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The clean development mechanism versus international permit trading: the effect on technological change

Abstract:
The clean development mechanism of the Kyoto Protocol may induce technological change in developing countries. As an alternative to the clean development mechanism regime, developing countries may accept a (generous) cap on their own emissions, allow domestic producers to invest in new efficient technologies, and sell the excess emission permits on the international permit market. The purpose of this article is to show how the gains from investment, and hence the incentive to invest in new technology in developing countries, differ between the two alternative regimes. We show that the difference in the gains from investment depends on whether the producers in developing countries face competitive or noncompetitive output markets, whether the investment affects fixed or variable production costs, and whether producers can reduce emissions through means other than investing in new technology.

Keywords: Climate Policy, Technology Adoption, Emission Trading, Clean Development Mechanism, Technological Change, Cournot Competition

JEL classification: L13, Q54

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1. Introduction

According to the Kyoto Protocol, developing countries have no quantified emission targets for the first Kyoto period (2008–2012). However, industrialized countries with quantified emission targets are allowed to partly meet their reduction commitments through investments in emission-reducing projects in developing countries (the CDM). The emission reductions generated by CDM projects can be used to offset the investor's own emission reduction obligations.

According to the Kyoto Protocol, the purpose of the CDM is twofold (see UNFCCC (1998), article 12). It is a means of reducing compliance costs for industrialized countries, and it is a means of assisting developing countries in achieving sustainable development.

Through spin-off effects from technological improvements in some production units, the CDM may increase the use of environmentally friendly technologies in developing countries.

A condition for the approval of a CDM project is that the reduction achieved by the project shall be *additional* to any that would occur without project activity (see UNFCCC (1998), article 12).[1] The *additional* requirement ensures that the certified emission reduction units (CERs) are based on real emission reductions such that the CDM does not lead to higher global emissions. However, the problem with this criterion is that it must be based on a counterfactual baseline for emissions. Furthermore, both the investor and the host have incentives to overstate the baseline emission to make the project more profitable[2]. The problems connected with baseline estimates and the potentially high transaction costs of CDM projects are arguments for alternatively including developing countries in a cap&trade regime.[3, 4] In a cap&trade regime, developing countries accept binding caps on their emissions. Countries receive emission allowances (or permits) corresponding to their caps on emissions and are allowed to participate in permit trading. If the cap for emissions is generous, a developing country gains from participating in this regime by implementing low-cost abatement options, and sell permits on the permit market.

In this article, we compare the cap&trade and CDM regimes in their ability to promote firms in developing countries to invest in more environmentally friendly technologies. Hence, we address the

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[1] An executive board is designated to approve CDM projects and issue certified emission reduction units (CERs).

[2] Fischer (2005) evaluated how different baseline methodologies affect the efficiency of the CDM when there is asymmetric information between the certifying agent and the participants in CDM projects.

[3] The necessary effort used in preparing CDM proposals, and the resources used to verify and certify emission reductions may lead to quite high transaction costs for acquiring CERs. See, among others, Michaelowa et al. (2003) for an overview of estimated transaction costs for various kinds of CDM projects.

[4] This argument was made by, e.g., Bohm (2002).

sustainable development role of the CDM, rather than its role in minimizing industrialized countries' costs of achieving targets for global emission reductions. We assume that, under a CDM regime, emission reduction credits can only be generated if a fixed investment occurs. Hence, in our model, CDM projects cannot be based on emission reductions that occur only because of output reductions, for instance[5]. We suggest that fixed investment in new technology represents a reasonable requirement for a CDM project. This is because the CDM is meant to promote sustainable development in developing countries[6].

In our analysis we take into account how the market environment on the output market for the goods produced by the firms in the developing countries affect their incentives for investment in new technology[7]. In the case of investment projects suitable for CDM funding it is relevant to consider both competitive and non- competitive output markets.

Because of the high transaction costs of initiating and implementing CDM investment projects, it is large emitters which attract CDM investors.[8] At United Nations Framework Convention on Climate Change's homepage there are descriptions of the various CDM projects registered[9]. Some of these projects are investments in energy efficiency improving technologies in capital intensive manufacturing industries. The output market for some of these industries can be characterized as imperfectly competitive. There are for instance several projects aiming at emission reduction from the cement production. Cement production involves high fixed costs, and the regional cement markets are characterized by a relatively small number of suppliers.[10] The aluminum industry is another industry, suitable for hosting CDM projects, where studies have indicated some degree of market power (see for example Lindquist (1994) and Yang (2001))[11]. Furthermore, electricity providers are also likely candidates for hosting CDM projects. The electricity markets are likely to face market power abuse

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[5] However, if an investment occurs, we assume that the emission credits acquired equal the difference between estimated business-as-usual emissions and ex post emissions, regardless of whether some of the emission reductions are due to reduced production. This is according to the UNFCCC's guidelines for estimating the emission reduction of a CDM project activity (see http://unfccc.int/resource/docs/2005/cmp1/eng/08a01.pdf).

[6] Fischer (2005) considered situations in which undertaking a fixed investment is not a requirement for participation in a CDM project.

[7] Note that it is only the output market for goods produced by potential CDM hosts (firms in developing countries) that are analyzed. We do not take into account that the agents financing the CDM projects also may produce goods exchanged at imperfectly competitive markets.

[8] Although high transaction costs associated with the CDM is an argument in favor of a cap&trade regime, we ignore transaction costs in our theoretical model.

[9] http://cdm.unfccc.int/index.html.

[10] For instance, one CDM project is to substitute biomass for fossil fuels in the cement manefucturing process of Lafarge Malayan Cement Berhard. Lafarge Malayan Cement Berhard is a leading producer of the Malayan cement industry and a major player in the Asian export market.

[11] For instance replacing the old Söderberg cell technology with the new Prebake cell technology in aluminum smelters implies lower energy use, in addition to lower local emissions of hazardous gases and particles. The aluminum industry is used as an example of an industry subject to strategic trade policy in Greaker (2003).

inter alia due to physical constraints on the transmission system and the capacity of interconnectors between regions and countries.

To evaluate the impact of imperfectly competitive output markets, we compare our results with the investment decisions for hosts operating in perfectly competitive output markets.

In the paper we show that there are two effects which influence the difference in investment incentives under the two types of regimes (cap&trade and CDM):

Firms in developing countries have access to the permit market whether or not they invest in new technology under the cap&trade regime, whereas the firms must host an *investment project* to obtain emission credits, and hence get access to the permit market, under the CDM regime.

The strategic effect of an investment on the output market may differ between the two regimes if the firms in developing countries face imperfectly competitive output markets.

We refer to the first effect as the *permit market access effect*, and the latter effect as the *strategic effect*, of an investment. Note that if investment were not a prerequisite for a CDM project, there would be no *permit market access effect.*

We show that the *permit market access effect* favors investment under the CDM regime, whereas the *strategic effect* favors investment under the cap&trade regime. We also describe situations in which the *strategic effect* dominates the *permit market access effect* and vice versa.

The strategic effects of investment are, among others, analyzed in Brander and Spencer (1983). The relationship between technological change and environmental policy instruments has been widely analyzed in the literature. (See, e.g., Jaffe et al. (2002) for an overview.) Montero (2002) and Requate (1998), among others, analyzed the incentives of imperfectly competitive firms to invest in new technology. However, in those studies, emission permits and standards were examined. There are apparently no studies in which differences in the strategic effect of investment under the cap&trade and CDM regimes are analyzed.

In the next section, we define the two climate policies that are available to developing countries. In Section 3, we derive the difference in investment incentives under the two regimes when firms in the developing countries operate in imperfectly competitive output markets. In Section 4, we derive corresponding results for perfectly competitive firms. Concluding remarks are given in the final section.

2. The CDM regime versus the cap&trade regime

We consider a developing country that has the option to choose between two climate policies. It can either join the Kyoto Protocol on equal terms with industrialized countries, in which case, it enters the cap&trade regime, or the country can allow domestic firms to host CDM projects, in which case, it enters the CDM regime.

Under the CDM regime, a foreign investor finances (some of) the cost of implementing the new technology. The host's emission reductions relative to baseline emissions generate CERs, which can be used by the investor to offset its own emission reduction obligations. The value of each CER thus equals the international permit price. We assume that emissions and emission reductions can be correctly calculated. The problem of baseline estimates and ex post emissions calculations is not the issue of this article.[12, 13]

Hence, baseline emissions equal business-as-usual (BaU) emissions, and the CERs accruing from a CDM project equal the difference between the BaU emissions and the ex post emissions following implementation of the project.

Furthermore, we also ignore informational asymmetries between the host and investor under the CDM regime.[14] Having made these simplifications, we can show how investment decisions by firms in developing countries are affected by the climate policy chosen by their governments—CDM regime or cap&trade regime—even in the case with no asymmetric or incomplete information.

If the developing country participates in emission trading, all domestic firms must hold permits corresponding to their emissions. In addition, all firms can trade their permits on the international permit market.

To facilitate comparison of the investment incentives under the two regimes, we assume that the emission reduction requirement of the cap&trade regime is no stricter than that of the CDM regime, which is zero by definition: the country is not obliged to achieve any emission reductions. Hence, a

[12] The implication of this assumption is briefly discussed in the concluding remarks.

[13] Developing countries have been reluctant to accept binding commitments. One reason for this is that uncertainty about the business-as-usual (BaU) emissions may incur less benefit than expected. If the BaU emissions turn out to be higher than expected when accepting the emission cap, the cost of the cap&trade regime may become higher than that of a CDM regime, in which emissions reductions are calculated based on project-specific baselines. Kallbekken and Westskog (2005) explored the costs and benefits of developing countries making binding commitments. They found that the efficiency gain from joining the emission trading regime compared with the CDM regime might not be very large compared with the risk incurred. We ignore problems related to uncertainty about BaU emissions.

[14] The host for the investment project may have more information about the effect of investment on production costs and emissions than do the investors. Such asymmetries may lead to inefficiencies. This is discussed by Hagem (1996) and Wirl et al. (1998), among others. Millock (2002) showed how technological transfer, as a part of the CDM contract, can create incentives for mitigating the inefficiency loss from asymmetric information.

country that accepts a cap is granted permits that cover the BaU emissions. Furthermore, we assume that the country redistributes its permits to the emitting firms based on their BaU emissions. The latter assumption, which is made only for simplicity, does not affect our results. The presence of an endowment of tradable permits represents a pure windfall gain and does not influence firms' investment decisions (assuming that pure changes in wealth do not affect these investment decisions).[15] Our assumptions about the cap on emissions and the distribution of the free permits imply that if firms do not act to reduce emissions, their incomes are identical under both regimes.

As stated in the introduction, we assume that, under a CDM regime, emission reduction credits can only be generated a fixed investment occurs. We consider the incentives for investment in energy efficiency improving projects. Such projects could typically lead to lower marginal and/or fixed production costs in addition to generating value in the form of emission reduction. In the following section, we consider investment in a (capital intensive) industry in which there are few producers, so that each producer has market power in the output market. A competitive output market is analyzed in Section 4.

3. An imperfectly competitive output market

To determine the effect of imperfect competition in output markets, we consider two symmetrical firms that operate in a developing country and engage in Cournot competition in the output market[16]. We apply the standard assumption that the reaction functions are downward sloping, i.e., increased supply by one of the firm leads to a decrease in the optimal supply from its competitor. We ignore any welfare effects arising from changes in the consumer surplus by assuming that the good produced are sold in a foreign country[17]. The firms are denoted 1 and 2, but we sometimes refer to firms i and j. Production is energy intensive. Each firm can reduce its use of energy per unit of output by investing in new technology.

In Section 3.1, we analyze the case in which investment increases the productivity of a variable (energy-intensive) production factor. In Section 3.2, we examine the case in which investment reduces the energy intensity of a fixed production factor.

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[15] The property of free tradable permits is discussed by, e.g., Hagem (2002).

[16] For simplicity we consider a model with only two firms. However, the main conclusions from our model still holds if there are more firms supplying the same market. The crucial assumption is that the firms in question have some degree of market power.

[17] See a brief discussion of the implication of this assumption in the concluding remarks.

3.1. Investment increases the productivity of a variable input factor

In this section, we consider the case in which emissions are caused by the use of a variable input factor. We ignore all production costs except the cost of the carbon-based energy used in production. Throughout, we use capital letters to denote the levels of physical variables under the cap&trade regime, and use small letters to denote the corresponding levels under the CDM regime. Hence, let *E* denote the use of energy measured in CO_2 units, let *X* denote output, and let *K* denote the technology parameter for the cap&trade regime. Let *e*, *x* and *k* denote the corresponding variables under the CDM regime.

To simplify the analysis we consider a linear relationship between production and emissions, for a given level of capital[18]:

(1)
$$E_i = (1 - K_i) \cdot X_i \qquad i = 1,2 \quad \text{(Cap\&trade-regime)}$$
and
$$e_i = (1 - k_i) \cdot x_i \qquad i = 1,2 \quad \text{(CDM-regime).}$$

Furthermore, we assume that there is (only) one investment option; i.e., $K_i = 0 \ \left(k_i = 0\right)$ if the firm does not invest, and $K_i = \bar{K} \ \left(k_i = \bar{K}\right)$ if the firm does invest.[19] Note that $0 < \bar{K} < 1$.

To find the Nash-equilibrium investment decisions of firms, we consider a two-stage game. In the first stage, firms choose whether to invest or keep the old technology. (Under the CDM regime, investment involves the firm entering into a CDM contract.) In the second stage, firms choose outputs. When firms make their investment decisions in stage 1, it is assumed, following Dixit (1980) and Brander and Spencer (1983), that they correctly anticipate the Nash-equilibrium outputs that emerge in stage 2. The Nash equilibrium at stage 2 is a function of both firms' investment decisions from stage 1. We solve the model backwards. In the next section, we derive the Nash-equilibrium outputs (stage 2). In Section 3.1.2, we compare the investment decision from stage 1 made under the two regimes.

3.1.1. The second stage: the output market

The cap&trade regime

For each firm, profit (Π) is the sum of net income from permit sales and net income from the output market, minus the investment cost (if the firm implements the new technology), as follows:

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[18] Although we use a very simple production function, it is sufficiently complex to illustrate how investment incentives differ under the two regimes.

[19] Having more than one investment option makes the comparison between the two regimes much more complicated without adding anything to the main result of our paper. The implication of having more than one investment option is discussed in the concluding remarks.

(2)
$$\Pi_i = t\cdot\left[E^0-(1-K_i)\cdot X_i\right] + \left[p\left(X_j+X_i\right)-q\cdot(1-K_i)\right]\cdot X_i - Q(K_i) \qquad i=1,2\ \ j=1,2\ \ i\neq j,$$

where E^0 is the firm's BaU emissions (which is equivalent to the allocation of free permits), q is the price of energy measured in CO_2 units, t is the international permit price, $p\left(X_j+X_i\right)$ is the output price (as a function of total supply), and $Q(K_i)$ is the investment cost. $Q(K_i)$ equals 0 when $K_i=0$, and equals $\bar{Q}$ when $K_i=\bar{K}$. The price of output is decreasing in quantity $(p'<0)$.

From (2) , maximizing Π_i with respect to X_i gives the following first-order condition:

(3)
$$p'\cdot X_i + p - (q+t)\cdot(1-K_i) = 0 \quad i=1,2.$$

From (3), each firm's optimal output level is a function of its own technology parameter and the other firm's output ($X_i\left(K_i, X_j\right)$)[20].

The Nash equilibrium in the output market is found by solving the two equations given by (1). Let $X_1\left(K_1,K_2\right)$ and $X_2\left(K_1,K_2\right)$ denote the Nash-equilibrium output levels in the output market.

The CDM regime

In what follows, we assume that the CDM contract is designed to maximize the joint total profit of the investor and host, which is the sum of profit from production and profit from the generation of emission permits (CERs). This implies that we assume there is no conflict of interest between the investor and the host when it comes to the implementation of the CDM project. Furthermore, we assume that no contract is signed unless it gives a non-negative increase in joint total profit. In the following we also assume that the profit of the CDM project goes to the host such that the investor is equally well off with the contract as without[21]. Another rule for profit sharing between the investor and the host would unambiguously make it less profitable for the host to enter into the CDM contract (see concluding remarks). However, by assuming that the profit goes to the host we are able to show how the two regimes differ regarding investment decisions even in the case where the firms in developing countries are able to capture all profit from the investment project under both regimes.

[20] To insure the existence of a unique, pure–strategy Nash-equilibrium, we assume that $p' + p''\cdot X_i < 0$.

[21] These two latter assumptions ensure that both the investor and host are at least as equally well off with the contract as without.

Given that we also have assumed that investment is a prerequisite for a CDM contract, the profit (π) of a firm that enters into a CDM contract is given by

(4)
$$\pi_i = t\cdot\left[E^0-\left(1-\bar{K}\right)\cdot x_i\right] + \left[p\left(x_i+x_j\right)-q\cdot\left(1-\bar{K}\right)\right]\cdot x_i-\bar{Q} \qquad i=1,2 \quad j=1,2 \quad i\neq j,$$

and is identical to the profit function of a firm that invests under a cap&trade regime.

Although the new technology reduces the need for energy per unit of production, we assume throughout that investment is not profitable unless the firm can sell emission permits. Hence, a firm that does not enter into a CDM contract does not implement the new technology, and thus has the following profit function:

(5)
$$\pi_i = \left[p\left(x_i+x_j\right)-q\right]\cdot x_i \qquad i=1,2 \quad j=1,2 \quad i\neq j$$

If a firm has entered into a CDM contract, the first-order condition for maximizing profit is obtained from maximizing (4) with respect to x_i. This first-order condition is given by

(6)
$$p'\cdot x_i+p-\left(q+t\right)\cdot\left(1-\bar{K}\right)=0 \quad i=1,2\,,$$

which corresponds to the first-order condition under a cap&trade regime.

If the firm does not enter into a CDM contract, the first-order condition is obtained by choosing x_i to maximize (5). In this case, the first-order condition is given by

(7)
$$p'\cdot x_i+p-q=0 \quad i=1,2\,.$$

From (6) and (7), each firm's optimal output level is a function of its investment decision (i.e., its decision to enter a CDM contract) and the output of the other firm. Let $x_i\left(\bar{K},x_j\right)$ denote the solution to (6) and let $x_i\left(0,x_j\right)$ denote the solution to (7).

The terms $\left(q+t\right)\cdot\left(1-\bar{K}\right)$ and $\left(q\right)$ in (6) and (7), respectively, express the marginal cost of producing x. Comparing (6) and (7), we see that the marginal cost of production decreases with investment if $\left(q+t\right)\cdot\left(1-\bar{K}\right)<q$ and increases with investment if $\left(q+t\right)\cdot\left(1-\bar{K}\right)>q$.

The Nash equilibrium in the output market, as function of the investment decisions, follows from (6) and (7). Let $x_1\left(k_1,k_2\right)$ and $x_2\left(k_1,k_2\right)$ denote the Nash-equilibrium outputs under the CDM regime.

An investment is said to have a positive (negative) strategic effect if other producers' responses to the action increase (decrease) the profit of the producer taking the action. (See, e.g., Tirole (1988), Chapter 8.) When there is Cournot competition in the output market, each firm's optimal output and profit are decreasing functions of its competitors' output levels. Thus, if investment in new more environmentally friendly technology increases the investing firm's output, such investment has a positive strategic effect. If, on the other hand, the investment causes the firm to decrease its production, the investment has a negative strategic effect.

By comparing the impact of investment under the cap&trade and CDM regimes, we derive the following proposition.

Proposition 1

Investing in a technology that increases the productivity of the variable input factor has always a positive strategic effect under the cap&trade regime. Under the CDM regime, the investment has a positive strategic effect if it causes the marginal costs of production to decrease $\left((q+1)\cdot(1-\bar{K})<q\right)$**, and has a negative strategic effect if it causes marginal costs of production to increase** $\left((q+1)\cdot(1-\bar{K})>q\right)$**.**

Proof. See appendix

Investment has two effects on the marginal cost of production under the CDM regime. On the one hand, investment increases the marginal cost of production because entering into a CDM contract also implies that emissions have become costly. Each unit increase in emission gives one unit less of CDM credits and, hence, decreases the benefit of the CDM project by the unit cost of the permits. On the other hand, investment increases energy efficiency and thus decreases the use of energy per unit of output, which, *ceteris paribus*, lowers the marginal cost of production. If the former effect dominates the latter $\left((q+t)\cdot(1-\bar{K})>q\right)$, the net marginal cost of production increases following investment[22].

In the next section, we explore how the difference in the strategic effect of investment under the two regimes influences the difference in investment incentives.

3.1.2. The first stage: the investment decision

In the first stage, each firm decides whether to invest/enter into a CDM contract. Let $\Pi_i\left(K_1,K_2\right)$ denote firm *i*'s profit under the cap&trade regime and let $\pi_i\left(k_1,k_2\right)$ denote firm *i*'s profit

[22] Bulow et al. (1985) showed how an increase in profit from one market may reduce the firm's profit in another (imperfectly competitive) market. In our model, it is the (voluntary) participation in the permit market (through the CDM contract) that may reduce the firms profit in the output market (if the CDM project causes an increase in marginal cost of production).

under the CDM regime. Under each regime, there are four different combinations of investment decisions and, hence, four different potential profit levels for each firm.

For the cap&trade and CDM regimes, respectively, in Tables 1 and 2, we summarize the investment game that takes place in stage 1, and summarize the payoffs that follow from the different outcomes in stage 2.

Table 1. Investment decisions and payoffs under the cap&trade regime

Firm 1 / Firm 2	Invest $\left(K_1 = \bar{K}\right)$	Do not invest $\left(K_1 = 0\right)$
Invest $\left(K_2 = \bar{K}\right)$	$\Pi_1\left(\bar{K},\bar{K}\right)$ $\Pi_2\left(\bar{K},\bar{K}\right)$	$\Pi_1\left(0,\bar{K}\right)$ $\Pi_2\left(0,\bar{K}\right)$
Do not invest $\left(K_2 = 0\right)$	$\Pi_1\left(\bar{K},0\right)$ $\Pi_2\left(\bar{K},0\right)$	$\Pi_1\left(0,0\right)$ $\Pi_2\left(0,0\right)$

Table 2. Investment decisions and payoffs under the CDM regime

Firm 1 / Firm 2	Invest $\left(k_1 = \bar{K}\right)$	Do not invest $\left(k_1 = 0\right)$
Invest $\left(k_2 = \bar{K}\right)$	$\pi_1\left(\bar{K},\bar{K}\right)$ $\pi_2\left(\bar{K},\bar{K}\right)$	$\pi_1\left(0,\bar{K}\right)$ $\pi_2\left(0,\bar{K}\right)$
Do not invest $\left(k_2 = 0\right)$	$\pi_1\left(\bar{K},0\right)$ $\pi_2\left(\bar{K},0\right)$	$\pi_1\left(0,0\right)$ $\pi_2\left(0,0\right)$

In what follows, we explain how the two regimes may lead to different Nash-equilibrium investment decisions even though firms have identical investment options and production functions under both regimes[23]. To find the solution to the first-stage games under the two regimes, we must rank the payoffs of the different outcomes of the games.

[23] There may not be unique Nash-equilibrium solutions of the games. See, e.g., Rasmussen (1989, chapter 1) for a discussion of the Nash equilibrium for different rankings of payoffs.

Because both firms have identical production functions, it follows that

(8)
$$\begin{aligned}&\Pi_1\left(\bar{K},\bar{K}\right)=\Pi_2\left(\bar{K},\bar{K}\right),\pi_1\left(\bar{K},\bar{K}\right)=\pi_2\left(\bar{K},\bar{K}\right),\\&\Pi_1\left(0,0\right)=\Pi_2\left(0,0\right),\pi_1\left(0,0\right)=\pi_2\left(0,0\right),\\&\Pi_1\left(0,\bar{K}\right)=\Pi_2\left(\bar{K},0\right),\pi_1\left(0,\bar{K}\right)=\pi_2\left(\bar{K},0\right),\\&\Pi_1\left(\bar{K},0\right)=\Pi_2\left(0,\bar{K}\right),\pi_1\left(\bar{K},0\right)=\pi_2\left(0,\bar{K}\right).\end{aligned}$$

In the following we restrict the attention to the ranking of the payoffs for firm 1, as any ranking of the payoffs for firm 1 determines a symmetric ranking of the payoffs for firm 2, given by (8).

From the first-order conditions given by (3) and (6), it follows that if both firms invest, the Nash-equilibrium outputs are identical under both regimes; i.e.,

(9) $$\Pi_1\left(\bar{K},\bar{K}\right)=\pi_1\left(\bar{K},\bar{K}\right).$$

To illuminate the consequences of the different strategic effects of investment under the two regimes, we consider an investment project for which, under both regimes, both firms prefer an outcome in which both invest to one in which no firm invests. This implies that

(10) $$\Pi_1\left(\bar{K},\bar{K}\right)>\Pi_1\left(0,0\right) \text{ and } \pi_1\left(\bar{K},\bar{K}\right)>\pi_1\left(0,0\right).$$

It follows from Proposition 1 that each firm under the cap&trade regime is better off if the other firm does not invest. Hence, given (10), the only possible ranking of the outcomes under the cap&trade regime is as follows:

(11) $$\Pi_1\left(\bar{K},0\right)>\Pi_1\left(\bar{K},\bar{K}\right)>\Pi_1\left(0,0\right)>\Pi_1\left(0,\bar{K}\right).$$

For this ranking, 'Invest' is the dominant strategy for both firms, and the unique Nash equilibrium in stage 1 is for both firms to invest under the cap&trade regime.

Under the CDM regime, the ranking of the different outcomes depends on whether the strategic effect of investment is positive or negative. If the strategic effect is positive, the ranking of the outcomes is the same as under the cap&trade regime. Hence, for $\left(q+t\right)\cdot\left(1-\bar{K}\right)<q$, and given (10), the only possible ranking of the outcomes is:

(12) $$\pi_1\left(\bar{K},0\right)>\pi_1\left(\bar{K},\bar{K}\right)>\pi_1\left(0,0\right)>\pi_1\left(0,\bar{K}\right),$$

and the Nash equilibrium in stage 1 is for both firms to invest under the CDM regime.
Let us now consider the case in which investment gives a strategic disadvantage, i.e., $\left(q+t\right)\cdot\left(1-\bar{K}\right)>q$.

When investment leads to a strategic disadvantage, each firm is better of if the other firm invests. If the strategic disadvantage of investment is sufficiently large, each firm prefers the strategy 'Do not invest', whatever the other firm chooses; i.e., $\pi_1\left(0,\bar{K}\right) > \pi_1\left(\bar{K},\bar{K}\right)$ and $\pi_1\left(0,0\right) > \pi_1\left(\bar{K},0\right)$.[24] In that case, 'Do not invest' is the dominant strategy, and outcomes are ranked as follows:

(13) $$\pi_1\left(0,\bar{K}\right) > \pi_1\left(\bar{K},\bar{K}\right) > \pi_1\left(0,0\right) > \pi_1\left(\bar{K},0\right).$$

This ranking leads to a unique Nash equilibrium in which no firm invests.

We can now state the following proposition.

Proposition 2

Consider the case in which the outcome under which both firms invest is preferred to the outcome under which no firm invests under both regimes. In this case, there is a unique Nash equilibrium in which both firms invest under the cap&trade regime. However, under the CDM regime, there may be a prisoner's dilemma outcome in which no firm invests.

Proof. See appendix

The difference in the gains from investment between the two regimes arises because investment in cleaner technology affects the marginal profit of production in different ways. As stated in proposition 1, the *strategic effect* of investment may be negative under the CDM regime, but is unambiguously positive under the cap&trade regime. Note that the *permit market access effect* favors investment under the CDM regime rather than investment under the cap&trade regime. Under the cap&trade regime, firms may benefit from reducing emissions without investing because they can sell surplus permits on the market. It is assumed that this is not an option under the CDM regime. Hence, the *permit market access effect* increases the gains from investing under the CDM regime (given that both firm invest).[25] In the example given in the proof of proposition 2, the *strategic effect* outweighs the *permit market access effect* ($\pi_1\left(0,\bar{K}\right) > \pi_1\left(\bar{K},\bar{K}\right)$ and $\pi_1\left(0,0\right) > \pi_1\left(\bar{K},0\right)$).

The prisoner's dilemma is less likely to occur the more energy efficient is the investment option (the higher is $\bar{K}$). There are two reasons for this. (i) The strategic disadvantage (advantage) of an

[24] If the strategic disadvantage of investment is lower, there may be other outcomes for the ranking of the payoffs.

[25] $\Pi_1\left(\bar{K},\bar{K}\right) = \pi_1\left(\bar{K},\bar{K}\right)$ but $\Pi_1\left(0,0\right) > \pi_1\left(0,0\right)$, so that $\Pi_1\left(\bar{K},\bar{K}\right) - \Pi_1\left(0,0\right) < \pi_1\left(\bar{K},\bar{K}\right) - \pi_1\left(0,0\right)$.

investment is decreasing (increasing) in $\bar{K}$.[26] (ii) The gains from using the permit market are increasing in $\bar{K}$. (From (4), for any given production level, income from permit sales is increasing in $\bar{K}$.)

From (4), for any given production level, income from permit sales is increasing in the permit price (t). Hence, an increase in t increases the gains from using the permit market. However, the strategic effect of an increase in t is negative. This is because an increase in t decreases the investing firm's optimal output.[27] Hence, the impact of an increase in the permit price on the likelihood of there being a prisoner's dilemma situation is ambiguous.

In the next section, we consider an abatement option that does not affect firms' marginal profits of production. We show that, in that case, the difference in investment incentives between the two regimes depends only on the *permit market access effect*.

3.2. Investment affects the emissions from a fixed production factor

The difference in the strategic effect of an investment between the two regimes, discussed in the previous section, is due to the fact that emissions are correlated with production. Consider the case in which the fixed production factor, rather than the variable production factor, generates emissions. This is, for instance, the case if emission is only generated by the heating or cooling of the production plant, (and the need for heating/cooling is independent of the production level). In that case, there is no difference in *strategic effect* of investment under the two regimes. If the only relevant abatement option is to invest in new less polluting (heating/cooling) technology, there is no difference in incentives for investment due to the *permit market access effect* either, as firms must invest in new technology to sell permits under both regimes. If, on the other hand, it is profitable for firms to reduce emissions from the fixed production factor without investing in new technology under the cap&trade regime, the *permit market access effect* favors investment under the CDM regime rather than investment under the cap&trade regime.

We can hence state the following proposition.

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[26] We find from total differentiation of (6) that $\frac{\partial x_i\left(\bar{K}, x_j\right)}{\partial \bar{K}} = -\frac{(q+t)}{p'' \cdot x_i + 2p'} > 0$.

[27] We find from total differentiation of (6) that $\frac{\partial x_i\left(\bar{K}, x_j\right)}{\partial t} = \frac{(1-\bar{K})}{p'' \cdot x_i + 2p'} < 0$.

Proposition 3

Given that investment is a prerequisite for a CDM project, and given that the only possibility for abatement is to reduce emissions from a fixed production factor, the gains from investment under the CDM regime exceed (or equal) those under the cap&trade regime.

Proof. See appendix

Furthermore, if investment were not a prerequisite for a CDM contract, investment incentives would be the same under the two regimes.

4. Competitive output markets

In the previous sections we considered situations in which firms faced an imperfectly competitive output market. When investment affects the marginal cost of production, it also affects firms' strategic positions in the output market (section 3.1). If we assume that firms only produce small shares of world output, their prices are independent of their output levels and thus unaffected by their investment decisions. Investment only affects the investing firm's output, and does not change the equilibrium output price. This implies that each firm considers its benefit from investment independently of the actions of other firms. There is no strategic effect of investment when firms face competitive output markets. The only difference in incentives for investment between the two regimes follows from the *permit market access effect*. Hence, the case of competitive output markets correspond to the case in which the fixed production factor, rather than the variable production factor, generates emissions, as discussed in section 3.2. We can hence state the following proposition:

Proposition 4

Given that investment is a prerequisite for a CDM project, and given that firms are perfectly competitive, the net gains from investment under the CDM regime exceed (or equal) those under the cap&trade regime.

Proof. See in appendix

If investment were not a prerequisite for a CDM contract, or if abatement were not profitable unless the firm had invested under the cap&trade regime, investment incentives would be the same under the two regimes (as there would be no difference in investment incentives due to the *permit market access effect*).

5. Concluding remarks

The purpose of this article was to compare the incentives for investing in new technology under two different climate regimes. We showed that if producers in a developing country face a competitive output market, or if investment does not influence marginal production costs, the gains from investing under a clean development mechanism (CDM) regime exceed (or equal) those from investing under a 'cap&trade' regime. When producers face an imperfectly competitive output market, investment may give the firm a strategic disadvantage in the output market under a CDM regime. This effect makes it less profitable to invest under a CDM regime than under a cap&trade regime.

Welfare comparisons of the two regimes are not in general trivial under oligopolistic output markets. This is because climate policies affect the already-distorted output market. However, because we assumed that firms produce output for a foreign market, we can ignore the effect of policy on the consumer surplus. In that case, a developing country's social surplus equals the sum of the producers' surpluses. Thus, an investment option that improves both firms' profits, and hence increases total welfare, would be implemented under a cap&trade regime, but would not necessarily be under a CDM regime (see Proposition 2).

Furthermore, if firms face competitive output markets, or if an investment option does not affect output, the firm is more likely to invest under a CDM regime than under a cap&trade regime if investment is a prerequisite for CDM credits. Hence, for a developing country seeking to promote investment in new technology, choosing a CDM regime may be better than participating in a cap&trade regime. However, because implementing investment through a CDM contract confers access to the permit market, a CDM regime may lead to the implementation of inefficient investment projects in the sense that it would be more cost-effective to undertake abatement efforts that did not require fixed investments.

We considered a situation in which there was only one investment option. However, there may be a range of different technologies that can reduce emissions or increase the energy efficiency of the firm. Because investment affects the firm's strategic position in the output market differently under the two regimes we considered, firms may choose different levels of investment under the two regimes.

We also assumed that a host for a CDM project receives all the net income from the project. However, it is likely that investors seek to profit from their investments. In that case, producers in the developing countries have a lesser incentive to invest in new technology under a CDM regime than under a cap&trade regime (when they do not have to share the profit with foreign investors).

We assumed that business-as-usual (BaU) emissions can be correctly calculated. We also assumed that emission credits under a CDM regime are equivalent to the difference between the BaU emissions and those following implementation of a CDM project. Any miscalculation of the BaU emissions (denoted by E^0 in the text) implies that emission credits do not correspond to real emissions reductions. Furthermore, overstating (understating) BaU emissions increases (decreases) incentives for investment under a CDM regime, relative to those under a cap&trade regime.[28]

According to the Kyoto Protocol, one option for compliance is to invest in specific projects in other countries with quantified emission targets—so-called joint implementation projects. For our model specifications, the incentives for investment would be identical whether a firm hosted a joint implementation project or whether it participated in emission trading. The reason for this is that, in a country with a binding emission target (a cap on emission), it is assumed that all firms are allowed to trade in permits. Their shadow cost of emissions is therefore equal to the international permit price whether they host a joint implementation project or whether they participate in emission trading. A joint implementation project therefore gives no *permit market access effect.* The *strategic effect* of an investment would also be identical whether a firm hosted a joint implementation project or whether it participated in emission trading. Furthermore, in our model, the host and investor are assumed to cooperate to maximize the profit of the investment project, and all profit is assumed to go to the host. Hence, the host's profit from an investment is identical whether it is financed by a foreign investor or funded by the host.[29]

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[28] See Fischer (2005) for a discussion of the effect on efficiency of over-allocating baseline emissions under a CDM regime.

[29] See, e.g., Breton et al. (2006) for an analysis of the merits of joint implementation in a game-theoretic setting with different model specifications to ours.

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Appendix

Proof of Proposition 1

We see from (1) that investment increases the productivity of emissions $\frac{\partial^2 X_i\left(E_i,K_i\right)}{\partial E_i \partial K_i}>0$

$\left(\frac{\partial^2 x_i\left(e_i,k_i\right)}{\partial e_i \partial k_i}>0\right)$. It follows from the standard literature that the strategic effect of an investment under Cournot competition is positive (negative) if the investment leads to higher (lower) output from the investing firm. The first-order condition under cap&trade, given by (3), implies that $X_i\left(\bar{K},X_j\right)>X_i\left(0,X_j\right)$. It thus follows from downward-sloping reaction functions that $X_i\left(\bar{K},K_j\right)>X_i\left(0,K_j\right)$. Comparing the two first-order conditions (6) and (7) under the CDM regime, we find that: $x_i\left(\bar{K},x_j\right)>x_i\left(0,x_j\right)$ if $\left(q+t\right)\cdot\left(1-\bar{K}\right)<q$ and $x_i\left(\bar{K},x_j\right)<x_i\left(0,x_j\right)$ if $\left(q+t\right)\cdot\left(1-\bar{K}\right)>q$. Downward-sloping reaction functions ensure that, for $\left(q+t\right)\cdot\left(1-\bar{K}\right)<q$, it follows that $x_i\left(\bar{K},k_j\right)>x_i\left(0,k_j\right)$. For $\left(q+t\right)\cdot\left(1-\bar{K}\right)>q$, we find that $x_i\left(\bar{K},k_j\right)<x_i\left(0,k_j\right)$.

Proof of Proposition 2

From the previous discussion, if $\Pi_1\left(\bar{K},\bar{K}\right)>\Pi_1\left(0,0\right)$, the unique Nash equilibrium in stage 1 is for both firms to invest under the cap&trade regime. To show that the same investment option may lead to a situation in which no firm invests under the CDM regime, despite the fact that $\pi_1\left(\bar{K},\bar{K}\right)>\pi_1\left(0,0\right)$, we use a numerical example. Let the demand function for the commodity produced by the two firms be $p(x)=30-x$. Note that $x=x_i+x_j$ under the CDM regime, and $x=X_i+X_j$ under the cap&trade regime. Furthermore, let q = 1, t = 2 and E^0 = 29/3.

For $\bar{K}$ = 1/5 and Q = 3, we find that

$\Pi_1\left(\bar{K},0\right)(\approx 105)>\Pi_1\left(\bar{K},\bar{K}\right)\approx 101>\Pi_1\left(0,0\right)\approx 100>\Pi_1\left(0,\bar{K}\right)\approx 97$ and that

$\pi_1\left(0,\bar{K}\right)\approx 103>\pi_1\left(\bar{K},\bar{K}\right)\approx 101>\pi_1\left(0,0\right)\approx 93{,}4>\pi_1\left(\bar{K},0\right)\approx 92{,}6$. Hence, the dominant strategy is to invest under the cap&trade regime. However, the dominant strategy under the CDM regime is to not invest.

Proof of Proposition 3

As there is no strategic effect of investment when the firm does not affect the marginal cost of production, this corresponds to the situation where $\Pi_1\left(\bar{K},\bar{K}\right)=\Pi_1\left(\bar{K},0\right)$, $\Pi_1\left(0,\bar{K}\right)=\Pi_1\left(0,0\right)$ and

$\pi_1\left(\bar{K},\bar{K}\right)=\pi_1\left(\bar{K},0\right), \pi_1\left(0,\bar{K}\right)=\pi_1\left(0,0\right)$ (See Table 1 and 2). A difference between the two regimes arises only because of the *permit market access effect*. Hence, the gains from investment cannot be lower under the CDM regime than under the cap&trade regime. (That is, $\Pi_1\left(\bar{K},\bar{K}\right)-\Pi_1\left(0,\bar{K}\right)\leq\pi_1\left(\bar{K},\bar{K}\right)-\pi_1\left(0,\bar{K}\right)$).

Proof of Proposition 4

As there is no strategic effect of investment when firms face competitive output markets, the proof of proposition 4 is identical to the proof of proposition 3.