairly intuitive. (ii) For a given τ_1 and for a given $\Delta\lambda = \lambda_1 - \lambda_{i1}$, the compensation is larger under relative baselines than under absolute ones (although the optimal profits are always larger under the absolute baseline). (iii) For a given baseline and for a given $\Delta\lambda$, the effect of an increase in the permits price ($\Delta\tau_1$) differs according to the baseline used: the compensation decreases significantly with the permits price under absolute baselines while it does not vary significantly under relative baselines (same shape of the curves).

Finally, particular attention must be devoted to sensitivity analyses related to the endowment effect (δ) and the uncertainty on future permits prices. An increase in the δ parameter (measuring the extent to which future allocation of permits are affected by current emission reductions) leads to a strong increase in the level of the compensation. An increase in the level of uncertainty on future permits prices also raises the compensation, but by a small amount. These results are observed under both baselines.

positive) values of $\Delta\lambda$. We limit these variations ($\Delta\lambda$) up to 100% of the corresponding optimal capital-energy ratio.

[12]Sensitivity analyses on the parameters have been performed and confirm the robustness of our results.

5 Multilateral instead of unilateral CDM projects

In sections 2 to 4, the way of modelling the behavior of a representative industry corresponds to what is usually called the unilateral approach as opposed to bi- or multilateral approach (see the discussion in Section 1). One may however wonder if the above results still hold in a multilateral approach. The purpose of this section is to give some insights on it. To simplify the analysis, we shall assume that there is no uncertainty and that future allocations of permits are not affected by the amount of emission reductions in the first period ($\delta = 0$).

Let then $\varphi \in [0, 1]$ be the share of net revenues (from the implementation of the CDM project) that comes in the hands of the developing country. If no CDM projects are implemented, the profit of the industry in the developing country reads as $\pi_1 \left(\overline{\lambda}_1\right) + \rho\pi_2 \left(\overline{\lambda}_1\right)$ where $\overline{\lambda}_1 = \frac{\beta p_e}{\alpha p_k}$. In this formulation, π_t is the current profit of the industry at time t. Hence, π_1 should not be confused with Π_1 that corresponds to the profit of the industry over both periods 1 and 2.[13] If CDM projects are implemented, its profit reads as

$$\pi_1 \left(\overline{\lambda}_1\right) + \varphi \left[\pi_1 (\lambda_{i1}) - \pi_1 \left(\overline{\lambda}_1\right)\right] + \rho\pi_2 (\lambda_{i1}), \; i = a, r \tag{18}$$

since it gets only a fraction φ of the CDM revenues. When $\varphi = 1$, we are back to the unilateral projects context.

The industry in the developing country will implement CDM projects only if such an implementation leads to higher profits than without it, that is, $\pi_1 \left(\overline{\lambda}_1\right) + \rho\pi_2 \left(\overline{\lambda}_1\right) < \pi_1 \left(\overline{\lambda}_1\right) + \varphi \left[\pi_1 (\lambda_{i1}) - \pi_1 \left(\overline{\lambda}_1\right)\right] + \rho\pi_2 (\lambda_{i1})$. This will always be the case for

$$\varphi \geq \underline{\varphi}_i = \frac{\rho \left[\pi_2 \left(\overline{\lambda}_1\right) - \pi_2 (\lambda_{i1})\right]}{\pi_1 (\lambda_{i1}) - \pi_1 \left(\overline{\lambda}_1\right)}, \; i = a, r. \tag{19}$$

If $\tau_1 \leq \tau_2$, the irreversibility constraint is not binding and $\pi_2 \left(\overline{\lambda}_1\right) = \pi_2 (\lambda_{i1})$, with $\underline{\varphi}_i = 0$. Therefore, the analysis is the same as under unilateral projects and the developing country implements CDM projects up to $\lambda_{i1} = \frac{\beta[p_e + \tau_1]}{\alpha p_k}$.

If $\tau_1 > \tau_2$, the irreversibility constraint is binding ($\overline{\lambda}_1 < \lambda_{i1} = \lambda_{i2}$) and $\pi_2 \left(\overline{\lambda}_1\right) > \pi_2 (\lambda_{i1})$, with $\underline{\varphi}_i > 0$. Hence, the share of the CDM revenues that the host country obtains must be sufficiently large in order to induce it to implement some projects. This is a new result compared to the unilateral projects context where the developing country always has incentives to participate in the CDM.

[13] Since we model only two period, $\pi_2 = \Pi_2$.

Moreover, when it participates in the CDM (i.e., when $\underline{\varphi}_i \leq \varphi < 1$ and $\tau_1 \geq \tau_2$), the developing country implements fewer projects under a multilateral approach than under an unilateral one. Indeed, as it can be seen from (18), $\varphi < 1$ implies that a lower weight is attributed to the first period relative to the second one. Accordingly, profit losses due to the irreversibility constraint (when binding) are relatively more important in such a situation than under unilateral projects, which leads to the choice of a lower level of the energy intensity than when $\varphi = 1$.

6 Conclusion

The purpose of this paper has been to analyze the interactions between the 'low-hanging fruits' issue and the alternative types of baselines from the point of view of a developing country. This has been done by modelling both absolute and relative baselines while taking into account future emission reduction or limitation commitments and as well as the irreversibility aspect of abatement measures.

In this framework, the relative baseline leads to a larger amount of production than the absolute baseline. Indeed, under a relative baseline emission reduction credits play the role of a subsidy to production. However, we have shown that the developing countries' industries where emission reductions take place always enjoy larger profits under the absolute baseline. When these profits can be interpreted as a proxy of the budget devoted to consumption, developing countries governments maximizing its citizens utility of consumption should foster the use of absolute baselines. Such a result is of particular concern since current developments tend to be directed towards the use of relative baselines.

When the developing country implements by itself CDM projects (in an unilateral context, that is the country is not passive and captures its part of the trade surplus), we have also highlighted the fact that the 'low-hanging fruits' problem is unfounded, whatever the type of baseline under consideration: developing countries should always implement at least some CDM projects, and should start by the low cost ones first. Moreover, the extent of the compensation that such a country should require if too many projects were to be implemented has been analyzed. Such a compensation is larger under a relative baseline than under an absolute one (although absolute baselines lead to larger profits). It always increases with the number of projects implemented and the extent to which future allocations of permits are affected by emission reductions due to the CDM also plays a key role on the size of this compensation. Moving to a situation in which the developing country captures only part of the surplus (i.e., in a bi or multilateral context) does not change fundamentally the results, except that, for large values for the first period permits price (i.e., when the irreversibility constraint is binding), the developing country needs to receive a minimal share of the surplus in order to have incentives to accept some CDM projects.

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