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Claudia Kemfert

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German Institute
for Economic Research

Königin-Luise-Str. 5
14195 Berlin,
Germany

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

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INDUCED TECHNOLOGICAL CHANGE IN A MULTI- REGIONAL, MULTI- SECTORAL INTEGRATED ASSESSMENT MODEL (WIAGEM)

Impact Assessment of Climate Policy Strategies

Claudia KEMFERT [a,b,]

[a] *German Institute of Economic Research, Berlin, Germany*

[b] *Humboldt University of Berlin, Department of Economics, Germany*

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Abstract

This paper illustrates the representation of induced technological change in the multi-regional, multi-sectoral integrated assessment model WIAGEM. The main aim of this paper is to investigate quantitatively economic impacts of climate policy measures due to induced technological changes that are considered. Improved technological innovations are triggered by increased R&D expenditures that advance energy efficiencies. Model results show that induced technological changes due to increased investment in R&D reduce compliance costs. Although R&D expenditures compete with other investment expenditures, we find that increased R&D expenditures improve energy efficiency that substantially lowers abatement costs. Without the inclusion of induced technological changes, emission targets are primarily reached by production declines, resulting in overall welfare reductions. With the inclusion of induced technological changes, emission mitigations can achieve fewer production drawbacks. Technological spill over effects also lead to improved terms of trade effects.

Key Words: Induced technological change, multi-regional applied integrated assessment model, technological spill over

JEL classification: C6, O3, Q4, D5

1 Introduction

A continued accumulation of anthropogenic greenhouse gases (GHGs) will ultimately have severe consequences on the climate as well as ecological and social systems. This occurrence of greenhouse gases makes the following clear: Irreversible climate changes induce significant economic costs. International climate control agreements intend to shrink this process. A substantial reduction of GHG emissions requires cooperation between countries. Furthermore, greenhouse gas emissions reduction is still an international public good necessitating long term and global economic efforts. The formulation of the Kyoto protocol and the following negotiation attempts represent one initial outcome of cooperative international climate control policy actions.

International climate policy measures cover so-called “flexible mechanisms” like Clean Development Projects (CDM) and Joint Implementation (JI). Clean development projects incorporate the option to transfer investment within specific emissions reduction projects from developed to less developed countries. These investment expansions trigger energy efficiency improvements in the host country and increase the share of new technologies. Joint implementation (JI) projects intend to achieve the same purpose as CDM but concentrate their activities within developed nations. The instrument of emissions trading can be implemented on the national or international level, and both reveal an opportunity to achieve emissions reduction targets at low abatement cost opportunities. Most analyses of the impacts of Kyoto Protocol implementations found that the allowance of international Kyoto mechanisms reduces the global and national costs of abatement significantly. An overview of this is given by Weyant and Hill (1999) and Edmonds, Scott et al. (1999). Economic costs of emissions reduction measures can be reduced if flexible mechanisms can be applied (Buonanno et al. (2003), Carraro et al (2003), Kemfert (2002a)).

Environmental and climate interventions create constraints and incentives that affect the process of technological change. The imposition of climate control instruments can stimulate invention and innovation processes. The invention and innovation practices are carried out primarily in private firms though increased research and development (R&D). A technological innovation can become widely available by technological diffusion processes. The induced innovation hypothesis recognizes R&D investments as profit-motivated investments stimulated by relative price changes. Climate policy measures that increase the price of fossil fuels augment the market for low carbon technologies. This effect creates incentives for increased R&D expenditures in those sectors affected by climate change. Increased R&D expenditures raise technological changes that lower the costs of low carbon technologies. These effects reduce compliance costs and can lead to increased profits (Porter and van der Linde (1995)). However, investment in R&D could also “crowd out” other investments (Gray and Shadbegian (1998)). This would reduce the profits of firms. Econometric tests confirm these ambiguous results. Jaffe and Palmer (1997) find that a carbon tax reduces aggregate R&D causing a decline of knowledge accumulation and the rate of technological progress, which results in a deterioration of income and output. Recent findings, however, illustrate that environmental policies can have a strong positive feedback on innovation and may induce beneficial economic outcomes (Popp, 2001 and 2002).

In economic-energy-environmental modeling concepts, the representation of technological changes is one of the most important sources of uncertainty in determining the economic costs of climate policy strategies (see Jaffe et al. (1995) and Jaffe (2000)). In previous modeling concepts, technological changes were treated as exogenous. Economy- climate models that incorporate technological changes endogenously determine technological innovations either by investment in R&D as “induced technological progress”, integration of spillovers from R&D, or by including technological learning processes, particularly “learning by doing” practices. Numerous modeling approaches investigate the economic effects of technological changes. On a micro or bottom-up scale, different kinds of technologies are assessed in detail. On a macro top-down scale, aggregated economic feedback effects of technological progress are evaluated. In top-down models, technological progress is mostly represented as an innovation to produce the same amount of output (GDP) with smaller amounts of input factors. This means an increase in input factor productivity. In contrast to an exogenous representation of technological progress, induced technological progress triggers endogenously increased productivities by different sources such as investment-induced technical progress or R&D- induced technological progress.

As modeling results confirm, the exclusion of the representation of endogenously determined technological changes tends to overestimate compliance costs (Loeschel 2002). As initial installations of technological innovations are very often expensive, costs decline over time with increasing experience. A learning curve describes technological progress as a function of accumulated experience in production. Many applied modeling concepts, including bottom-up modeling concepts with a detailed representation of energy technologies, apply learning curves as a meaningful description of technological changes (Grübler et al. (1999), Gerlagh and van der Zwaan (2003) or Azar and Dowlatabadi (1999)). Dowlatabadi (1998) finds that emissions abatement costs decline substantially if technological change is induced by technological progress, and when learning by doing is considered. Gerlagh and van der Zwaan (2003) find that the learning by doing effects that make cheaper non-carbon technologies available induce positive economic impacts and reduce the costs of climate policies.

Some models that incorporate induced technological changes by increased investment in R&D but also increased opportunity costs do not find large impacts on abatement costs (Goulder and Schneider (1999), Nordhaus (2002) and Buannano et al. (2003)). Popp (2004) finds that induced technological change leads to substantial welfare gains but only small climate imapcts in the long run. Goulder and Matthai (2000) find that abatement costs are lower with the existence of induced technological change than without. The main difference between the former and the latter modeling experiment is that some approaches find productivity increases for some sectors positively influenced by induced technological changes, but decreased productivity for other sectors that are influenced negatively. These exercises find that induced technological changes significantly raise the benefits of a specific climate policy strategy, but do not largely reduce the costs.

In this paper, we intend to investigate economic impacts of international climate policies that induce technological changes through increased R&D investment. We assume that binding emissions reduction targets as imposed by the Kyoto Protocol induces increased investment in R&D that improve energy efficiencies.

The main intention of this paper is to introduce induced technological progress in an applied, multi-regional, multi-sectoral integrated assessment model and to evaluate the differences in regional and sectoral outcomes. One primary aim is to investigate whether or not endogenous technological progress has a substantial impact on compliance costs.

One special focus is on the impacts of climate control policies. As previously mentioned, international flexible mechanisms particularly allow project transfer to increase energy efficiencies in developed and developing countries. The study focuses on whether or not induced technological change can support environmentally friendly technologies and how compliance costs of developed and developing countries are affected. Furthermore, technology spillover effects are assessed.

The main feature of this paper is that endogenously determined induced technological changes are represented using the multi-sectoral, multi-regional integrated assessment model WIAGEM (**W**orld **I**ntegrated **A**ssessment **G**eneral **E**quilibrium **M**odel) that additionally covers the impacts of climate change. The model presents different emissions abatement options which include domestic action, international flexible mechanisms such as international emissions trading (ET), Clean Development Mechanisms (CDM) and Joint Implementation (JI). In contrast to many other previously mentioned studies, we investigate economic consequences of the latter two climate policy options, and the inclusion of induced technological changes. The main intention is to study whether or not induced technological change could reduce emissions abatement costs, and assess economic impacts of different climate policy options. We compare the results to previous scenarios of Kemfert (2002a) where technology changes are modeled exogenously.

Section two of this paper describes the applied multi-regional, multi-sectoral integrated assessment model WIAGEM that includes induced technological change. Section three illustrates the scenario definition, while section four summarizes the main model outcomes and compares different climate control policies. The last section concludes.

2 Model Description

Model simulations are based on the applied general equilibrium model WIAGEM, an integrated assessment model merging an economy and energy market model with a detailed climate module and ecological impact studies. This approach is based on a recursive dynamic general equilibrium approach. WIAGEM covers a time horizon of 50 years that are incremented into five-year time steps. A detailed model description is provided by Kemfert (2002b). The basic idea behind this modeling approach is the evaluation of market and non-market impacts induced by climate change. The economy is represented by 25 world regions aggregated into 11 trading regions (countries) with each region covering 14 sectors. The sectoral disaggregation contains five energy sectors: coal, natural gas, crude oil, petroleum and coal products, and electricity. The dynamic international energy market for oil, coal and gas is modeled by global and regional supply and demand. The oil market is characterized by imperfect competition. The model describes that OPEC regions as using their market power to influence market prices. Energy-related greenhouse emissions occur as a result of economic and energy consumption and production activities. Currently, a number of gases have been identified as having a positive effect on radiative forcing (IPCC (1996)) and are included in the Kyoto protocol as “basket” greenhouse gases. The model includes three of these gases: carbon dioxide (CO2), methane (CH4) and nitrous dioxide (N2O), which are considered the most influential greenhouse gases within the short term modeling period of 50 years. Excluding the other gases is not believed to have substantial impacts on the analysis’ insights.

Because of the short-term application of the climate sub model, we consider only the first atmospheric lifetime of greenhouse gases, assuming that the remaining emissions have an infinite lifetime. As CO2 is a long-living gas, we divide the atmospheric lifetime of gases into special time sections. The atmospheric concentrations induced by energy-related and non-energy-related emissions of CO2, CH4 and N2O have impacts on radiative forcing, influencing potential and actual surface temperature and sea level. Market and non-market damages determine regional and overall welfare development.

In each region, production of the non-energy macro good is captured by an aggregate production function. It characterizes technology through transformation possibilities on the output side and substitution possibilities on the input side. In each region, a representative household chooses to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. In each period, households face the choice between current consumption and future consumption, which can be purchased via savings. The trade-off between current consumption and savings is given by a constant intertemporal elasticity of substitution. Producers invest as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by a uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and a unit of consumption is equalized within and across countries. Domestic and imported varieties for the non-energy good for all buyers in the domestic market are treated as imperfect substitutes by a CES Armington aggregation function, constrained to constant elasticities of substitution. Emission limits can be reached by domestic action or by trading emission permits within Annex B countries (initially) allocated according to regional commitment targets. Those countries meeting the Kyoto emissions reduction targets stabilize their mitigated emissions at 2010 levels. A full description of the regions and sectors and the calibration of the model are shown by Kemfert (2002b).

Goods are produced for the domestic and export market. Production of the energy aggregate is described by a CES function reflecting substitution possibilities for different fossil fuels (i.e., coal, gas, and oil), capital, and labor representing trade-off effects with a constant substitution elasticity. Fossil fuels are produced from fuel-specific resources and the non-energy macro goods subject to a CES technology.

Induced technological change is considered as follows: We assume that climate change has substantial impacts on the economy. Furthermore, climate policy interventions have an impact on relative factor prices, e.g. fossil fuels becoming more expensive. Countries react to negative climate impacts and climate control policy measures by spending a specific amount of their investments on R&D. In the benchmark year, we assume that the share of R&D investment to total output is 2 %.[1] These R&D investments are used to improve technological processes, especially energy technologies resulting in lower energy intensities. Energy efficiency is improved endogenously by increased expenditures on R&D. This means, in the CES production function, energy productivity is endogenously influenced by changes in R&D expenditures. The CES production structure combines nested capital and labor at lower levels, a mathematical description can be found in Annex II. However, not the whole amount of R&D is used to improve energy efficiency. If no cooperation between countries takes place, the share of R&D investment that leads directly to improved energy efficiency is around 20 % and rises with cooperation up to 65 % of sectoral R&D investments.

Energy is treated as a substitute of a capital labor composite determining (together with material inputs) overall output. Energy productivity is increased endogenously by increased R&D expenditures. This means that energy intensity is affected by technological change. The incentives to invest in technology innovations are market driven. Climate policies as well as negative climate change impacts induce incentives to invest in knowledge though R&D investments. This means that there are two driving forces that induce increased expenditures in R&D: negative climate impacts and climate policy. This mechanism works as follows: increased sectoral emissions increases climate change impacts. If welfare is negatively affected by climate change, measured in percentage of GDP and exceeds a certain threshold (0.5 % of sectoral GDP), sectors start to invest in climate protection. If sectors are affected by negative impacts of climate change, they increase protection costs as well as investment in R&D. Furthermore; sectors invest in R&D if they have to meet binding emissions reduction targets. New knowledge produces new processes and products, which lower the energy intensity of output. Figure 1 compares the energy intensities of different scenarios. If we assume a high share of R&D investment share (3 % of GDP) emission intensity is decreased

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[1] We follow Nordhaus (2002) who applied an average share of 2 % per year. In 2002, the USA spent 2.7 % R&D investment as percentage of national GDP. Japan has spent 3 percent, 2.2. percent by France, 2.5 by Germany, 1.9 percent by UK and 1.8 by Canada , Source:National Science Foundation.

[2] In the mathematical description, we refer to the *dual approach*. That means we show the cost minimization where the independent variable is the price and not the quantity as in the primal case. For further explanations about the theoretical framework for determining the general equilibrium, see Shoven and Whalley (1992). A full description of the model including all equations and interlinkages is provided in Kemfert (2002b).

[3] The notation Π with the subscript Y is used to consider the activity subset, which is represented by production Y. Because of the zero profit condition, this equation needs to be equal to zero.

[4] As we incorporate the variations of energy productivity in a CGE modelling framework, energy productivity changes must be profit-neutral.

[5] As with the previous notation, we use the zero profit hypothesis for capital activity K.

substantially. A lower share of R&D investment leads to less significant emission intensity declines.

3 Scenario Definition

We will include induced technological change to investigate the economic consequences of international climate policy strategies. We assume that an international climate policy treaty such as the Kyoto Protocol comes into force. This means that developed countries face binding emissions reduction targets.

Emissions reduction targets can be reached by either domestic policy measures or more flexible, international mechanisms that allow for lower abatement cost options. Almost all countries committing themselves to reducing greenhouse gas (GHG) emissions project significant emissions increases in the absence of measures to mitigate their emissions. However, the negotiated emissions reductions obligations do not represent real diminution targets for all countries.

Economies in Transition (EIT) have already reached their emissions reduction targets. This is a result of their economies and therefore emissions declining considerably; their actual emissions now lie far below their 1990 baseline emissions. That means, as this implies no real emission reduction to comply with the target, emission permits can be sold if they are not used otherwise. This is known as the so-called “hot air” effect. Besides the opportunity to reduce emissions domestically, international Kyoto mechanisms allow for low abatement cost options by trading certified emissions reductions from investment projects in developed (JI), developing countries (CDM), or emissions permits (emissions trading). Although the participation of cooperating Kyoto Protocol countries is still unclear, we assume that all countries participate in an international climate policy strategy, as was initially agreed upon in Kyoto. International mechanisms need to be supplemental to domestic action, allowing it to constitute a “significant element” of the effort made by each Annex I country to meet its emissions reduction obligations. The CDM executive board calls for a prompt start to the CDM and JI activities, and the latter have already been implemented by activities implemented jointly (AIJ). The recent Conference of the Parties (COP 9) also agreed that all decisions on whether a CDM /JI project activity assists in achieving sustainable development must be made by the host countries. Emissions reduction units (ERU) or certified emissions reductions (CER) should not be generated from nuclear facilities to meet their emissions reductions commitments. Because of this, our analysis uses CDM technologies covering nuclear-free, new carbon-free technologies.

Clean development mechanisms (CDM) incorporate the option of transfer investment within specific emissions reduction projects from developed to less developed countries. These investment transfers are explicitly modeled as increased capital flows to developing countries that are applied for energy efficient technologies. These investment expansions trigger induced technological changes as energy efficiency improvements in the host country and increase the share of new technologies. We assume that countries investing in CDM or JI projects increase R&D investment shares that improve energy efficiencies. Joint implementation (JI) projects intend to achieve the same purpose as CDM but concentrate their activities within developed nations. We compare this induced technological change option in contrast to a pure investment strategy.

We distinguish between the following scenarios:

a) The *CDM -ITC* scenario simulates the investment projects as additional project *and R&D* investment decisions by Annex I countries that increase energy efficiencies in host countries.
b) The *CDM-ITC with Sinks* scenario includes additional sinks projects like afforestation and reforestation within the first commitment period 2008-2012.
c) The *JI-ITC* scenario represents the investment projects from industrialized countries to countries in transition (here REC region) as additional project *and R&D* investment decisions by Annex I countries increasing energy efficiencies in host countries.

The most important indicator of economic impact assessment explains the overall welfare changes measured in real income variations of different world regions. Even more interesting are the different components and influencing factors shaping world welfare changes. This paper sheds some light on this issue and decomposes overall economic welfare of different world region changes in (1) pure autarkic domestic effects of impacts by domestic actions to reduce emissions and (2) competitiveness effects by the changes in terms of trade and (3) spillover effects induced by knowledge capital flows.

4 Model Results

The economic implications achieving quantified emissions reductions targets accomplished by the implementation of Kyoto mechanisms are assessed by the previously described model WIAGEM that simulates world economic relations up to 2050. It is assumed that the Kyoto mechanisms are initiated in the first commitment period 2008 – 2012 and last until the end of the projection period. We evaluate the economic impacts of Kyoto mechanisms implementation by a comparison of full welfare effects measured in real income variations

(Hicksian equivalent variation), contrary to a so-called “business as usual” (BAU) scenario where no policy measures take place.

The first conclusion drawn from the scenario analysis is that the achievement of the Kyoto reduction targets is costly for the developed regions having to commit to quantified emissions reduction targets (as also found by Carraro et al. 2003, Kemfert (2002a and (2003)). We measure economic impacts in welfare changes, and Table 1 summarizes the results by revealing the full welfare effects in terms of Hicksian equivalent in comparison to the BAU scenario. As we can see from the results, developed nations such as Europe, USA and Japan have to accept higher welfare losses than those countries without binding emissions reduction targets. With the inclusion of endogenous technological changes, compliance costs are reduced see table 1). For example, if the USA spends R&D investments to improve technological progress, compliance costs are reduced by almost 0.10 percent of total welfare.

If we consider induced technological changes, negative economic welfare impacts in all regions are less substantial (see Table 1). This is because energy efficiency is improved through increased R&D expenditures. Although R&D expenditures are not completely applied for the improvement of energy efficiency and “crowded out” investment, we find that increased R&D expenditures improve energy efficiency, which lowers abatement costs. Without the inclusion of induced technological changes, emission targets are primarily reached by production declines resulting in overall welfare reductions. With the inclusion of induced technological changes, emission mitigation can be reached with fewer production drawbacks. This can be explained primarily by the high abatement costs of responsible nations: Because of future high abatement costs, and climate policy interventions and negative impacts through climate change, countries decide to invest a substantial amount in R&D measures. This means that protection costs of climate change exceed crowding out costs of R&D investments. This triggers energy efficiency improvements at a lower cost with the inclusion of induced technological change than without. This finding is in contrast to the model results by Buannano et al. (2003) and Goulder and Schneider (1999), as they view R&D investment as crowded out investment that induces weak impacts on gross costs of abatement. The main difference of this study to the previously mentioned studies is that we consider impacts of climate change and increased protection costs of climate change. Countries spend less investment in protection costs that are pure costs without any positive economic growth impact. Investments in R&D are investments that trigger energy efficiencies and can lead to production increases, especially in these sectors negatively affected by climate change.

The share of R&D expenditures from total expenditures is endogenously determined as previously described. However, this also means that investment in R&D expenditures competes with other expenditures (crowding out). Spillover effects of technological innovations are reflected through trade effects and capital flows. This means that non-R&D-cooperating countries having technological innovations can benefit from spillover effects through trade of technological innovations and capital flows that can be used for R&D investments. Model calculations show that capital flows increase to non-cooperating countries because of improved competitiveness effects and trade effect terms. This also triggers spillover effects of technological innovations and energy efficiency improvements through increased R&D investments. Although an increased share of R&D investment crowds out other investment, we detect only very small capital stock declines in those regions investing in R&D. Other regions benefiting form technology spillover effects (developing countries) increase not only investment but also capital stock.

The decomposition of welfare effects exhibits that the pure domestic emissions abatement effect is determined by the reduction target that Annex I nations must accomplish. Because of high emissions abatement costs, Japan, Europe and the USA suffer welfare losses from domestic action. The only regions, which could benefit are the countries in transition (see Table 2). Domestically, the effort needing to be taken by Annex I regions remains the same independent of whether further flexible abatement measures are implemented or not. If no induced technological change would be allowed, the negative domestic welfare effects would be higher. This is because induced technological change offers less costly abatement options.

Because energy efficiency is improved by increased R&D expenditures, emissions reduction targets can be reached with fewer production burdens. Furthermore, investment in R&D technological innovation gives a comparative advantage. Technological spillover effects also lead to improved terms of trade effects.

The competitiveness effect demonstrates the composed welfare effects resulting from terms of trade changes; the spillover effect is determined by knowledge capital transfer. Induced technological changes improve welfare effects, as the decomposition of the full effects into competitiveness effects and spillover effects demonstrate. The Clean Development Mechanism stipulates positive competitiveness effects in the host countries of China, Sub-Saharan Africa and Asia. The CDM increases overall and R&D investment activities in the host countries, so there is not only an energy efficiency growth, but also increased overall economic activities, which induce an improvement in the trade balance. On the other hand, supporting countries needing to reach their intended emissions reduction targets experience export losses because of an increased economic effort and competitiveness deficit. If we are considering CDM projects (with induced technological change) with sink opportunities, neither economic advantages nor disadvantages for host and funding countries achieve the same extent reached if sinks would not be included. This is because sink projects are not modeled as additional investment projects, but as existing sinks in the host country that could be accounted for by the emissions baseline level. Because of this, investment activities are lower as in the pure CDM case, so favorable effects on the overall economy and energy efficiency are diminished. In comparison to the case where emissions reductions must be reached but no emissions trading is allowed, beneficial welfare effects in terms of pure competitiveness effects occur to all world regions without exemption if permit trading is endorsed. The main beneficiaries are the regions in transition that also profit by the implementation of Joint Implementation projects.

Positive spill over effects mainly occur in host countries of CDM projects because of the beneficiary situation in the participating regions. These induce competitiveness advantages and profitable technology and knowledge externality spillover effects. Knowledge capital transfer leads to increased production and welfare changes. Production increases with fewer energy-intensive technologies. The positive spill over effects due to increased knowledge capital trigger self-enforced investment processes stipulating positive terms of trade and welfare changes. Because of the assumed knowledge of spillover effects as a percentage of capital flows, the decomposed spillover welfare changes extend a larger share as pure competitiveness effects in the host countries (see Table 2).

CDM project transfer to developing nations like China, Asia, Latin South America and Sub Saharan Africa stimulate self-enforcing investment processes that additionally augment the energy efficiency by an application of new, carbon-free technologies. This is because R&D investment transfers additional to pure economic project transfers induce technological changes, which on the other hand open emissions abatement options at a lower compliance cost. Energy intensities in developing countries are reduced (see Figure 4). Both aspects improve the economic situation drastically so that developing regions can benefit considerably, expressed in welfare increases.

If sink options are included in CDM projects, negative economic implications in developed regions do not reach the extent described earlier, and also cannot stipulate self-enforcing investment activities triggering economic growth in developing regions. Economies in Transition (represented in this context by the REC region) can primarily benefit by the Joint Implementation program, which exhibits large welfare gains in comparison to the BAU case.

This effect is stronger if additionally induced technological changes are considered. This comes primarily from an increase in competitiveness due to improved production options. But it can also be explained by the fact that incentives to invest in R&D expenditures are market driven. To improve competitiveness effects, countries invest in R&D expenditures that advance technological innovations and energy efficiencies. The share of R&D expenditures changes according to production variations. Trade effects consider technological spill over effects and capital flows. Technological innovation products are traded internationally. Host countries can substantially benefit from spillover effects of technological innovations.

Both scenarios demonstrate that host countries benefiting from self-enforcing investment activities can reach welfare gains. This improves the economic development, additional to the effect of increasing energy efficiencies, both of which enhance the distinct production processes. Moreover, this effect augments the competitiveness of project host countries so that all world nations could benefit from advanced terms of trade conditions. The share of new and less carbon-intensive technologies is increased, as Figure 3 illustrates. For example, in China the share of hydro power plants can be increased, which intensifies the energy efficiency, leading to a slower emissions increase or even an emissions reduction. The share of carbon-free technologies increases if ITC is further considered (see Figure 2).

The positive economic effects of self-enforcing investment growths by CDM projects succeed in an increasing share of carbon-free technologies. The positive spill over effects supports the rise of carbon-free technologies in developing countries. Positive production effects in fast growing regions like Asia and China occur mainly in industrial sectors that can benefit from new technologies. CDM projects focusing on forestration induce positive economic effects of agricultural sectors in regions like Sub-Saharan Africa and Latin South America, as Figure 2 demonstrates.

5 Conclusion

This paper shows an integration of induced technological change in a multi-regional, multi-sectoral trade integrated assessment model. We investigated the economic consequences of international climate policy strategies with an inclusion of induced technological change. We found that negative economic welfare impacts of reaching quantified emissions reduction targets are less substantial if we include induced technological change options. Without the incorporation of induced technological changes, emissions targets are primarily reached by production declines resulting in overall welfare reductions. With the integration of induced technological changes, emission mitigation can be reached with fewer production drawbacks.

This is because increased R&D expenditures improve energy efficiency that substantially lowers abatement costs.

Flexible instruments allow investment project transfers that increase energy efficiencies to reach admissions reductions. Model simulations demonstrate that investment projects improving energy efficiencies can lead to economic welfare increases in the host countries. A decomposition of welfare effects shows that a positive knowledge spill over effect plays a major role. The positive economic effects of self-enforcing investment growths by investment projects succeed in an increasing share of carbon-free technologies. Positive spills over effects support the rise of carbon-free technologies in developing countries. This leads to enhanced competitiveness effects and trade options. These results are interesting for both policy maker and scientists: in contrast to some other scientific studies, we find that endogenous technological change leads to a reduction of abatement costs. Policy maker may be interested in this results as a decision to spend more R&D investment to improve technologies that are relevant for climate change may be alternative to other adaptation strategies.

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7 Annex I: Tables and Figures

Tables

	CDM	CDM with sinks	JI	CDM-ITC	CDM-ITC with sinks	JI-ITC	Reduction of compliance costs
JPN	-0.4	-0.2	-0.6	-0.35	-0.15	-0.58	0.05
CHN	0.8	0.6	-0.4	0.9	0.7	-0.36	0.10
USA	-0.9	-1	-1.1	-0.81	-0.91	-1.06	0.09
SSA	0.3	0.1	-0.3	0.32	0.12	-0.27	0.02
ROW	-0.5	-0.1	-0.5	-0.44	-0.04	-0.46	0.06
can	-0.5	-0.2	-0.5	-0.42	-0.12	-0.45	0.08
EU15	-1.3	-1.2	-1.6	-1.21	-1.11	-1.52	0.09
REC	0.3	0.6	1.5	0.39	0.69	1.65	0.09
LSA	0.5	0.3	-0.1	0.55	0.35	-0.08	0.05
ASIA	1.2	0.8	-0.9	1.34	0.94	-0.8	0.14
MIDE	-0.8	-0.1	-0.8	-0.71	-0.01	-0.75	0.09

Table 1: HEV Changes in Comparison to BAU

	Domestic			Competitiveness			Spill Over		
	CDM-ITC	CDM_ITC with sinks	JI-ITC	CDM-ITC	CDM_ITC with sinks	JI-ITC	CDM-ITC	CDM_ITC with sinks	JI-ITC
JPN	-0.024	-0.002	-0.002	-0.2879	-0.1340	-0.4019	-0.0320	-0.1140	-0.3861
CHN	0.000	0.000	0.000	0.1294	0.0890	-0.0593	0.2890	0.2490	-0.1660
USA	-0.087	-0.009	-0.009	-0.4315	-0.3057	-0.3362	-0.2538	-1.0460	-1.1564
SSA	0.000	0.000	0.000	0.0255	0.0085	-0.0255	0.1163	0.0388	-0.1163
ROW	0.000	0.000	0.000	-0.1206	-0.0243	-0.1213	-0.1941	-0.0386	-0.1931
CNA	0.000	0.000	0.000	-0.2607	-0.1114	-0.2786	-0.2221	-0.1334	-0.3592
EU15	-0.040	-0.004	-0.004	-0.5395	-0.4980	-0.6640	-0.5615	-0.9924	-1.3424
REC	0.006	0.006	0.006	0.0527	0.2123	0.5307	0.1763	0.2105	0.5537
LSA	0.000	0.000	0.000	0.0383	0.0230	-0.0077	0.2444	0.1467	-0.0489
ASIA	0.000	0.000	0.000	0.1014	0.0447	-0.0503	0.5457	0.5697	-0.6409
MIDE	0.000	0.000	0.000	-0.1961	-0.0194	-0.1548	-0.0413	-0.0258	-0.2064

Table 2: Decomposed Welfare Effects in Percentage Change to BAU

8 Figures

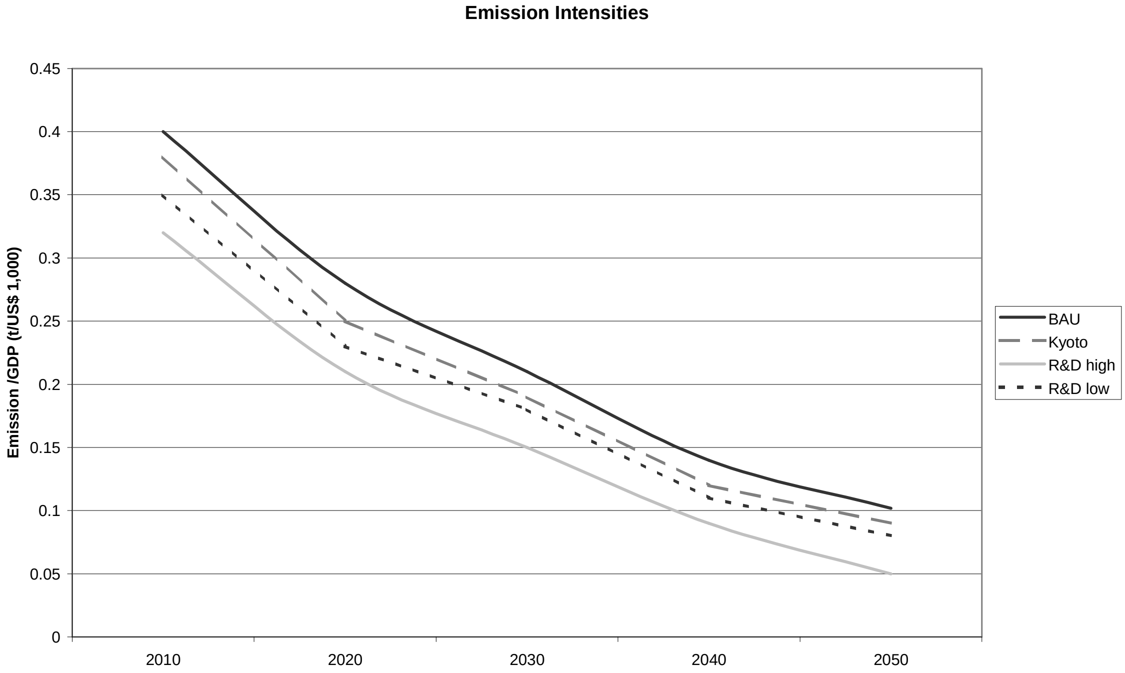

Figure 1: Total Emissions Intensities in Different Scenarios

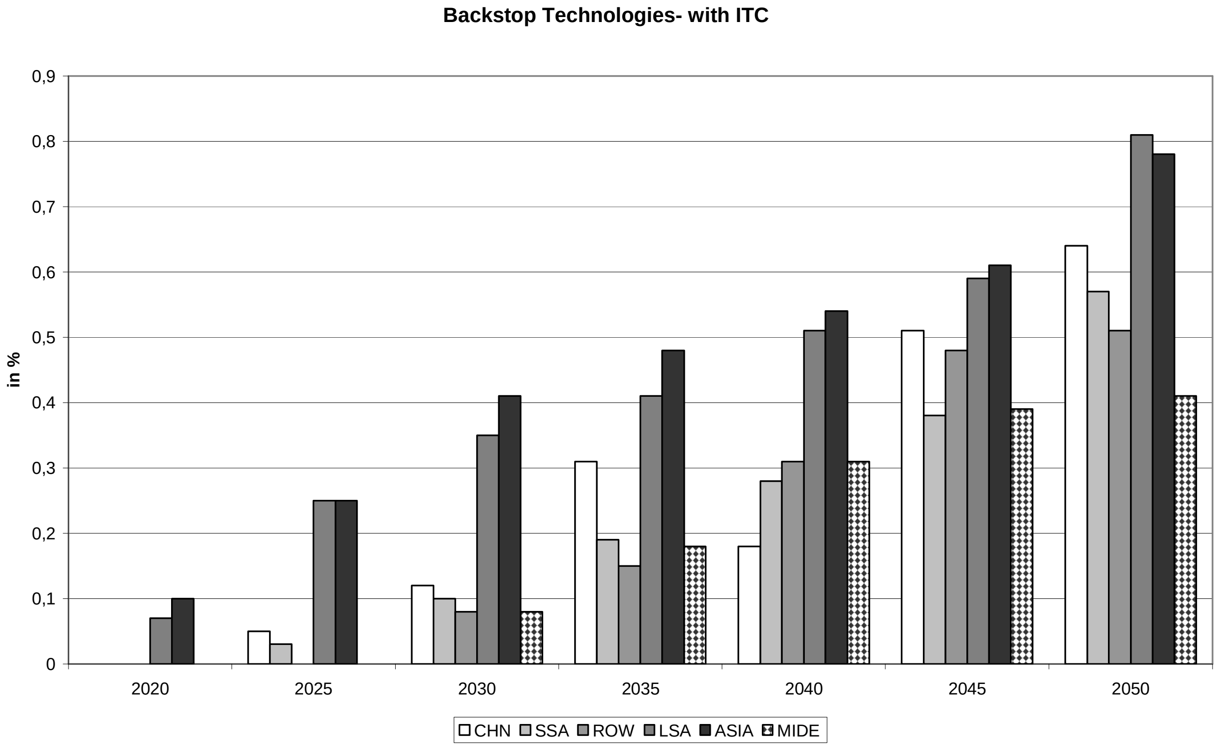

Figure 2: Backstop Technologies in CDM Scenario- with ITC

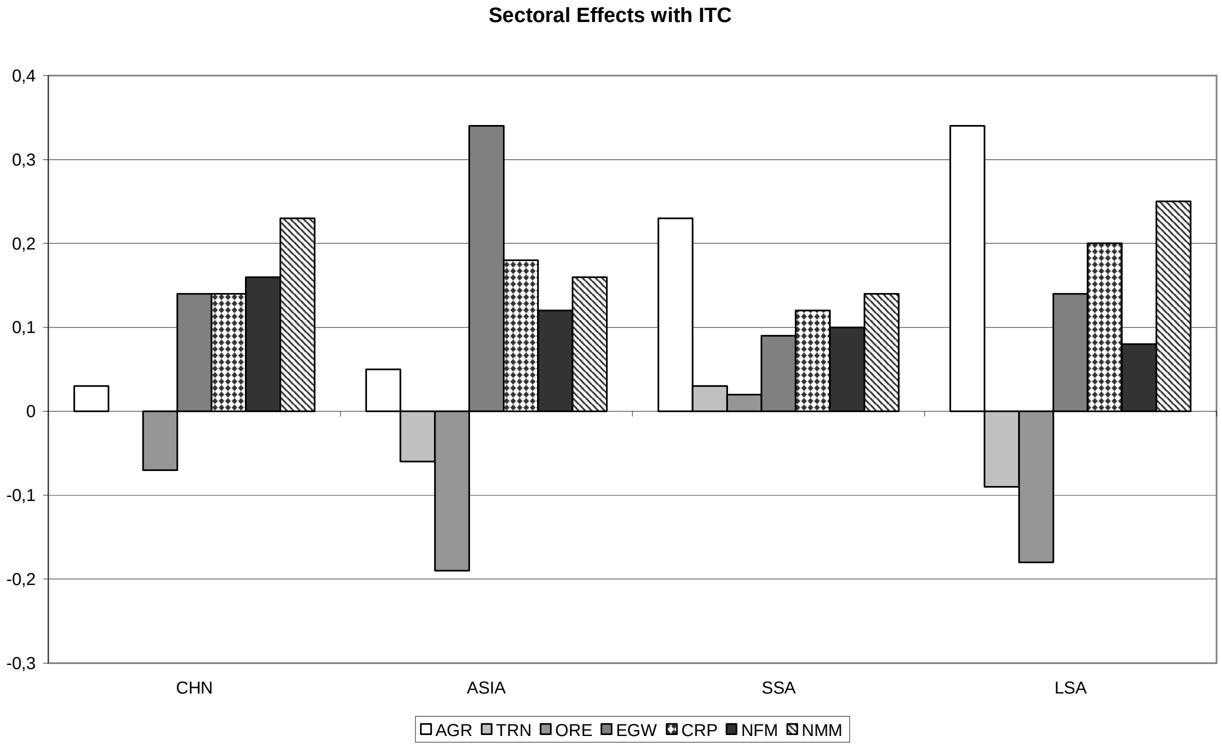

Figure 3: Sectoral Welfare Effects with ITC Percentage Change to Baseline

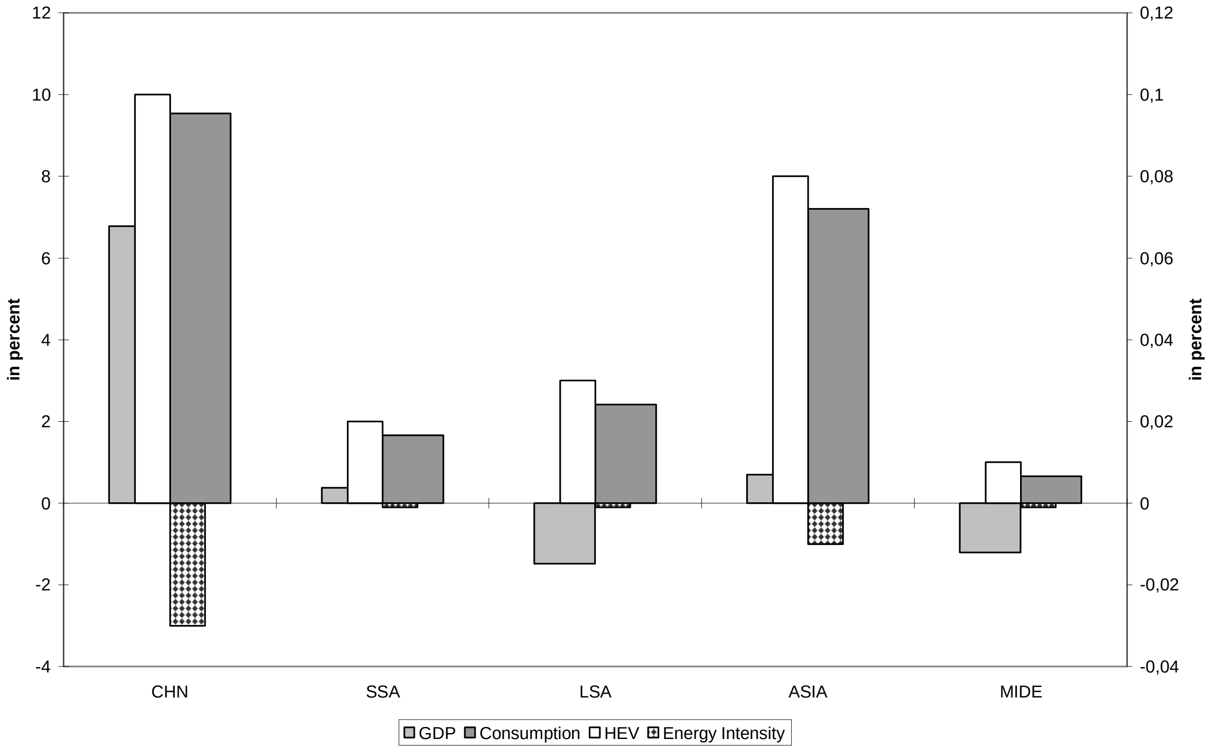

Figure 4: GDP, Consumption, HEV and Energy Intensity Changes in the CDM-ITC Scenario

9 Annex II. Mathematical Description

We apply a similar modeling approach as Goulder and Schneider (1999), Buonanno et al (2003) and Popp (2004).[7] We assume that the energy output ratio, the energy productivity, is influenced by a knowledge improvements that are determined by the accumulation of R&D investments. Only those countries invest in R&D and knowledge stock that cooperate on climate control. The representative producer of sector j ascertains the CES *profit function.* In this description, we stick to the dual approach in order to be consistent with previous publications of WIAGEM and because of better comparison to other CGE modeling approaches.[8]

$$\Pi_i^Y(p) = A\left[a_j^{dx}(p_j^{1-\sigma_{dx}} + (1-a_j^{dx})p^{fx1-\sigma_{dx}}\right]^{\frac{1}{1-\sigma_{dx}}}$$

$$-\left[a^m p_j^{m1-\sigma_{klem}} + (1-a^m)\left[EP_j^e p_j^{e1-\sigma_{kle}} + (1-EP_j^e)\left[a_j^k(p_j^{rk})^{1-\sigma_{kl}} + (1-a_j^k)(p_j^l)^{1-\sigma_{kl}}\right]^{\frac{1-\sigma_{kle}}{1-\sigma_{kl}}}\right]^{\frac{1-\sigma_{klem}}{1-\sigma_{kle}}}\right]^{\frac{1}{1-\sigma_{klem}}}$$

with:

Π_j^Y: Profit function of sector j[9]

Y_j: Activity level of production sector j

A: Productivity factor

a_j^{dx}: Domestic production share of total production by sector i

a_j^k: Value share of capital within capital-energy composite

a_j^l: Value share of labour within capital-energy-labor aggregate

a_j^m: Value share of material within capital-energy-labor material aggregate

p_j: Price of domestic good j

p^{fx}: Price of foreign exchange (exchange rate)

p^{rk}: Price of capital

p_j^e: Price of energy

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[6] A full description of the model including all equations and interlinkages is provided in Kemfert (2002b).

[7] In contrast to Goulder and Schneider we do not assume a special R&D sector that translates human capital investments into productivity changes. We assume that investments in R&D directly changes energy productivity. We assume that only those countries invest in R&D that implement climate control initiatives.

[8] A full description of the model including all equations and interlinkages is provided in Kemfert (2002b).

[9] The notation Π with the subscript Y is used to consider the activity subset, which is represented by production Y. Because of the zero profit condition, this equation needs to be equal to zero.

p_j^m : Price of material/land

p^l: Price of labor

σ_{dx}: Elasticity of transformation between production for the domestic and production for the export market

σ_{ke}: Substitution elasticity between capital and energy

σ_{kle}: Substitution elasticity between labor, capital, and energy composite

σ_{klem}: Substitution elasticity between material and labor, capital, and energy composite

CET: Constant elasticity of transformation τ

CES: Constant elasticity of substitution σ

$EP_{j,t}^E$: Increase of Energy Productivity[10]

$EP_{j,t}{}^E = \delta_{j,t}^E \cdot KR\&D_{j,t}{}^\theta$ represents the energy productivity which is increasing. R&D expenditures (*KR&D*) improve innovations in more energy efficient technologies. δ parameterizes the efficiency of research and development. This share is endogenously determined by investment changes of R&D-cooperating countries: $\delta_{coopj,t}^E = \phi Y_{coopj,t}^E$ with ϕ as the share of cooperating countries. Cooperating nations are those nations that cooperate on climate control activities. We assume that with increasing R&D investment energy productivity would increase as well.

The stock of R&D investments increase over time by $KR\&D_{j,t+1} = R\&D_{j,t} + (1+\lambda)KR\&D_{j,t}$ which determines the accumulation of knowlege stock due to R&D expenditures with a depreciation rate of λ. We assume that cooperating nations have an additional incentive to cooperate on climate control if they also cooperate on technological innovations. However, countries that do not cooperate on climate control activities can also benefit from knowledge spill over effects. Knowledge spillover effects from cooperating to non-cooperating countries of climate control activities are considered by capital flows: $\delta_{coopj,t}^E = \phi Y_{coopj,t}^E \cdot CAPFLOW_{non-coop,t}^E$.

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[10] As we incorporate the variations of energy productivity in a CGE modelling framework, energy productivity changes must be profit-neutral.