DIW Berlin
German Institute
for Economic Research

Discussion Papers

454

Claudia Kemfert
Hans Kremers

A computable general equilibrium assessment of a developing country joining an Annex B emission permit market

Berlin, November 2004

DIW Berlin

German Institute
for Economic Research

Königin-Luise-Str. 5
14195 Berlin,
Germany

Phone +49-30-897 89-0
Fax +49-30-897 89-200

www.diw.de

ISSN 1619-4535

A computable general equilibrium assessment of a developing country joining an Annex B emission permit market.

Claudia Kemfert
Department of Energy, Transportation, and Environment, DIW Berlin and Wirtschaftswissenschaftliche Fakultät, Humbolt Universität zu Berlin

Hans Kremers
Department of Energy, Transportation, and Environment, DIW Berlin

Abstract: During the last years, the developing regions have come under increased pressure by the developed countries, in particular the USA, to join the international effort in global greenhouse gas abatement. On the one hand, the participation of the developing regions would offer the developed world with low cost opportunities for abatement. On the other hand, the economies of some developed regions such as China and India exhibit such fast growth that they are expected to be responsible for a significant part of future emissions during the next decade. The latter regions object to the imposition of emission targets on their economy as it would significantly hamper their economic growth. This paper focusses on the consequences of certain proposals to set emission targets for developing countries, here China. One of these proposals follows the USA by letting China accept its projected 'Business-as-Usual' emission level for 2012 as its target. A proposal by the Center for Clean Air Policy takes more consideration for the viewpoint of the developing countries by imposing a so-called 'growth-baseline' for China, where a target is set on its emission efficiency.

1 Introduction

The success of international climate agreements such as the Kyoto Protocol depends heavily on the willingness of its participants to achieve the targets agreed under such agreements. A crucial factor for such willingness are the costs of abatement. Since climate change is a global issue, the location of such abatement does not matter, which makes it optimal to look for the cheapest options available. The inclusion of developing regions into the international effort to mitigate the consequences of climate change on the international economy offers opportunities for low cost abatement that cannot be found in the developed countries. Including developing regions into, for example, emission permit trading, would therefore significantly decrease the cost of abatement for all participants of emission permit trading. The significance of including developing regions into emission permit trading has also been recognized by Kemfert and Zhang (2003) who investigate the economic and environmental implications of regional coalitions cooperating on R&D investment to trigger the adoption of low cost environmentally friendly technologies in their economies. One of the results of Kemfert and Zhang (2003) is that developing countries need to be involved in these coalitions in order for the negative economic effects of emission reduction commitments on both industrialized and developed countries to be completely offset.

Emission permit trading not only offers a cost saving opportunity to Annex B regions to meet the targets in the Kyoto Protocol, but it offers also a new source of export earnings for non-Annex B, in particular developing regions. Achieving the goals set in the Kyoto Protocol will change consumption and production patterns within the Annex B regions and these changes will have a significant effect on international trade. As a result, the developing regions will be affected through conventional trade linkages with the Annex B regions. These effects will be diminished to the extent that emission trading reduces the cost of achieving the Kyoto target.

The number of developing regions in the world is large and very diverse depending on the state of their development. On the one hand there are African developing regions which are just at the beginning of their development. Then there are fast growing regions as China and India, Brazil and Mexico, that, over the years have developed an industrial infrastructure and, apart from being primary goods exporters, have developed manufacturing as a base for their exports. On the other hand, there are developing regions such as the so-called East-Asian tiger economies of whom South-Korea is short before being allowed to the OECD. The consequences of joining an emission permit trading market are therefore most significant for the latter regions which are already closely entwined in international trade structures.

The fast growing developing regions have a rapidly growing consumption of fossil fuel energy and it is expected that these regions will soon be responsible for a significant contribution to greenhouse gas emissions in the atmosphere. Among others, the United States therefore required a significant contribution of these regions in the international effort to mitigate the consequences of increasing greenhouse gases on our society, for example by imposing a realistic target. These developing regions claimed that imposing such emission targets would seriously hamper their growth. Consequently, the inclusion of such fast growing developing regions into an emission permit market regime would require some thought on imposing a realizable target of emissions on these regions.

This paper focusses on the consequences of setting emission targets for developing countries, here China. It considers the situation where the Annex B countries have an emission permit market for 2010 and forward in place where, for each period after 2010, emissions for participating Annex B regions are tied to 1990 levels as mentioned in the Annex B to the Kyoto Protocol. The Annex B emission market is modeled using an intergovernmental trading model (see Zhang (2000)), where governments decide not to allocate the assigned amounts to the production sectors, and retain the sole right to trade. Each production sector then decides whether to control emissions or to buy sufficient permits to cover their emissions by comparing the control costs with the market price of permits. It then studies the consequences of a developing region, China, joining the Annex B regions on this permit market under the following regimes of allocating an initial endowment of emission permits to China, in comparison to a 'Business-as-Usual' scenario, where no action to cut emissions is undertaken, as well as to a scenario where an Annex B emission permit market is in place after 2010:

- China is allocated its official 1990 level of CO_2 emissions as its initial endowment of permits. This scenario resembles the official requirements as stated in the Annex B to the Kyoto Protocol,
- China is assumed to adopt emission growth targets equal to its 'Business-as-Usual' emissions level for 2010. This scenario is based on United States (1998),
- China's emissions target is established by tying its emissions budget to improvements in the ratio of carbon emissions to gross domestic product. This scenario has been proposed by the Center of Clean Air Policy as stated in Hargrave (1998).

Including China into an international emission permit trading regime according to one of these scenarios has a major impact on international trade flows, and consequentially, consumption and production patterns in all regions, and in China, changes. It is not straightforward to see who benefits and who looses as many effects oppose each other. Computable General Equilibrium models offer a solution to study the direct as well as indirect effects of such shocks on international trade flows, due to the modeling of an equilibrium on more than one market simultaneously. We use the 'World Integrated

Applied General Equilibrium Model' (WIAGEM) which is an Integrated Assessment (IA) model that combines a multi-sectoral multi-regional general equilibrium model, based on the MS-MRT computable general equilibrium (CGE) model, with a climate model, and a damage assessment model. For the purpose of our simulations, we limit WIAGEM to its CGE model. The regional aggregation of this CGE model consists of 12 trading regions, among which the Annex B regions and China. The sectoral aggregation in each region consists of 15 production sectors among which five energy sectors. Primary production factors are capital and labour (see Kemfert (2002)).

In Kemfert et al. (2003), WIAGEM was used to analyze possible strategies to convince the United States into adopting more stringent greenhouse gas targets in 2010. One of these strategies is to involve commitments by developing countries, a point often stressed by the United States (see United States (1998)). Our paper recognizes the importance of the role of the developing countries in the ongoing discussion on the mitigation of climate change effects on the economy. We however focus on the allocation of commitments to these developing regions, using the different proposals described in the aforementioned scenarios.

This paper is subdivided as follows. In Section 2, we provide a brief description of the WIAGEM model. We concentrate this description on the economic sub-model in WIAGEM. The interested reader is referred to Kemfert (2002) for the technical details on the economic model and the other sub-models. In Section 3, we describe the setup of the simulations, by constructing a 'Business-as-Usual' scenario, an Annex B permit trading scenario, and three counterfactual scenarios, the latter corresponding to the aforementioned policies. In Section 4, we analyze the simulation results. The paper is closed with some conclusions in Section 5.

2 The model

WIAGEM combines an inter-temporal general equilibrium model, based on the 'Multi-Sector Multi-Regional Trade' (MS-MRT) model, with an energy market model, a climate model, and a damage impact model. For the MS-MRT model, we refer to Bernstein, Montgomery, and Rutherford (999a) and Bernstein, Montgomery, Rutherford, and Yang (999b). Within the scope of this paper, we limit our attention to the economic part of WIAGEM and refer the interested reader to Kemfert (2002) for more information on these extensions. The time horizon is 50 years, incremented in 10-years time steps. It takes 1995 as its benchmark year but it is calibrated using the GTAP4 database complemented with GTAP5 data. The model considers the period from 2000 to 2050.

2.1 Economy

WIAGEM aggregates the world into 12 trading regions, which we enumerate in Table 1. Within this set, we distinguish the subset $\texttt{AnnexB} = \{\texttt{CAN}, \texttt{EU15}, \texttt{JPN}, \texttt{REC}, \texttt{USA}\}$ referring to the regions that signed the Annex B to the Kyoto Protocol.

`ASIA`:	India and other Asian countries
`CHN`:	China
`CAN`:	Canada, New Zealand, and Australia
`EU15`:	European Union
`JPN`:	Japan
`LSA`:	Latin America
`MEX`:	Mexico
`MIDE`:	Middle East and North Africa
`REC`:	Russia, Eastern and Central European Countries
`ROW`:	Rest of the World
`SSA`:	Sub Saharan Africa
`USA`:	United States of America

Table 1: The regional aggregation in WIAGEM.

WIAGEM extends the originally 9 production sectors in the MS-MRT model in each region to 15 production sectors. These sectors produce 13 tradable goods, which we summarize in Table 2, and another good that refers to investment.

Agriculture
Coal
Chemical rubber and plastics
Crude oil
Electricity
Natural gas
Nonferrous metals
Nonmetal mineral products
Petroleum and coal products
Other manufactures and services
Iron and steel
Pulp and paper
Transport industries

Table 2: The sectoral aggregation of traded goods in WIAGEM.

The production factors used in WIAGEM are capital and labour. Physical capital is malleable but cannot be transferred across sectors. Capital stocks increase over time due to investments from output produced for domestic sales, and decrease due to depreciation at a constant geometric rate. The MS-MRT model assumes a two year gestation lag for capital investment and a uniform pattern of investment within a given 10-years period. This means that, if $I(t)$ is the rate of investment in period t, then $2I(t)$ units of capital enter the current capital stock and $3I(t)$ units of capital are delivered in the next period. The labour force in each period is determined by population growth and labour-augmenting technical progress. These growth factors are externally given.

For each fossil fuel sector in each region, there exists a resource of this fossil fuel at each time period. The relation between depletion effects on the supply of oil, gas, and coal, and the actual supply of these fuels is ignored. The model does not keep a record of the current stock of each fuel in each time period. This resource therefore represents the demand for this fossil fuel resource in each time period. This demand is assumed to be constant over time.

Each tradable good in Table 2 is produced in each region by one unique production sector using a constant returns to scale production technology with the goods in Table 2 as intermediate goods, and labour and capital as production factors. Under these conditions, the optimal demand for these inputs are given by the cost minimizing amounts to produce one unit of output times the activity level. According to Bernstein et al. (999a), the competitive firms also undertake investments which arbitrage current investments against future returns. All investments are forward looking and the producer anticipates the effects of announced policies that are to take effect in the future.

We distinguish between non-energy and electricity production sectors on the one hand and fossil fuel production sectors on the other hand. Output of each non-energy sector and the electricity sector is decomposed into the intermediate (non-energy) inputs and in a sector specific 'Energy-Value-added' composite using a Leontief functional form. The non-energy intermediate inputs are composites of domestically produced goods and their imported equivalents. The 'Energy-Value-added' composite is decomposed into an energy composite and a value-added composite using a Constant Elasticity of Substitution (CES) functional form. WIAGEM decomposes value-added into its constituents capital and labour also using a CES functional form.

For each fossil fuel production sector, the output good is decomposed into a sector specific fossil fuel resource of this fuel, and a sector specific aggregate good which contains labour, capital, and this fossil fuel input itself in fixed proportions. The first decomposition uses a CES-function, while the second layer uses a Leontief production function to represent the fixed proportions.

Final demand in each region is modeled by a representative household, who maximizes it's region's discounted utility over the model's time horizon given his income. WIAGEM assumes that the utility function is of a Constant Inter-temporal Elasticity of Substitution (CIES) type. The consumer obtains income from its endowments of time which it can sell as labour, from his initial endowment of capital in each production sector, from the rents it obtains on fossil fuel production, and from tax revenue.

The description of the consumer's choice between consumption and investment in each period is derived from growth theoretic models, see Barro and Sala-i-Martin (1995). This model is essentially a so-called Ramsey model. In such models, the consumption-investment decision of an infinitely living consumer is taken under consideration, where consumption and investment ultimately reach a steady state growth rate which is constant. The model here differs in two important aspects from the growth theoretic approach: The CGE model considers a finite horizon, and the CGE model computes a sequence of equilibria which do not imply the existence of a steady state growth rate in consumption and investment. The solution to the first problem is often to split the life time of the infinitely living consumer into two parts. The first part consists of the periods under consideration, while the second part considers all remaining time periods. Utility maximization over the first part starts with an initial endowment of capital in each stock. Utility maximization over the second part starts with a capital endowment in each stock that would result at the beginning of the next period. The latter stocks are taken from the income of the consumer at the first period. We have to choose a value for each of these computed capital stocks, which determines optimal consumption and investment. WIAGEM chooses them by imposing a constant growth rate on investment in the last period. This condition then becomes an extra condition for the utility maximizing problem.

Solving the inter-temporal optimization problem results in an optimal consumption plan for the time span and optimal savings follow indirectly from the remaining income after consumption. Since we assume the utility function of the consumption household to be homogeneous of degree one, we use expenditure minimization to obtain the optimal amounts of each good providing one unit of utility. Total expenditure on consumption equals expenditure per unit of util times the amount of utils. Total expenditure on consumption plus total expenditure on buying the investment good equals the consumer's income in each period.

The model uses a CES function to obtain the aggregate consumption good from a non-energy composite good and an energy composite. The consumer price index of this composite consumption good is then obtained from the minimum expenditure on the non-energy composite and the energy composite to obtain one unit of this aggregate consumption good. The non-energy composite is decomposed into the non-energy goods using a Cobb-Douglas function. The expenditures on the non-energy goods are composites of domestically produced goods and their imported equivalents. CGE modelers often call such composite goods so-called 'Armington goods', referring to Armington (1969).

The consumption and production of non-energy goods contain an energy composite which is decomposed into the output goods of the energy and electricity production sectors. See also Bernstein et al. (999b) for a clarification of the energy composite. We use a CES function to decompose each aggregate into its constituent parts. The energy composite is decomposed into the electricity good and a fossil fuel aggregate. The electricity goods in these CES functions are again composites of domestically produced goods of the electricity sector and its imported equivalents. The fossil composite is decomposed into a coal good and a non-coal composite. The non-coal composite is decomposed into a gas good and an oil good.

The use of a unit of a fossil fuel will lead to a certain share of emissions in each greenhouse gas. WIAGEM considers emissions in CO_2, and considers the other greenhouse gases, CH_4 and N_2O, in CO_2 equivalents. CO_2 emissions are computed proportional to the fossil fuel consumption in each production sector.

Oil is traded internationally as a homogenous good at one price, hence the producer prices of oil in each region are determined by the world market price. The non-oil fossil fuels as well as the non-energy goods are represented as 'Armington goods' to approximate the effects of infrastructure requirements and high transport costs between some regions. This means that these goods are composites of its domestically produced and its imported equivalent.

The traded non-oil fossil fuel and non-energy goods are supposed to have different prices depending on whether they are produced for domestic use or for export. WIAGEM uses a Constant Elasticity of Transformation (CET) function to decompose the output good of these production sectors. The composite traded non-oil fossil fuel and non-energy goods are decomposed into a good produced for domestic sales and its equivalents produced for exports using a CET function.

WIAGEM assumes that there is perfect competition on the markets. We define an equilibrium in this economy as a set of prices and activity levels such that the economy exhibits

- *market clearing*: the activity levels of each production sector clear the market for the particular output good, while the market for production factors are cleared by the underlying price.

- *zero profits*: the price of each tradable good is determined by the minimum cost to produce one unit of this good.

The market clearing condition depends on whether a tradable good market is considered or a market for production factors. In the case of a market for tradable goods, the market price of this good is determined by the marginal cost to produce this good, while the activity level of the production sector is determined by total demand for this good. The output good of a region's production sector is produced to satisfy domestic sales and exported sales. Domestic sales satisfy the demand for this good as an intermediate good in other domestic production sectors and as final consumption. Furthermore, we assume that part of domestic sales are meant to represent investment costs for this production sector.

In any period, a region can be running a trade deficit or a trade surplus, but by the terminal year, the debt of a region must have been returned to baseline levels. In any infinite horizon model, this closure rule immediately follows naturally from the budget constraint and prevents the possibility of an infinite accumulation of debt (the literature refers to a 'no-Ponzi games' condition). WIAGEM, as a finite horizon model, approximates this infinite horizon condition by assuming that there be no net change in foreign indebtedness over the finite horizon. Such closure is consistent with neoclassical economics (See Bernstein et al. (999a)).

The investments of all production sectors are combined into an aggregate investment good particular to the region. The activity level of these investment sectors then satisfies demand for these investment goods. The regional households spend their savings on buying this investment good. WIAGEM adopts a closure on investment and savings, assuming that there is equality between total savings of the consumers, i.e. total demand for the investment good, and the supply of this good by the regional investment sector.

Notice that, in equilibrium, the optimal amount of utils for a representative consumer follows immediately from equating expenditure per unit of util times the optimal amount of utils to this consumer's income. In some sense, the amount of utils of a consumer household plays a role similar to the activity level of a production sector. It follows from the homogeneity of degree zero property of the utility functions that the price of a util equals the expenditure to obtain one unit of it. This util price can be interpreted as a consumer price index.

In the case of a market for production factors, the equilibrium market price arises as the price clearing the market for this production factor. The capital market is a production sector specific market. Hence, the price of this sector's capital good is such that the demand for capital by this sector is satisfied by the regional endowment of this capital good. The labour market is a regional market, which makes the wage rate the clearing price between demand for labour by the regional production sectors and the regional endowment of time spent for labour. Due to the homogeneity of degree zero in the excess demand and the supply functions in the equilibrium equations, any positive multiple of an equilibrium price vector will result in an equilibrium. We therefore have to choose a numeraire good. WIAGEM chooses the wage rate as numeraire.

There will be a gap between producer prices and consumer prices due to possible taxes or subsidies imposed by the regional government on this good. Similarly, there will be a gap between export producer price and consumer price due to possible tariffs or export subsidies imposed by a regional government.

2.2 Climate

The total emissions in each period follow from adding the CO_2 emissions over regions and over production sectors and over consumption households during this period. These emissions result from economic activities. Economic activities such as consumption and production require a certain amount of fossil fuel use. We take CO_2 emissions as a fixed share of the equilibrium demand for coal, oil, gas, and petroleum by producers and consumers.

3 Policy scenarios

In this paper, we are interested in the consequences of China as a developing country joining an emission permit market among the Annex B regions under different assumptions with respect to the allocation of emission targets to China. Within the CGE modeling framework, this is translated in the allocation of an endowment of emission permits to the participants on the emission permit trading market. Zhang (2000) distinguishes between governmental trading of emission permits, where permits are allocated to the regional governments who are then the sole actors on the permit market, and trading by firms, where the permits are allocated to the regional production sectors. Under the latter regime, the regional governments have to find a rule that allocates their emission permit endowments over the production sectors. Jensen and Rasmussen (2000) recall that this can be done by so-called 'grandfathering' allocation rules, e.g. depending on the sector's emissions or depending on the share of the sector in regional GDP. By auctioning the permits over the interested production sectors instead, the government can obtain the sector's value of these permits.

Truong (2003) argues that emission permits are likely to be distributed according to some grandfathering rule because the issue of equity is an important argument in convincing countries to participate. Under a grandfathering rule, there are several rules to choose from. Truong (2003) mentions

- the rule of equiproportionate reduction in emission levels, where all countries are required to reduce their emission levels by the same proportion relative to the base year to achieve a particular global target;

- the equal per capita rule, where each human is required to be assigned the same emission rights;
- the equal per GDP emission rule, where each country is entitled to the same emission rights per unit of this country's GDP.

The first rule is the most straightforward, and it was used for the setting of most of the emission reduction targets for Annex B countries in the Kyoto Protocol. As an example of such a rule, we define a 'Kyoto scenario', where China is allocated an initial endowment of emission permits equal to their 1990 Business-as-Usual levels of CO_2 emissions.

The rule of equiproportionate reduction in emission levels may however be considered inequitable by many countries such as the developing countries. Developing countries argue that, historically, the industrialized countries are responsible for the current concentrations of GHG's in the atmosphere and these developed countries should therefore bear the greater burden of emission reductions. Industrialized countries, in particular the USA, on the other hand argue that, although current levels of emission levels may be low, on the mid or longer term, some developing countries, notably China and India, will have emission levels that are as high as those of industrialized countries. The United States demanded a higher share of the developing countries in the international effort to reduce emissions, for example by setting a growth target, i.e. tying emissions to a certain level of GDP (see United States (1998)). As such, we define a so-called 'US'-scenario, which can also be seen as an example of the third rule.

If the more equitable and more effective equal per GDP emission rules are to be applied, this will put a great burden on the developing countries during the initial years when the major concerns in these countries are for social and economic development that environmental protection. A compromise solution may be to apply these rules gradually, or, as proposed by the Center for Clean Air Policy (CAP) by setting a so-called 'growth-baseline' for these developing countries such as China. By imposing such a growth-baseline for the developing countries, emissions are allowed to rise, but they are tied to GDP growth (see Hargrave (1998)). We define a 'CAP'-scenario to capture the consequences of imposing such a rule.

These scenarios are then compared to a 'Business-as-Usual scenario' (BaU). In order to determine the impact of China joining an Annex B emission permit market, we also define an 'Annex B' scenario (Annex B) where there is an emission permits market among the Annex B regions in place. This allows us to assess the impact of China on the price of emission permits.

Business-as-Usual (BaU) No action is undertaken to reduce emissions. This scenario assumes no specific intervention to limit the rate of greenhouse gas emissions but it does allow for anticipated changes in demographic, economic, industrial, and technological developments as well as environmental policies not directly aimed at limiting greenhouse gas emissions. Greenhouse gas emissions both for Annex B countries and non-Annex B countries are expected to rise unconstrainedly. Hence in this scenario, no market for emission permits exists. We could suppose that the price of emissions is zero so that nobody takes account of their emissions.

Annex B (Annex B) Under this scenario, we assume that only the Annex B regions are participating in a market for emission permits. Let $e(r)$ denote the 1990 level of carbon emissions in each region r. Table 3 gives an overview of these levels as stated in Kemfert (2002).

r:	ASIA	CAN	CHN	EU15	JPN	LSA
$e(r)$:	1.1025	0.2658	1.3215	1.1258	0.3012	0.2845
r:	MEX	MIDE	REC	RoW	SSA	USA
$e(r)$:	0.1016	0.2146	0.7985	2.3158	0.1126	1.6854

Table 3: The 1990 levels of carbon emissions (in billions of tons carbon equivalent), $e(r)$, in each region r. Source: Kemfert (2002).

Define an emission permit as an allowance for the owner to emit a certain amount of CO_2. Then, $e(r)$ refers to the initial endowment of CO_2 emission permits in region $r \in \mathcal{R}(\texttt{co}_2)$ where the set $\mathcal{R}(\texttt{co}_2)$ refers to the set of regions that participate in the emission permit market. In the Annex B scenario, we therefore take $\mathcal{R}(\texttt{co}_2) = \texttt{AnnexB}$.

Each production sector s in region r has a cost minimizing input demand $a_{sr}(\texttt{coal})$ of the coal good, $a_{sr}(\texttt{gas})$ of the gas good, and $a_{sr}(\texttt{oil})$ of the oil good. We assume that, per unit of input of fossil fuel h, $h \in \{\texttt{coal}, \texttt{gas}, \texttt{oil}\}$, there is an emission of $\text{co}_2\text{shr}(h)$ units of CO_2. Table 4 gives an overview of these shares as stated in Manne et al. (1995).

h:	coal	gas	oil
$\text{co}_2\text{shr}(h)$:	0.02412	0.0137	0.0199

Table 4: CO_2-coefficients, $\text{co}_2\text{shr}(h)$, for each fossil fuel h, $h \in \{\texttt{coal}, \texttt{gas}, \texttt{oil}\}$ (in tons of carbon equivalent per gigajoule of crude oil equivalent.). Source: Manne et al. (1995), Table 2.

In the Annex B scenario, we assume that each production sector s, in order to be able to maintain its activity level, exercises a demand for

$$\sum_{h \in \{\texttt{coal,gas,oil}\}} \text{co}_2\text{shr}(h) \cdot a_{sr}(h) \tag{1}$$

emission permits. This demand for emission permits depends on the permit price $p_{\texttt{co}_2}$ that clears the underlying regional market $\mathcal{R}(\texttt{co}_2)$. Within this region, this leads to an excess demand $z_r(p_{\texttt{co}_2})$ of emission permits equal to

$$\sum_{s \in \mathcal{S}} \sum_{h \in \{\texttt{coal,gas,oil}\}} \text{co}_2\text{shr}(h) \cdot a_{sr}(h) - e(r). \tag{2}$$

Since WIAGEM takes account of possible sinks, the excess demand for emission permits is reduced with the amount of permits equivalent to the amount of emissions absorbed by these sinks.

On the market of emission permits there is a total excess demand equal to $\sum_{r \in \mathcal{R}(\texttt{co}_2)} z_r(p_{\texttt{co}_2})$. This market is cleared by the price of emission permits $p_{\texttt{co}_2}$. The Annex B equilibrium is then computed by adding the good 'CO_2 emission permits' to WIAGEM and a complementarity condition

$$\textstyle\sum_{r \in \mathcal{R}(\texttt{co}_2)} z_r(p_{\texttt{co}_2}) = 0 \quad \perp \quad p_{\texttt{co}_2} \geq 0, \tag{3}$$

for periods 2010 and forward.

Kyoto (Kyoto) Under this scenario, we assume that China is officially obliged, like any other Annex B region, to stabilize emissions on its 1990 level. We take $\mathcal{R}(\texttt{co}_2) = \texttt{AnnexB} \cup \{\texttt{CHN}\}$ in (3) and add $e(\texttt{CHN}) = 1.3215$ for each period from 2010 on, as an initial endowment for China when entering the market. This endowment is assumed to be the Annex B Kyoto target for China following 2010. In the literature, such a scenario is often referred to as 'Kyoto forever'.

United States (US) One of the objectives of the United States in the Kyoto negotiations was to secure a meaningful participation of the developing countries. A developing country could for example voluntarily adopt an emission target. United States (1998) thinks that, if a developing country chooses to adopt a growth target and participate in international emissions trading, it could potentially enjoy substantial economical and environmental gains. Even with this participation, a country's emissions could continue to grow beyond current levels, as economic development continues.

In order to simulate such a scenario, we take $\mathcal{R}(\texttt{co}_2) = \texttt{AnnexB} \cup \{\texttt{CHN}\}$ in (3) and add $e(\texttt{CHN}) = 1.7571$ for 2010 and later, which equals the 'Business-as-Usual' emissions level of emissions of China in 2010 as calculated by WIAGEM in its 'Business-as-Usual' scenario, as an initial endowment for China when entering the market.

Center for Clean Air Policy (CAP) In order to establish an international climate change policy that fully accommodates a developing country's economic growth but requires that this growth be achieved in a carbon-efficient manner, Hargrave (1998) proposes to apply the concept of a *growth baseline*. The main benefit of adapting a growth baseline is the occurrence of substantial capital inflows through emission trading. If baselines were set so that developing countries could meet and go beyond their emission commitments through low cost measures alone, these countries would be able to generate emission trading possibilities at low expense and then sell emission allowances to industrialized ones.

This scenario is implemented by taking $\mathcal{R}(\texttt{co}_2) = \texttt{AnnexB} \cup \{\texttt{CHN}\}$ in (3). Following Hargrave (1998), let $e(\texttt{CHN})$ be tied to the growth in GDP in China. Hargrave (1998) estimates a carbon efficiency in 1995 of 1.29 $^{\text{tC}}/_{\text{US\$1000}}$ when using a market exchange rate. We then can set $e_t(\texttt{CHN}) = 1.29 \cdot \text{GDP}_t(\texttt{CHN})$ for periods t following 2010.

4 Simulations

In order for China to participate in an existing emission permit market, we should provide China with a realizable target for its emissions in 2010 and onwards. The policy scenarios introduced in the previous section provide three different approaches. The 'Kyoto' scenario lets China accept its BaU 1990 levels of CO_2 emissions as its target for 2010 and onwards, like any other Annex B party on the permit market. But it may be that such an approach is very likely to severely hamper China in its development. The two alternative scenarios therefore take account of this observation and choose a more realistic target. The main issue in these simulations is how these opposing effects on the development of China work out on welfare under the different policy options. We therefore concentrate on the effects on emissions, the permit price that arises on the market, and on welfare in particular. Welfare is measured by the Hicksian Equivalent Variation and alternatively by changes in GDP.

We start our analysis with the consequences of implementing the four scenarios described in Section 3 on emission levels in China after 2010. Table 5 provides the simulation results with respect to total emissions of China for each scenario.

We notice in Table 5 that implementing any of the scenarios will result in lower levels of emissions in China compared to the BaU scenario. The Kyoto scenario looks most successful with respect to limiting the growth of emissions, − at least initially −, but it is also the most stringent one by imposing 1990 levels on its 2010 target. It is interesting to note that the CAP scenario level of emissions overtakes the Kyoto scenario level of emissions after 2030. This is probably due to the fact that, by improving energy efficiency

Year	BaU	Kyoto	US	CAP
2010	1.7571	1.3275	1.6771	1.3626
2020	1.9812	1.5899	1.8812	1.6069
2030	2.1086	1.7723	1.9886	1.7727
2040	2.2040	1.9692	2.0640	1.8832
2050	2.3762	2.2248	2.2282	2.0604

Table 5: Total emissions of China (in billions of ton carbon equivalent) for each scenario.

in China, the constant limit on emissions imposed under the Kyoto scenario becomes less and less stringent, while this limit keeps adjusting itself with the improving efficiency under the CAP scenario, causing no relaxation of the pressure imposed by this limit. The United States scenario looks the least promising with respect to reducing emissions but, as Table 6 will show, it has the least negative impacts on China's GDP levels. In Table 6, we summarized the computed GDP levels of China under these scenario's.

Year	BaU	Kyoto	US	CAP
2010	659	647.97	657.96	648.40
2020	988	971.95	986.94	972.60
2030	1573	1551.49	1571.47	1552.35
2040	2564	2530.89	2560.86	2532.18
2050	4121	4077.30	4117.25	4079.02

Table 6: GDP levels of China in billion 1995 US$ for each scenario.

As Table 6 shows, the Kyoto scenario also has the most negative impact on China's GDP levels after 2010. It shows the lowest levels of GDP of all scenarios. This was to be expected since the other two scenarios were meant to take account of the possible negative impact of a too stringent target on GDP in China. The Center for Clean Air Policy scenario offers a lower GDP level than the United States scenario. GDP levels of CAP will be generally lower than in the BaU scenario, providing China with lower endowments of emission permits than under the United States scenario. It should therefore either buy more permits on the market or put more effort in decreasing emissions by itself, than it does under the United States scenario. This invokes extra costs on the efforts of China to curb emissions. All this results into a lower development of GDP under the Center for Clean Air Policy scenario. GDP levels under the United States scenario are consistently lower than under the BaU scenario, where China does not impose itself a growth target. Hence our simulation does not confirm the expectations of the US that adopting a growth target and participating in international emission permit trading would potentially bring substantial economical and environmental gains to China. Nevertheless, economic development continues, be it at a slightly lower level as under BaU. The United States scenario does have the least negative impacts on economic development when compared to the other scenario's though.

United States (1998) expects that a world with the participation of developing countries in an international emission trading market with growth targets slightly below their BaU projections would likely result in lower greenhouse gas emissions relative to a world with more narrow participation. In Table 7 we have depicted total global emissions for each scenario. It confirms this claim.

Year	Annex B	Kyoto	US	CAP
2010	12.8111	11.3492	11.6988	11.3843
2020	14.6906	13.3927	13.6841	13.4097
2030	15.6556	14.2459	14.4622	14.2463
2040	16.6032	15.1408	15.2355	15.0547
2050	17.8373	16.3601	16.3635	16.1958

Table 7: Total global emissions (in billions of ton carbon equivalent) for each scenario.

The Center for Clean Air Policy scenario imposes a growth baseline on the emissions in China. Under such a growth baseline, the developing country's emissions would not be capped, but these countries would have to make sure that their greenhouse gas emissions grew at a rate tied to their economic output. In this way, the growth of the developing countries would not be restrained, but countries would commit to improving the 'emission-intensity' of this growth compared to the BaU. Table 8 provides the emission intensity of China under each scenario. The Center for Clean Air Policy scenario clearly shows an improvement in intensity. Under each scenario, emissions intensity is improving over the years. Also under the BaU scenario, Table 6 shows a sharp increase in GDP levels in China over the years, while Table 8 indicates a decrease in emission levels in China itself. So, the development in China will show an improvement in emission intensity.

Under the Kyoto and United States scenarios, emission intensity improves better than under the BaU scenario. The Kyoto scenario obviously ends worst in comparison to the United States and the Center for Clean Air Policy scenarios. Emission intensity in the United States scenario improves below the Kyoto scenario only in 2050, while this already occurs in 2030 for the Center for Clean Air Policy scenario.

When we introduce the possibility of a market in emission permits, we can interpret the

Year	BaU	Kyoto	US	CAP
2010	2666.94	2048.47	2548.99	2101.51
2020	2004.73	1635.76	1906.14	1652.14
2030	1340.26	1142.33	1265.43	1141.96
2040	859.73	778.10	805.97	743.70
2050	576.63	545.64	541.19	505.13

Table 8: Emission intensity in China for each scenario.

emissions of each production sector as a demand for emission permits. The supply of these emission permits is then given by the allocation of emission allowances under the different scenarios. In Table 9, we have given an overview of the endowments of emission permits for China in each period under each scenario.

Year	Kyoto	US	CAP
2010	1.3215	1.7571	0.8501
2020	1.3215	1.7571	1.2745
2030	1.3215	1.7571	2.0292
2040	1.3215	1.7571	3.3076
2050	1.3215	1.7571	5.3161

Table 9: The endowments of emission permits for China (in billions of ton carbon equivalent) for each scenario.

When we compare total emissions for China under each scenario as presented in Table 5 with the amounts of emissions allowed to China by its permit allocation in Table 9, we see the following. Under the Kyoto scenario, China always demands emission permits since its allocated endowment of permits is obviously too low. The US scenario allocates a much higher endowment of permits to China. This allocation is so high that China will be able to supply its excess permits to the market for the first two periods. After 2030, China's economy and hence its emissions have grown so high that its allowance is overtaken and China becomes a demander for emission permits. The CAP scenario exhibits a completely opposing effect. China, under the CAP scenario, demands emission permits for the first two periods, and turns into a supplier of emission permits from 2030 onwards. This effect is due to linking emission permit endowments in each period to the level of GDP. A developing country like China will exhibit a comparably large growth in GDP, and therefore its allowance of emission permits will rise accordingly. The initial shortage of emission permits under the CAP scenario might indicate a too low estimation of emission intensity in Hargrave (1998) when applying our model.

On a market for emission permits, the participating regions will start trading these permits, and a price of such emission permits clears the market. In Table 10, we have provided the emission permit price that arises under each scenario. We have added the price of emission permits that would arise in the Annex B scenario, when only the Annex B regions participate on the market.

Year	Annex B	Kyoto	US	CAP
2010	5	21	15	21
2020	21	45	32	35
2030	54	78	64	68
2040	71	101	85	91
2050	101	121	105	103

Table 10: The price of emission permits (in 1995 US$ per ton carbon) under the different scenarios.

Under the Kyoto scenario, we assume that China intends to stabilize its 2010 emissions to 1990 levels. Consequently, China will demand emissions permits. Introducing this extra demand on the emission permit market leads to a higher permit price compared to the Annex B scenario. Furthermore, since emissions increase over time, demand for emission permits will also increase so, over time, the price of emissions will also increase.

The United States scenario chooses an emission target for China slightly below its BaU emission level for 2010. Since this level is lower than the 1990 level of emissions for China, the inclusion of China into an emissions market adds an excess demand for emission permits to this market that will be lower than under the Kyoto scenario. Hence, the smaller rise in excess demand on the permit market under the US scenario implies a lower permit price to clear the market compared to the Kyoto scenario.

China is obliged to improve its emissions efficiency under the Center for Clean Air Policy scenario, which requires higher emission reductions as compared to the United States scenario that only required a stabilization of emissions to BaU level. Hence the permit price under the Center for Clean Air Policy scenario is mainly higher than under the United States scenario.

The price of emission permits as calculated by WIAGEM in Table 10 are in general much lower than the emission permit prices mentioned in other publications that are often based on partial equilibrium models. With respect to partial equilibrium models, WIAGEM, like other CGE models, allows the production sectors to substitute away from emission intensive technologies, which may also give rise to a lower excess demand for permits in comparison to partial equilibrium models. Partial equilibrium models only consider one market and abstract away from substitution effects.

The impact of policies on welfare are often measured in computational general equilibrium modeling by looking at the consequences of these policies on the welfare of the regional household. We ask ourselves with how much we should compensate the regional household in income, to make him as well off as under the BaU scenario. This measure is known in economic theory as the Hicksian Equivalent Variation. On the other hand, policy makers like to refer to the consequences of implementing policies on GDP levels in each region. We have summarized the consequences of implementing the different scenarios on the welfare of each region through the Hicksian Equivalent variation in Table 11. The consequences on GDP in China were already given in Table 6.

Region	Kyoto	US	CAP
ASIA	−0.0638	−0.0638	−0.0633
CAN	−0.0672	−0.0673	−0.0670
CHN	−0.0273	−0.0023	−0.0262
EU15	−0.1719	−0.1706	−0.1660
JPN	−0.1014	−0.0999	−0.0975
LSA	−0.0426	−0.0426	−0.0424
MEX	−0.0329	−0.0329	−0.0326
MIDE	−0.0232	−0.0232	−0.0219
REC	0.0660	0.0560	0.0635
ROW	−0.0413	−0.0429	−0.0424
SSA	−0.0315	−0.0328	−0.0328
USA	−0.0067	−0.0060	−0.0066

Table 11: The change in welfare in each region as measured by the Hicksian Equivalent Variation.

Under the Kyoto scenario, we see that welfare as measured by the Hicksian Equivalent Variation as well as in GDP declines in China and also in other countries because of the increase in the permit price. Under the United States scenario, there is a lower permit price which leads to a lower economic decline. Russia (REC) will obtain lower revenues from selling its hot air, hence welfare improvement for Russia is lower. Consequently, China's welfare is improved compared to Kyoto. The Center for Clean Air Policy scenario shows a China that experiences higher welfare losses but also a higher permit price because China demands permits. This leads again to higher revenue gains for Russia (REC) as compared to the United States scenario.

5 Conclusions

During the last years, the developed countries, in particular the United States, have increased pressure on the developing countries to provide a significant contribution to international efforts to curb the sharply increasing trend in greenhouse gas emissions generated by global economic activities. The developing countries have objected to this pressure by claiming that their economic development would be severely hampered by the sharp increase in costs on their economies following such an effort. In this paper, we study the consequences of a developing country, China, joining the Annex B regions on a market for emission permits. When China joins an emission trading regime, some consideration should be given to the emission target that should be set. This target defines the initial endowment of permits with which China enters trading on such a market. We considered two proposals with respect to setting such a target. One proposal was provided by the United States to set the target of a developing country equal to its 'Business-as-Usual' level in 2010. Another proposal was given by the Center for Clean Air Policy which introduces a 'growth baseline' for the developing country, which ties this country's emissions to its growth in GDP. We have compared the results of these two proposals with a situation where China is obliged to fulfill the conditions set in the Kyoto Protocol and with a 'Business-as-Usual' scenario.

From our simulations, we conclude that all scenarios will decrease the welfare of China as measured by the Hicksian Equivalent Variation. The impact on welfare under the different scenarios do not differ for all the regions, except for China. To China, it is of major difference whether the 'Kyoto' proposal or the 'CAP' proposal is accepted, or the US proposal. The US proposal leaves China best off as compared to the other proposals but it is least successful with curbing emissions, globally as well as for China.

All scenario's also show a decrease in GDP levels in China. This trend is comparable with what we saw with respect to China's welfare measured with the Hicksian Equivalent Variation. So, both measures of welfare are in agreement here. This is not always the case, as the Hicksian Equivalent Variation also takes account of a policy measure's beneficial aspects to welfare.

The decrease in welfare for nearly all regions including China indicates that the expectations stated in United States (1998) that a developing country which chooses to adopt a growth target and participate in international emission trading could potentially enjoy substantial economical gains cannot be confirmed by the simulations in this paper. A similar result holds for the CAP scenario. This scenario intended to account for the objections of the developing countries by setting a growth baseline on emission efficiency such that economic growth would not be hampered. The simulations with WIAGEM indicate that the growth baseline set in Hargrave (1998) does not achieve this goal, thereby requiring a lowering of this baseline.

The increased price of emission permits when applying the alternative scenarios seems to be the driving force behind the welfare decreases compared to the BaU scenario. This price refers to the (opportunity) costs of emission reduction in the regions that participate on the emission permit market. WIAGEM follows the existing CGE and IA models in modeling the cost of emission policies for the production sectors, and omits the possibly beneficial effects of decreasing emissions on society. This causes an underestimation of the welfare effects associated with climate change policies. We therefore call to include these so-called second-order effects into the model by providing a complete coupling of the economic model and the climate model. Consequently, the simulations in a model that includes such second-order effects may give more support to the proposals studied in this paper.

Notice that none of the scenario's discussed here nor in the literature takes account that a developing country such as China will in due time become a developed country. As for the US scenario, this would oblige China to adhere to the conditions underlying the Kyoto scenario after some period of time. Since the CAP scenario requires China to improve its energy efficiency over time, it can be expected to meet the Kyoto scenario requirements after such a period of time.

References

Armington, P. (1969). A theory of demand for products distinguished by place of production. *IMF Staff Papers 16*, 159–178.

Barro, R. and X. Sala-i-Martin (1995). *Economic Growth.* New York: McGraw-Hill.

Bernstein, P., W. Montgomery, and T. Rutherford (1999a). Global impacts of the Kyoto agreement: results from the MS-MRT model. *Resource and Energy Economics 21*, 375–413.

Bernstein, P., W. Montgomery, T. Rutherford, and G. Yang (1999b). Effects of restrictions on international permit trading: the MS-MRT model. *The Energy Journal*, 221–256. Kyoto Special Issue.

Hargrave, T. (1998, January). Growth baselines: reducing emissions and increasing investment in developing countries. Executive summary, Center for Clean Air Policy.

Jensen, J. and T. Rasmussen (2000). Allocation of CO_2 emission permits: A general equilibrium analysis of policy instruments. *Journal of Environmental Economics and Management 40*(2), 111–136.

Kemfert, C. (2002). An Integrated Assessment model of economy-energy-climate − The model WIAGEM. *Integrated Assessment 3*(4), 281–298.

Kemfert, C., E. Haites, and F. Missfeldt (2003, December). Can Kyoto Protocol Parties induce the United States adopt a more stringent greenhouse gas emissions target? *Interdisciplinary Environmental Review V*(2), 119–141.

Kemfert, C. and Z. Zhang (2003). Linking developing countries' cooperation on climate control with industrialized countries' R&D and technology transfer. Discussion paper, SPEED, University of Oldenburg.

Manne, A., R. Mendelsohn, and R. Richels (1995). MERGE. A model for evaluating regional and global effects of GHG reduction policies. *Energy Policy 23*(1), 17–34.

Truong, T. (2003). *Global warming and emission trading*, Chapter 34, pp. 615–631. Handbook of Transport and the Environment.

United States (1998, July). The Kyoto Protocol and the President's policies to address climate change: Administration Economic Analysis. Technical report, Washington DC: Department of State.

Zhang, Z. (2000). The design and implementation of an international trading scheme for greenhouse gas emissions. *Environment and Planning C: Government and Policy 18*, 321–337.