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Efficacy of the clean development mechanism in reducing greenhouse gas emissions: a theoretical model

Abstract

In this research a theoretical model is put forward, which explains the impact of the clean development mechanism (CDM) on greenhouse gas emissions in Annex I and non-Annex I countries. This paper shows that on the one hand, emissions in the non-Annex I country decline because of abatement sponsored by the Annex I country under the CDM; on the other hand, global emissions may increase because (1) the Annex I country increases emissions in its own country after obtaining the Certified Emission Reduction (CER) credits, and (2) the non-Annex I country crowds out the benefits from the CDM projects by increasing its domestic emissions. For the CDM to be effective in reducing global emissions, the model demonstrates why partial CER credits should be given to the Annex I country that sponsors CDM projects in the non-Annex I country. The article also suggests that the CDM Executive Board should allow the CDM projects to be hosted by the non-Annex I countries that are producing at their optimum level because they have sufficiently high tolerance for pollution. The model explains why such countries will not expand their production and thus domestic emission in response to abatement sponsored by the Annex I country under the CDM project.

Keywords: clean development mechanism (CDM), Kyoto Protocol, emission, abatement, incentive.

JEL Classification: D01, Q54, Q58.

Introduction

In response to the pressing concern over the problem of climate change due to high concentration of greenhouse gases (GHGs) in the atmosphere, the international community agreed on the United Nations Framework on Climate Change Convention (UNFCCC) in 1992. The ultimate aim of this international convention is to reduce the GHG emissions. To put together concrete mechanisms to be adopted by the member countries, 40 Annex I countries ratified the Kyoto Protocol, which is an international agreement linked to the UNFCCC. The major feature of the Kyoto Protocol is that it sets binding targets for the Annex I countries to reduce the GHG emissions by 2012 (UNFCCC, 2010). The recently concluded United Nations Climate Change Conference in Durban, South Africa at the end of 2011 brought together the conclusions at previous conferences specifically the Kyoto Protocol, Bali Action Plans and the Cancun Agreements and agreed that a legally binding deal would be prepared by 2015 which the member states should adhere to (UNFCCC, 2011).

The Kyoto Protocol offers the Annex I countries some flexibility in meeting their emission reduction targets by introducing 3 mechanisms, namely emission trading scheme (ETS), clean development mechanism (CDM) and joint implementation (JI). ETS allows countries that have not used all the emission permitted to them to sell their excess capacity to countries that have exceeded their targets. JI allows the Annex I countries to pay for emission reduction projects in other Annex I countries. CDM allows the Annex I countries to invest in GHG reduction projects or ventures in the non-Annex I countries as an alternative to

more expensive emission reductions in their own countries. Among these different innovative mechanisms under the Kyoto Protocol, this paper focuses on evaluating the efficacy of the CDM in reducing GHG emissions in Annex I and non-Annex I countries by using a theoretical framework.

The objectives of CDM are twofold: first, it helps Annex I countries to achieve their emission reduction targets by earning emission reduction credits from their investment in the emission reduction projects in non-Annex I countries, and second, it contributes towards sustainable development in non-Annex I countries. However, the question arises about the net impact of the CDM – will it actually lead to a reduction in global GHG emissions? This is the key concern we try to address in this paper, with the aid of a theoretical model.

According to the World Bank (2010, p. 262), the CDM is expected to produce carbon dioxide emission reduction of around 1.5 billion tonnes between 2001-2012. Most of these reductions are through renewable energy, energy efficiency, and fuel switching. Wara (2007) points out that about two thirds of the CDM projects are not involved in reducing carbon dioxide, which is key if we are to tackle global warming. He recommends that CDM should aim at reducing carbon dioxide and, in the future, emphasis should be placed on tackling global warming.

Carbon Trust (2009) points out that there are difficulties involved in judging whether or not projects truly make additional savings in GHG emissions. Environmental NGOs have argued that the diverse interpretations of additionality from the CDM could allow the developing countries to increase emissions, while failing to produce emission reductions

in the CDM host countries (International Rivers, 2007). Schneider (2007), by conducting a systematic evaluation of 93 randomly chosen registered CDM projects, as well as interviews and a literature survey, casts some doubts over the additionality of a significant number of CDM projects between 2004–2007, making the emission reduction from the CDM projects questionable.

By reviewing the literature on CDM, we find that there are diverse issues related to CDM addressed by the existing papers, namely CDM's contribution to sustainable development in the non-Annex I country (Watson and Frankheuser, 2009; Sutter and Parreño, 2007; Olsen, 2007); establishing additionality of the CDM projects (Michaelowa and Purohit, 2007; Haya, 2007; Schneider, 2007); low-hanging fruit problem (Narain and van't Veld, 2008; Brechet et al., 2004; Millock, 2002); assessment of technology transfers that take place through the CDM (Dechezleprêtre et al., 2008; Haites et al., 2006); distribution of CDM projects across non-Annex I countries (Jung, 2006; Zhang and Mariyuma, 2001); forecast of future GHG emissions with CDM (Hagem and Holtmark, 2009); and whether CDM has been effective in reducing GHG emissions (Fischer, 2005). We focus on the particular parts of the literature that are relevant to the theoretical analysis presented in this paper, that is the efficacy of CDM in reducing GHG emissions and the determination of non-Annex I countries to host the CDM projects.

Rübelke (2006) has developed a theoretical analysis to analyze the role played by international transfer (through a mechanism like CDM) in the international climate policy, particularly in consideration of the air quality. His analysis shows that the conditional transfers may induce a rearrangement of environmental policy in the non-Annex I countries, which end up benefitting the whole world. Paulson (2009) points out that the literature on CDM seems to devote much effort in fine-tuning the CDM. Invitation was given to academics to theoretically analyze CDM in order to take it into the future. We respond to this and make a contribution to this strand of literature.

First of all, this paper provides a formal theoretical model which allows us to evaluate the efficacy of the CDM in terms of reducing the global emissions of greenhouse gases, i.e. the total level of GHG emissions across the Annex I and non-Annex I countries. In our paper, we use a two-country (Annex I and non-Annex I country) framework to study the efficacy of CDM in reducing the global emissions of GHG. The Annex I country is subject to a binding limit on emissions set by the Kyoto Protocol. It can invest in a CDM project in the non-Annex I

country to receive a given proportion of its abatement as CER credits to be offset against its own emission level.

The non-Annex I country is not bound by any legally binding emission reduction targets under the Kyoto Protocol but is subject to a voluntary emission limit, which helps capture our observation that some developing countries have GHG emission reduction and tackling of climate change on their national agenda. As on February 1, 2010, some non-Annex I countries sent their pledges, including high emitters like Brazil, China and India (BBC, 2010). The level of pollution that each country is willing to tolerate voluntarily is an issue that should not be ignored in the research and measures taken to reduce global emission levels.

There are several papers which have raised concern that CDM could result in increasing global emission. Hogem and Holtmark (2011) show using numerical simulations why CDM may not contribute to the ambitious target of reduction in GHG emissions. Böhringer (2002) explains why the reduction in global emission will be negligible even if the agreed targets were reached with the aid of programs such as the CDM. Michaelowa (2008) highlights how the incentive of the firms in the non-Annex I countries hinders the CDM from reducing the GHG emissions. In particular, by anticipating that the low-carbon technology will be transferred to them under the CDM projects, the firms in the non-Annex I countries might have incentives to delay the adoption of such technology, which they intend to acquire in any case through their own funds. In this sense, the CDM does not result in substantial additional reduction in greenhouse gas emissions. Our paper adds to this literature using a theoretical model and some different dimensions which will be evident from the discussion below.

Another important feature in the theoretical model is that it allows for a parameter that captures the proportion of the abatement that should be awarded as CER credits and demonstrates that only partial credit should be given. This means, more should be abated through the CDM project, than what can be offset in developed countries. If the cost of abatement in host country is less costly than having to reduce production in its own country, the developed country would choose to invest in CDM projects so long as it is worthwhile. Moreover, the model is able to demonstrate how the level of partial credit should be chosen to assist the quest to tackle global emissions – the proportion should be set to be just sufficient to make it worthwhile for investments to be made in the CDM project.

According to the rules of the Kyoto Protocol, full credit may be given although, partial credit is called for because of possible overestimation of abatement and carbon leakage. Several papers have shown that estimations are not reliable, so there is a need to improve this system (Michaelowa and Umamaheswaran, 2006; Schneider, 2009, Vöhringer et al., 2006). Hagem and Holtsmark (2011) also discuss how emissions can be increased because of CDM: carbon leakage and wrong estimation of additionality which are reasons why the CER credits given should be less than what is actually supposed to have been abated. When emission reduction by one project is offset by increasing emission elsewhere, this is called carbon leakage. Glomsrod and Taoyen (2005) show how a coal cleaning CDM project resulted in emission increase because people responded by using more coal which became more efficient and thus cheaper.

Finally our paper makes a contribution to the CDM literature by introducing a characteristic of a host country that should be considered. It investigates and recommends that the choice of non-Annex I countries to host the CDM projects should be on the ground of non-Annex I countries' voluntary emission limits, instead of basing the distribution of CDM project on the ground of income as in the existing literature. Emission tolerance of the non-Annex I countries and whether they are emitting at their maximum that they can tolerate is something that has not been looked at in the literature of CDM and worth introducing into the discussion.

According to Jung (2006), Zhang and Mariyuma (2001) and Dutschke and Michaelowa (2006) the CDM projects have been over-concentrated in the middle-income developing countries such as China and India, while the least developed countries have been mostly neglected. A possible reason could be that it is easier to establish additionality in the middle-income developing countries and there is more opportunity to find suitable projects to participate in the CDM scheme. Lecocq and Ambrosi (2007) suggest that CDM projects should only be hosted by least developed countries. These suggestions are to assist least developed countries to get some benefit from CDM. According to the empirical analysis in Flues et al. (2008), political-economic variables determine the final decision of the CDM Executive Board. The CDM Executive Board membership of the country or countries concerned raises the chances of a CDM project to be approved.

Based on a theoretical analysis, we argue in this paper that the CDM does not necessarily lead to a reduction in the total level of greenhouse gas emissions, owing to the incentives of non-Annex I and Annex I countries to expand production and thus emis-

sions. The results from our formal analysis show the following. For the Annex I country, the opportunity to reduce GHG emissions abroad at a cheaper cost would cause it to sponsor CDM project in the non-Annex I country, expanding its domestic production thus generating more domestic emissions. In this case, the reduction in the GHG emission in the non-Annex I country will be offset by an increase in GHG emissions in the Annex I country, leaving the global level of GHG emissions unchanged despite the presence of the CDM project. The outcome in the non-Annex I country depends on two scenarios.

If the non-Annex I country already produced at its optimum level in the absence of the CDM, it will not respond to the presence of CDM projects by increasing its domestic production. Thus, the emissions in such non-Annex I country will be reduced by the amount generated by the CDM project sponsored by the Annex I country. The other scenario is when the non-Annex I country is sufficiently environmentally conscious, so produces less than its capacity in the absence of CDM. With abatement resulted from the CDM project, it will expand production and thus domestic emissions. This is due to the fact that abatements achieved through the CDM project help relax the non-Annex I country's voluntary limit on GHG emissions. In this case, the CDM will lead to an increase in the global GHG emissions. Helm (2003) uses a similar idea in emission trading mechanism. His model shows that compared to non-tradable allowances, tradable allowances would result in more or less allowances being chosen by countries, depending on whether they are environmentally conscious or not respectively, so that the net effect may not be a reduction in overall GHG emissions.

We acknowledge some problems that have to be faced if this recommendation was to be carried out. The main problem is whether the Executive Board would be able to find out the emission toleration level of the non-Annex I countries and whether they are operating at their optimal production capacity. If this condition is publicly known, it provides a disincentive for countries to set stricter emission targets for themselves. It is important to stress that our recommendation is based on whether a country would respond to the CDM project by increasing emission which it otherwise would not have. This is a problem that has been discussed in the literature already. Our paper provides another dimension to why this problem could happen in countries that are actually more environmentally conscious. This is worth bearing in mind when making evaluating the estimation of additionality and abatement of proposed projects.

The remainder of the paper is structured as follows. Section 1 presents the model and the analysis in the absence of the CDM. In Section 2, we present the

analysis for the case in which we allow the Annex I country to sponsor the CDM project in the non-Annex I country and make some comparisons between the two cases, followed by a summary of the results. The final section concludes the paper.

1. The model in the absence of the CDM

Consider two countries, an Annex I country and a non-Annex I country. The Annex I country is subject to a binding limit on emissions set by an outside authority such as the Kyoto Protocol, k , where $k > 0$ ¹.

The non-Annex I country is not subject to such legally binding limits on emission but, due to its concern on the impact of its production on the environment, it subjects itself to a voluntary limit on emissions. The voluntary limit on emission reflects how much emissions the country can tolerate². This is an issue which has not been discussed widely in a theoretical framework in the literature of environmental economics. Later in the paper we show how this voluntary limit on emission in the non-Annex I country plays a role in determining the efficacy of CDM.

We denote this voluntary limit on emission of the non-Annex I country by s . Annex I country also has its own voluntary limit on emission but we assume that it is higher than k .

First, we study what happens in the Annex I country, which produces an industrial output y . Its benefit function is given by $B(y)$, where we assume that $B(y)$, satisfies the conditions:

$B'(y) \geq 0, B''(y) < 0, \lim_{y \rightarrow 0} B'(y) = \infty$ and $\exists \bar{y}$, where $0 < \bar{y} < \infty$, such that $B'(\bar{y}) = 0$, (i.e. \bar{y} is the maximum amount of output the Annex I country is able to produce).

Each unit of y generates $e > 0$ units of emission as a by-product. To comply with k , the Annex I country can choose to undertake some domestic abatement, denoted by a . The abatement cost function is given by $c(a)$, where $c'(a) \geq 0$ and $c''(a) > 0$. We assume that $k < e\bar{y}$ ³.

The Annex I country chooses output, y , and abatement, a , to maximize its net benefit subject to the constraint on emissions set by the Kyoto Protocol.

$$\text{Max}_{y,a} (B(y) - c(a))$$

subject to

$$ey - a \leq k; a \geq 0; y > 0. \tag{1}$$

The Kuhn-Tucker conditions are given by (2)-(4)⁴.

$$B'(y) = \lambda e, y > 0, \tag{2}$$

$$\lambda \leq c'(a), a \geq 0, \tag{3}$$

$$ey - a \leq k, \lambda \geq 0. \tag{4}$$

Lagrange multiplier in the above equations is given by λ . Let (y^*, a^*) be the solutions to the above maximization problem. From above, it can be easily shown that the constraint on emissions will always bind, i.e. the Annex I country will have to choose to produce so that its emissions will be equal to what is allowed by the Kyoto Protocol. Thus, $ey^* - a^* = k, \lambda > 0$.

It, therefore, follows from equation (2) that $y^* < \bar{y}$, and thus the Annex I country needs to undertake some output reduction (i.e. producing less than \bar{y}) in order to meet its binding limit on emission set by the Kyoto Protocol, k . If $c'(0) \geq \lambda$, the Annex I country meets k solely through a reduction in output (i.e. $a^* = 0$) while if $c'(0) < \lambda$ it meets its allowed limit through a combination of output reduction and abatement (i.e. $a^* > 0$).

Next, we study what happens in the non-Annex I country. The benefit function of the non-Annex I country is given by $\tilde{B}(\tilde{y})$, where (\tilde{y}) denotes the industrial output produced in the non-Annex I country. We assume that $\tilde{B}(\tilde{y})$ satisfies the following conditions: $\tilde{B}'(\tilde{y}) \geq 0, \tilde{B}''(\tilde{y}) < 0, \lim_{\tilde{y} \rightarrow 0} \tilde{B}'(\tilde{y}) = \infty$ and $\exists \bar{\tilde{y}}$, where $0 < \bar{\tilde{y}} < \infty$, such that $\tilde{B}'(\bar{\tilde{y}}) = 0$ (i.e. $\bar{\tilde{y}}$ is the maximum amount of output the non-Annex I country is able to produce).

Each unit of \tilde{y} generates $\tilde{e} > 0$ units of emission as a by-product. To comply with its voluntary emission limit, s , the non-Annex I country can choose to undertake some domestic abatement, denoted by \tilde{a} . The abatement cost function is given by $\tilde{c}(\tilde{a})$, where $\tilde{c}'(\tilde{a}) \geq 0$ and $\tilde{c}''(\tilde{a}) > 0$. Lying at the core of the CDM, it is important to emphasize the differ-

¹ We recognize that in reality the Kyoto target is the GHG emissions reduction. However, we model it as the limit on emission level itself.

² In Narain and van't Veld (2008) and Brechet et al. (2004), instead of modelling the voluntary emission limit on the part of non-Annex I country, the authors model commitments by non-Annex I countries by a two-period model, where the non-Annex I country takes on emission reduction objectives in the second period. In this paper, we consider only a one-period model and capture the commitment on the part of non-Annex I country in the form of a voluntary emission limit.

³ If $k \geq e\bar{y}$, no emission reduction is required by the Annex I country.

⁴ Note that given Lagrangian function, L , the Kuhn-Tucker conditions are given by,

$$\left(\frac{\partial L}{\partial y} \leq 0, y \geq 0 \right); \left(\frac{\partial L}{\partial a} \leq 0, a \geq 0 \right); \left(\frac{\partial L}{\partial \lambda} \right) = k - ey + a \geq 0, \lambda \geq 0.$$

ence in the abatement cost functions in the Annex I and non-Annex I countries because it is the difference in the abatement cost function that accounts for the cost advantage of the non-Annex I country in undertaking abatement.

To capture this point, for a given level of abatement in the Annex I country, a , we assume that the total and marginal cost for the Annex I country for abating a units of emissions in non-Annex I is strictly less than abating a units of emissions domestically, i.e. $\tilde{c}(a) < c(a)$ and $\tilde{c}'(a) < c'(a)$. However, without the CDM, the option to undertake abatement abroad is not available for the Annex I country. This case will be analyzed in section 2.

The non-Annex I country chooses output, \tilde{y} , and abatement, \tilde{a} , to maximize its net benefit subject to the self-imposed constraint on emissions:

$$\text{Max}_{\tilde{y}, \tilde{a}} (\tilde{B}(\tilde{y}) - \tilde{c}(\tilde{a}))$$

subject to

$$\tilde{e}\tilde{y} - \tilde{a} \leq k; \tilde{a} \geq 0; \tilde{y} > 0. \tag{5}$$

We assume that $\bar{y} < \tilde{y}$, and $\tilde{e} > e$ which mean the non-Annex I is poorer and uses a dirtier technology, respectively.

The Kuhn-Tucker conditions are given by:

$$\tilde{B}'(\tilde{y}) = \tilde{\lambda}\tilde{e}, \quad \tilde{y} > 0, \tag{6}$$

$$\tilde{\lambda} \leq \tilde{c}'(\tilde{a}), \quad \tilde{a} \geq 0, \tag{7}$$

$$\tilde{e}\tilde{y} - \tilde{a} \leq k, \quad \tilde{\lambda} \geq 0. \tag{8}$$

Lagrange multiplier is given by $\tilde{\lambda}$.

Let $(\tilde{y}^*, \tilde{a}^*)$ denote the solutions to the above program. There are two cases to be considered: when the non-Annex I country's voluntary limit on emission, given by equation (8), does not bind and when it binds. When the voluntary emission limit of the non-Annex I does not bind, the non-Annex I can produce up to its preferred level of production, \bar{y} , while when the voluntary limit binds, the non-Annex I has to produce less than its preferred level, \tilde{y} , because it does not want the emission to exceed the voluntary limit. For future reference, the subscripts 1 and 2 are used to refer to the case where the non-Annex I country's voluntary limit on emission does not bind (scenario 1) and binds (scenario 2), respectively.

Under scenario 1, when s is sufficiently high such that its voluntary constraint on emission does not

bind (i.e. country does not care too much about the environment), it implies that this non-Annex I country will produce up to its maximum ($\tilde{y}_1^* = \bar{y}$), choose to undertake no abatement ($\tilde{a}_1^* = 0$) and emission in the non-Annex I country will be $\tilde{e}\bar{y}$. When this is the case, the total level of emissions across the two countries or the global emission is $E_1 = k + \tilde{e}\bar{y}$ and the total production across the two countries or the global production level is $Y_1 = y^* + \tilde{e}\bar{y}$.

Under scenario 2, when s is sufficiently low such that the non-Annex I country's voluntary emission constraint binds (i.e. country is comparatively conscious about the environment and produces less than what it is capable of to limit emission), it follows from equation (6) that $(\tilde{y}_2^* < \bar{y})^1$. This means that the non-Annex I country will produce less than the maximum. The level of emissions in non-Annex I country under scenario 2 is s . When this is the case, the global emission is given by $E_2 = k + s$ and the global production is $Y_2 = y^* + \tilde{y}^*$.

2. The analysis in the presence of the CDM

Now we consider what happens in the two countries after the CDM is introduced by the Kyoto Protocol. As noted in the introduction, the CDM allows the Annex I country to meet its legally binding limit on emission under the Kyoto Protocol by sponsoring the emission abatement projects in the non-Annex I country. In this paper, we model the CDM arrangement as follows. Given that the Annex I country's participation constraint (to be discussed later) is satisfied, the Annex I country undertakes some emission abatements in the non-Annex I country and the CDM Executive Board issues CER credits. The non-Annex I country then sells the issued CER credits to the Annex I country in the carbon market. We consider only one configuration of the CDM, that is a *unilateral* CDM, whereby only the non-Annex I country can sell the CER credits to the Annex I in the carbon market and the Annex I can only use such credits to comply with the legally binding emission limit under the Kyoto Protocol, k . Although, in many cases, the Annex I country pays for the emission reduction and then gets the credits to sell in the carbon market, we do not consider this configuration of the CDM here.

¹ Same as for the case of the Annex I country, if $\tilde{c}'(0) \geq \tilde{\lambda}$, the non-Annex I country meets its voluntary limit on emissions solely through a reduction in output (i.e. $\tilde{a}^* = 0$); however, if $\tilde{c}'(0) < \tilde{\lambda}$, it will meet its voluntary limit on emission through a combination of output reduction and abatement (i.e. $\tilde{a}^* > 0$).

With the CDM, the cost of abatement for the Annex I country is given by $c(a) + \tilde{c}(\tilde{a})$, where a and \tilde{a} denote units of domestic abatement and abatement abroad, respectively. Recall that $\tilde{c}(\tilde{a}) < c(a)$, and $\tilde{c}'(\tilde{a}) < c'(a)$, for all levels of a . This captures the cost reduction from sponsoring emission abatement projects in the non-Annex I country. In addition to the cost of investing in the CDM projects, the Annex I country also has to incur some cost towards the purchase of CER credits from the non-Annex I country. The price of CERs is denoted by p ¹.

Suppose the Annex I country receives a CER credit, φ , for each unit of abatement it undertakes in the non-Annex I country, where $0 < \varphi \leq 1$. We assume that the CER credit, φ , can be used by the Annex I country to meet its legally binding limit on emission under the Kyoto Protocol. Note that $\varphi = 1$ corresponds with the situation where the Annex I country is given *full credit* by the CDM Executive Board. When $0 < \varphi < 1$ it means partial credit is given. The Annex I country's total cost for the purchase of CER credits is $p\varphi\tilde{a}$. According to the rules of the Kyoto Protocol full credit can be given. However, as pointed out in the introduction, partial credit is called for because of possible overestimation of abatement and carbon leakage. In our model we assume that these problems do not occur. Even so, partial credits could help avoid the problem of countries increasing production because of the abatement. In this model, we consider CER credit to be $0 < \varphi \leq 1$, even when additionality is estimated correctly and there is no carbon leakage.

In what follows, we study the decision problem of the Annex I country in the presence of the CDM. The Annex I country chooses output, y , domestic abatement, a , and abatement in the non-Annex I country, \tilde{a} , to maximize its net benefit subject to the constraint on emission:

$$\text{Max}_{y, a, \tilde{a}} B(y) - c(a) - \tilde{c}(\tilde{a}) - \rho\varphi\tilde{a}, \tag{9}$$

subject to

$$ey - a - \varphi\tilde{a} - \tilde{a} \leq k; \quad a \geq 0; \tilde{a} \geq 0; y > 0.$$

$$B'(y) = \lambda e, \quad y > 0, \tag{10}$$

$$\lambda \leq c'(a), \quad a \geq 0, \tag{11}$$

$$\varphi\lambda \leq \tilde{c}'(\tilde{a}) + \rho\varphi, \quad \tilde{a} \geq 0, \tag{12}$$

$$ey - a - \varphi\tilde{a} = k, \quad \lambda > 0. \tag{13}$$

¹ The price of CER credit, p , is determined by supply and demand of CER credits, which are normally traded on the forward basis in the carbon market. However, for our modeling purpose, we have assumed that the Annex I country can use information from the forward market for CER credit to find out p .

Let $(y^\circ, a^\circ, \tilde{a}^\circ)$ be the solutions to the maximization problem (9). In order for the Annex I country to participate in the CDM project, the net benefit it receives from participating in the CDM should be more than the net benefit from refraining from participating. By not participating in the CDM, the Annex I country's net benefit is $B(y^*) - c(a^*)$, while, by participating in the CDM, the net benefit for the Annex I country is $B(y^\circ) - c(a^\circ) - \tilde{c}(\tilde{a}^\circ) - \rho\varphi\tilde{a}^\circ$. The Annex I country's participation constraint is, therefore, given by:

$$B(y^*) - c(a^*) < B(y^\circ) - c(a^\circ) - \tilde{c}(\tilde{a}^\circ) - \rho\varphi\tilde{a}^\circ.$$

When equation (14) is satisfied, the Annex I country will participate in the CDM. So long as participation is more beneficial because of cheaper abatement in non-Annex I country, more abatement can be obtained in order to increase production in the Annex I country, i.e. $y^\circ > y^*$. Therefore, with the CDM, the Annex I country is able to expand its production and thus domestic emission. In order to comply with its emission limit under the Kyoto Protocol, k , it is necessary that the Annex I country undertakes more abatements relative to the situation in which there is no CDM. By participating in the CDM, the level of emissions in the Annex I country is

$$ey^\circ = k + \varphi a^\circ. \tag{15}$$

Equation (15) suggests that, by participating in the CDM relative to not participating in the CDM, the Annex I country can use the CER credits it obtained, φa° , to generate emissions above the limit on emission under the Kyoto Protocol, k . In other words, the CER credits the Annex I country earned under the CDM helps relax its emission constraint. Thus, with the flexibility of sponsoring abatement projects in the non-Annex I country under the CDM initiative, the net emission in the Annex I country goes up by the amount of CER credits it obtained, $\varphi\tilde{a}$.

For the non-Annex I country, after taking into account the abatement resulted from CDM project sponsored by the Annex I country, \tilde{a}° , its decision problem becomes:

$$\text{Max}_{\tilde{y}, \tilde{a}} \tilde{B}(\tilde{y}) - \tilde{c}(\tilde{a}) \tag{16}$$

subject to $\tilde{e}\tilde{y} - \tilde{a} - \tilde{a}^\circ \leq s; \tilde{a} \geq 0; \tilde{y} > 0$.

The Kuhn-Tucker conditions are:

$$\tilde{B}'(\tilde{y}) = \tilde{\lambda}\tilde{e}, \quad \tilde{y} > 0, \tag{17}$$

$$\tilde{\lambda} \leq \tilde{c}'(\tilde{a}), \quad \tilde{a} \geq 0, \tag{18}$$

$$\tilde{e}\tilde{y} - \tilde{a} - \tilde{a}^\circ \leq s, \quad \tilde{\lambda} > 0. \tag{19}$$

As in the analysis in the absence of the CDM, there are two cases to be considered: when the non-Annex

I country's voluntary constraint on emission (19) does not bind (scenario 1) and when such constraint binds (scenario 2).

If the voluntary limit on emission of the non-Annex I country does not bind in the absence of CDM, it will not be binding after the CDM is introduced since some emissions are now abated under the CDM initiative. Let the results in this scenario be $(\tilde{y}_1^\circ, \tilde{a}_1^\circ)$. Thus, with the CDM, the non-Annex I country will continue to produce up to its maximum, $(\tilde{y}_1^\circ = \bar{y})$, and will choose to undertake no abatement $(\tilde{a}_1^\circ = 0)$. It follows that the net emissions in the non-Annex I country are $\tilde{e}\bar{y} - \tilde{a}^\circ$, thus the level of emissions in the non-Annex I country goes down by the amount of abatement achieved through the CDM project sponsored by the Annex I country.

Recall from equation (15) that, with the CDM, the net emissions in the Annex I country are $k + \phi\tilde{a}^\circ$, which suggests that the level of emissions in the Annex I country increases by the amount of CER credits it obtains from sponsoring the abatement abroad under the CDM initiative. By aggregating the level of emissions across the Annex I and non-Annex I countries, with the CDM, the global emissions are¹:

$$E_1^\circ = k + \tilde{e}\bar{y} - (1 - \phi)\tilde{a}^\circ. \tag{20}$$

The last term on the RHS of equation (20), given by $(1 - \phi)\tilde{a}^\circ$, is the partial credit effect. It is important to note that, if the Annex I country receives a full credit for undertaking its abatements abroad (i.e. $\phi = 1$), the presence of CDM will not have any effect on the global emissions as $E_1^\circ = E_1 = k + \tilde{e}\bar{y}$, where E_1 denotes global emissions in the absence of the CDM. All the CDM does is to provide a more efficient allocation of abatement, which may improve the Annex I country's compliance with the legally binding emission limit under the Kyoto Protocol. This is one of the objectives the CDM aims to achieve. However, if the Annex I country receives only a *partial credit* (i.e. when $\phi < 1$), the CDM, in this case, can lead to a reduction in the global emissions as $E_1^\circ < E_1$. It is clear from equation (20) that, the lower is ϕ , the greater will be the reduction in global emissions.

The global production across the two countries, when the voluntary emission constraint of the non-Annex I country does not bind, is $Y_1^\circ = y^\circ + \bar{y}$. Since $y^\circ > y^*$, it follows that $Y_1^\circ > Y_1$. This implies that the presence of CDM increases the total level of production across the two countries.

¹ $E_1^\circ = \tilde{e}\bar{y} - \tilde{a}^\circ + k + \phi\tilde{a}^\circ$.

Next, we consider what happens in the non-Annex I country if its voluntary constraint on emission binds. Condition (19) now becomes:

$$\tilde{e}\tilde{y} - \tilde{a} - \tilde{a}^\circ = s, \tilde{\lambda} > 0.$$

Let $(\tilde{y}_2^\circ, \tilde{a}_2^\circ)$, denote the solution to the non-Annex I country's maximization problem given in equation (16) when the non-Annex I country's voluntary emission constraint binds. If the voluntary constraint on emission binds, it implies that the non-Annex I country is forced to produce less than \bar{y} before the CDM is introduced because doing so would generate emission which exceeds its toleration level (given by its voluntary limit on emission). The abatement resulted from the CDM project sponsored by Annex I country thus relaxes the non-Annex I country's voluntary constraint on emission, and it allows the non-Annex I country to produce more while still complying with its voluntary emission limit $e\tilde{y}_2^\circ - \tilde{a}_2^\circ - \tilde{a}^\circ = s$. Here, the net emissions in the non-Annex I country remain unchanged at s . Note that $\tilde{y}_2^* < \tilde{y}_2^\circ \leq \bar{y}$.

Therefore, the presence of CDM project in the non-Annex I country, leads to an increase in the emissions in the non-Annex I country by an amount \tilde{a}° , which is the abatement resulted from the CDM project. On the part of the Annex I country, its domestic emissions increase by $\phi\tilde{a}^\circ$, which is the CER credits it obtained from its sponsored CDM project. Overall, when the non-Annex I country's voluntary constraint on emission binds, the global emissions in the CDM are given by:

$$E_2^\circ = k + \phi\tilde{a}^\circ + s + \tilde{a}^\circ - \tilde{a}^\circ = E_2 - \tilde{a}^\circ + \tilde{a}^\circ + \phi\tilde{a}^\circ. \tag{21}$$

The first term on the RHS of equation (21), E_2 , is the global level of emissions before the CDM was introduced. The second term, \tilde{a}° , is the reduction in emissions in non-Annex I country because of the abatement efforts of Annex I country through the CDM project. The third term, \tilde{a}° , is the *double counting effect*, which shows the increase in the emissions by non-Annex I country in response to the abatements carried out under the CDM project sponsored by the Annex I country. The last term is the *partial credit effect*, which shows the increase in the emissions in Annex I resulted from the CER credit it obtained from the CDM project it sponsored. It is clear that

$$E_2^\circ = E_2 + \phi\tilde{a}^\circ. \tag{22}$$

So $E_2^\circ > E_2$ for all values of $\phi > 0$. When $\phi = 1$, the global emission increases by the entire amount of abatement undertaken under the CDM project, and $E_2^\circ = E_2 + \tilde{a}^\circ$. The higher is ϕ , the greater will be the level of global emissions when CDM is in operation.

Therefore, when the non-Annex I country's voluntary constraint on emission binds the CDM results in a rise in the global emissions as long as $\varphi > 0$.

3. Summary of results

We have shown that the presence of CDM results in an increase in the level of emissions in the Annex I country. Moreover, the presence of the CDM also results in an increase in the emissions in the non-Annex I country whose voluntary constraint on emissions binds. However, there is no change in the level of emission in the non-Annex I country if its voluntary constraint on emission does not bind. On the whole, the global emissions increase as a result of the CDM.

Our analysis clearly demonstrates that in both cases – when the voluntary constraint on emission for the non-Annex I binds and does not bind, partial credit should be given by the CDM Executive Board. The lower is the amount of CER credit the Annex I country receives for each unit of abatement sponsored by the Annex I country under the CDM, the greater will be the reduction in the global emissions due to the presence of CDM. However, the partial credit should be carefully chosen by the CDM Executive Board. In particular, φ should be chosen in such a way that the Annex I country's participation constraint (14) is satisfied so that the Annex I country has an incentive to participate in the CDM. There is much discussion about the choice of φ by the Executive Board, which plays an important role in the operation of CDM and the subsequent reduction in net emissions. This model provides a formal way of thinking about this issue, and what would be the optimal choice.

In the presence of CDM, the global production when the voluntary constraint of the non-Annex I country binds is $Y_2^c = y^c + \tilde{y}_2^c$. Note that $Y_2^c > Y_2$ because both the Annex I country and the non-Annex I country are able to produce more in the presence of CDM. The increase in production in the Annex I country does not differ across the two cases. The extent of the increase in the Annex I country goes up with the extent of CER credit φ . If the Annex I country is given a full CER credit, its production will increase by the entire amount of abatements undertaken through the CDM project it sponsors. However, if the non-Annex I country is not bound by its voluntary limit on emission, the existence of the CDM does not change its level of production.

With the above results in mind, the question that arises is how to make the CDM work more effectively in reducing the global emissions? We argue that the CDM will be more effective if the non-Annex I country that hosts the CDM project has non-binding

voluntary constraint on emission. This is because in this case, the non-Annex I country will not respond to the presence of CDM project by expanding its production and thus emissions. This suggests that the CDM Executive Board should allow the CDM projects to be hosted by the non-Annex I country that has high voluntary emission limits which are already producing at their optimal level.

Even though it may be argued that at present, several non-Annex I countries tend to have quite high levels of voluntary emission limit, it is important to keep in mind that over time, such limit can change. The authorities overseeing the operation of the CDM should be alert to how a country hosting CDM projects change with respect to its sensitivity to emission levels. Once the voluntary limit on emission becomes sufficiently low and therefore the countries limit their production to be below the optimal level, the authority should be cautious in approving such non-Annex I countries to host the CDM projects. As demonstrated in our analysis, in such a situation, the non-Annex I country will respond to abatements achieved through the CDM projects by increasing production and emitting more.

It is important for us to acknowledge that these suggestions do have practical problems as to how the Executive Board can find out whether a country is operating at less than its optimal production level because of its pollution tolerance level. This is a theoretical model, which has made this observation and the authorities can make use of this as much as practically feasible.

Conclusion

The CDM has attracted substantial interest from both non-Annex I and Annex I countries alike because of its cost effectiveness and flexibility for the Annex I countries in meeting their emission reduction targets under the Kyoto Protocol. In this paper, we use a simple theoretical model to evaluate the efficacy of CDM in reducing the global GHG emissions.

The results from our analysis show that the net impact of CDM on the global emissions of GHG is ambiguous. On the one hand, some GHG emissions in the non-Annex I country are reduced due to the CDM projects sponsored by the Annex I country. On the other hand, the global emissions can be increased due to the following reasons: first, the Annex I country increases its domestic emissions because of the CER credits it receives from sponsoring the CDM project, and second, the outcome in the non-Annex I country critically depends on its voluntary limit on emission. If the non-Annex I country's voluntary limit on emission is sufficiently low, it will respond to the abatement through CDM projects, by increasing its domes-

tic emissions so that the net emission in the non-Annex I country does not change. In this case, the global emissions will, in fact, increase in the presence of the CDM. However, if the non-Annex I country's voluntary limit on emission is quite high, its emissions do not change in response to the CDM projects so that its net emission will be reduced by the abatement carried out by the Annex I country. In this case, global emissions are reduced by the amount of abatement carried out through the CDM projects.

Our analysis supports the literature that calls for partial credit to be given to the Annex I countries that sponsor the CDM project. The model explains how it affects the total emissions and how the partial credit should be chosen so that it is sufficiently high to ensure Annex I country's participation in the CDM scheme. The analysis emphasises how to make the CDM work more effectively in terms of reducing the global emissions of GHGs. Firstly, CDM projects should be approved to hosted by non-Annex I countries which have higher voluntary limit on emission so that they choose to

operate at the optimal production level with emissions less than their voluntary limit. This will help ensure that the non-Annex I countries will not offset the benefits of the CDM projects by expanding their production thus increasing the global emissions. This point adds to the literature on the distribution of CDM projects across the non-Annex I countries, which tends to emphasize more on the ground of income and level of development (see Michaelowa, 2005; Jung, 2006; Zhang and Mariyuma, 2001). The analysis suggests that the CDM Executive Board should not only consider income as the factor in making its decision on which non-Annex I countries should host the CDM projects if it endeavors to reduce some global emissions of GHG through the CDM.

For future research, it would be interesting to see what would happen if more than one non-Annex I country competes for sponsorship from the Annex I country under the CDM. Moreover, the model could be extended to a dynamic framework and explicitly model the trading of CER credits in the carbon market.

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