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Abstract

Climate change is a serious concern worldwide. Policy research on climate change in the past decades has largely focused on applied modelling exercises. However, the implications of specific policy strategies such as the clean development mechanism (CDM) for global and regional economic and environmental developments has received relatively little attention. This is partly caused by the complexities of modelling an instrument like CDM. By using and modifying the GTAP-E modelling system, this paper sets out to trace the combined economic and environmental impacts of CDM policies. Particular emphasis is placed on technology transfer induced by alternative CDM policies. Specific attention is devoted to the possible negative consequences of non-participation of the USA in the global coalition, and the associated distributional impacts world-wide.

Key-words: Climate Change, Clean Development Mechanism, Regional Development
JEL codes: F18, O13, Q54, Q56

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1. Introduction

During the last two decades of the 20th century, the importance of transboundary environmental problems, especially related to water, air and biodiversity, has been increasingly recognized, resulting in the adoption of many international agreements and associated policy plans (e.g., Nijkamp and Castells 2001).[2] Climate change as a result of greenhouse gas emissions is one of those areas that have become a source of both policy concern and scientific inspiration (see, e.g., Lieberman et al. 2007). Dedicated policies to cope with climate changes – at regional, national and international levels – are normally characterized by much uncertainty and substantial costs. Various countries have decided to resort to market-based principles within a system of regulations and legally binding targets. A tradeable permit system is one of such examples, where maximum constraints on environmental quality (i.e., fixed reduction rates of CO_2 for different main regions of our world) are imposed. A world-wide system of emission rights and sales (or transfers) does, however, cause very complex policy responses that ought to be investigated in the context of multiregional economic-environmental equilibrium modelling (see, amongst many others, Castelnuovo et al. 2005, Copeland and Taylor 2005, and Gerlagh and Van der Zwaan 2006).

Global climate change policies prompt of course responses in the production and consumption system and hence in international trade, but are seen to be desirable to combat the externalities of CO_2 emissions (see also IPCC 2007). There are evidently winners and losers in this competitive game. The nations of our world have tried to resolve the coordination issues inherent in international climate change policy through the establishment of the UN Framework Convention on Climate Change and its subsequent Kyoto Protocol (KP). This Protocol reflects essentially different national interests based on the principle of common but differentiated responsibilities in a global climate change policy (see, for example, Kuik 2005, Kuik and Mulder 2004, Kuik and Verbruggen 2002, and OECD 1999). The long negotiation procedures until its final (partial) acceptance in 2005 and the very recently experienced new problems in Bali (Indonesia) are clear reflections of the complexity of consensus formation on issues where different interests are at stake.

In particular, in view of the welfare losses resulting from an international climate change policy regime, the policy instruments of emission trading, joint implementation (JI) and the clean development mechanism (CDM) may mitigate the costs of such a policy intervention by providing so-called ’where’-flexibility. This type of flexibility enables countries involved to achieve the emission reduction targets in other countries against the lowest possible costs

[2] Examples of such agreements are the Rio de Janeiro Declaration on Environment and Development (1992); the Convention for the Protection of the Marine Environment of the North-East Atlantic (1999); the UN Convention on the Law of the Non-Navigational Use of International Watercourses (1997); the Convention on Long-Range Transboundary Air Pollution (1979, 1985, 1988, 1994); the Montreal Protocol on Substances that Deplete the Ozone Layer (1987, 1990, 1991 and 1992); the UN Framework Convention on Climate Change (1992, and further); the Convention on Biodiversity (1992); and the International Tropical Timber Agreement (1994).

of a climate change policy (see, e.g., Bramoulleé and Olson 2005, and Kverndokk et al. 2004).

As one of the flexible instruments from the Kyoto Protocol (KP), CDM is designed and foreseen as a cost-effective way for emission reduction of Greenhouse gases (GHG), by stimulating technological change in the non-Annex I countries (which consists of mainly the developing countries). In this respect, CDM policies have attracted much attention, as these policies are, in comparison with more traditional policies involving tax and/or property rights systems, relatively novel in that they explicitly recognize the relevance and potential of technological change for complying with environmental restrictions. The policy question addressed in this paper is: "*What are the impacts of CDM policies on the economic performance of (groups of) countries in our global economic system?*"

This paper is organized as follows. Section 2 first gives an overview of some selected and relevant issues regarding the introduction of CDM in an international policy and research context. Then, Section 3 puts the global analysis of CDM in a conceptual-methodological perspective of economic-ecological interactions and research challenges. An operational global framework for CDM is next offered in Section 4, with a particular view to the design of an empirically-oriented assessment system. Next, Section 5 describes the specific model framework deployed in our analysis, viz. GTAP-E, and offers various simulation results on CDM policies, including the economic and environmental implications for major regions of our world. The next section is then devoted to the assessment of the impacts of non-participation by the US, while the final section offers retrospective and prospective remarks on climate change modelling research.

2. The Economic Logic, Politics and Modelling of CDM

Logic and unresolved economic issues

CDM is a product of a last minute `Kyoto surprise' (Yamin 2000), which was introduced to overcome the opposition of the G77-countries (i.e., the developing countries) to the use of JI in the developed countries (Mathy et al. 2001). As such, JI and CDM are defined as different instruments in the KP. The objectives of CDM policies are defined in Article 12 of the KP as: (i) to assist non-Annex I countries in achieving sustainable development; (ii) to assist non-Annex I countries in contributing to the ultimate objective of the Convention; and (iii) to assist Annex I countries in achieving compliance with their quantified emission limitations and reduction commitments.

CDM refers to technological change induced in destination regions as a result of dedicated R&D investments from source regions. The principle behind the operation of CDM policies is that these policies would allow Annex I countries – more specifically, the source regions which are obliged to control GHG-emissions – to satisfy all or part of their emission obligations by financing, directly or indirectly, technological change resulting in emission reductions in the non-Annex I countries. For this purpose, the assignment of `Certified Emission Reduction units' (CERs) plays an important role in the international negotiations concerned.

The common rationale underlying CDM policies is the expected efficiency gain from: (i) differences in the level of technology between countries at different stages of development and (ii) lower abatement costs in developing countries because of the current use of less efficient technologies in these countries in transforming a given volume of inputs into a volume of outputs. It is expected that flexible mechanisms like CDM would be more cost-effective and that these policies may improve the relatively feeble economic situation in developing countries due to induced technological changes. A serious trade-off arises, however, due to the possibility of leakages emerging from increases of emissions in non-Annex I countries (e.g., Bollen et al. 1999).

Other discussions centre around questions like: "should CDM policies take place on a project basis?"; "how should arrangements for compensation be set up?" and "should sinks be considered?". Further practical complications on the design of CDM instruments stem from the current international political context, since the acceptance of these instruments depends on the possible national impact of these designs. Further interesting questions are related to the effect of the design of the instrument on various economic and ecological key variables. For example, how will economic activities change as a result of emission constraints and CDM policies? And will CDM policies really generate the intended effect, i.e. a reduction of overall CO_2 emissions? And how will costs and benefits be distributed globally in view of the North-South relationships and the burden-sharing? And should CDM policies be incorporated in the broader debate on foreign investment and financial assistance? (see, e.g., Toman and Hourcade 2000).

Negotiation issues

In addition to the above issues, most negotiations tend to focus on the following aspects of CDM policies: (i) the institutional structure; (ii) the additionality principle; (iii) sinks; (iv) baselines; and (v) compliance and verification mechanisms. With reference to the institutional structure, the Marrakech Accords allow the following three approaches to set up CDM projects (see, e.g., Michaelowa 2003). First, the multilateral approach advocates a CDM institution to operate as a fund for financing CDM projects. Secondly, the bilateral approach calls for a CDM institution as a clearinghouse which facilitates CDM projects (Yamin 2000). Thirdly, the unilateral approach refers to countries' own responsibilities in initiating and accepting projects. In this respect, the Executive Board of CDM is a major institution which has been set up to oversee the project cycle of CDM. This protocol consists of rules and procedures for design, validation, monitoring, verification and issuance of the CERs of the CDM projects.

The additionality issue originates from Article 12.5c of the KP, which states that *"...emission reductions should be 'additional' to any that would occur in the absence of such activities"* (i.e., CDM). This article prompted many discussions, as it is unclear in which way 'additionality' should be defined. In the negotiations, many `additionality' principles were brought forward, often partly overlapping. The environmental additionality condition presupposes that all abatements as a result of CDM investments are emission reductions which would not have occurred otherwise. The development additionality condition requires that CDM investment should encourage economic development in the developing countries which would not be achieved otherwise (see, e.g., Mathy et al. 2001).

The concept of investment or economic additionality is usually applied as a requirement for CDM projects. This concept is advocated to exclude projects from CDM policies, which would otherwise be implemented anyway by market transactions. It is argued that including these projects will only be a `relabelling' of existing projects and will not contribute to emission reductions (see, e.g., Shrestha and Timilsina 2002; Greiner and Michaelowa 2003).

The issue of which of the additionality principles should be chosen is important for the functioning of CDM and KP. On the one hand, the environmental additionality principles will increase the attractiveness of CDM projects and lower the costs of CDM, as existing projects would also fall under this category. However, this may undermine global climate change policy, because the KP emission reduction targets at the global level would not be met, as the CERs would be subtracted from the participating countries' targets, while the non-Annex I countries would not be affected, as they have no emission reduction targets. On the other hand, investment additionality will increase the transaction costs, as it is not easy to prove that some investments would otherwise not be made. In this way, CDM projects may become less attractive due to many information requirements and administrative reviews. This applies especially for small-scale projects (see, e.g., Shrestha and Timilsina 2002; Mathy et al. 2001; and Greiner and Michaelowa 2003).

The issue of sinks is a broad issue which is also applicable for other flexibility mechanisms. However, as part of CDM policies, it is a politically-loaded issue (Noble and Scholes 2001). From an economic point of view, it does not matter whether emissions will be reduced or whether these emissions will be `removed' by, for example, sinks (see Noble and Scholes 2001). In the case of sinks, land use, land-use change and forestation are important forms of human induced activities which affect the functioning of these removals. It should, however, be investigated further how the recurrences would be within the ecological system. The problem is that sinks may offer a backdoor which could jeopardise the whole intention of the KP for several reasons. First, there is the fear of insufficient accuracy of measurement of emissions that could be removed by land use and forestation. In addition, the emissions which are pooled by forestation could be released back into the atmosphere (e.g., in the case of fire or in the case of land-use change). This would raise the question of how these releases should be accounted for. The non-Annex I countries have, after all, no emission reduction targets. On the other hand, the non-Annex I countries may fear the loss of sovereignty, as the land-use agreements due to CDM activities will bring long-run commitments. Furthermore, it is also possible that a non-Annex I country could designate a region under CDM for reforestation, while exploiting another part of the country by deforestation activities (i.e., the problem of leakage resulting from the fact that these countries do not have emission reduction targets). Thus, the issue of sinks relates to the intergenerational and intragenerational distribution of welfare in the economic system, and uncertainties associated to the ecological processes.

The issue of baselines refers to the question how the amount of emission reductions should be calculated as CERs (Böhringer et al. 1998). This is an important issue, as the emission reductions from the CDM activities should be additional. On the one hand, it directly affects the profitability of CDM investments from the Annex I countries and thus the willingness of producers in the Annex I countries to implement their emission reductions, while it also affects the effectiveness of this instrument for emission reductions. The reason is that a higher assignment of CERs would reduce the shadow costs associated with emission reductions. On the other hand, it would affect the effectiveness of the voluntarily-agreed emission targets, as a higher assignment of CERs would lead effectively to a lower total emission reduction target by the Annex I countries.

Finally, the issue of compliance is related to legal sanctions if the countries cannot or do not achieve their voluntarily-agreed environmental targets and commitments. The monitoring issue covers the integrity of the resulting credits, as the baseline cannot actually be measured. The difficulties concerning these issues may be overcome by the proper introduction of the project cycle for CDM policies. However, it remains to be seen how effectively the institutional bodies will function.

Research directions

The main body of literature concerning CDM policies is policy-oriented. This consists largely of a review of climate change negotiations (see, e.g., Toman and Hourcade 2000, Michaelowa 2003, and IISD 2002). Some authors have in the meantime reviewed the usefulness of CDM policies. Hardner et al. (1999), for example, discuss the mitigation effects of CDM policies for carbon emissions and the related positive effects for socio-economic developments and for biodiversity. Woerdman (2000) argues that CDM policies would be more advantageous than other global climate change policies like international emission trading. The majority of the literature, however, provides and discusses proposals for the functioning of some aspects of CDM policies. Parkinson et al. (1999), for example, discuss the importance of rules for the banking of CERs. The issue of sinks was, among others, addressed by Noble and Scholes (2001). Geres and Michaelowa (2002) illustrated possible leakage effects caused by CDM policies. Various policy alternatives, such as a cap on sinks, were discussed by Forner and Jotzo (2002). As the issue of sinks is still a politically-loaded issue, Schwarze and Niles (2000), for example, discussed some long-term requirements of forestry for CDM policies.

In addition, empirically-oriented and quantitative studies have analyzed CDM policies on a project level. De Leeuw and Van Ierland (2003), for example, analyzed some Dutch projects carried out under the Activities Implemented Jointly program in order to highlight some practical issues, which are also important for the ongoing negotiations, such as baselines and monitoring, that are involved with carrying out a CDM project, as well as the attractiveness of such projects as tools for climate change policies. Furthermore, other empirically-oriented studies have tried to estimate the CDM potential. This kind of studies may be found on a sectoral level in several countries (see e.g., Bosi and Ellis 1999), on aggregate possibilities of the CDM potential in a given country (see e.g., Jackson 1995; Fichtner et al. 2001; and Duic et al. 2003), or on a global level (see, e.g., Halsnaes 2002).

From a modelling point of view, the CDM market potential has been estimated by means of a few models using the marginal abatement cost approach (see, e.g., Zhang 2001). Recently, the CDM potential in economic models was simulated by adding transaction costs components to the marginal abatement costs (Jotzo and Michaelowa 2002, and Chen 2003). In the literature, there are models which capture the technology aspects of CDM (e.g., the RICE model; see Nordhaus and Yang 1996) or substitution between energy commodities due to CDM policies (see, e.g., Bollen et al. 1999). Clearly, the main features of CDM, i.e., technological solutions and the resulting emission reductions as well as the CERs, remain difficult to capture completely adequately in models. There are some notable contributions in this field. For example, Böhringer et al. (2003) have studied technology transfer through productivity gaps and capital transfer between industrialized and developing countries. Other interesting contributions on technological knowledge transfer in traded goods in a GTAP system can be found in Das (2000). And finally, technology transfer through total factor productivity rise in developing countries and investments in more efficient abatement technologies was investigated by Aronsson et al. (2006). The next section elaborates on some of the key conceptual and methodological complexities inherent in CDM policy.

3. Conceptual and Methodological Complexities in Analyzing CDM and Associated Economic-Environmental Interactions

In analyzing the economic impacts of global environmental policies, such as CDM, modelling studies face several conceptual and methodological complexities. A central concept in the field of environmental economics originates from Marshall's notion of "external economy" (Marshall 1910). Indeed, two fundamental concepts in the field of environmental economics are the 'externality' and 'public goods' character of environmental amenities (Baumol and Oates 1987). In economic analysis, an externality is generally conceived of as a divergence between the marginal social and private cost of a good. Environmental damage thus typically involves a negative externality, when it is not (or not optimally) priced. The result is that a tax, subsidy or other governmental measure is justified in order to correct the impact of such an externality. This description of an externality implies thus that (i) an externality exists when some agents' action influences the utility of other agents, without this effect being properly reflected in prices (see e.g., Mishan 1971), and (ii) necessary conditions for a socially optimal situation (i.e., the Pareto-optimality conditions) are violated (Buchanan and Stubblebine 1962, Baumol and Oates 1987, Mas-Colell et al. 1995).

While externalities are a central concept in neoclassical economics, the ecological economics' perspective emphasizes that economic growth will result in an increased use of natural resources or increased damage to ecological systems as a result of pollution, even when externalities are internalized (Meadows et al. 1972; Daly 1990, 1997). More specifically, sustainable growth from a mainstream economic perspective (Solow 1974; Hartwick 1977) may even have a different interpretation (Common and Perrings 1997) than the concept of 'sustainable development' from an ecologically-oriented economic perspective (Holling 1973). That is, even when increasing scarcity of an environmental good would be coped with by an increase in environmental taxes – or, more broadly, in taxes that would in addition reflect intergenerational equity considerations (Withagen 1995, 1996) – the outcome may still not be regarded as strictly sustainable (over an infinitely long time frame). This conclusion may derive from fundamental laws of thermo-dynamics (see also Van den Bergh 2000).

In a similar vein, regarding materials use, the concept of 'material balance' has been put forward by ecological economists (Kneese et al. 1970, Ayres 1978, Ruth 1993, Van den Bergh 1996). This means that the same mass of input (material use) in the economic system, which is extracted from the ecological system, should return as output of the economic system into the ecological system. This feedback could be represented by, for example, material waste or pollution. In this interpretation, the resources are materials that initially have low entropy and become waste, which are materials of high entropy (Ayres 1999, Van den Bergh 1996).

A synthesis of insights from both perspectives raises the question of whether flows of inputs necessary to achieve a sustainable development in terms of production and consumption flows can be extracted from intrinsically finite stocks with bounded regeneration, over an infinitely long time span and for a possibly permanently growing world population, while keeping environmental quality at an acceptable ('sustainable') level.

Another central theme of interest is 'space'. Both the economic system and the ecological system operate in an open spatial landscape, so that various spatial externalities that arise from the interaction between the economic and the ecological system may be envisaged at the level of individual regions rather than at the level of individual actors. If no divergence exists between the marginal social costs and the marginal private costs for the economic subjects, climate change issues would not be so prominent, because, in the preference rankings of economic subjects, the sustainability of the ecological system would already be taken into account (assuming that marginal social costs would go to infinity when sustainability conditions are violated). However, due to the complexities of the ecological system and due to peculiarities of ecological goods, i.e. the non-rivalry and the non-excludability properties of, for example, the air, these goods are not properly priced. The simultaneous analysis of spatial externalities and spatial economic interactions (trade, migration, capital flows) is so complex that any model that aims to map out the economic-environmental interactions under conditions of spatial externalities is fraught with many uncertainties, and is at best a rough approximation of a complex global system.

The problem associated with climate change is pre-eminently a dynamic problem, as climate change involves the long-run effects of human activities on the physical environment, as well as the long-run effects of the climate system on the future generations. The literature on climate economics focuses on this long-run relationship (e.g., Carraro 1999; Daly and Townsend 1993; Goodland 1995). This indicates that the general-dynamic direction of the time-integrality surface deserves due attention, but this direction involves at present too much complexity. Therefore, our study will be modest and analyze climate change issues in a Computable General Equilibrium (CGE) model of an open economic system, in order to highlight a part of the complexity. The model is not so general that it could endogenize the choice of emission standards, or represent consequences of violating these.

In that respect, the approach resembles the `cake-eating' problem in a dynamic programming context. The ‘cake’ then refers to an exogenously specified carrying-capacity of the ecological system, e.g. the concentration of GHGs in the climate system. In this setting, carbon emission restriction in a given period could be derived from the trade-off between the utility that could be obtained in the following periods and the utility that could be obtained in the preceding period – but even this will not be done in our static model. We instead work with objectives in terms of the allowed aggregate (global) flow of emissions, not the stock. But, given the size of this cake, which will be reduced by a certain policy initiative, we can analyze how it will be divided between the regions, and how this distribution would affect the economic performance of various regions. Although it is ultimately the stock that matters, not the flow, our approach has two main advantages, namely that it more closely follows the type of constraints as specified in actual policies, and that it is far less complex than having to deal with optimal time paths of stocks of emissions.

The static framework gives us the opportunity to analyze the relationships between relevant components in the spatial-functional interaction in more detail. The general spatial economic equilibrium framework is an appropriate tool for this purpose, as it takes into account all relevant components within the economic system, while the ecological system is reduced to an exogenous constraint. Section 4 will now be devoted to an attempt to operationalize some of the above notions in the context of applied climate policy modelling.

4. Modelling Framework

Operationalization of CDM

It ought to be recognized that CDM policies – despite much empirical work – still encompass many uncertainties. For modelling purposes, in our paper CDM policies are stylized and operationalized as follows:

- producers in Annex I countries finance their CDM investment by levying `self-imposed' taxes. These investments are collected by the CDM coordinator, a situation which is analogous to the way savings are collected by the global bank;
- producers in non-Annex I countries receive these investments from the CDM coordinator, in the sense that they will 'experience' a resulting technological change in their production processes;
- technological change leads, ceteris paribus, to a reduced use of energy inputs and thus to emission reductions in the non-Annex I countries, i.e., it is 'biased' towards the energy input; and
- emission reductions in the non-Annex I countries, as a result of technological change in non-Annex I countries, will be assigned to producers in Annex I countries and allow these producers to acquire a certain amount of emission credits (CERs).

In the simulations carried out in this paper, the emission reductions from CDM investments are calculated in terms of the "actual" output as baseline, by comparing the level of emissions between "old" and "new" level of technology for the "new" output level. The reason for this approach will be explained below.

The operationalization of the relationship between CDM investments and the amounts of CERs obtained is visualized in Figure 1. In our modelling of CDM policies, the emphasis will be on the modelling of technological impacts in the non-Annex I countries. Furthermore, our study only models CERs in terms of carbon emission reductions, although the reduction of other GHGs may be implemented analogously. We neglect the project basis of CDM in practice, as in a computable general equilibrium (CGE) framework the level of aggregation is higher.

In this operationalization of CDM in a CGE framework, some simplifying assumptions have to be made. In the modelling of decisions in Annex I countries, the development additionality condition is not explicitly taken into consideration. Implicitly, all CDM activities, through their beneficial impact on the state of technology in non-Annex I countries, satisfy this requirement. For this reason, the producers in Annex I countries will be compensated through receiving CERs. The value of CERs will depend on the shadow price of emissions, which in its turn is determined by the emission restriction targets and other rules of the climate change regime. Clearly, also the incorporation of transaction costs and investment risks in a global model framework is far from easy. Finally, we neglect afforestation and deforestation.

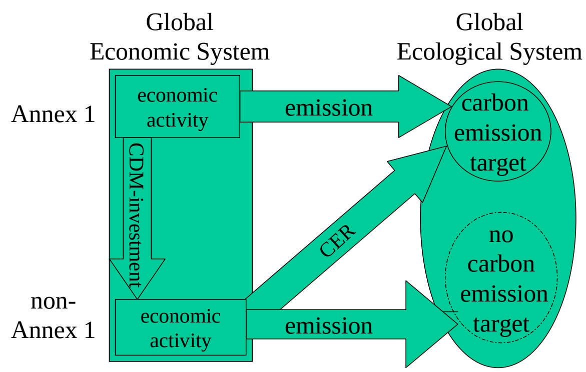

Figure 1**.** Stylized operationalization of CDM

A brief description of general applied equilibrium models[3]

The model to describe the economic system is an extension of the so-called GTAP-E modelling framework. This is a static multi-region, multi-sector applied general equilibrium model developed by the Global Trade Analysis Project (GTAP) team at Purdue University, and extended by Truong (1999). The global data base of GTAP-E combines detailed bilateral trade, transport and protection data, characterizing linkages among regions together with individual country input-output data bases which account for intersectoral linkages within regions. This data set has essentially the form of a Social Accounting Matrix. Together with estimated values of the substitution elasticities obtained from the literature, the equilibrium problem can also be solved for its parameter values. In this way, the equilibrium is calibrated based on the underlying dataset. In a static equilibrium model like GTAP-E, we may interpret the benchmark equilibrium as a representation of the world economy over a period of time.

In the GTAP-E model, the world-economy is subdivided into a number of distinct regions. In each of the regions, an aggregate regional household represents the consumption side of the economy. This regional household is a hypothetical agent that collects all income in the region. This amount of income is spent on private expenditure by the private household, on government expenditures by the government household, and on savings such that the region's welfare is maximized.

GTAP-E applies, like most other applied general equilibrium models often do, a nested structure to represent the production technology. The first nest in the production tree produces units of the output from units of value added and units of composite intermediate

[3] Details can be found in Wang (2005).

commodity using a Leontief production function. The energy commodities (i.e. coal, gas, crude oil, petroleum and electricity) are transferred to the capital-energy composite in the value-added nest. The subsequent nests are in turn characterized by Constant Elasticity of Substitution (CES) production functions (see Hertel and Tsigas 1997).

GTAP-E uses the Armington assumption for international trade, which implies that the composite intermediates are imperfect substitutes, i.e. are different according to the location where they are produced. In other words, the CES function has as intermediate production factors: (i) domestic inputs and (ii) foreign inputs, where the foreign inputs are in turn assumed to be composed of foreign inputs from the individual foreign regions. Two relevant substitution parameters related to the Armington assumption are the elasticity of substitution between domestic versus foreign intermediates and the elasticity of substitution between foreign intermediates from different regions.

The taxes and subsidies are introduced as net tax values. This means that a value of these variables larger than one implies the imposition of a tax on the good, while a value less than one implies a subsidy. Private households pay a tax on the consumption of domestically produced commodities and another tax on the consumption of the imported commodities.

The GTAP-model contains two global sectors, a global bank that collects all savings from the different regions and invests it back into the regions, and a transportation sector. The savings of a region form the input of the global bank. This global bank sector is modelled as a producer whose output good is a composite investment good. Each region demands units of the output good of a global bank sector at a market price per unit. In GTAP, the demand for the investment good may be formulated either as a fixed relationship with the initial amount of capital good in the region, or as a function of the price of the investment output.

The transportation sector produces a homogeneous transport good using the exports of any tradable commodity as input into its production technology. The production technology of the transportation sector is represented by a Cobb-Douglas production function with share parameters corresponding to each flow of export between regions. GTAP does not impose export taxes on the transportation of goods, so that the price of the transport good is determined via the zero-profit condition on the transport production technology.

An equilibrium in this economy is defined as a set of market prices, and a set of activity levels of each producer such that the market price of each good equals the marginal costs of production, and the activity level of a production technology clears the market of the output good. The first condition is a result of the zero-profit condition that is usually made when the production technologies in the economy exhibit constant returns to scale. The second condition is known as the market clearing condition. The equilibrium conditions provide a set of (complementary) equations and variables. We refer to the solution of this complementary problem as the equilibrium problem. Applied general equilibrium models are constructed such that the equilibrium problem has a uniquely determined solution.

Modelling CDM

An impact assessment of CDM strategies in a CGE setting should at least address the following issues: (i) impacts of emission restrictions, (ii) impacts of (self-imposed taxes for) financing CDM investments in source regions, and (iii) impacts of technological change in destination regions. To do so, it is of course natural to distinguish between emission-generating commodities and other commodities. The emission-generating commodities in our model are coal, gas and petroleum, while the other commodities are oil, electricity and the other non-energy commodities. These inputs are, except for the endowments, also intermediates. We will now briefly discuss some of the key mechanisms involved.

Emission restrictions in a subset of regions, in our case the participating Annex I countries, will have various consequences. To begin with, emission restrictions will result in an increase of the shadow prices of intermediates, in particular, the emission-generating commodities (the market price, in contrast, may fall due to reduced demand). In CGE models with multilateral trade flows, the increases in prices will have an impact on the demand for the emission-generating commodities as well as for other commodities, in both the participating and the non-participating regions. Furthermore, emission restrictions will also affect the price of output, the demand, and the aggregate regional output, i.e., GDP. And finally, as a result of a decreasing demand for emission-generating commodities in the participating countries, the outputs from these sectors will also be lower, while the outputs for the same commodities in the non-participating countries will be higher.

From the perspective of spatial-economic interaction, price increases in output will result in a loss of competitiveness and, therefore, a decrease in exports and a relocation of production. Production of the emission-generating sectors may shift to the non-participating countries. Alternatively, production expansion in the non-participating countries may also occur via their own capacity-building mechanisms in the regions themselves.

Next, the CERs from CDM investments will mitigate the price-increasing effects of emission restriction targets that should otherwise be carried out entirely domestically. The reason is that the amount of domestic reductions will be lower, which will result in a lower shadow price for emissions. Clearly, a self-imposed tax has a price-increasing impact. To begin with, the price of output commodities will increase in the Annex I countries. To some extent, the effects will be analogous to the price-increasing effects of carbon taxes or emission restrictions. The difference is that, in the case of carbon tax, it is the prices of emission-generating inputs that are largely affected, while the price of the output is only slightly affected as a result of substitution possibilities. In the case of an output tax, the price and the demand for the outputs are all affected directly.

The combination of a self-imposed tax and the mitigation effects of CERs means that the shadow prices of emission-generating inputs will be lower than in the case of an emission restriction. The prices of non-emission-generating inputs will, in comparison with emission restriction, be higher. This is due to the price-increasing effect of the self-imposed tax, which is absent for the non-emission generating commodities in case of emission-restriction. As a result, the leakage-effect will also be slightly affected, as the prices of emission-generating intermediates are changed on the world market. However, the net aggregate impact of these effects is a priori not certain.

CDM presupposes the occurrence of technological change and this will likely have a direct impact on the demand for inputs by the producers in the non-Annex I countries, because in general technological change in the efficiency of emission-generating inputs in the non-Annex I countries lowers the relative price of these inputs, while also the price of outputs will decrease. In turn, these price effects on input and output will affect the conditional demand for intermediates by the producers from other sectors. It seems thus plausible that a higher price in the participating Annex I regions will result in a lower output in these countries, but in a higher output in the non-participating regions. These substitution effects also result in a difference between the domestic and imported energy intermediates, as both are imperfect substitutes (see for more details Wang 2005).

As a result of price impacts of emission reduction targets on the output in the participating Annex I countries (i.e., increased output price), spatial-economic interactions via international trade will affect the export, as other regions will import less commodities from the participating Annex I regions. For the non-participating Annex I countries, there will be, as a result of the production structure according to the Armington-conditions, (i) substitution between the imported intermediates from other regions, and (ii) substitution between domestic intermediates and aggregate imports. Generally, this will result in (a) an increase in domestic demand; (b) an increase in imports from regions without emission restriction, and (c) a decrease in imports from regions with emission restrictions. This increased demand for domestic intermediates in the non-participating regions is also called `leakage effect', meaning that a part of the emission reduction target is cancelled out by increased emissions abroad, as a result of the substitution effects.

The overall effect of CDM on the actual emission reduction on the world level is, however, not certain beforehand. The reason is that this overall effect depends on many model parameters representing the responsiveness of the economic subjects to changes resulting from technological change.

5. Results of Applied Simulation Modelling Experiments on Climate Change Policies

Given the developments in the international negotiations on climate change policies – in particular the scenario of USA non-participation – it is clear that the global environmental policy regime based on Kyoto targets is rather fragile. For analyzing the policy impacts of global climate policies, this fragility of the climate regime leads us to consider the policy impacts of some interesting and relevant options for a climate policy strategy. This section maps out several variants to analyse the impacts of CDM policies, notably: the CDM standard regime, the Cap regime, and the USA participation regime. The CDM standard regime is based on the situation where only the EU and the Other OECD countries (OO) participate as source countries of CDM activities. The USA are assumed not to have an emission target and not to participate in this class of CDM activities. The Cap regime will assume that the Annex I regions impose a minimum amount of emission reductions by domestic activities. Clearly, alternative options and scenarios may be possible. The policy-option of a cap on CDM activities originates from the EU proposal, e.g. during the CoP-7 negotiations, in which a certain cap on flexible mechanisms was proposed to promote domestic emission reduction policies by the participating Annex I regions. Finally, the USA participation regime assumes that the USA become full partners in a global DCM policy approach. We will now first present our empirical results on the CDM standard and Cap regimes.

A self-imposed CDM tax in Annex I regions

Table 1 presents the market size of emission reductions in the case of a CDM standard regime, as well as a cap on CDM and on the intraregional emission trade regime. In the intraregional emission trade policy regime, the participating regions comply with the emission reduction targets solely by domestic emission reductions. Table 1 shows that in the intraregional emission trade regime, the costs of emission reduction amount to US$ 842.3 million for the Annex I producers (US$ 471.5 million for the EU, and US$ 370.8 million for the OO countries).

Table 1. Market size of emission reductions

	Intraregional Emission Trade			**CDM Cap**			**CDM Standard**		
	Volume	Price	Value	Volume	Price	Value	Volume	Price	Value
Market for emission permits									
EU	158.70	2.97	471.52	150.66	2.79	420.73	129.81	2.38	308.75
OO	99.67	3.72	370.79	75.41	2.79	210.59	63.97	2.38	152.15
Subtotal	258.37		842.30	226.07		631.32	193.78		460.91
CDM market									
EU	NA	NA	NA	8.04	2.32	18.69	28.90	2.38	68.74
OO	NA	NA	NA	24.25	2.32	56.39	35.70	2.38	84.91
Subtotal	NA	NA	NA	32.29		75.07	64.59		153.64
Total	258.37		842.30	258.36		706.39	258.37		614.55

As expected, CDM possibilities reduce the amount of emissions that would otherwise be achieved from intraregional emission trade. In the CDM standard regime, the amount of emissions achieved within the Annex I regions is 193.8 Mt CO_2, as compared to 258.4 Mt CO_2 in the intraregional emission trade regime. The other 64.6 Mt CO_2 of the voluntarily-agreed target of emission reductions is achieved by CDM activities (that are calculated based on the assumed baseline method). In addition, CDM activities reduce the shadow price of the emissions because of the `where'-flexibility of CDM policy, i.e. to achieve the emission reduction targets through CDM investments in non-Annex I regions. The Cap regime forms, as it partly includes CDM activities, a midway between these options. Clearly, it would be possible to present more detail here, e.g., the differences in abatement potential and cost characteristics of CDM host countries in non-Annex I regions.

An interesting result is that the CDM activities, as modelled in this study, would result in an equalization of the shadow prices of emissions between the participating Annex I regions. This is an indirect form of efficiency which is comparable with interregional trade, because domestic marginal abatement costs will be equalized to the uniform price of CER's in each of the participating Annex I regions.

Table 1 shows that the uniform price of US$ 2.38 per tonne of CO_2 in the CDM standard regime – and US$ 2.79 in the Cap regime – is lower than in the intraregional emission trade regime, which is US$ 2.97 per tonne of CO_2 for the EU and US$ 3.72 per tonne of CO_2 for the OO countries. As a result, the CDM standard regime leads to lower costs for the Annex I producers than the intraregional emission trade regime. Table 1 shows that the costs for the Annex I producers are US$ 614.6 in the CDM standard regime and US$ 706.39 in the Cap regime. These costs are lower than the US$ 842.3 in the intraregional emission trade regime. Thus, a first conclusion is that the CDM standard regime is more cost-effective for the Annex I producers than the intraregional emission trade regime, making it seem a more attractive option. However, as we will discuss in the next section, leakage effects may alter this tentative conclusion.

The impact of CDM investment on non-Annex I regions

What is the impact of CDM on non-Annex I countries? Table 2 shows the impact of CDM on the demand for intermediates in the Rest of the World (ROW) in the CDM standard and the CDM Cap regime. The results in Table 2 result from two opposite effects. First, under a *ceteris paribus* condition, we would expect that technological change will result in a lower demand for inputs, as a more efficient use of the inputs requires less input for the same level of output. But second, the demand for products in ROW will be higher because of: (i) feedback effects from lower output prices (resulting from higher efficiency, and thus lower factor use); and (ii) substitution effects from policies in the Annex I regions, i.e., emission restriction policy and CDM tax. A higher price in the participating Annex I regions results in a lower output in these countries, but a higher output in the non-participating regions. These substitution effects also result in a difference between the domestic and imported energy intermediates, as both are imperfect substitutes. This table demonstrates the far-reaching impacts of CDM policies in non-Annex I countries.

Table 2. Impact of CDM on ROW (non-Annex I regions)

	CDM standard					CDM Cap				
	Oil	Gas	Petrol	Electr.	Other	Oil	Gas	Petrol	Electr.	Other
change domestic intermediates (in %)										
Coal	–0.95	–1.60	–0.49	0.11	0.09	–0.53	–1.25	–0.52	0.54	0.50
Oil	–0.35	–1.28	–0.45	0.45	0.42	–0.28	–1.05	–0.14	0.39	0.33
Gas	–0.95	–1.60	–1.04	–0.61	–0.64	–0.45	–1.08	–0.37	–0.14	–0.19
Petroleum	–0.33	–1.57	–1.02	–0.54	–0.57	–0.27	–1.07	–0.34	–0.07	–0.12
Electricity	–0.35	–1.33	–0.49	–0.08	0.12	–0.28	–1.08	–0.17	–0.06	0.12
change imported intermediates (in %)										
Coal	–0.95	–1.60	–0.49	0.10	0.08	–0.09	–0.81	–0.08	0.98	0.94
Oil	–0.42	–1.35	–0.53	0.37	0.34	–0.34	–1.10	–0.19	0.34	0.28
Gas	–0.95	–1.60	–1.04	–0.61	–0.64	–0.39	–1.02	–0.31	–0.08	–0.13
Petroleum	–0.43	–1.67	–1.12	–0.64	–0.66	–0.36	–1.15	–0.43	–0.16	–0.21
Electricity	–0.54	–1.52	–0.68	–0.27	–0.07	–0.49	–1.28	–0.37	–0.27	–0.08

Impacts on regional economies

Let us now turn to the regional impacts. The following supra-regional entities are distinguished in our GTAP-E modelling framework: USA, EU, OO (other OECD countries), EIT (Economics In Transition) and ROW (Rest Of the World). The GTAP-E data base allows a detailed assessment of all economic and environmental emission effects (based on energy inputs) for these five blocks of countries. Table 3 shows the results of CDM activities on GDP and of the sectoral disaggregation on the CDM standard and the CDM Cap regime. Real GDP appears to decrease for the participating Annex I regions, while it increases for other regions. A disaggregation to sectoral output shows that all sectors in the participating Annex I regions are faced with a declining output. For the other countries, the basic energy sectors (i.e., coal, oil, gas and petroleum) are, except for petroleum in the USA, faced with lower production, while the other sectors (electricity and `other', non-energy commodities) are gaining in volumes.

Impacts on emissions

Finally, we will investigate the impacts on emissions. As a result of CDM policies and the related baseline calculations, there are four emission levels which are interesting to compare: (i) `actual' emissions in the case of no additional policies; (ii) `actual' emissions under the emission restriction regime; (iii) `actual' emissions under the CDM regime; and (iv) baseline emissions under the CDM regime. Table 4 gives an overview of the emissions of (ii), (iii) and (iv) relative to the benchmark equilibrium (i).

Table 4 shows that the CDM regime is slightly more effective in reducing the world level of emissions than the emission restriction regime in Annex I regions alone. The real emission reduction in the world as a whole, which is 0.81% for the CDM standard regime, is lower than the `calculated' emission reduction (1.11%) according to the `baseline' method, but higher than in the case of the emission restriction regime. In the emission restriction regime, the reduction for the world as a whole is 0.80%. The calculated emission reduction under the CDM regime for the world as whole is larger than the actual emission reduction under the CDM regime, as the CERs attributed to the participating Annex I regions are not deducted from the actual emissions in the non-Annex I regions. Without CDM (i.e., in the intraregional emission trade regime), emissions in the ROW would increase.

Table 3. Regional economic performance (in percentage change)

	CDM Standard					**CDM Cap**				
	USA	EU	OO	EIT	ROW	USA	EU	OO	EIT	ROW
Price GDP	0.07	0.03	0.06	0.00	0.00	0.08	0.04	0.07	0.00	0.03
Real GDP	0.00	–0.03	–0.02	0.00	0.04	0.00	–0.04	–0.03	0.00	0.02
Sectoral desaggregation										
Coal	–0.62	–1.26	–2.03	–0.61	–1.25	–0.67	–1.46	–2.26	–0.67	–1.26
Oil	–0.12	–0.16	–0.24	–0.20	–0.23	–0.10	–0.11	–0.22	–0.17	–0.19
Gas	–0.09	–0.74	–2.42	–0.91	–1.21	–0.08	–0.85	–2.79	–1.02	–0.98
Petroleum	0.19	–0.15	–0.81	–0.10	–0.51	0.15	–0.23	–1.00	–0.12	–0.18
Electricity	0.07	–0.67	–0.01	0.49	0.06	0.09	–0.76	0.00	0.56	0.07
Other	0.01	–0.03	–0.03	0.04	0.04	0.01	–0.04	–0.03	0.05	0.03
Capital goods	0.26	–0.25	–0.03	0.33	0.22	0.28	–0.36	–0.06	0.35	0.25

Table 4. Changes in emissions under various regimes

	USA	**EU**	**OO**	**EIT**	**ROW**	**World**
Emission restriction	20.78	–158.70	–99.67	19.83	50.22	–167.53
	0.41%	*–5.00%*	*–5.00%*	*0.67%*	*0.64%*	*–0.79%*
CDM Cap	19.45	–150.66	–75.41	18.35	20.19	–200.37
	0.38%	*–4.75%*	*–3.78%*	*0.62%*	0.26%	*–0.80*
Baseline Cap	19.45	–158.7	–99.7	18.35	52.48	–32.29
	0.38%	*–5%*	*–5%*	*0.62%*	*0.67%*	*–0.95*
CDM standard	18.92	–129.81	–63.97	16.46	–11.59	–169.94
	0.37%	*–3.98%*	*–3.13%*	*0.55%*	*–0.21%*	*–0.81%*
Baseline CDM standard	18.92	–158.7	–99.7	16.46	53.05	–234.53
	0.37%	*–5%*	*–5%*	*0.55%*	*0.68%*	*–1.11%*

This result confirms the basic assumption for the introduction of CDM as an effective instrument for global climate change policies. In addition, this result corresponds to the models of induced technological change in which the positive effects of cleaner technologies are stronger. The reason is that, in our model, we have biased technological change towards more efficient technologies for emission generating inputs. However, alternative models with exogenous technological change – in which technological change results in economic development and thus a demand for emission-generating commodities – may lead to other results (for a review, see, e.g., Grubb 2000; Löschel 2002). In that case, the scale effect as a result of technological change is larger than the lower demand for emission-generating commodities as a result of increased efficiency.

6. CDM and USA Participation

The possible scenario of USA non-participation shows the fragility of the Kyoto Protocol in particular and climate change policies in general (see also Weyant and Hill 1999). The simulation in the present section aims to investigate whether the decision of a possible USA non-participation is plausible on economic grounds. As an evaluation criterion, this section focuses on the following two indicators: (i) total costs of emission reductions, and (ii) real GDP. The reason for using real GDP as an indicator is that the `self-interested' state would only cooperate if it made a gain from the participation in a treaty. In our study, a gain is expressed by indicators describing regional economic performance, i.e. real GDP. It should be noted that this is a somewhat narrow indicator, as it neglects the feedback effects of the ecological system on the economic activities, i.e. the valuation of the environmental aspects.

Impact on participating Annex I regions

In order to illustrate the impact of US participation (US_P), we will compare three regimes. These three regimes are: (i) intraregional emission trade for US_P, i.e. the USA, the EU and the OO countries carry out emission restriction policies through intraregional emission trade; (ii) implementation of a US_P regime, i.e. emission restriction policies and CDM activities by the USA, the EU and the OO countries; and (iii) introduction of a CDM standard regime, in which the USA does not participate.

Table 5 presents the costs of emission reductions for the Annex I regions. As expected, USA participation involves higher total costs of emission reductions (equal to US$ 1224 million) in comparison with the CDM standard regime (equal to US$ 615 million). In addition, CDM would lower the costs in comparison with the intraregional emission trade regime with USA participation (total costs are US$ 1547 million). In the US_P regime, the volume of CERs for the US is low (8.2 Mt CO_2). This indicates that, for the US, the CDM is not a very relevant policy alternative. This is reflected in the relatively equal price of emission reductions of US$ 2.38 per tonne CO_2 between the US_P and the CDM standard regime (the price in the US_P regime is slightly higher than that in the CDM standard regime, but this difference is not visible due to rounding).

Table 5. Market size of emission reductions in US_P

	Intraregional			CDM US_P		
	Volume	Shadow Price	Costs	Volume	Shadow Price	Costs
Costs of intraregional trade						
USA	255.53	2.50	638.65	247.30	2.38	589.04
EU	158.70	3.21	509.61	117.98	2.38	281.01
OO	99.67	4.00	398.91	56.40	2.38	134.34
Subtotal	513.89		1547.17	421.68		1004.39
Costs of CDM						
USA	NA	NA	NA	8.22	2.38	19.59
EU	NA	NA	NA	40.73	2.38	97.01
OO	NA	NA	NA	43.26	2.38	103.05
Subtotal	NA	NA	NA	92.22		219.65
Total	513.89		1547.17	513.89		1224.04

The lower costs in the CDM standard regime in comparison with the US_P regime are mainly due to the volume effect. The lower volume of emissions in the CDM standard regime is evident, as only the EU and the OO countries are committed to emission reduction targets. The slightly lower price in the CDM standard regime (not visible in Table 5 due to rounding off) is due to the decreasing marginal productivity characteristics of the marginal cost function of emission reduction through CDM activities. The reason why the price of emission reductions through CDM activities is not much higher than US$ 2.38 per tonne of CO_2 in the CDM US_P regime is that, for the calculation of the marginal costs, not only the size of CDM investments but also the level of emissions in the new equilibrium is relevant. For a comparison, in the Cap regime, halving the CDM investments appears to result in a decrease from US$ 2.38 to US$ 2.32 per tonne CO_2.

Impact on non-Annex I regions

Table 6 presents now the effects of the USA-participation regime for the non-Annex I regions. The results are shown relative to the CDM standard regime, i.e. the results from the US_P regime divided by the results from the CDM standard regime. We present the results to three decimal places in order to highlight the differences between the distribution of CDM investments and the CERs. In this table, we see that the impacts in the US_P region are, in general, larger than the CDM standard regime, as the amount of CDM investment is higher. However, because of the above mentioned substitution effects, the demand for some goods is different. Especially in relation to coal as intermediate commodity, we see a substitution of the demand for the imported coal in the electricity and other, non-energy commodities for domestic coal as intermediates, as well as for the use of imported coal in other sectors.

Table 6. Impact on ROW (US_P relative to CDM standard)

	Oil	Gas	Petroleum	Electricity	Other
Demand for domestic intermediates					
Coal	1.962	1.490	0	0.336	0.672
Oil	0	0	1.053	2.293	2.484
Gas	1.664	1.279	1.310	1.530	1.482
Petroleum	0	1.279	1.320	1.216	1.176
Electricity	0	0	0	2.442	1.275
Demand for imported intermediates					
Coal	0.593	0.683	0	12.918	16.780
Oil	0	0	1.233	2.279	2.511
Gas	0	1.306	1.338	1.601	1.550
Petroleum	0	1.280	1.318	1.228	1.193
Electricity	0	0	0	1.756	1.836

Impacts on regional economies and their emissions

We will now present the results for a regional subdivision of our world. Table 7 shows the regional impact on real GDP as a result of the USA-participation regime and the CDM standard regime. In terms of regional economic performance, the USA would be worse off in the US_P regime compared with the CDM standard regime. The real GDP decreases by 0.01% instead of an increase very slightly more than 0.00%. This result implies that, for the USA, a participation in the CDM regime involves slightly more costs in terms of real GDP. In addition, all other regions benefit from USA participation.

Table 7. Impacts on GDP

	Real GDP		Price of GDP	
	USA_P	CDM standard	USA_P	CDM standard
USA	–0.01	0.00	0.09	0.07
EU	0.02	–0.03	0.09	0.03
OO	–0.01	–0.02	0.10	0.06
EIT	0.01	0.00	0.03	0.00
ROW	0.06	0.04	–0.01	0.00

Next, we will investigate the sectoral subdivision in the energy sector. Table 8 shows the disaggregated sectoral output in the US_P regime relative to the CDM standard regime. The results are diverse. In general, US_P enlarges the substitution effects, which are present in the CDM standard regime. So, there is less demand for coal, oil, gas and petroleum because of the reduced emission reductions for the world as a whole due to US participation. In addition, it is interesting to note that USA participation results in shifts of competitiveness within the participating regions. This is the case for the petroleum sector and capital goods in the EU and electricity and capital goods in the OO countries. For these sectors, the negative effects in the CDM standard regime become positive in the US_P regime.

Table 8. Sectoral disaggregation

	USA	EU	OO	EIT	ROW
Relative to CDM standard					
Coal	6.00	1.36	1.46	1.72	1.55
Oil	6.10	3.28	2.60	2.33	2.54
Gas	58.96	1.09	1.05	1.00	1.19
Petroleum	–8.34	–0.75	0.72	0.45	1.20
Electricity	–2.79	1.06	–3.05	1.33	0.79
Other	–3.78	0.40	0.69	1.53	1.78
Capital goods	–0.83	–0.14	–2.02	1.43	1.30

Finally, Table 9 presents the impacts of USA participation on emissions of the world as a whole, as well as the contribution of each region. We see that in the USA participation case, the world emissions would be reduced by -1.94%, while if only the EU and the OO countries participate, the world emissions would only be reduced by -0.81%. However, the difference in the emission reductions for the world as a whole is largely due to the emission reductions in the USA.

Table 9. Impact on emissions

	USA	EU	OO	EIT	ROW	World
CDM standard	0.37	–4.09	–3.21	0.55	–0.15	–0.81
US_P	–4.84	–3.72	–2.83	0.78	–0.15	–1.94

7. Conclusion

Our study on the economic aspects of climate change policies has focused on Clean Development Mechanism (CDM) policies. CDM policies explicitly acknowledge the relevance of technological change for dealing with environmental constraints. Another goal of CDM policies is to support developing countries in their economic development towards the direction of energy-saving technologies. Clearly, CDM policies form only part of the flexibility mechanisms of the Kyoto Protocol (KP). This implies that the issues related to the establishment of a climate change regime, such as in the case of the KP, form the context for the implementation of CDM policies. The present paper has focused on the consequences of CDM policies in the framework of the GTAP-CDM model.

From the simulations discussed in this study, our general finding is that CDM policies lower the total costs of emission reductions in comparison with policies focused only on intraregional emission reduction targets. A closer look at various parts (in terms of inputs, sectors and regions) of the economic system shows that the impacts are diversified. First, emission restrictions increase the relative price and decrease the demand of the emission-generating inputs in the participating regions. The self-imposed output taxes increase the prices and thus decrease the demand of the outputs. Secondly, the CERs will partly mitigate the price increases of the emission-generating inputs in comparison with the intraregional emission reduction policy. Thirdly, technological change resulting from CDM activities decreases both the price and the demand for emission-generating inputs in the non-Annex I regions.

In the CDM standard regime, it is found that the non-Annex I regions would, in terms of real GDP, gain most from CDM policies as a result of technological change. The participating regions would lose as a result of the emission reduction targets. The non-participating regions would slightly gain. In addition, the results for the Cap regime show that it is midway between the CDM standard regime and the intraregional emission trade regime. Thus, in the Cap regime, the impacts on technological change and demand in ROW are lower than the impact on demand in the CDM standard regime. For all regions, the impacts of CDM policies on real GDP are lower in the Cap regime in comparison with the CDM standard regime. US participation enlarges the impacts of (i) the relative prices of the emission-generating inputs; (ii) the self-imposed output taxes; and (iii) technological changes in the non-Annex I regions in comparison with the CDM standard regime. Moreover, this regime highlights the substitution within the participation regions. The negative impacts of CDM policies in the CDM standard regime for the EU and OO are lessened by US participation. The interplay of these three major processes associated with the CDM activities is shown more in detail by the disaggregated results on sectoral output.

In addition, it is important to see how the emissions are affected. The `baseline' calculation for the CDM standard regime suggests a greater emission reduction than the `real' reductions, compared with the case of the emissions restriction policy only. The reason is that the `baseline' calculation is based on the old level of technology, with which more inputs would be needed to produce the `new' amount of output than with the new level of technology. Second, we find that, though the participating Annex I regions would reduce their emissions less domestically, the level of emissions for the world as a whole would, in the case of the CDM regime, be less than in the case of the intraregional trade regime. The reason is that, in the non-Annex I regions, the leakage effects from emission reductions in the participating Annex I regions are partly offset by the technology effects from the CDM investments. This indicates that CDM policies are indeed a promising complementary alternative for emission restriction policy.

By incorporating conditional technological change in a CGE model, our study also gives detailed insights into the spatial-economic impacts of CDM policies involving technological change, on economic activities. Indeed, the results confirm the intuitive notion that technological change will have a positive impact on economic performance in comparison with emission restriction policy only. In the first place, this holds for the non-Annex I regions. In the second place, via spatial-economic interaction, the positive impact spills over to other countries. Whether the results will be positive or negative for a particular region largely depends on the regime setup and interplay of various processes within the global economy. Finally, it should be noted that the numerical results are of course sensitive to the model environment which is chosen for the CDM standard regime.

We may thus conclude that in order to ameliorate the human impacts on the global environmental system in general, and on the climate system in particular, global environmental policies are desirable and, in principle feasible. In a complex climate policy context, sustainable global environmental policies, and specifically climate change policies, are difficult to formulate due to the transboundary nature (in political-economic perspectives) of the environmental externalities and the ecological system. The ongoing negotiations are complex, because a balance needs to be found between sound economic principles, environmental sustainability conditions and political acceptability requirements. Climate modelling may then be helpful to uncover some of their complexities.

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