A computable general equilibrium assessment of a developing country joining an Annex 1 permit trading market.

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Abstract

The rejection of the United States to verify the Kyoto Protocol, has focussed some attention on the contribution of the developing countries in mitigating the consequences of climate change on our economy. While the USA insisted on an important role for the developing countries, for example by voluntarily accepting an emission target in 2012, the developing countries themselves found their growth hampered by such measures. This paper focusses on the consequences of setting emission targets for developing countries, here China. We consider different proposals for setting such targets. One of these proposals is the proposal of the USA to let China accept its projected 'Business-as-Usual' emission level for 2012 as its target. A proposal by the Center for Clean Air Policy took more consideration for the viewpoint of the developing countries by imposing a so-called 'growth-baseline' for China, where a target is set on emission efficiency.

1 Introduction

Recently, two developing countries, China and India, announed that they are willing to join the Annex B countries in ratifying the Kyoto Protocol. Formally, this means that these countries will be asked to stabilize their carbon emissions at 1990 levels by the year 2012. But is this the correct way to go given the specific problems that these countries face in their stage of development, such as the limitations that a strict limit on emissions imposes on the growth-rate in these developing countries.

This paper considers the situation where the Annex B countries have an emission permit market for 2012 and forward in place. The Annex B emission market is modelled 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 1 regions on this permit market under the following regimes of allocating an initial endowment of emission permits to China:

1. 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.

2. 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).

3. 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).

We use WIAGEM, which is a multi-sectoral multi-regional general equilibrium model. The regional aggregation consists of 11 trading regions, among which the Annex B regions, China, and the rest of the world. The sectoral aggregation in each region consists of 15 production sectors among which five energy sectors. Primary production factors are capital, labour, and land (see Kemfert (2002)). In this setup, the study focusses on the particular problems faced when a developing country wants to join a permit market.

Apart from considering the impacts of climate change policies on the economy, WIAGEM also contains a climate model and a damage assessment model. The climate model calculates the changes in temperature, percipitation, and sea-level following an increase in greenhouse gas emissions. The damage assessment model provides estimates for the damages of climate change. Another distinctive characteristic of WIAGEM is the inclusion of the possibility of so-called induced technological change into the model.

The latter characteristic of WIAGEM is extensively used in Kemfert and Zhang (2003) to investigate the economic and environmental implications of climate control coalitions cooperating on R&D investment that triggers low cost environmentally friendly technologies. One of the results of Kemfert and Zhang (2003) was that developing countries need to be involved in order for the negative economic effects of emission reduction commitments on both industrialized and developed countries to be completely offset.

In Kemfert et al. (2003), WIAGEM was used to analyze possible strategies to induce the United States in 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.

In Section 2, we provide a description of the WIAGEM model. The interested reader is referred to Kemfert (2002) for the technical details. In Section 3, we describe the setup of the simulations, and in Section 4 we analyze the simulation results. The paper is closed with some conclusions in Section 5.

2 The model

For specific details on WIAGEM, we refer to Kemfert (2002). WIAGEM is a computational general equilibrium (CGE) model where the 'Multi-Sector Multi-Regional Trade' (MS-MRT) model is extended to the inclusion of a climate model and of the possibility of incorporating so-called induced technological change. For the MS-MRT model, we refer to Bernstein, Montgomery, and Rutherford (1999) and Bernstein, Montgomery, Rutherford, and Yang (1999). WIAGEM combines a recursive dynamic general equilibrium model with an energy market model, a climate model, and a damage impact model. The *time horizon* is 50 years, incremented in 10-year time steps. It takes 1995 as its *benchmark year* but it is calibrated using the 1994 GTAP4 database complemented with GTAP5 data. The model considers the period from 2000 to 2050.

2.1 Economy

WIAGEM aggregates the world into 11 trading regions, which we enumerate in Table 1. We distinguish the subsets Annex B $=\{\text{CAN}, \text{EU15}, \text{JPN}, \text{REC}, \text{USA}\}$ referring to the regions that signed the Annex B to the Kyoto Protocol, a set OECD $=\{\text{CAN}, \text{EU15}, \text{JPN}, \text{USA}\}$ of OECD member countries, and the set DEV $=\{\text{ASIA}, \text{CHN}, \text{LSA}, \text{MEX}, \text{ROW}, \text{SSA}\}$ of developing countries.

WIAGEM extends the originally 9 production sectors in the MS-MRT model in each region to 15 production sectors. These contain 13 tradeable goods, which we summarize in Table 2. Furthermore, each region contains two extra production sectors, one of them referring to an investment sector 'INV' and the other one to a Research and Development sector 'R&D'.

The production factors used in WIAGEM are capital, labour, and a sector-specific fossil fuel resource. Physical capital is malleable but cannot be transferred accross 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-year 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 at each time. 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.

WIAGEM considers emissions in CO_2, and considers the other greenhouse gases CH_4, and N_2O in CO_2-equivalents.

Each tradeable 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. 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 modelled by a representative household, who maximizes it's region's discounted utility over the model's time horizon given his income. The assumes that the utility function is of a Constant-Intertemporal-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 energy 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). In these models, the consumption-investment decision of an infinitely lived 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 theory approach: (1) The CGE considers a finite horizon, and (2) The CGE 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 stated 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 intertemporal optimization problem then 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 to obtain 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 and R&D 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 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 (CD) function. The expenditure on non-energy goods are composites of domestically produced goods and their imported equivalents.

Consumption and the production of non-energy goods contain an energy composite which is decomposed into the energy products of the non-energy and electricity production sectors. Furthermore, this decomposition also contains the emissions in greenhouse gasses, CO_2, CH_4, and N_2O, which accompany production. See also Bernstein et al. (1999) 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 aggregate. The electricity goods in these CES-functions are again composites of domestically produced goods of the sector EGW and its imported equivalents. The fossil composite is decomposed into a coal composite good and a noncoal composite. The non-coal composite is decomposed into a gas composite good and an oil composite.

We consider each fossil fuel as a composite of the 'pure' fossil fuel part and parts for the greenhouse gases. The use of a unit of a fossil fuel composite will lead to a certain share of emissions in each greenhouse gas. WIAGEM models this using a Leontief functional form with these shares as its share parameters. Similarly, it uses a Leontief function, with the share of each greenhouse gas per unit of input of fossil fuel consumed in each region as its share parameters.

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 so-called 'Armington goods', to approximate the effects of infrastructure requirements and high transport costs between some regions. This means that these goods are composites of a domestically produced and the imported good.

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 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.

There is a sector which produces the 'investment good' in the economy, using investments of each other production sector as inputs. The investment of a production sector is modelled as the part of the output level of this sector which is produced for investments. The production function of this sector is a Leontief-type, hence with fixed shares of each input. Investments in research and development is modelled similarly.

WIAGEM assumes that there is perfect competition on the markets. In this model this means that the prices of each good equals the marginal cost to produce them. Demand on each market is then cleared by the output levels of the production sectors. The capital market is a production sector specific market. The labour market is a regional market, while the other goods are traded as imperfect substitutes on the international markets. We hence define an equilibrium as a set of prices and activity levels such that

1) (*market clearing*) The activity levels of each production sector clear the market for the particular output good.

2) (*zero profits*) The price of each good is determined by the minimum cost to produce one unit of this good.

Under the market clearing condition, the activity level of each production sector in each region satisfies the total of domestic demand for this good as an intermediate good in other production sectors, as final consumption, as investment good, and as R&D good.

Notice that there will be a wig between producer prices and consumer prices due to possible taxes or subsidies posed by the regional government on this good.

The output level of each non-energy and oil production sector in each region satisfies the total of exported demand for this good as an intermediate good in production sectors and, as exported final consumption.

There will be a wig between export producer price and consumer price due to possible tariffs or export subsidies imposed by a regional government on this.

Part of the domestic production of each good is reserved for investments in its capital stock. All these investments are combined into one unit of an aggregate investment good particular to each region.

This investment good is then used to update the capital stock for the next period. Similarly, a composite R&D good is constructed from the sector-specific investments in R&D. This R&D good is then used to adjust the productivity parameter of capital in the production function of the corresponding production sector in the next period. In this way, Kemfert (2002) introduces the possibility of so-called induced technological change into the model. The activity level of these investment sectors then satisfies demand for these investment goods.

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. Similar, it follows from the zero profit conditions that the price of a util equals the expenditure to obtain one unit of it. This can be interpreted as a consumer price index.

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.

2.2 Climate

The total emissions in each period follow from adding the CO_2emissions over regions and over production sectors and over consumption households, during this time period. Although the emissions are modelled in the economic model as an (input) demand, they offer a supply of emissions in each greenhouse gas to the climate model.

Sinks are included exogenously into the model. During each period, a certain amount of CO_2 is taken up as a sink into the biosphere. We have to subtract this from the annual emissions in the current period.

WIAGEM considers the relation between emissions and atmospheric concentrations and their resulting impact on global temperature and sea level. Due to the short term until 2050, classes of atmospheric greenhouse gas stocks with different atmospheric lifetimes are neglected. The WIAGEM model follows the MERGE model with respect to incorporating the consequences of increased emissions on climate. For the MERGE model, we refer to Manne et al. (1995).

2.3 Damage impact

Following Manne et al. (1995), the impacts of climate change are subdivided into *market damages* and *non-market damages*. Market damages consider sectoral damages, production impacts, loss of welfare etc., while nonmarket damages consider ecological effects such as diversity losses, migration, natural disasters.

The impacts of climate change are calculated from the simulation results using *damage functions* as introduced in Tol (2002). These damages consider the loss in value of ecosystems, the increase in diseases, mortality rates, and space heating and cooling energy demand following climate change. WIAGEM follows the approach taken in Tol (2002) by using an estimated relationship between temperature changes, GDP, and protection costs due to sea-level rise. The protection costs of sea-level rise are included into WIAGEM in a way that is compared to the inclusion of investments.

3 Policy scenarios

In this paper, we are interested in the consequences of China as a developing country joining a market of emission permits among the Annex B regions, under different assumptions with respect to the allocation of emission targets to China. We define a 'Kyoto scenario', where we set a target for China that follows the official guidelines in the Annex B of the Kyoto Protocol. We define a 'United-States scenario', where we follow the official position of the United States as stated in United States (1998) that the developing countries should voluntarily set a target in order to provide a significant contribution to international emission reduction. We also define a 'CAP scenario', following a proposal by the Center for Clean Air Policy (CAP) as stated in Hargrave (1998) to set a so-called 'growth-baseline' for China. These scenarios are then compared to a 'Business-as-Usual scenario' (BaU).

Business-as-Usual (BaU). This is a scenario that occurs when 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.

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

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

Each production sector s in region r has a cost minimizing input demand $a_{sr}(\text{coal-co}_2)$ of a coal-CO_2-composite good, $a_{sr}(\text{gas-co}_2)$ of a gas-CO_2-composite good, and $a_{sr}(\text{oil-co}_2)$ of an oil-CO_2-composite good. We assume that, per unit of input of the h-composite, $h \in \{\text{coal}, \text{gas}, \text{oil}\}$, 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 Kemfert (2002),

In the benchmark, we assume that each production sector s, in order to be able to maintain his activity level, exersizes a demand for

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

emission permits. Within region $r \in \mathcal{R}(\text{co}_2)$ this leads to an excess demand $z_r(p_{\text{CO}_2})$ of emission permits equal to

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

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

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

for periods 2010 and forward.

Kyoto. By joining the Annex B emission market, China is officially obliged, like any other Annex B country, to stabilize emissions on its 1990 level. So, in this scenario, we bluntly stick to this rule. We take $\mathcal{R}(\text{co}_2) = \text{Annex B} \cup \{\text{CHN}\}$ in (2) and add $s(\text{CHN}) = 171$ 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.

United States (US). One of the objectives of the United States in the Kyoto negotiations was to secure a meaningful participation of key developing countries. Although the Kyoto Protocol foresees in a participation by developing countries through the Clean Development Mechanism, the United States want to urge these countries to do more to participate meaningfully in the effort to combat global warming. A developing country could voluntarily adopt an emission target. United States (1998) think 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 $\mathcal{R}(\mathrm{co}_2) = \text{Annex B} \cup \{\text{CHN}\}$ in (2) and add $s(\text{CHN}) = 176$, 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). Developing countries are growing more quickly than Annex B countries and are expected to account for nearly one-half of global emissions by 2015. This trend makes it clear that reducing greenhouse gas emissions will require both industrialized and developing countries to adapt emission commitments. Developing countries however expect to have a full opportunity to achieve economic growth. 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 occurence 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 $\mathcal{R}(\mathrm{co}_2) = \text{Annex B} \cup \{\text{CHN}\}$ in (2). Following Hargrave (1998), let $s(\text{CHN})$ be tied to improvements in carbon efficiency, i.e. the ratio emissions/GDP should be required to improve over time. Hargrave (1998) estimates a carbon efficiency in 1995 of $1.29\ {}^{\text{tC}}/_{\text{US\$1000}}$ when using a market exchange rate. We set $s(\text{CHN}) = 1.29\ \text{GDP}_t(\text{CHN})$ for periods following 2010.

4 Simulations

In order for China to participate in an existing emission permit trading market, we should provide China with a realizable target in emissions for 2010. The policy scenarios introduced in the previous section provide three different approaches. The 'Kyoto' scenario lets China accept the obligations in the Annex B to the Kyoto Protocol, like any other party on the permit market. But it may be that such an approach is very likely to severely hamper China in its development. The other two scenarios therefore take account of this observation, and these alternatives choose a more realistic target. The main issue in these simulations is how these opposing effects on the development of China on welfare work out 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 then measured by the Hicksian Equivalent Variation and 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 'Business-as-Usual'. The Kyoto scenario looks most successfull with respect to limiting the growth of emissions, but it is also the most stringent by imposing 1990 levels on its 2010 target. The United States scenario looks the least promissing 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.

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, as under the Center for Clean Air Policy scenario, China is obliged to improve its efficiency levels over time after 2010. 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 participate in international 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.

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 slower rate than the 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. 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 interprete the 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 Kyoto Protocol. 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 9, 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 Benchmark scenario, when only the Annex B regions participate on the market.

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 benchmark 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 less than under the Kyoto scenario. Hence, the smaller rise in excess demand on the permit market implies a lower permit price to clear the market. This is what we see in Table 9.

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

The impact of the policies on welfare are often measured in computational general equilibrium modelling 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. This measure is known in economic theory as the Hicksian Equivalent Variation (HEV). 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 10. The consequences on GDP in China were already given in Table 6.

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.

The Hicksian Equivalent Variation computes the loss in welfare of the regional household with respect to the BaU scenario under the different scenarios. WIAGEM offers the possibility to compute damages following the non-market impacts of climate change. Non-market impacts were mentioned in Section 2 under the damage assessment submodel. These damages are translated into a percentage of GDP. Table 11 gives an overview of non-market damages of climate change under the different scenarios. These estimates follow roughly the total emission levels in Table 7.

5 Conclusions

During the last years, the developed countries, in particular the countries that signed the Annex B to the Kyoto Protocol, 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 three proposals with respect to 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 requires this country to improve its emissions intensity over time. 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 significantly 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 successfull 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 the beneficial aspects to welfare of a policy measure.

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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.

AGR:	Agriculture
COL:	Coal
CRP:	Chemical rubber and plastics
CRU:	Crude oil
EGW:	Electricity
GAS:	Natural gas
NFM:	Nonferrous metals
NMM:	Nonmetal mineral products
OIL:	Petroleum and coal products
OMS:	Other manufactures and services
ORE:	Iron and steel
PPP:	Pulp and paper
TRN:	Transport industries

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

r	ASIA	CHN	CNA	EU15	FSU	JPN	MIDE	USA
$s(r)$	305	171	10.79	136	53	63	5	71.38

Table 3: The 1990 levels of CO_2 emissions in billions of metric tons/Exej., $s(r)$, in each region r. Source: Kemfert (2002), Table 9.

h	coal	gas	oil
$\mathrm{co_2shr}(h)$	0.2412	0.1994	0.1374

Table 4: CO_2 coefficients $\mathrm{co_2shr}(h)$, for each h-composite, $h \in \{\mathrm{coal}, \mathrm{gas}, \mathrm{oil}\}$, in billions of metric tons/Exej.,. Source: Kemfert (2002), Table 3.

	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 bil. t carbon equivalent for each scenario.

	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 for each scenario.

	BaU	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 bil. t carbon equivalent for each scenario.

	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.

	Benchmark	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 9: The price of an emission permit under the different scenarios.

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

	BaU	Kyoto	US	CAP
2010	0.1842	0.1584	0.1674	0.1594
2020	0.3821	0.3712	0.3742	0.3731
2030	0.4825	0.4712	0.4712	0.4724
2040	0.5028	0.4916	0.4958	0.4926
2050	0.5471	0.5012	0.5125	0.5085

Table 11: The non-market damage of emissions on the economy as a percentage of GDP.