Decomposing Direct and Spillover Costs of Global Climate Change on Regional Economies

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PRELIMINARY. COMMENTS ARE WELCOME

Abstract

We present a dynamic multi-region, multi-good dynamic CGE model, which reacts sensitive to changes in regional climate.

In the assessment of economic effects of global warming we distinguish between direct effects (impacts in the considered region) and spillover effects (impacts from foreign regions which spillover into the domestic region). This paper shows how these spillover effects work and quantifies the contributions of such spillover effects to the total costs of climate change for a region. Climate scenarios are exogenous given by output of a General Circulation Model. The decision makers will minimize the costs of a given scenario and adapt trade relationships.

We observe for the end of century very heterogeneous costs for different regions between 23 and 50 % of regional GDP, compared with a scenario without climate change. The application of the Harrison, Horridge, and Pearson (2000) decomposition procedure shows a significant contribution of spillover effects for the total costs of climate change of a region. This result underline the fact that climate change is a real global problem and that international trade makes it even more global.

Keywords: Climate Change, Multi-regional Dynamic CGE Model, International Trade, Decomposition of General Equilibrium Effects.

JEL-Classification: C68, D58, F47, O41

1 Introduction

There is no doubt, the global climate is changing. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC)(Solomon, Qin, Manning, Chen, Marquis, Averyt, M.Tignor, and Miller 2007) provides striking evidence that during the last century the world's average surface temperature has increased by 0.6 ℃, and concludes that a further increase by additional 1.4 to 5.8 ℃ must be expected by 2100. These changes already have visible environmental impacts. Examples are the increased frequency and intensity of droughts in large parts of Asia and Africa or the global sea level rise. In average the sea level has risen by 10 to 20 cm over the last 100 years, and is projected to rise by additional 10 to 90 cm till the end of this century.

Today, the impact, global climate change might have on life on earth, is still less well known than the basic science of climate change. Nevertheless, present knowledge suggests that global warming will have and already has multiple socio-economic effects, which in future might range from merely inconvenient to disastrous. For example, Stern (2006) just recently has estimated that the world economy might suffer losses of 5-7% GDP annually, if global average temperature rises by 5-6 ℃ till the end of 2100. Mendelsohn, Morrison, Schlesinger, and Andronova (2000) have reported lower damages, which nonetheless range from 1 % to 5 % of the world's GDP in case that the average world temperature rises by 2 ℃ by middle of the present century.

Integrated assessment analysis of climate change usually discerns between two kinds of impacts. There are market damages on one hand side, and there are non-market damages on the other. Market damages are costs, which can, in principle, be expressed in terms of GDP losses. In contrast, non-market damages cannot directly be expressed in monetary units. For example, in case of agriculture market prices exist by which the value of output losses can be measured. But there are no market prices for valuing damages such as species losses.

Since regions differ with respect to their exposure to the risks of climate change as well their abilities to adapt, which depends on the societies' institutions, the level of education and economic wealth (see Brooks, Neil Adger, and Mick Kelly (2005)), market and non-market damages can significantly vary across region. For example, Nordhaus and Boyer (2000) have shown that India's economic losses due to a 2.5 ℃ warming till 2050 will be eleven times higher than the costs, the USA is expected to bear. In general, the societies which will be most heavily exposed the various impacts of global warming are the ones which are the least able to cover the resulting costs and losses.

Now, since regions differ in both how they are affected by climate change and how they are able to cope with the resulting economic effects, the societies' welfare, the costs of production as well as relative prices of factors will differ from region to region. This must have an impact on international trade. Consequently, global climate change imposes not only damages, which are directly attributed to a single region. In a world with highly integrated markets costs of global climate change, which originate in some region, might spill over to other regions via these channels. For an illustration let us consider two examples.

One of the most prominent examples of how damages, which occure in one region, spillover, was observed in the case of the hurricane Katrina. Katrina directly caused total damages of 81 billion U.S. Dollars (in prices of 2005) of property damage in regions Mississippi, Louisiana and Alabama (Blake, Rappaport, and Landsea 2007). The massive disruption of energy supply from the Gulf of Mexico's facilities has lead to a shortage in gasoline supply. However, since the price of fossil fuel globally increases quite rapidely. In the week after the storm, U.S. gasoline prices have jumped up by as much as 60 cents per gallon (New York Times, 04.09.2005). In United Kingdom gasoline prices increased by 3-4 pence per liter in the aftermath of the hurricane (BBC News, 02.09.2005). I.e.

british consumers and firms, far away from the Gulf of Mexico, were confronted with higher energy costs, at least in the short run[1].

Another example of spillovers and hence a possible scenario what could happen if further global warming takes place, is observable on the world markets for rice. A severe drought over several years led to a reduction of Australia's rice crop by 98 percent. Australia produces only 0.2 % of the world rice production, but his rice industry is highly export oriented and is responsible for over 4% of world trade in rice. Although the drought in Australia is just one of several factors contributing to a doubling of rice prices between January and April 2008, but the consequences were violent protests in countries including Egypt, Haiti, Indonesia, Thailand and Ivory Coast (New York Times, 17.04.2008). These riots indicate the magnitude such indirect effects of climate change could have.

It is the purpose of this paper to explore both, qualitatively and quantitatively, direct and indirecr costs of global climate change on a regional economy.

Therby direct costs are market and non-market damages, global climate change causes in an economy. Indirect costs are welfare losses which result from changes in places and supply due to direct costs which have occured in a different regions

the magnitude and the quantitatively contribution of those spillover effects on the total costs of climate change for an individual region and break up the origin of this costs.

We define indirect effects as effects of climate change which affect the welfare of consumers in regions other than the regions where the impact occurs. The transmitter are changing relative prices of commodities or factors.

This is of particular importance for small, open and highly developed economies where welfare heavily depends on imports and exports. A typical example for an economy of this kind is Switzerland. Switzerland owns almost no natural resources and depends on imports of fossil energy, raw as well as basic materials. If in some region of the world the production of such commodities is negatively affected through climate change, this will affect imports and costs of production in Switzerland. In some cases it even might happen these effects will dominate the market costs of climatic change in the country itself.

For an accurate estimation of these effects we use a multi-sector, multi-regional, dynamic computable general equilibrium (CGE) model, where the future climate states are exogenous given by data from global circulation models. The exposure of countries to climate change is very different. To capture the region's different vulnerability we identify the key determinates of climate change on the economy and construct an impact function which maps the sensitivity of a region's economic output to a change in climate. Some countries have to bear only small costs or even benefit from climate change

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[1] Note that the correlation between stronger hurricanes and climate change is still highly debated. Although the example shows very well the functionality of such spillover effects

whereas other countries, mainly at lower latitudes, are confronted with serious impacts on their production capacities. To assess how the differentiated impacts influence international trade and in which magnitude they spillover into other regions, we apply a decomposition method for general equilibrium effects. This allows us to calculate the individual contribution of a region's climate impact on the cost of climate change for other regions.

Our results show that costs from climate change are uneven distributed. Regions in mid-latitudes have an higher adaptive capacity and have to cope with a less pronounced warming compared to regions in lower latitudes. The model shows a difference in GDP at the end of the 21st century of about 50% between a scenario with and without climate change for South Asia, whereas the NAFTA countries have only losses of about 23% to bear. The Swiss economy has in 2100 a 34% lower GDP if climate changes happens. The decomposition of this general equilibrium impacts shows that the mentioned spillover effects are responsible for a significant part of an individual country. On the climate bill of a region spillover effects are responsible for about 10 to 40% of the total costs.

The exogenous climate previsions are an important difference to the standard integrated assessment analysis. In these kind of models, economic agents trade off the costs and benefits of emitting or mitigation greenhouse gases. Since we focus on the analysis of spillover effects as described above, we are not interested in the 'optimal' climate policy and regions face given impacts of global climate change. Abatement strategies are not a policy option. The calculated costs are the results of a laisser-faire climate policy. The presented approach is therefore a cost-effectiveness approach, where the economic agents minimize the costs of a given emission scenario.

The regions minimize their exposure to spillover effects through adaptation of the trade relationships, let some regions gain and other loose competitiveness through climate change.

Due to the complexness of climate and economic systems most studies deal only with the costs of a changing world average temperature. Several contributions to the integrated assessment literature examine the effects of global climate change on a regional disaggregated level. The RICE model (Nordhaus and Boyer 2000) differentiates between various regions, but has no sectoral disaggregation. MERGE (Manne, Mendelsohn, and Richels 1995) distinguishes also between different regions, but allows international trade only in an aggregated good. It includes also non-market damages like loss of biodiversity as willingness to pay of regional consumers to avoid such damages. The valuation of ecological damages is independent of whether the damage occurs, inside or outside of regional boundaries. This kind of modelling of non-market damages is in his philosophy an extreme case of a spillover effect where the whole damage spillover due to the public good character of this destroyed values, to all other regions on earth. But note that the valuation of the ecological damages depends on the willingness to pay to avoid and on the GDP per capita. The FUND model (Tol 2006) allows for very detailed analysis of climate impacts and captures the differences in regional temperature changes as well, but its economic module is rather simple, since the decision making is not based on optimization behavior.

However, as far as we know, only on study examines the magnitude of spillover effects for an economy explicitly. Infras (2007) try to calculate the vulnerability of Swiss imports and exports of climate change a study for the Swiss Federal Office for the Environment. But they examine the problem only roughly for Switzerland and do not consider general equilibrium effects in other regions as well as changes in terms of trade. They estimate that, taking into account a probable development of the world economy until 2050, between 1.6 and 3.1% of Swiss exports will be vulnerable to changes in climate abroad. This will result in a annually GDP loss between 0.6 and 1.1% until 2050. Impact on imports and on welfare due to changing prices for basic materials and other commodities are neglected in this study.

A further interesting literature examines the relation between trade and comovement in business cycles. Recent empirical research finds evidence that increased trade between a pair of countries increases the magnitude of transmission of productivity shocks between this two countries (Frankel and Rose 1998),(Baxter and Kouparitsas 2005). Kose and Yi (2006) reproduce this effects in a real business cycle model. This spillover of shocks has the same cause and and the transmission flows in the same channel, although our and those models have large differences in the considered time horizons and the capture of monetary markets[2]

Several studies link international trade and environmental change in their analysis. Scott Taylor and Brian Copeland examine in several papers within an international trade framework different sorts of externalities and different possibilities to abate the externality. See Copeland and Taylor (2004) for a survey of the theory and empirical work about the environmental consequences of growth and international trade. Benarroch and Thile (2001) analyze the effect of transboundary pollution as the emission of greenhouse gases may an example for, on trade and welfare in a two country, two sector model, considering market damages. Unlike here, only one sector is affected by environmental impacts, whereas the other sector is responsible for emission of the impact causing pollution.

Another branch of literature examines the effects of environmental policy on international trade and welfare quantitatively with help of general equilibrium models. Manne and Stephan (1999) study the coherence between climate change policies and international interest rate differentials. Bernstein, Montgomery, and Rutherford (1999) investigate in a multi-sector, multi-region trade model the distribution of impacts of the Kyoto agreement on welfare, international trade and investment. Boehringer and Rutherford (2002) study the spillover effects from carbon abatement policies on trade as well as on welfare and present a decomposition into a primary domestic market effect and

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[2] In bringing together new business cycle theory with the impact of environmental changes on the economy, we are going back to one of the first business cycle theories at all, proposed by William Jevons, which relates business cycles with eruption of sunspots. According to his theory sunspots influence the weather, which, in turn, affected crop yield.

a secondary international spillover impact. In Böhringer and Rutherford (2004) the same decomposition methodology is applied to assess the spillovers from carbon abatement in industrialized countries to developing countries.

As these examples show, the most frequently asked questions are how trade affects the environment or what may be the welfare effects of environmental policies, if we also consider changes in terms of trade. This study changes the perspective and asks how international trade and welfare may be affected by regional different impacts of global climate change.

The work is arranged as follows: Section explains the impact of climate change on trade and on a not affected country in a simple model of economic exchange. Section III discusses regional impacts of climate change and looks for potential spillover channels via trade. Section IV describes the climate scenario whereas Section V and VI describe the computable general equilibrium model and the calibration procedure. Section VII discusses the results and section VIII applies a decomposition methodology and examines the different contributions of the different regions to the total costs of climate change of other regions. Section IX discusses the results of this study under the light of climate policy and concludes.

2 Expectations from Economic Theory

In this section we would like to discuss shortly the role of spillover effects in a simple economic model of exchange. In climate economics impacts from environmental changes on markets are mostly modelled as productivity shocks. We have some hints from standard economic theory what the effect of such a negative productivity shock on a country integrated in international trade may be and how through market forces trading partners could affected by this shock.

Think of a simple exchange economy as displayed in an Edgeworth box in figure (1). We assume two different countries, N and S, are endowed with two goods, x and y. In a Heckscher-Ohlin context we could say that Country S has a comparative advantage in the production of good y and vice versa. We assume that x (y) is more capital (labor) intensive in production. According to their factor endowments, S would produce the amounts γ of y and λ of x. So in autarchy would allocation a be realized. If we now assume that trade between the both takes place, N would sell a fraction of his x production against a fraction of S's output in y. The red line denotes the relative price of the commodities. As we know from economic introduction lectures, trade increases the welfare of both countries and both countries will end up in the allocation b.

Now we assume that a negative asymmetric productivity shock occurs and country S can supply only half of his ex ante production, $\frac{\gamma}{2}$ and $\frac{\lambda}{2}$. Think of this productivity shock as a highly stylized kind of a massive market damage due to a change in climate. Since country S is relatively more engaged in the production of y, y becomes more scarce and relatively more expensive. Terms of trade are worsen from N's perspective. N gets

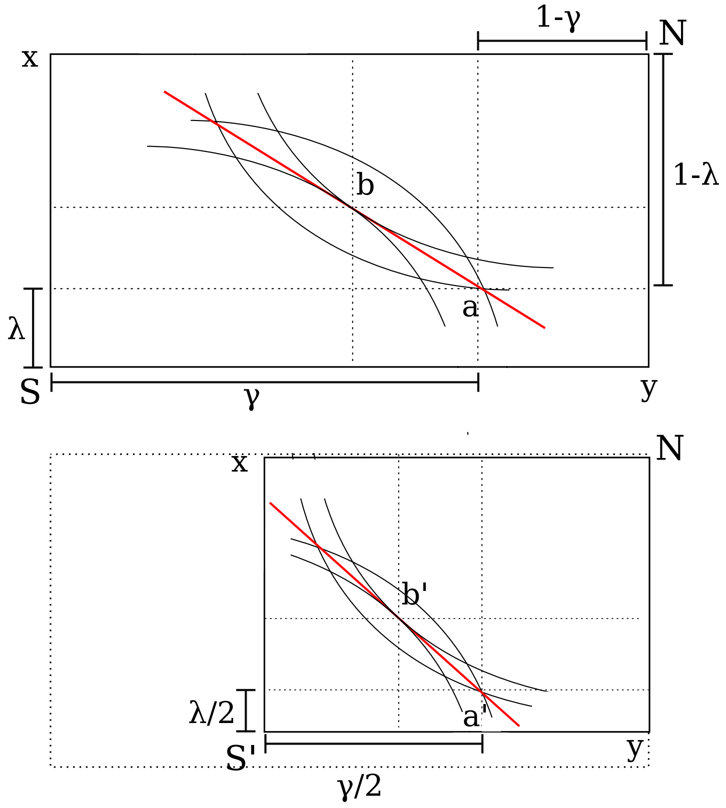

Figure 1: The Edgeworthbox above shows the situation before the shock. In the figure below S has lost half of his output after the shock.

less for his sold x commodities and benefits therefore less from trade. Compared with the situation before the shock, although not directly affected, B looses welfare from the impact in A [3].

The figure shows also the maximum amount of costs from those spillover effects for N. In case of a total extinction of country S, N falls back to the welfare level in autarchy. The maximal negative spillover effects are equal to the total benefits from trade.

In an Heckscher-Ohlin context the competitive advantage of S in the labor intensive sector would decrease and welfare gains from international trade and specialization are decreasing. The capital abundant country N has to produce more of the labor intensive good. According to the Stolper-Samuelson Theorem the wage rate in the not directly affected country will increase and the interest rate of capital will decrease.

The affected country profits from the integration into world trade. The change in terms of trade in favor of the affected country dampens the the welfare losses from the negative shock.

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[3] Note that potentially also positive spillovers from a negative productivity shock in the other country are possible. When we assume the shock would affect only the sector, in which the affected region has a comparative disadvantage, this would enforce the existing terms of trade into the direction of the not affected country. It is possible that the additional purchasing power makes the not affected country better off.

The integration into trade leads to a partial burden sharing between the participating countries. The decreasing marginal utility and factor productivity decreases the overall damage if countries are integrated into trade, sharing costs between more parties.

After this short discussion of the core economic principles behind the spillover effects, we will present a full-blown dynamic CGE model to examine this issue. With the help of a decomposition methodology we will be able to address the contribution of a single region to the total observed climate damages and explore the order of magnitude of this effects. But let us first discuss the vulnerability of varied world regions to climate change.

3 Climate and Impact Analysis

In this section we want to identify the climate sensitive sectors and discuss their vulnerability in order to define a function which captures the sensitivity of a regions' economy to climate change. We focus on impacts which can be expressed in monetary values and affect the price system of factors and goods. We neglect non-market impacts like changes in amenity values or losses in biodiversity, since their relationship with country borders are unclear and the effects are highly uncertain and difficult to assess.

3.1 Vulnerable Sectors

Most studies assess the following sectors as most vulnerable to climate change. See Nordhaus and Boyer (2000) or Mendelsohn, Morrison, Schlesinger, and Andronova (2000), for an empirical overview including non-market impacts see Rosenzweig, Karoly, Vicarelli, Neofotis, Wu, Casassa, Menzel, Root, Estrella, Seguin, et al. (2008).

- Agriculture & Forestry
- Coastal resources
- Energy
- Human health
- Water resources
- Catastrophic Impacts

Agriculture and Forestry

The agricultural sector, the main income generating sector in most developing countries, will be affected mainly at lower latitudes, where even small increases in temperature will decrease productivity of crops. The IPCC Forth Assessment Report (Parry, Canziani, Palutikof, van der Linden, and Hanson 2007) projects for East and Southeast Asian areas a crop yield increase up to 20% while in central and more southern parts of the continent yield could decrease up to 30%. Nordhaus and Boyer (2000) account for

Japan an annual benefit of 0.5% GDP, whereas India losses 1.54 % GDP in agricultural production if CO2 concentration doubles compared to the pre-industrial level. Hitz and Smith (2004) accentuate that in most cases the existing disparities in crop production between developed and devolving countries were estimated to increase.

The protective market for agricultural commodities reduces the potential direct spillover of costs to less affected regions, but since the agricultural sector is the main source of income for most developing countries, it can be expected that this impact will lead to a decreasing demand in this regions for other goods as well.

In timber production an analogue heterogeneous picture can be observed. New results let expect that global timber supply increases. A pole-ward migration of more productive species lead also in this sector to an increasing disparity of economic opportunities (Sohngen, Mendelsohn, and Sedjo 2001),(Parry, Canziani, Palutikof, van der Linden, and Hanson 2007).

Coastal Resources

In the case of coastal resources is the vulnerability obvious. Most studies estimate that adverse impacts increase linearly with the rise of the sea level (Hitz and Smith 2004). But since the melting of pole ice and the exact physical reaction of the sea on higher temperature are complicated processes, estimates of sea level rise are uncertain. Note that in contrast to other impacts areas, sea-level rise depends not on the regional temperature change and the rise will be similar in all regions. Impact depends on topography and adaptive capacity. Whereas developed countries may handle this problem, the challenge for developing countries is much larger. The smaller adaptation capacity of developing countries has consequences for coping with expected sea-level rise. The most vulnerable mega-deltas in Asia and Africa are densely populated today and have only a low adaptive capacity. For Africa, the current IPCC report (Parry, Canziani, Palutikof, van der Linden, and Hanson 2007) estimate costs of adaptation of 5-10% of GDP to safe highly populated, low-lying coastal areas from the impact of sea-level rise. The build-up of adaptation measures binds large amounts of capital in a non-productive sector.

Energy

The energy sector is identified as an especially vulnerable sector in industrial societies. Hydro power plants need water to produce electricity[4] and nuclear power plants have to shut down if the cooling water, mostly taken from rivers, is too warm, as it happened in the summer heat-wave in Europe in 2003. But Climate Change will also affect the demand of energy via a decreasing demand for space heating and increases for cooling. Tol (2002a) estimates benefits due to reduced heating of 0.75% of GDP and costs due to an increasing need for cooling of 0.45% by 2100. Electricity is not traded over large distances, because transmission losses are too large. Additional impede the

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[4] The OCCC report (2007) predicts a decrease in energy production of 5-10% in Switzerland because of a smaller water run-off till 2050.

binding on a physical grid a world wide trade with electricity. We expect therefore no relevant spillover impacts in the electricity market. In the case of primal energy goods, especially crude oil, markets are much more integrated. The industrialized countries are important demander of oil but have no own relevant sources. This makes them vulnerable to changes in the state and stability of oil exporting countries. Important oil exporting countries are already water stressed and more water stress, as we can expect under further climate change, can destabilize the societies and oil export from this regions.

Human Health

Hitz and Smith (2004) conclude that health risks are more likely to increase than decrease as global mean temperature rises. Whereas in the case of malaria the evidence for an increase or decrease of the probability of infection is uncertain, is it possible that diarrheal diseases may increase as climate changes. As Patz and Kovats (2002) pointed out that there is evidence that climate change lead to an increasing magnitude or frequency of the El Niño phenomena, for which is was showed that this weather pattern may increase the risk of diseases transmitted by mosquitoes, such as malaria and dengue fever. This diseases are most prominent in developing countries. In higher latitudes changes in the frequency of heat- and cold-related mortality are expected. Tol (2002b) suggests that reductions in cold-relates mortality will be less significant while increases in heat-related mortality will dominate. Apart from the sorrow such impacts can cause, this is also important from an economic point of view. Human capital will destroyed, influences wage rates and skill premiums and decreases the economic growth prospects in the affected regions.

Water Resources

The melting of the Himalaya glaciers and the decrease of fresh water stocks stored in the glaciers endanger the water supply of one-sixth of the world population. In already dry regions at mid-latitudes and in the dry tropics a decrease in water availability by 10-20% is expected. According to the IPPC AR4 are between 75 and 250 million people in Africa alone exposed to an increase of water stress by 2020 due to climate change. This has not only severe consequences for agricultural production, but causes also problems for health and human well-being.

Catastrophic Impacts and Extreme Events

We do not fully understand the mechanisms of all geophysical processes on earth. It exists a positive, but not exact computable, probability that impacts occur with high consequences for mankind. Potential severe events are a collapse of large ice sheets in the Antarctic and Greenland or changes in ocean currents. As Weitzman (2008) pointed out, rational actors should be willing to pay significant amounts to avoid this uncertain, high consequences impacts. The only study which includes this in the calculation of impacts in the framework of an integrated assessment model is Nordhaus and Boyer (2000). The authors asked experts about the likelihood of occurrence of such events at a certain temperature and calculated then the willingness to pay to avoid catastrophic damages. This insurance premiums are significant for some regions. For example India (because of a potential shift in monsoon pattern) and the European OECD countries (because of a potential change in the termohaline circulation) are willing to pay about 2% of GDP to avoid this risks.

But climate change can also induce the incidence of less dramatic extreme events like European winter storms. This storms may inflict substantial economic damages. A study which couples a climate model with an insurance loss model (Schwierz, Heck, Zenklusen, Bresch, Vidale, Wield, and Schär 2007) shows that the intensity of winter storms and the losses in most parts of Europe increase. Annual expected European-wide losses from winter storms will increase by 44% in 2071-2100 compared to today in the SRES A2 scenario.

3.2 Regional Aspects

As pointed out in the introduction the vulnerability of a region depends, besides the sectoral composition of the economy, on the geographical location of a region.

The today's most important trading partners of Switzerland are relatively invulnerable to impacts related to climate change. On one hand, most studies argue that low-latitude, less developed regions have a higher sensitivity for impacts (Schneider, Semenov, Patwardhan, Burton, Oppenheimer, Pittock, Rahman, and Smith 2007) and on the other hand are the developed, highly integrated trading partners mostly wealthy enough to adapt their economic and social structures to at least part of the expected impacts.

An idea about the regional distribution of the above described impacts can deliver the Climate Change Index (CCI) by Bättig, Wild, and Imboden (2007). The Climate Change Index is the weighted mean of four indicators: (i) the changes in annual temperature, (ii) the changes in annual precipitation, (iii) the changes in extreme temperature events, and (iv) the changes in extreme precipitation events, and maps then the sum of the atmospheric geophysical climate processes on one number. Figure (3.2) depicts the index, calculated on a country basis for the period 2071-2100 compared to the control period 1961-1990 under the assumption of IPCC emission scenario SRES A2. The darker the color, the larger the changes in the indicators representing climate change. The CCI indicates that climate will change most strongly relative to today's natural variability in the low latitudes and the tropics. The high values in the tropics are mainly caused by precipitation changes but also seasonal temperature events.

But the CCI is not an impact measure and neglects effects the adaptive capacity of a region and climate induced impacts as sea level rise.

Tol, Downing, Kuik, and Smith (2004) classifies countries by their exposure to climate change impact and adaptive capacity. The first group are vulnerable countries as

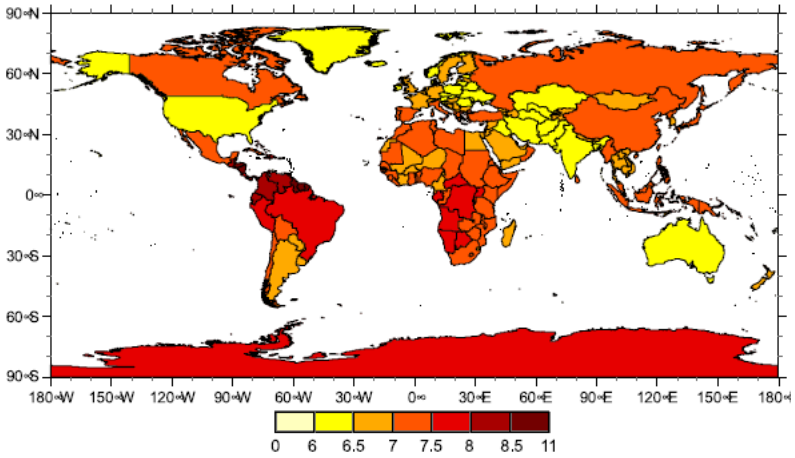

Figure 2: Climate Change Index on a country basis for the period of 2071 - 2100. Source: Bättig et al. (2007)

Bangladesh, which is highly exposed due to sea level rise and cyclones and is one of the least developed countries in the world. The second group has a low adaptive capacity as well, but is not exposed in the same magnitude. To this category belong countries as Namibia or Mongolia. In countries like Australia and the United States the society has the opportunity and capacity to act against possible significant impacts. The last category comprehends countries with high adaptive capacity and low impacts. To this group belong countries in the northern hemisphere such as Norway and Canada.

As these findings indicate there is not only an uneven distribution of environmental changes, but also an uneven distribution of adaptive capacity and vulnerability to this changes. Regions which are confronted with more severe environmental changes have often only a small adaptive capacity, makes impact even worser and and the disparity even larger.

3.3 Aggregation

As far as we know only few studies aggregate the climate change impacts over different sectors with an uniform metric for all world regions. Mendelsohn, Morrison, Schlesinger, and Andronova (2000) proposed the Global Impacts Model (GIM), which considers reactions on climate change in agriculture, forestry, coastal resources, energy, and water availability. The response functions depend on regional temperatures, annual precipitation, sea-level rise for coastal structures and on changes in the carbon dioxide concentration for bio-mass producing sectors agriculture and forestry . GIM includes implicitly the different ability of certain sectors to adapt. Sectors with large immobile capital stocks as forestry and coastal resources cannot adapt quickly. But overall, GIM is very optimistic about adaptation and estimates only small costs from climate change. For a 2 ℃ global warming scenario, the authors calculate benefits for North America between 0.47% and 0.83% of GDP, depending on the estimation methodology. For Africa, the

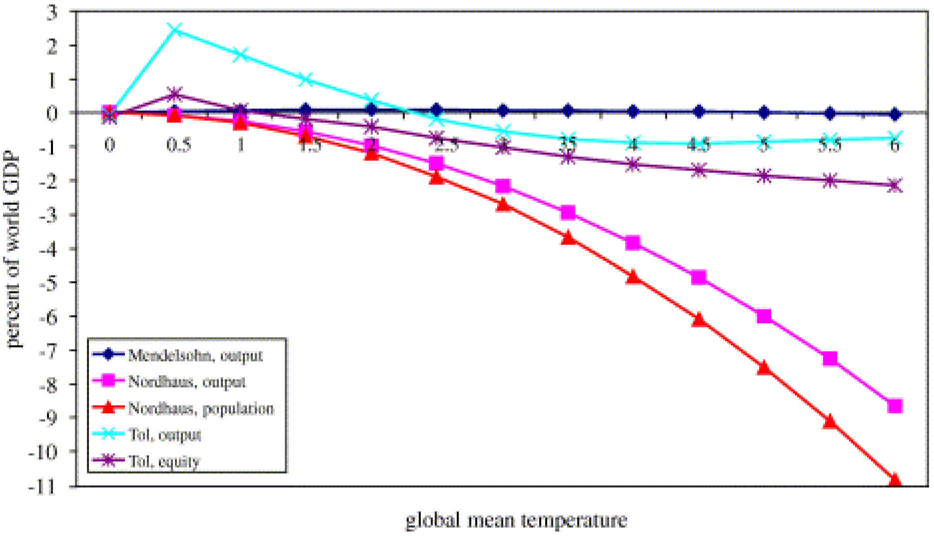

Figure 3: Expected impacts of climate change in percent of world GDP. Source: Smith et al. (2001)

expected impacts will be between costs of 1.82 % of GDP and a small benefit of 0.28 %.

Tol (2002b) includes additionally in his estimates of the damage costs the impacts on ecosystems and on mortality from vector-borne diseases, heat- and cold stress. Global costs are either weighted by output or by the ratio of global average per-capita income to regional per-capita income. He finds that for small increases in global mean temperature net global benefits results. A warming of 0.5 ℃ leads to an 2.5% increase in the Global World Product (output weighted). Beyond 2 ℃ benefits become costs and increase slowly to costs of 1-2% of GWP.

As mentioned already above, Nordhaus and Boyer (2000) present the only model which includes willingness to pay to avoid catastrophic impacts. This is the main difference to the other both discussed studies and the main reason for the significant larger aggregated impacts for temperatures above 2 ℃. If weighted by output, global costs are about 2% of GWP for a 2.5 ℃ warming and 9% for temperature increase of 6 ℃ . Further impacts on the agricultural sector, on coastal resources, on human health, non-market amenity impacts, and results from impacts studies on other vulnerable sectors as forestry, energy- and water systems, construction, fisheries and outdoor recreation are included in this study

Figure (3.3), taken from Smith, Schellhuber, and Mirza (2001), summarize the above discussed findings. The models differ strongly in the amount of the impacts, but all models estimate costs for temperature changes of more than 2.5 ℃ [5]

In this study here we will use the impact model and damage estimates from the work of Nordhaus and Boyer (2000). We have taken the RICE model because it includes a broad set of affected sectors, captures the regional differences in adaptive capacity, is

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[5] For a broader discussion of impact estimates in the integrated assessment literature, see Stern (2007). Previous models are discussed in Tol and Fankhauser (1998).

transparent in the aggregation of damages and it was relative easy possible to adapt the regionalized structure of the RICE model to our needs. To calibrate the damage function we use the same data and estimates as Nordhaus and Boyer (2000).

3.4 Calibrating the Damagefunction

As in the RICE model we include the vulnerability of several sectors to define the regional specified damage function[6].

We consider damages in the agricultural sector, in other vulnerable markets as [...], on settlements, and on human health. All this impacts are depending on the regional temperature change. In contrast depend the willingness to pay to avoid catastrophic impacts and expected rise of sea level, which may affect coastal resources, in our simplified view on the global average temperature change.

The impact of global warming on regional GDP is calibrated for three points: a 0, a 2.5, and a 6 ℃ warming above pre-industrial level. For the calibration were the same data used as in the RICE model.

A 2.5 ℃ warming, which corresponds circa with a doubling of pre industrial CO2 concentration in the atmosphere, would induce in the agricultural sector benefits of 0.87 % of regional GDP in GUS and to annual costs of about 0.5 percent of GDP in Easter Europe. For a six degree warming, annual costs in agricultural production are estimated on about 0.75 % in South Asia and Sub-Sahara Africa. Whereas costs for human health are negligible for a 2.5 ℃ warming, has a 6 ℃ warming severe impacts. In India and in Africa costs of about 1.6, respective 1.8 % of regional GDP are expected. But a 6 ℃ has also severe impacts on coastal infrastructure. The studies considered in Nordhaus and Boyer estimated costs of 3.3 % of GDP for India to safe their coastline, whereas Europe has to invest nearly 2.2 % in unproductive adaptation measures.

The willingness to pay to avoid catastrophic impacts is the main driver for the expected high damages for higher temperatures in European regions and in South Asia. The catastrophic events which cause that high costs, are in the case of Europe the shutdown of thermohaline circulation and in South Asia. To avoid this risk for a six degree warming, the two regions would be pay insurance premium of 13 and 15 % of regional GDP, respective.

The sectoral impacts are summed up to get overall impact for each region. Then a system of two quadratic functions for each regions is solved to obtain the damage coefficients for the damage function (1) so that the equations fit to the estimated damages for a 0, 2.5 and a 6℃ warming.

$$D_{t,r} = \theta_r^1 \Delta T_{t,r} + \theta_r^2 \Delta T_{t,r}^2 + \theta_r^3 \Delta AT_t + \theta_r^4 \Delta AT_t^2 \tag{1}$$

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[6] Nordhaus and Boyer have considered in their study the change in non-market time use as climate changes in a monetary metric. Since the right consideration of such non -market damages in unclear in the analysis of spillover effects, as mentioned above, we will neglect in opposite to the RICE model such damages

Region	θ_r^1	θ_r^2	θ_r^3	θ_r^4
Switzerland	0.347	-0.003	-0.238	0.401
China	-0.234	0.055	-0.044	0.112
East Asia	-0.424	0.125	0.083	0.128
South East Asia	0.839	-0.052	-0.083	0.169
South Asia	1.454	-0.151	-0.059	0.531
NAFTA	-0.024	0.038	-0.025	0.098
South America	0.189	0.047	-0.102	0.217
Oceania	-1.038	0.203	-0.077	0.207
Sub-Sahara Africa	1.763	-0.185	-0.047	0.084
MENA	0.433	0.017	-0.044	0.101
GUS	-0.707	0.095	0.095	0.264
Eastern Europe	0.331	-0.021	-0.060	0.101
Northern Europe	0.347	-0.003	-0.092	0.438
South & Southeastern Europe	0.339	-0.012	-0.076	0.270
Western Europe	0.347	-0.003	-0.092	0.438

Table 1: Estimated coefficients of the damage function. The here listed regions are identical with regions in the CGE model. For an explanation and justification of the regional specification, see section 5.

The values of θ_r^1, θ_r^2, are calculated for the regions used in the here presented model and correspond to damages relating to changes in regional temperature ,$\Delta T_{t,r}$, and capture impacts in the agricultural sector, on settlements, and on health. Sea level rise impacts and catastrophic impacts depend on the change in the global average anomalies (very simplified) ΔAT_t and is captured by the coefficients θ_r^3, θ_r^4 See table (1) for the coefficients.

Note that Switzerland as sole region has no coast line and therefore no damages related to sea level rise. The European regions have all the same damage coefficients, because Nordhaus does in his data not distinguish between different European regions and a presents the damage estimation only for the aggregate "OECD Europe". In cases where our model regions do not correspond to a RICE region, average damage coefficients of the involved regions where chosen.

The damage function will be inserted into the final good production function as follows:

$$\Omega_{r,t} = 1/(1 + D_{t,r}) \tag{2}$$

The output of economic production is multiplied with $\Omega_{r,t}$, so that climate impacts lead to a change in output and induces costs or benefits for the affected societies. Figure (3.4) shows the expected impacts for the model regions as a function of the increase in temperature above pre-industrial.

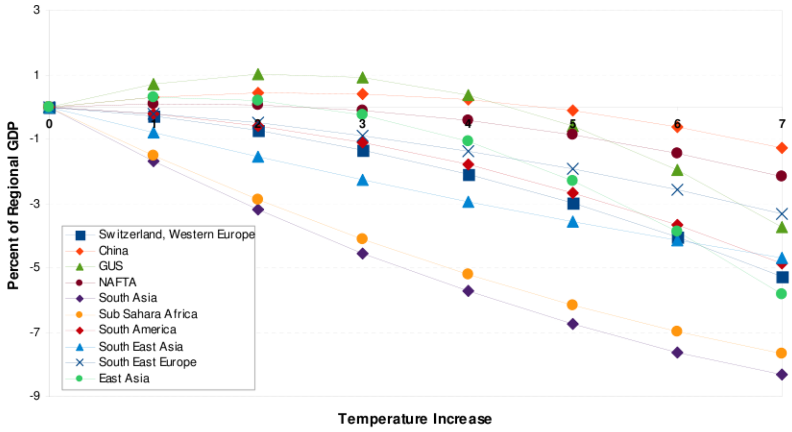

Figure 4: Regional damage as a functions of temperature increase

4 Climate Data

To estimate the future climate on earth we use data from general circulation models (GCM). We take output from the ECHAM5 model (Roeckner, Bauml, Bonaventura, et al. 2005), developed at the Max Planck Institute for Meteorology in Hamburg and the Meteorological Institute of Hamburg University. The ECHAM5 model has an horizontal resolution of about 200 km, which is high enough to calculate the average temperature of a region as a proxy for other changes in the atmosphere such as changes in precipitation et cetera. The ECHAM5 model has delivered significant findings for recent IPCC AR4 (Solomon, Qin, Manning, Chen, Marquis, Averyt, M.Tignor, and Miller 2007, ch.10).

The main driver of the atmospheric warming is the onward emission of greenhouse gases. Although based strongly on economic processes, emission paths are exogenous for the climate models. Since we are not interested in the examination of mitigation measures and optimal policies, just on the reaction on the impacts, this approach should not be problematic. The assumption about future greenhouse gas emissions are based on the calculations of the IPCC SRES Scenario A1B (Nakicenovic and Swart 2000). This scenario is the major one in IPCC AR4. The assumptions behind A1B describe a future world of rapid economic growth, low population growth, and a fast introduction of new and more efficient energy technologies. Among regions, an economic convergence occurs with a substantial reduction in regional differences in per capita income. Cultural and social interactions between regions will increase. The A1 scenario family distinguish between three sub scenarios on their technological emphasis. Whereas A1F assumes a stronger use of fossil energy, assumes A1T more emphasis for non-fossil energy sources. The mostly by the community used A1B scenario assumes a balance across all sources, with similar progress apply to all energy supply and end-use technologies. In the SRES A1B Scenario the CO2 concentration in the atmosphere is reaching a plateau on 720 ppm in 2100 and is stabilizing then.

The ECHAM5 model provides amongst others average monthly surface temperature data for every grid point in the three periods 2011-2030, 2046-2065, and 2080-2099. The

Region	ΔT
Switzerland	4.27
China	4.89
East Asia	3.90
South East Asia	3.55
South Asia	5.03
NAFTA	5.28
South America	4.12
Oceania	4.00
Sub-Sahara Africa	4.71
MENA	4.56
GUS	6.30
Eastern Europe	4.15
Northern Europe	4.44
South & Southeastern Europe	4.20
Western Europe	4.00
World Average	3.80

Table 2: Average regional annual temperature anomaly in 2091 in degree Celsius. The calculations base on the ECHAM5 A1B experiment.

temperature anomaly is calculated relative to the mean of the period 1961-1990 [7]. To be consistent with our chosen model regions, we construct the annual mean temperature anomaly for every region and assume that between the by the GCM declared periods temperature will increase linearly. See table (2) for the regional mean temperatures in 2091.

We observe the strongest temperature increase in high latitudes around the polar regions. The large temperature increase in GUS and in the NAFTA region can be explained mainly through the exceeding warming in their northern parts. Since neither in GUS nor in NAFTA are northern parts densely populated and of economic importance, we may overestimate damages in this two regions. Apart from this two regions, South Asia is confronted with the highest warming of about 5 ℃ in 2091. In Europe it will be 4 ℃ warmer than nowadays. In already hot areas such as Sub-Sahara Africa, temperatures will disproportionate increase 4.7 ℃Ȯn average the world temperature will be 3.8 ℃ higher than in the control period.

5 Model Description

The question how the different exposed regions respond to climate change is evaluated in a dynamic computable general equilibrium model. The model is programmed in

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[7] Output from ECHAM5 experiments can be downloaded from http://www.ipcc-data.org

Agg. Good	Involved Products
Agriculture (A)	Crops, Wheat, Forestry, Diary Products ...
High Value Goods (H)	Machinery, Motor vehicles, ...
Basic Material (B)	Textiles, Metals, ...
Services (S)	Financial Services, Tourism, ...
Fossil Energy (F)	Coal, Oil, Gas
Non-Fossil Energy (NF)	Renewable electricity

Table 3: Commodities in the model and the assigned goods

GAMS/MPSGE.

Since the ongoing process of climate change is known to the economic agents with perfect foresight, they will minimize the costs from these impact and adapt their trade relationships and production decisions. This dealing with pre-determined costs assigns the model to the domain of cost-effectiveness analysis.

To capture the long term effects of climate change, the model comprise a period of one hundred years. Its starting point is the year 2001, because the economic data set is based on that year, and ends in 2101. The model is solved with a time resolution of five years.

In order to examine the transportation of climate related productivity shocks through the global economic system, the world is represented as a conglomerate of open economies which trade with each others. The analysis should indicate the main influence channels, but with enough simplification to recognize the assumptions behind. In this stylized framework we distinguish only between five international tradeable goods: High Value Goods, Basic Material, Agricultural Products, Services and Fossil Fuel.

The primary sector contains agriculture products as crops, wheat, but also forestry products and fishery belong to that sector. High value goods are capital intensive manufacturing goods, such as machinery, motor vehicles, chemicals, pharmaceutical products, and electronic equipment, whereas basic material covers more labor intensive goods like clothes. Services contains transport and financial services, but also recreation and health. In energy production we distinguish between international tradeable fossil energy goods as coal, oil, and natural gas and non-tradeable non-fossil energy, which contains mainly renewable produced electricity. Since the transport of electricity is based on fixed networks and large distance transportation is not profitable due to physical constraints, we assume an autarchic supply of non-fossil energy. Table (3) summarizes the aggregated composite commodities and the products which belong to that commodity.

Since the main goal of this work is to identify the magnitude of impacts from climate change abroad to other economies we have to define regions which are (i) uniformly vulnerable to changing climate conditions and (ii) have a relevance for the international trading system. The model distinguish between five teen regions which are different in their role for world trade and in their exposure to climate change. Even in Europe the expected impacts are heterogeneous for different European regions, therefore we divide

Region	Associated Countries
Western European Union (*WEU*)	Fra, Esp, Prt
Eastern European Union (*EEU*)	Aut, Cze, Pol, ...
South-Eastern Europe (*SEE*)	Ita, Grc, Tur, ...
Northern Europe (*NEU*)	Deu, UK, Swe, ...
NAFTA (*NAF*)	USA, Can, Mex
South America (*SAM*)	Arg, Ven, Bra, ...
Middle East and North Africa (*MEN*)	Sau, Mar, Tun, ...
Sub-Sahara Africa (*SAF*)	Zaf, Uga, Tza, ...
Oceania (*OCE*)	Aus, Nzl, ...
China (*CHN*)	Chn
East Asia (*EAS*)	Jpn, Kor, Twn, ...
Southeast Asia (*SEA*)	Ino, Mys, Tha, ...
South Asia (*SOA*)	Ind, Bgd, Lka, ...
GUS (*GUS*)	Rus, Kaz, Ukr, ...
Switzerland (*CHE*)	Swi

Table 4:

Europe in five parts. The regions Western and Southern Europe (*WEU*, *SEE*) contain countries at lower latitudes where more severe impacts like droughts and increasing water stress are expected. For Northern and Eastern Europe (*NEU, EEU*) we even expect benefits from climate change in the near future due of better conditions for agricultural productions and less heating costs. But also there the algebraic sign of impacts changes after 2040. Despite the very different geographic characteristics of Canada and Mexico, we pool Canada, Mexico and the USA to the NAFTA (*NAF*) region. The rest of the American continent belongs to the region South America (*SAM*). Australia, New Zealand and Papua New Guinea are summarized to Oceania (*OCE*). The main oil exporting countries of the Middle East as Iran, Libya, and Saudi Arabia constitute the group of the Middle East and North African Countries (*MEN*). Due to the increasing importance of China, we treat it as an own region (*CHN*). The rest of Asia is divided into highly developed East Asia (*EAS*) with Japan and Korea, into Southeast Asia (*SEA*) with growing countries as Indonesia and Malaysia and into South Asia (*SOA*) including countries which are stronger exposed to and have a lower adaptive capacity as India and Bangladesh. Countries which belonged to the former Soviet Union are pooled to the *GUS*-group. The vulnerable, but periphery countries in Sub-Sahara Africa are summarized to Southern Africa (*SAF*). And since we are focused on the case of Switzerland (*CHE*), we address Switzerland as an own region. The regional aggregation is summarized in table (5).

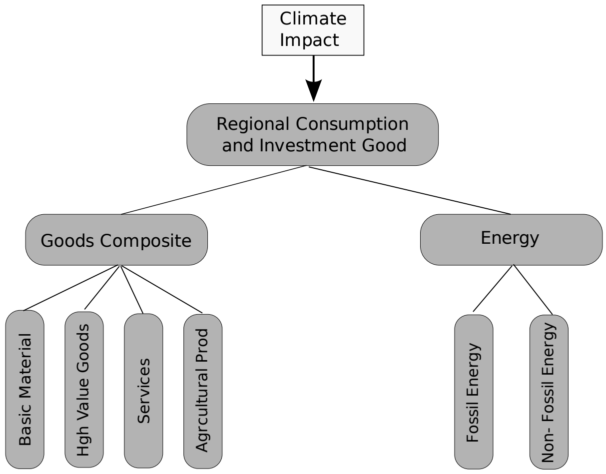

Figure 5: Final output Y is an aggregate of goods and energy. Goods are a composite product of the different domestic used amounts of that commodities as well. Energy is based on international tradeable fossil energy and non-tradeable non-fossil energy.

5.1 Production

The production functions have constant elasticities of substitutions and returns to scale. All regions use the same technology with the same elasticities of substitutions. On the top-level of the economic hierarchy the consumption and investment good $Y_{r,t}$ is produced by a composite good $G_{r,t}$ and a composite energy input $E_{r,t}$.

$$Y_{r,t} = \Omega_{r,t}(\theta_r^Y E_{r,t}^{\rho_Y} + (1-\theta_r^Y)G_{rt}^{\rho_Y})^{1/\rho_Y} \tag{3}$$

The subscript r indicates the region in which the production occurs, t labels the time. $\Omega_{r,t}$ is the loss of GDP due to the impact of climate change as described in the section before. The impacts of global climate change influence the economy on the aggregated level and decrease the productivity. The higher the exogenous given impacts are, the less is available for consumption and savings.

The final good $Y_{r,t}$ can be consumed, invested in the capital stock or used as an intermediate in the production of $AY_{r,t}$, $BY_{r,t}$, $HY_{r,t}$, and $SY_{r,t}$. We define the set $i \in \{A, B, H, S\}$ of all tradeable goods. So the following market clearance condition has to hold:

$$Y_{r,t} = C_{r,t} + I_{r,t} + \sum_i IM_{r,t,i} \tag{4}$$

The markets for labor and capital have to be cleared as well. Labor supply has to be equal to the sum of labor and capital demand in the tradeable good production sectors plus in the non-fossil energy production.

$$\begin{aligned} \overline{L}_{r,t} &= \sum_i L_{r,t,i} + L^{NF}_{r,t} && (5) \\ K_{r,t} &= \sum_i K_{r,t,i} + K^{NF}_{r,t} && (6) \end{aligned}$$

Tradeable goods i are manufactured with capital, labor and a fraction of final good Y as intermediate input.

$$\begin{aligned} G_{r,t,i} &= (\theta^i_r IM^{\rho_i}_{r,t,i} + (1-\theta^i_r) KL_{r,t,i}{}^{\rho_i})^{1/\rho_i} && (7) \\ KL_{r,t,i} &= (\theta^{KL_i}_r K^{\rho_{KL_i}}_{r,t,i} + (1-\theta^{KL_i}_r) L^{\rho_{KL_i}}_{r,t,i})^{1/\rho_{KL_i}} && (8) \end{aligned}$$

For the production of non-fossil energy we assume that only capital and labor are necessary inputs.

$$N_{r,t} = (\theta^N_r KN^{\rho_N}_{r,t} + (1-\theta^N_r) LN^{\rho_N}_{r,t})^{1/\rho_N} \tag{9}$$

5.2 International Trade

Note that the economies do not act in autarchy. They are connected through trade, which makes them vulnerable to spillover impacts from climate change. A, B, H, and S will be traded on international markets. So produced units of a good can be consumed in the domestic country ($D_{r,t,i}$) or exported to other regions ($X_{r,t,i}$).

$$G_{r,t,i} = D_{r,t,i} + X_{r,t,i} \tag{10}$$

Figure (5.2) describes the production set up of the model. Production factors and the intermediate input lead to to the domestic output of that good. A part of the production will sold abroad.

Together with the imported amount $M_{s,r,t,i}$ the remaining domestic production yield the domestic used amount $DU_{r,t,i}$ of that commodity, which serves then again as an input of the goods-composite as shown in figure (5.1).

Because empirical findings indicate a non-perfect substitutionability between domestic and imported goods, we adopt the Armington (1968) assumption for all tradeable commodities except for fossil energy.

$$DU_{r,t,i} = (\theta^{Ai}_r D_{r,t,i}{}^{\rho_{Ai}} + (1-\theta^{Ai}_r)\sum_s M_{s,r,t,i}{}^{\rho_{Ai}})^{1/\rho_{Ai}} \ , \tag{11}$$

whereas s indicates the region of origin of the imports.

Obviously market clearance has to hold on international markets as well. The exports of basic materials (agricultural products, high value goods, services) by one region have to be equal to sum of basic materials (agriculture products, high value goods, services) imports by all other regions:

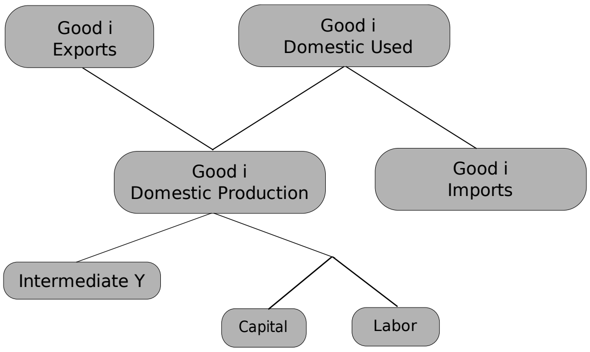

Figure 6: The figure shows the set up of the production structure. Capital, labor and an amount of the final good as intermediate are the input for the manufacturing of good i. The output will divided into an exported part and a domestic used part. The domestic used part is together with the imports from foreign the input for the goods composite.

$$X_{r,t,i} = \sum_{s} M_{s,r,t,i} \tag{12}$$

And the sum of all exports has to be equal to the sum of all imports of all countries.

$$\sum_{r} X_{r,t,i} = \sum_{r} \sum_{s} M^{i}_{s,r,t,i} \tag{13}$$

In the case of fossil energy carriers we skip the Armington assumption and suppose that fossil energy carriers will be imported and exported as homogeneous products. Each region is endowed with $\overline{F}_{r,t}$ resources. The supply path of fossil fuel is exogenously given, depending on data of the world energy outlook 2006 and projections by the DOE (Wood, Long, and Morehouse 2004). The supply has to be equal to the fossil fuel demand $FD_{r,t}$,

$$\sum_{r} \overline{F}_{r,t} = \sum_{r} FD_{r,t}. \tag{14}$$

5.3 Consumption

The aggregate demand of each region is represented through the inter-temporal consumption choice of a representative agent. The representative agent maximizes the discounted log of consumption over the time horizon, starting 2001 and ending 2101.

$$U_r = \sum_{t=2001}^{2101} \beta_{r,t} ln(C_{r,t}) \tag{15}$$

Future utility will be discounted by the factor $\beta_{r,t} = (1 + \delta + \gamma_r)^{-(t-2001)}$, whereas δ describes the discount rate and γ_r the long term population growth rates of the economy. Households are constrained in their consumption choice by their budget:

$$p^{Y}_{r,t}(C_{r,t} + I_{r,t}) = w_{r,t}\overline{L}_{r,t} + rk_{r,t}K_{r,t} + p^{F}_{t}\overline{F}_{r,t}\ , \tag{16}$$

so that expenditure for consumption and investment purposes has to be equal to capital and labor income plus the rent from selling the supply of fossil energy.

5.4 Savings and Investment

To optimize intertemporal utility regional households shifts consumption into other periods and accumulate capital. The rental rate from this capital stocks generates income streams to the households. Capital can only be invested in the domestic region.

Capital stocks are therefore region specific and depreciate at a constant rate, η, which is the same for all regions. The equation of motion for capital is

$$K_{r,t+1} = (1-\eta)K_{r,t} + I_{r,t}. \tag{17}$$

Although the consideration of factor mobility is important to map the whole magnitude of indirect climate change impacts we neglect the possibility of foreign direct investments and other types of investments in regions outside of the own in this study.

6 Calibration

The model is calibrated with data from the GTAP6 database (Dimaranan 2006). For simplification we neglect government as a self-contained actor and for consistency purposes we equilibrate trade balance and adjust for coherence consumption and investment in the base year with the assumed dynamic processes.

We presume that the economies, if climate change would not happen, move along their balanced growth path with γ_r. The economic growth rate is one of the main drivers of the future emissions of greenhouse gases and influence strongly the climate change signal. To assure that the temperature change the economies are confronted with are consistent with the state of the economies, exogenous growth rates are taken from the IPCC SRES emission scenario A1B. The base year interest rates are chosen to assure that the optimal growth rate is consistent with the potential GDP growth rate in the underlying emission scenario, since on a balanced growth path the relationship $ir_r = \delta + \gamma_r$ holds. In table (5) will the parameters be specified.

Since we examine a long time horizon of one hundred years, we need to consider the depletion of fossil energy stocks. But it only a few studies exist which try to estimate the long term development of world oil supply. To assign the path of availability of fossil fuel, we use the findings of Wood, Long, and Morehouse (2004). The authors tried to identify the so called peak-oil and the rate of decrease in output of oil fields. Figure (6) shows this findings for the model regions.

6.1 Finite Horizon Problems

Since the time horizon of the model is finite, but the maximizing household should act as if his horizon would be infinite, problems related to end of time effects may

Region	Growth Rates (γ_r)	Interest Rate (ir_r)	Depreciation Rate (η)	Discount Rate (δ)
OCE	1.8	4.8	5	3
CHN	4.5	7.5	5	3
EAS	4.5	7.5	5	3
SEA	4.5	7.5	5	3
SOA	4.5	7.5	5	3
NAF	1.92	4.92	5	3
EEU	3.1	6.1	5	3
NEU	1.8	4.8	5	3
WEU	1.8	4.8	5	3
CHE	1.8	4.8	5	3
SEE	1.83	4.83	5	3
GUS	3.1	6.1	5	3
MEN	4.1	7.1	5	3
SAF	4.1	7.1	5	3
SAM	4.1	7.1	5	3

Table 5: Calibration Data. Values in Percent. Potential Growth Rates base on IPCC (2000). In cases where the model regions did not map with SRES regions, the average growth rate, weighted by country GDP was calculated.

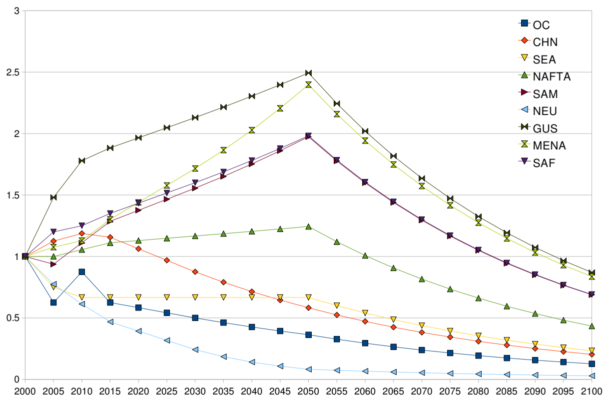

Figure 7: The figure shows the development of the oil supply in the different regions, normalized to one in the base year. The figure is based on the World Energy Outlook 2006 and Wood (2004).

appear. Numerical models can only be solved for a finite number of periods. Adjustments are therefore required to produce a model which approximates choices over an infinite horizon. For an discussion of terminal problems and an explanation of the applied used methods, see Lau, Pahlke, and Rutherford (2000). To avoid the problem of under-investment in final periods, we implement a further constraint, relating the growth rate of investment in the terminal period T to the growth rate of output:

$$\frac{I_{r,T}}{I_{r,T-1}} - \frac{Y_{r,T}}{Y_{r,T-1}} \geq 0. \tag{18}$$

Ownership of capital is an additional issue in dynamic models with multiple infinitely lived agents, how it the different regions are. Changes in net asset positions across households over the finite horizon have to be accounted within the model in order to obtain a precise approximation of the infinite horizon solution. We therefore have to distinguish between the value of capital goods and the stock of financial assets of regions and have to adjust the intertemporal budget constraint over the finite horizon to account for changes in net financial wealth.

The intertemporal budget constraint has to be adjusted by the factor Δ_r between the regions share on ownership of global financial assets and the value of the capital stock of a region in $T+1$:

$$\Delta_r = \theta_r \sum_s p^K_{s,T+1} K_{s,T+1} - p^K_{r,T+1} K_{r,T+1} \ , \tag{19}$$

where θ_r is the share of region r on global financial assets in $T+1$. The stock of financial assets in $T+1$ is the residual of labor earnings and rents from selling fossil fuel from $T+1$ to infinity minus the present value of consumption expenditure.

$$\theta_r = \frac{\sum_{t=T+1}^{\infty} (p^y_{r,T} C_{r,T} - w_{r,T} L_{r,T} - p^F_T F_{r,T})((1+\gamma_r)/(1+r))^{(t-T)}}{\sum_s \sum_{t=T+1}^{\infty} (p^y_{s,T} C_{s,T} - w_{s,T} L_{s,T} - p^F_T F_{s,T})((1+\gamma_s)/(1+r))^{(t-T)}} \tag{20}$$

6.2 Elasticities

Finding realistic elasticities of substitution is a difficult and often unsatisfied challenge. Difficult because the choice can influence strongly the results. Unsatisfying because not enough empirical evidence exits, which would help to choose the 'right' elasticity. The determination is often based on ad hoc assumptions and gathered from the existing literature. In the absence of a better approach, we are go in line with the scarce existing literature. In cases where no empirical estimations exist, values are chosen on the base of ad hoc assumptions.

A crucial value is the elasticity of substitution for the Armington composites. The higher the substitutionability between imported and domestic goods, the more cross-linked are international markets and the higher is the magnitude of climate impacts transported through the economic system in other regions. We refer to the empirical literature and take the Armington elasticities from Gallaway, McDaniel, and Rivera

	Elasticity of Substitution	Range of Estimates
Goods and Energy	0.2	-0.065 - 0.96
Agriculture, Basic Mat-, High Value, Services	-0.24	-1.183 - 0.711
Intermediate and Capital-Labor composite (A prod)	-0.03	-0.027
Capital and Labor (A production)	0.02	0.023
Intermediate and Capital-Labor composite (B prod)	-0.15	-0.564 - 0.253
Capital and Labor (B production)	0.25	0.139 - 0.358
Intermediate and Capital-Labor composite (H prod)	0.74	0.391 - 1.087
Capital and Labor (H production)	0.17	0.046 - 0.295
Intermediate and Capital-Labor composite (S prod)	0.18	-1.103 - 0.37
Capital and Labor (S production)	0.2	0.055 - 0.370
Capital and Labor (R production)	0.46	0.460
Armington Agricultural products	1.94	1.005 - 2.885
Armington High Value Goods	2.27	0.529 - 4.003
Armington Basic Material	1.66	0.119 - 3.195
Armington Services	0.3	
Non-Fossil and Fossil Energy	0.6	

Table 6: Elasticities of substitution

(2003). They estimated Armington elasticities for 309 manufacturing sectors in the US economy. Due to lack of data for other world regions we assume that their findings hold for the rest of the world as well.

Other elasticities like the elasticity of substitution between capital and labor in the different sectors are taken from Okagawa and Ban (2008) and Kemfert and Welsch (2000). All values and the range in the empirical estimates for different subsectors is depicted in table (6).

In the production of agricultural commodities the substitution between capital and labor is the lowest for all production sectors, followed by High Value production and Services. In Basic Material production the replacement of one input factor through another is most simple. Note also that in the production of high value goods the elasticity of substitution between the capital-labor nest and the intermediate input is highest. In the characterization of trade relationships we observe the highest Armington elasticity in High Value commodities. It seems that in the case of sophisticated goods as computers etc. the origin plays only a minor role for the demand. Contrary to this is supposed that services depend strong on their origin of production, which makes a replacement of domestic and imported services difficult.

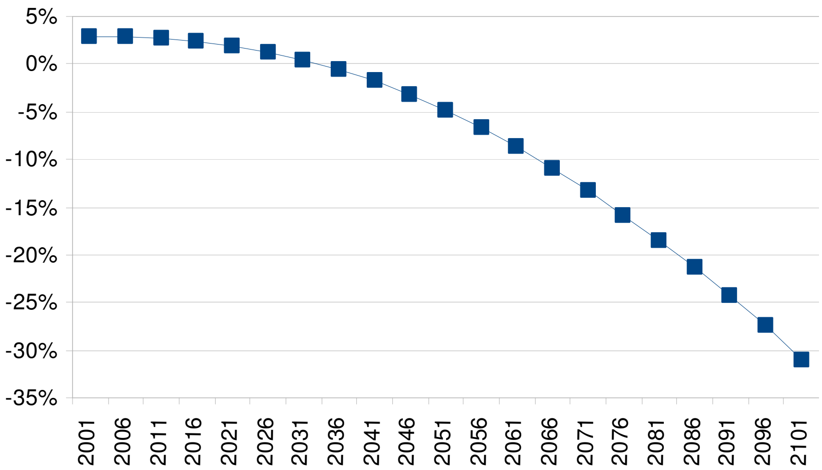

Figure 8: Losses in GWP percent relative to the baseline scenario.

7 Results

To calculate the costs of climate change, we compare the outcome of a scenario called *baseline* where climate stays constant on the mean of the period of 1961 - 1990 with the outcome of a scenario with a temperature anomaly as described above. Because the climate signal from the global circulation model is based on the assumption and calculations of the correspondent IPCC SRES (Nakicenovic and Swart 2000) scenario we name this scenario *A1B*.

Note that the losses in the *A1B* scenario are the result of *Laissez-faire* policy. The economic agents have not the option to avert the impacts of climate change, since evaluation of different climate policies is not the topic of this study.

7.1 World Wide Impacts of Climate Change

If the world do not act against climate change, societies were confronted with severe costs. When add up the regional GDP to Gross World Product and compare both scenarios, we observe a higher GWP in the first third of the 21st century in the climate change scenario. This has two reasons. First leads a small warming to benefits in some regions. Second the regions accumulate more capital since they have perfect foresight on the severe damages later to smoothen the consumption stream over time. Note that this additional capital accumulation is a kind of adaptation against the damages caused by climate change. After 2036 losses strongly increase to 30 % relative to the baseline scenario (see figure (7.1).

We can separate this costs into several parts. At the end of the century, temperature anomaly is between 3.5 and 6.3 °C in the different world regions. According to the calibrated impact functions such an warming would lead to an loss of GDP between 1 and 9.2 % per year. But this neglects the inherent economic dynamics. As noted by Fankhauser and S.J. Tol (2005) “horizontal linkages” can explain a relevant part of the story. Fankhauser and S.J. Tol distinguish between two types of dynamic effects. The *capital accumulation effect* describes that under the assumption of a constant saving rate, the loss of output due to climate change leads to a reduction of savings and investments and therefore lowers future production, because capital stocks accumulate slower. In a Ramsey-Cass-Koopmans model, as applied here, a second kind of effect plays a role because forward-looking agents anticipate the future climate costs and adapt their saving decisions. It may possible that savings increase to compensate the deficit in future income. Or saving rates may decrease because the climate impacts reduce capital productivity.

A comparison of investment trajectories of the world regions under the both scenarios shows evidence for both cases. In the first thirty years of the simulation period, the sum of world wide investments is slightly higher in the climate change scenario than in baseline to compensate future shortfalls. Obviously this result depends on the choice of the discount rate. A lower discount rate would increase the concern about future time periods and increase savings to smooth the consumption stream over time. The second depicted case can be observed in final periods, when world wide investments are about 14 % lower than in the baseline scenario.

A further part of the costs, which was pointed out by Stern (2007, p.152), is the *intermediate effect.* The production of most goods depends on intermediates as input and if this input is already affected by climate change, damages in one sector can multiply damages in others. Impacts in the water sector may amplify impacts in agriculture, for example. This is captured in the model by use of (affected) GDP as intermediate in sectoral production.

But these costs are not uniformly distributed among the regions. The world map in figure (7.1) shows large differences in 2101 between the model regions. Whereas the NAFTA region looses about 23% of their gross domestic product compared to baseline, South Asia has to cope with costs of 50%. Most other regions like Oceania and the different European regions loose between 26 and 37% of their gross regional product. Note that in absolute terms (e.g. in 2101 dollars) the 23 % loss in NAFTA is larger than the 50% loss in South Asia. But nevertheless, the today less developed regions in Sub-Sahara Africa, South Asia and partly South America, the regions with the least contribution to the anthropogenic greenhouse gas emissions are the most affected regions.

If we look deeper into single sectors and their respond to climate impacts, we observe in all sectors significant less production compared with *baseline*. The most affected sector is agriculture, the least affected sector is high value goods. Since low-latitude regions have to cope with the most severe impacts, the process of economic convergence as assumed by (Nakicenovic and Swart 2000) will be reversed by climate change. This has the consequence that instead of an structural change in the composition of the economies, development regions stay only competitive in low-capital-intensive sectors as the production of agricultural commodities. In the section below, we will discuss

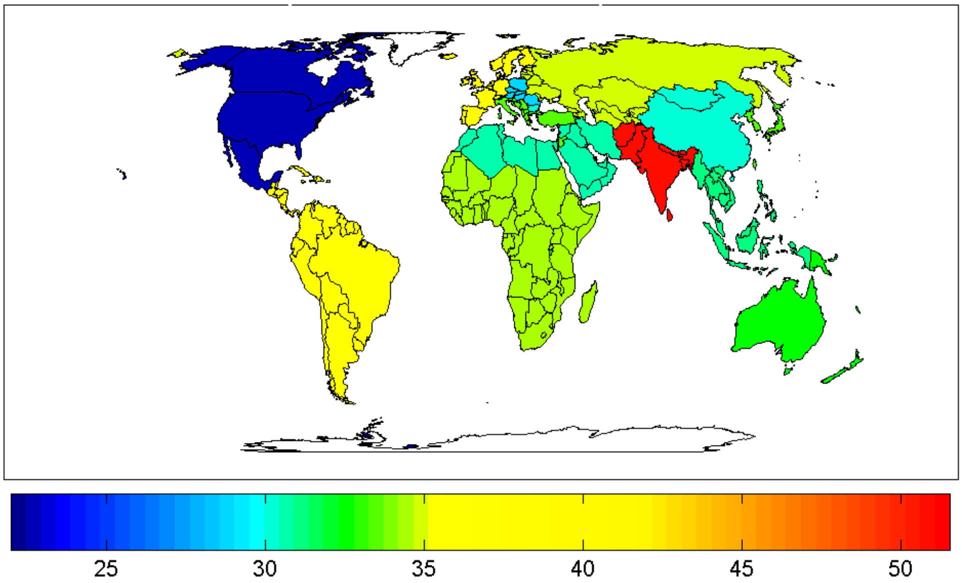

Figure 9: Losses in GDP for the model regions in percent relative to the baseline scenario.

question about competitiveness more comprehensive.

Interesting is the case in non-fossil energy production (see figure (7.1)). Because climate change leads to losses in productivity and a slower accumulation of the capital stocks, the production of renewable energy will be more expensive. The opportunity costs for a structural change in the energy system is higher in a scenario with climate change, whereas prices for fossil energy are more increasing because of the absence of a cheap substitution opportunity.

7.2 Changes in Trade Patterns

Since regions are not uniformly affected by climate impacts, the regional different vulnerability, exposure, and temperature changes have also consequences for trade and productions patterns on the economic world map and as we already mentioned above, climate change may influence the competitiveness of a region and their production portfolio.

As supposed has the regional divergent impacts from global warming also large consequences for international trade. Table (ref{tab:tradechange) shows the percentage change in bilateral trade in the final period of the model. The regions in columns are importers, considered products are all tradeable products with exception of fossil energy. The table shows that especially regions at the upper and lower bound of the impact range have large shifts in their relationships. Whereas NAFTA imports less from most regions and exports significant more, South Asia is hard hit by climate change and has to import more goods and can export less. This corresponds directly with the divergent vulnerability and exposure to climate change. Whereas South Asia has to cope with severe impacts, leading to massive lower productivity and international competitiveness, the

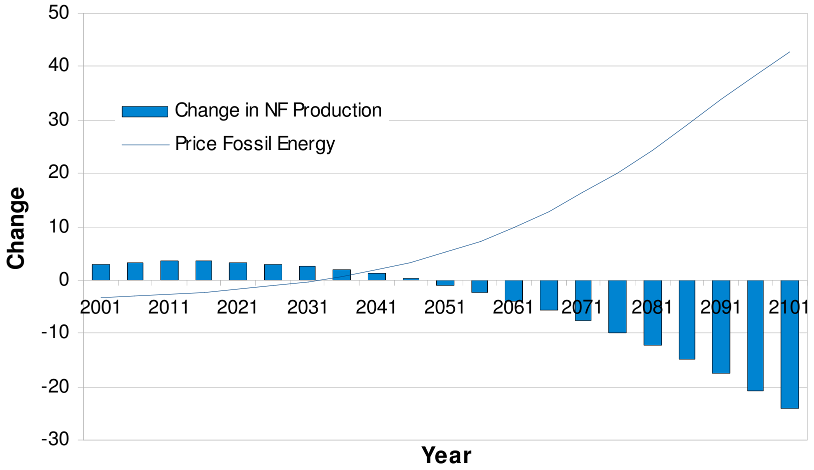

Figure 10: Relative change in percent compared between the two scenarios for the price of fossil energy and output of renewable energy carriers.

disproportionate impact and the disproportionate productivity losses on NAFTA allows for gains in competitiveness.

For most region around the mean of the impact range, such as the European and East Asian regions, the implications are mixed. They will import more from NAFTA and less from South Asia.

To examine more in detail the competitiveness of a country, Balassa (1965) proposed an index that "reveals" comparative advantage by analyzing trade patterns.

$$RCA_{r,i} = \frac{X_{r,i}}{\sum_i X_{r,i}} / \frac{\sum_r X_{r,i}}{\sum_r \sum_i X_{r,i}} \tag{21}$$

where r represents a region and i an industrial sector. The revealed comparative advantage measures a region's exports of a commodity relative to his total exports and to the exports of all other regions. If RCA is higher than unity, the region has a comparative advantage in producing this good. If $RCA < 1$, the country has a comparative disadvantage in this sector.

The trade pattern of agricultural goods seems also under climate change relative persistent. South Asia has already a large comparative advantage in agricultural production and climate change will further increase this comparative advantage. But in all other sectors it looses significant. An increasing dependency on the world market for agricultural goods is the consequence. Since South Asia is the most exposed region, it cannot accumulate capital in the same manner as other regions and can therefore not compete in more capital intensive sectors than agricultural goods.

In the basic material sector looses Sub-Sahara Africa, the GUS and South Asia as well. The most pronounced shifts are observable in high value goods, in nearly all regions significant changes can be observed. NAFTA gains, where most other regions looses comparative advantage in this sector. The explanation is identical to that in the

	OCE	CHN	EAS	SEA	SOA	NAF	SAM	EEU	NEU	WEU	CHE	SEE	GUS	MEN	SAF
OCE		-7.42	-0.65	-8.66	50.25	-58.78	5.63	-8.75	6.18	9.22	-1.85	2.06	11.76	-3.06	-1.61
CHN	4.07		6.75	-3.1	73.8	-58.82	12.41	-2.58	12.6	16.27	4.49	9.57	20.29	1.12	3.85
EAS	-7.64	-10.48		-14.46	64.07	-65.85	1.05	-13.52	0.8	4.68	-7.45	-2.01	8.62	-11.15	-7.84
SEA	0.13	-3.52	5.2		73.04	-62.32	9.38	-6.34	9.4	13.48	0.71	6.41	17.79	-2.43	0.69
SOA	-39.71	-43.57	-33.51	-44.7		-75.23	-35.43	-45.29	-35.36	-34.27	-43.04	-40.13	-35.93	-40.62	-41.57
NAF	133.37	122.43	116.77	120.22	312.78		154.68	118.53	151.6	163.12	140.19	151.65	184.29	114.46	134.26
SAM	-10.18	-15.11	-7.16	-17	44.69	-64.35		-16.82	-2.4	0.47	-10.66	-6.52	2.38	-11.28	-10.1
EEU	5.58	1.17	7.79	-1.53	73.88	-57.49	13.81		14.05	17.74	6.13	11.14	21.97	2.74	5.42
NEU	-14.92	-17.8	-7.9	-21.12	38.57	-65.51	-8.1	-20.41		-5.07	-16.11	-11.49	-3.49	-15.85	-15.43
WEU	-14.92	-17.99	-8.27	-21.14	37.15	-65.23	-8.2	-20.49	-7.84		-16.17	-11.67	-3.8	-15.66	-15.41
CHE	-8.75	-11.61	-2.44	-15.21	52.11	-63.64	-1.27	-14.4	-1.24	2		-4.39	4.87	-10.94	-9.34
SEE	-5.8	-9.78	-1.57	-12.25	49.83	-60.611	1.00	-11.87	1.45	4.24	-6.54		6.33	-7.24	-6.43
GUS	-6.59	-12.09	-4.45	-12.34	38.03	-57.65	-1.39	-13.48	-0.91	1.01	-8.86	-5.23		-8.29	-8.27
MEN	-0.92	-5.06	1.77	-7.3	53.49	-57.35	5.99	-6.97	6.42	9.45	-1.19	3.2	12.44		-1.3
SAF	-4.12	-9.35	-1.7	-11.23	56.54	-62.26	3.69	-11.09	4.12	7.29	-4.21	0.17	9.86	-5.74	

Table 7: Percentage change in bilateral trade between regions in 2101, comparing baseline and A1B scenario. Regions in columns are importers and regions in row are the exporters. The change is calculated relative to baseline trade. All traded goods with the exception of fossil energy are considered.

Sector	AG		BM		HV		SV	
Region	*Base*	*A1B*	*Base*	*A1B*	*Base*	*A1B*	*Base*	*A1B*
OCE	1.13	1.11	0.87	0.84	0.51	0.41*	1.17	1.23
CHN	1.59	1.58	1.73	1.73	1.47	1.33	0.62	0.65
EAS	0.65	0.63	0.92	0.91	1.11	0.98	1.03*	1.09
SEA	1.71	1.73	1.12	1.13	1.43	1.23	0.72*	0.77
SOA	2.82	2.92	1.27	1.13*	0.76	0.54*	0.75	0.83*
NAF	0.64	0.67	0.88	0.95	0.96	1.39*	1.09	0.92*
SAM	1.74	1.71	1.02	0.98	0.68	0.54*	0.99	1.05
EEU	1.55	1.54	1.28	1.29	1.05	0.93*	0.85	0.89
WEU	0.87	0.83	0.86	0.82	0.93	0.71*	1.07	1.17
SEE	0.96	0.93	1.26	1.22	0.83	0.68*	1.02	1.09
GUS	2.58	2.57	1.2	1.16	0.89	0.76*	0.75	0.8
MEN	1.72	1.67	0.74	0.71	0.45	0.36*	1.11	1.17
SAF	2.63	2.6	1.02	0.99	0.73	0.6*	0.83	0.88
CHE	0.58	0.57	0.87	0.84	1.19	0.95*	1.03	1.12
NEU	0.69	0.66	0.85	0.8	0.95	0.71*	1.09	1.2

Table 8: Calculated RCA in 2101 for the baseline and the A1B scenario. * indicates changes in the RCA larger than 10 % between the two scenarios.

case of South Asia for agricultural commodities: NAFTA is the region with the least impact from climate change and has therefore the least difficulties to accumulate capital. The more and cheaper capital in charge allows to gain market shares in capital intensive industries as the high valued good production represents.

But how does trade act as a whole in the case of climate change? What is the role, world trade plays, if regions are confronted with regional different exposures? If we define the ratio $\sum_r \sum_i X_{r,i,t} / \sum_r Y_{r,t}$ as an indicator for the openness and intensity of world trade and plot this for both scenarios, we observe mainly in the second half of the century, when impacts will have a higher magnitude, a divergence in the trajectories between the two scenarios. Compared with the *Baseline*-scenario, the intensity of world trade is increasing. It seems that the increasing imbalances due to climate change increase the potential for trade. And increased openness of the world economy helps to outbalance the regional different exposure to climate change and is an indicator for the existence of spillover effects.

7.3 Costs of Climate Change for Switzerland

If we compare the outcome of the two scenarios in terms of Swiss GDP (see figure (7.3)), we observe a relative large difference at the end of the century between the two scenarios. Until 2030 capital stocks, investment and GDP are slightly higher than in baseline but

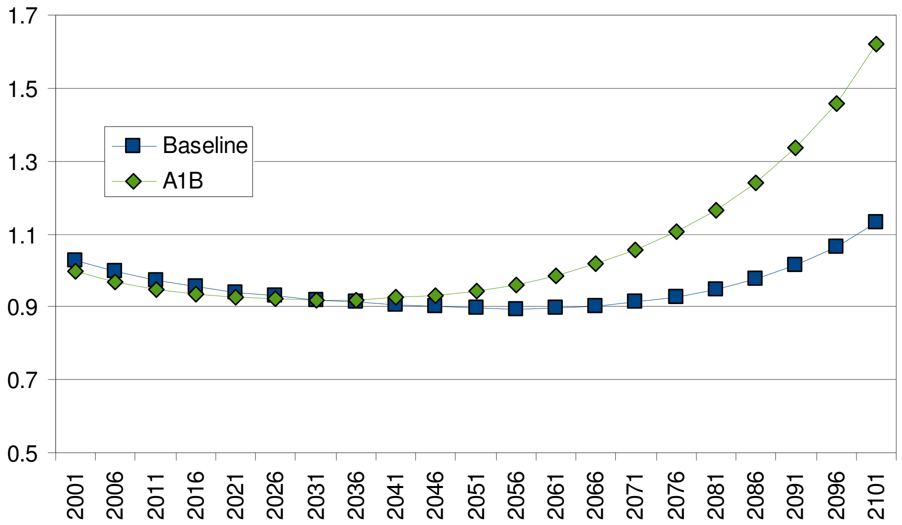

Figure 11: Ratio of world exports to GWP for both scenarios.

then costs are increasing affect Swiss welfare, lead after 2060 to a contraction of the Swiss economy. In 2101 the Swiss economy has a 34.7 % lower GDP relative to the baseline scenario if climate change would affect Switzerland in the above described way[8].

If we examine the differences of investment trajectories of Switzerland between both scenarios, we find evidence for an increase in investments in earlier periods to compensate for the shortfall in later periods. The 37 % difference in investments at the end of the century are though an indication of large dynamical effects. The more pronounced change in investments compared to that in GDP signals that besides the capital accumulation effect a decreasing marginal productivity of capital also affects the capital accumulation.

A further interesting point is the reaction of the sectoral composition to the changing environment. Figure (13) shows the sectoral performance relative to the baseline case. The non-fossil energy sector, which is not internationally tradeable, has the smallest reduction in production to bear. In contrast to the High Value goods sector, here the most significant changes are apparent.

An explanation for this results can be found if we examine the changes in exports. Today a large contributor to the Swiss export positions in the trade balance, High Value goods loose due to climate change as far as 17 % per year. The large gains in the competitiveness of the NAFTA region in the production of High Value goods lead towards a specialization of NAFTA in this capital intensive product and influences the production pattern of that good world wide. This shows the effectiveness of trade spillovers exemplary.

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[8] Note that a significant part of this costs can be explained by the willingness to pay to avoid the catastrophic impacts a change in the termohaline circulation could have.

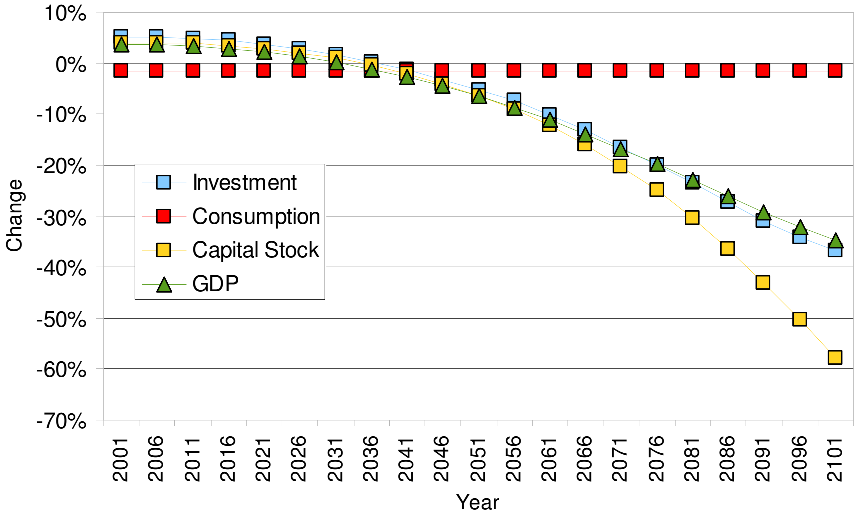

Figure 12: Changes in Switzerland, relative to the baseline case.

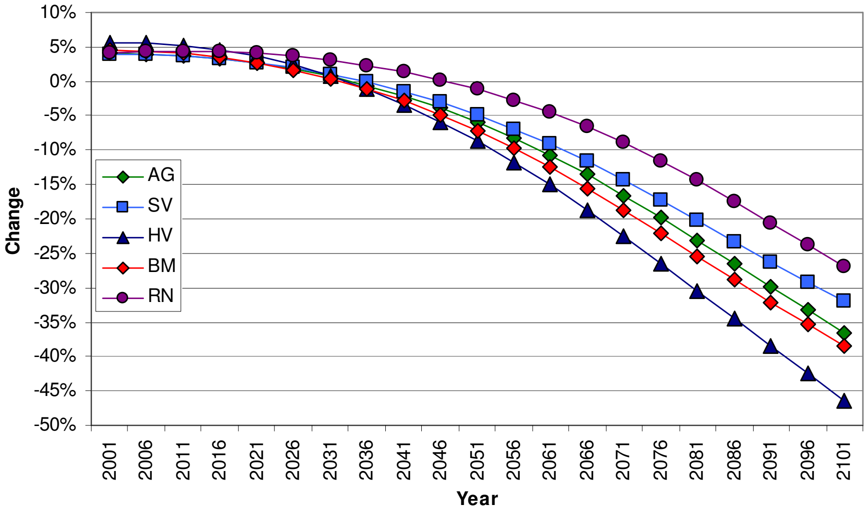

Figure 13: Changes in per cent of Swiss production sectors relatively to baseline.

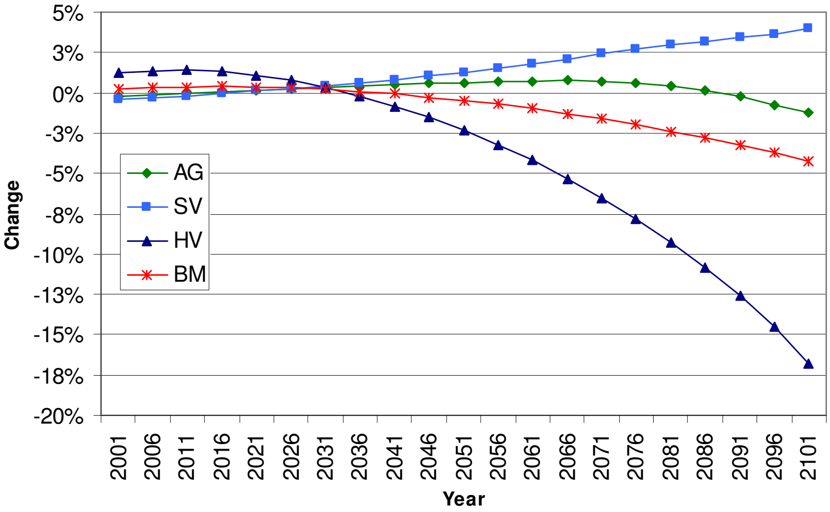

Figure 14: Changes of Swiss exports, relative to baseline.

7.4 Sensitivity Analysis

We have done a careful sensitivity analysis for all crucial parameters in the model. We compared the outcome in final period GDP for both scenario and calculate the median loss of the regions. The model responds quit robust for most of the changes. In general, assuming an complementary or a nearly perfect substitution relationship in the CES production function changes the median loss only about 5% in terms of baseline GDP over the range of substitution possibilities.

But we identify one elasticity which seems crucial for the model outcome. The model reacts quit sensitive on different values of the elasticity for the High Value Armington Composite good, indicating the product differentiation between domestic and imported goods. Note that this elasticity can also be interpreted as an indicator for the openness of foreign and domestic markets. High Value good trade has a significant share on total world trade and can therefore also influence the transport of the spillover effects through the economic system. The less well foreign and domestic High Value goods can be substituted, the higher is median GDP loss. This result indicate the finding that a better substitutionability of foreign and domestic goods, e.g. an intensivation of world trade integration may help to dampen the costs of global climate change for the world economy as a whole.

Figure (15) shows the difference in final period GDP for different values of substitution. Since our chosen parameter is in the middle of the possible range, our results should not strong under- or over-estimate the correct value .

Another often discussed topic in the integrated assessment literature is the choosing of the “right” discount rate. Since the costs and benefits of greenhouse gas abatement are not part of this model the discount rate plays not this crucial role. Nevertheless, we examined the sensitivity of the model for different discount rates, see figure (16). The

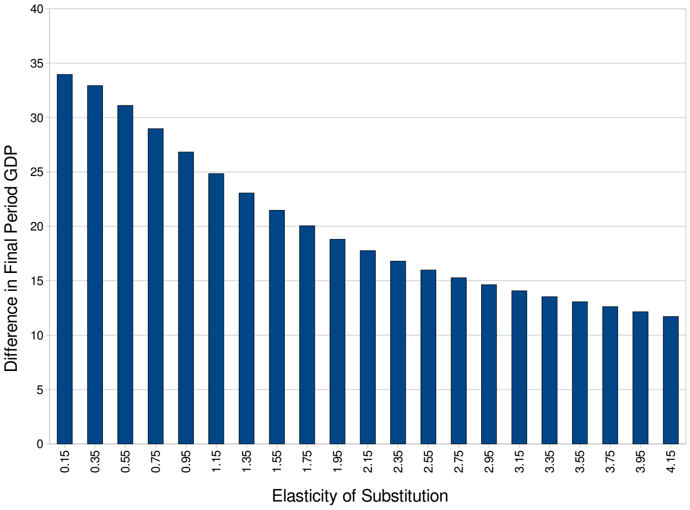

Figure 15: Difference in percent of Baseline and A1B final period GDP for different elasticities in the High Value Armington composite good.

lower the discount rate, the lower is the observed GDP loss. The explanation is straight forward. A smaller discount rate leads to a higher concern for the future and lead to a faster accumulation of the capital stock in recent years to absorb the stronger impacts in the second half of the twenty-first century and decreases the difference between the two scenarios. But a change in the discount rate has not an significant impact on the observed median costs. A low discount rate of 1 % leads to costs at the end of the century of about 31 % of baseline GDP, whereas a more "myopic" discount rate 9 % increases costs up to 38 %. Overall the model behaves quit robust.

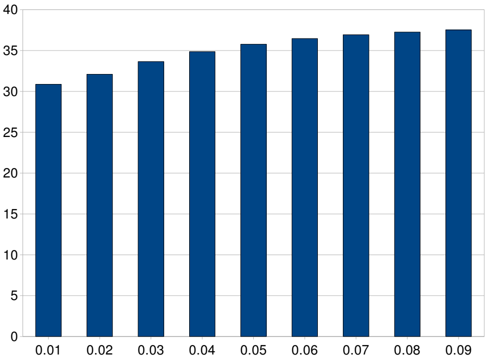

Figure 16: Difference in percent of baseline versus A1B terminal period GDP for different discount rates.

8 Decomposition of Climate Change Impacts

In order to assess the transmission of spillover impacts from one region to another, we need a methodology to decompose the aggregate costs of climate change into the domestic contribution and the individual spillover contributions from other regions.

The application and interpretation of a general equilibrium model has, beside the advantage of a more realistic image of the functionality of the economy, the disadvantage that many processes happen simultaneous and positive or negative feedbacks may lead to an amplification or a reduction of an injected shock. If different exogenous shocks happen at the same time an assignment of the economic impact of a certain shock is difficult. Unlike a partial *ceteris paribus* analysis an assignment of the economic impact of shocks is difficult within a general equilibrium model.

If we were only interested in the total contributions of direct and spillover effects for the Swiss Gross Domestic Product, we could assume that Switzerland is too small to affect world prices and and treat Switzerland as a small open economy. Then we could run counterfactual simulation runs. In a first artificial scenario we would assume that Switzerland is untroubled by direct impacts whereas the other regions are affected by climate change. This should indicate what would happen, if Switzerland would not affected by climate change and its non-exposure would not affect terms of trade. The reduction of GDP in Switzerland compared with the baseline scenario should then indicate the contribution of foreign spillover effects to the domestic climate bill. The second scenario assumes climate impacts only in Switzerland and all other regions were confronted with a world climate as in the reference year 2001 over the whole simulation. Under the assumption that the impact on a small country like Switzerland does not influence world market prices, we get approximately an impression about the magnitude of direct effects.

Boehringer and Rutherford (2002) propose an idea similar to this thoughts. They examine domestic and terms-of-trade effects of carbon abatement policies. Under their setting, each region of a multi-region model can be represented as a small open economy with fixed terms of trade. This allows to distinguish between a domestic policy effect and the international spillover effect. But a shortcoming of this approach is that it does not enable to identify the single contributions of the individual regions to welfare loss of other regions.

8.1 Decomposition Method

To assign the contributions of home and foreign impacts we use therefore a different method suggested by Harrison, Horridge, and Pearson (2000) which allows to account the individual contributions of a region to the climate bill of other regions. It lies is the nature of the problem that climate impacts happen contemporaneous in different regions. In a *ceteris paribus* examination one regional climate impact after another would shock the system. Obviously the magnitude of the shock would depend on the order of his

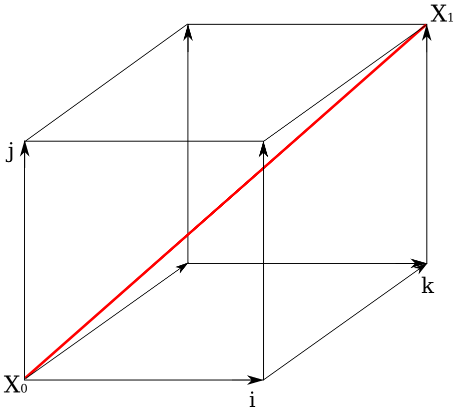

Figure 17: Decomposition of general equilibrium effects

incidence. The effect of NAFTAs climate impact on the terms of trade of East Asia depends on the order and if China or the Middle East or none of them were confronted on the damages before. But with n regions, $n!$ different orders of shocks are possible. To solve this problem Harrison, Horridge, and Pearson present a generic decomposition method which is order-independent. They calculate the contributions of a shock on welfare losses as a line integral, where the rate of change across all exogneous shocks is kept constant (Böhringer and Rutherford 2004). This implies that regional contributions to the total costs are determined along a straight line, following what Harrison, Horridge, and Pearson call a 'natural' path from the situation ex ante to the situation ex post.

The intuition behind the approach goes as follows: If n shocks occur, an shock space exits with n dimensions. We can visualize this as an n-dimensional cube (see figure 8.1). The point in the vertex bottom left describes the value of the shock variable *ex ante*. The vertex diagonally opposite describes the situation *ex-post*. Moving along the edges of the cube is a decomposition method, setting one shock after the other. But there are $n!$ ways of travelling along the edges, starting in the bottom left and ending in the top right. The straight line between the two points is the mean of all possible edgewise routes and lies in the middle of the range of the different routes.

Let us assume that an implicit function G describes the relationship between the measurement variable Z_m and the exogenous shock parameter X_n.

$$G_j(Z_1, ..., Z_m, X_1, ..., X_n) = 0 \text{ with } j = 1, ..., m \tag{22}$$

X_n is a vector of exogenous values such as the impact of climate change in a certain region. Suppose $\tilde{X} = (X_1, ..., X_n)$ moves from the *ex ante* state $\tilde{X_0}$ to the *ex post* value $\tilde{X_1}$. The change from $\tilde{X_0}$ to $\tilde{X_1}$ can be expressed with some function $H(t)$, which describes the path along the change in X with t as a parameter moving from 0 to 1, so from $X_0 = H(0)$ the system moves to $X_1 = H(1)$.

What we are interested in is the contribution of a regions climate impact on the changes of GDP on all other regions, or more formaly in the contribution of X_n to the change of Z_m.

If we partially differentiate equation (22) with respect to X_i, it follows from the Chain Rule

$$\sum_{k=1,m} \frac{\partial G_j}{\partial Z_k} \frac{\partial Z_k}{\partial X_i} + \frac{\partial G_j}{\partial X_i} = 0 \tag{23}$$

since $\frac{\partial X_s}{\partial X_i} = 0$ for $s \neq i$. Rearranging and multiplying by $\frac{dX_i}{dt}$, the change in X_i if we change the path parameter t, we get a system

$$A\tilde{v_i} = \tilde{w_i} \tag{24}$$

where A is the $m \times m$ matrix with $\frac{\partial G_j}{\partial Z_k}$ in row j and column k. $\tilde{v_i}$ and $\tilde{w_i}$ are $m \times 1$ vectors whose entries in row j are $\frac{\partial Z_j}{\partial X_i} \frac{dX_i}{dt}$ and $-\frac{\partial G_j}{\partial X_i} \frac{dX_i}{dt}$ respectively.

By solving the equation system (24), we can calculate numerically the values of $\frac{\partial Z_j}{\partial X_i} \frac{dX_i}{dt}$ at any point along the curve $H(t)$.

It follows that the contribution of a regions impact to the costs of climate change for another region can defined as $\tilde{X}$ moves along the path H

$$\int_{t=0}^{1} \frac{\partial F_j}{\partial X_i} \frac{dX_i}{dt} dt \tag{25}$$

The numerical values for the gradients $\partial F_j \partial X_i \frac{dX_i}{dt}$ along the 'natural path' can be computed by solving a system of nonlinear equations. If we linearize the respective line integral, we can approximatly calculate the contributions of a change in the impact variable X_i. The original decomposition procedure by HHP was implemented in GEMPACK, Böhringer and Rutherford (2004) present an adaptation for CGE models written in GAMS. The Böhringer and Rutherford (2004) approach needs a repeated call of the solver to evaluates derivatives numerically, makes the decomposition computational time intensive. Since we apply the methodology on a dynamic model, a 'correct' application should calculate the contribution of a regions climate impact in a certain time period on all other time periods in all other regions. For computational efficency reasons we simplify the application and calculate only the contribution of a region impact change in one periode on all other regions in that period, implicit assuming that climate shocks have not static impact on regions abroad. We doing this by a static image of the model, which replicates the periodic equilibrium of the dynamic model. When then apply the decomposition methodology on the static model. It needs about twelve hours, if the approximation error from the linearization should minimized to an accurate level.

8.2 Decomposition of Climate Impacts According Their Regional Provenance

The decomposition of climate change impacts according their provenance shows that regional impacts can through trade interlinkages affect other economies geographically far away from the location where the impact appears. In the table 9 we present the percentage contribution of all region to the total damages of a region. The stream of costs and benfits was discounted by 3 % per annum. Note that this contribution react sensitive on different discount rates, due to the fact, that all regions have quit different damage paths along the time line.

The results show that in most countries the direct impacts are responsible for about the 85 - 95 % of the total costs of climate change. Exept from two regions which show different results. Discounted over all periods, we expect small benefits from climate change in the NAFTA zone, in the region of the former Soviet union and in Oceanina. In the case of Switzerland, a highly developed small open economy which is not strong affected directly form climate change, about 7% of the discounted damages are related to international spillovers, whereas two thirds are the consequence of domestic impacts.

In NAFTA cause the direct impact a damage. But this can be overcompensated from benefitial spillovers from abroad, mainly due to the fact, that NAFTA can increase his international competitivness, export more to and import less from foreign economies. Note that the shorttime benefits are mainly related to the warming in the northern parts of the region, which belong mainly to Canada. If for the U.S. only the results would also be positive is uncertain. Still, the increase in capital intensive goods may be a rationale for the U.S. government against an international effort to abate greenhouse gases. The relative well beeing of NAFTA has also an benefitial influence on Oceanina, China and the GUS.

If we compare the sum of incoming spillovers with the sum of outgoing spillovers we can identify winners and losers of the international trade regime. The regime is expressed in a certain Armington elasticity. Some countries have larger incoming than outgoing spillovers and for others the opposite holds. Compared to autarchy the NAFTA zone is better off because their outflow of costs is larger than their inflow. China, East Asia, South East Asia, most European Regions and Sub Saharan Africa are have larger incoming costs and are worse off under international trade. Northern Europe, South Asia and MENA have costs of more than 30 % of their 2001 GDP related to spillovers from climate change impacts. Note that an even heavy affected region as South Asia is even worser affected from international trade.

It is not clear how a deeper integration of international trade would affect this figures. But under the assumption that a further integration would amplify the the difference between winners, are perhaps transfers between winners and losers necessary for an agreement.

9 Conclusion & Policy Implications

We show in a general equilibrium model that cost from global climate change are not uniformly distributed between regions. Whereas the NAFTA region has at the end of

	Region where the climate impact appears															
	OCE	CHN	EAS	SEA	SOA	NAF	SAM	EEU	NEU	WEU	CHE	SEE	GUS	MEN	SAF	$\sum$Spillover
OCE	**86.46**	1.63	3.96	0.66	0.33	1.92	0.76	0.36	2.01	0.39	0.13	0.34	0.18	0.58	0.30	**13.54**
CHN	0.63	**61.01**	11.62	1.31	0.92	1.11	2.39	1.90	9.29	4.65	0.45	2.68	0.50	0.94	0.59	**38.99**
EAS	0.07	0.07	**102.37**	0.09	-0.3	1.43	-0.4	-0.3	-0.9	-1.09	0.00	-0.7	-0.22	-0.2	0.02	**-2.4**
SEA	0.25	2.50	5.85	**77.95**	0.46	3.10	1.00	0.98	4.37	1.49	0.27	0.88	0.00	0.53	0.37	**22.05**
SOA	0.21	1.64	4.70	0.58	**84.75**	1.85	0.84	0.50	2.65	0.83	0.16	0.56	0.04	0.44	0.25	**15.25**
NAF	0.15	14.59	43.93	4.88	7.56	**2.15**	9.21	2.86	4.51	2.12	0.25	1.00	0.60	3.89	2.31	**97.85**
SAM	0.33	2.46	6.96	0.94	0.72	2.46	**77.07**	0.78	4.09	1.45	0.23	0.99	0.29	0.80	0.43	**22.93**
EEU	0.36	3.02	.730	1.34	0.79	3.25	1.53	**72.58**	4.98	1.74	0.28	1.08	0.37	0.89	0.48	**27.42**
NEU	0.43	33.36	8.39	1.48	0.98	3.54	1.92	1.13	**73.07**	1.90	0.29	1.23	0.63	1.08	0.57	**26.93**
WEU	0.49	3.81	9.83	1.60	1.15	4.01	2.23	1.22	5.99	**65.32**	0.32	1.36	0.76	1.27	0.65	**34.68**
CHE	0.46	3.64	8.95	1.67	1.01	4.14	2.08	1.25	5.86	2.04	**65.10**	1.30	0.76	1.14	0.61	**34.90**
SEE	0.46	3.58	9.36	1.41	1.13	3.78	2.04	1.17	5.73	1.96	0.32	**66.75**	0.60	1.12	0.59	**33.25**
GUS	0.10	1.48	4.02	0.48	0.52	1.96	0.36	0.25	1.60	0.30	0.12	0.27	**88.25**	0.14	0.13	**11.75**
MEN	0.30	2.36	6.23	1.04	0.61	2.66	1.113	0.86	4.18	1.43	0.25	0.89	-0.04	**77.73**	0.37	**22.27**
SAF	0.25	2.12	5.33	0.87	0.55	2.26	1.03	0.71	3.41	1.14	0.20	0.76	0.15	0.63	**80.59**	**19.41**

Table 9: Percentage contribution to the discounted regional climate impacts between 2001 - 2101. The last column displays the discount impact of climate change in percent of 2001 GDP, the second last column the sum of the indirect effects in percentage the total loss in GDP. The bold values are direct impacts. The discount rate is 3 %.

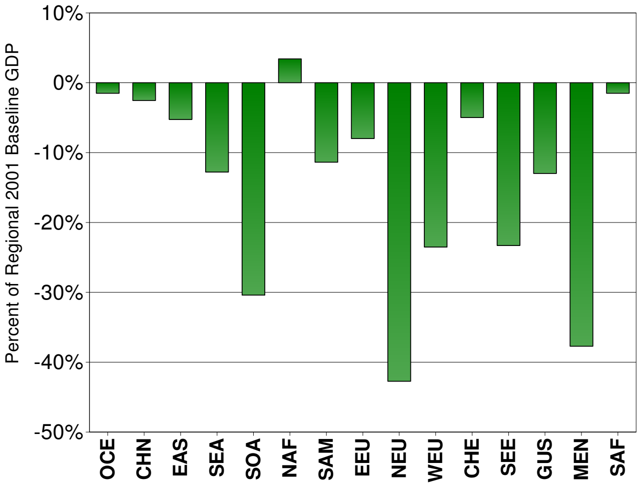

Figure 18: Discounted in- and outflows of spillovers in GDP of 2001.

the century twenty percent less GDP compared to a situation without climate damages, South Asia has to cope with loss in GDP of fifty percent. This heterogeneity influences also regional competitiveness and the structure of international trade relations.

We show in the model as well that interlinkages via trade matter for an accurate assessment of the costs of climate change. The impacts of climate change on regional productivity affect competitiveness and terms of trade of a region. Since the todays less developed regions will be harder affected from environmental change, imbalances in regional competitiveness will pronounced. The main driver for the changing competitiveness is the impact of climate change on capital accumulation. The largest changes in the revealed comparative advantage index can therefore be observed in High Value goods, which are the most capital intensive tradeable commodities. Regions which have nowadays still a large capital stock and are not so strong affected by global warming like the most OECD countries gain competitiveness in this goods compared to a world without climate change whereas the developing regions losses competitiveness in this kind of goods, since climate change slows or reverses the convergence process between developing and developed regions. The different vulnerability and increased imbalances lead to an increase in the world trade intensity compared to the baseline scenario.

Another consequence of the impact from climate change on the accumulation of capital are the higher opportunity costs for a structural change in the energy system. Since the building of renewable electricity power plants is capital intensive compared to the use of fossil energy the increased scarcity of capital makes it harder to switch to a less fossil fuel based energy system and energy prices increase.

The interlinkages between regions through international trade lead via changing relative prices and changing international competitiveness independent from climate impacts in the domestic economy to spillover effects, which may affect a regions welfare. To identify the magnitude and origin of this spillover effects for an individual region we apply an decomposition method proposed by (Harrison, Horridge, and Pearson 2000).

The costs related to those spillover effects may be relative severe. Due to the large gains in competitvness, NAFTA benefits from spillovers, whereas Northern Europe, South Asia and the Middle Eastern countries are confronted with costs in the magnitude of 30 % of their GDP in 2001.

It is an often mentioned fact that the poorest regions, which made the least contribution in terms of emitting greenhouse gases to the global climate change problem are the regions facing the most severe impacts. In regions with an already extreme climate today, mainly located in tropical areas, a further warming increases the existing imbalance in the worldwide distribution of income and welfare.

The effect of international trade on the costs is ambiguous. On the one hand decreases international trade the global costs of climate change since regions may minimize their exposure to climate change through an adaptation of production and trade pattern. On the other hand may international trade increase the inequality between severe affected developing countries and less affected industrialized countries.

This study shows that the two topics climate change and international trade should be discussed in a common context for an accurate assessment of the costs of climate change for different regions. The link between trade and climate change costs should also be included in international negotiations about future climate and/or trade agreements. Transfer schemes or the funding of adaptation in developing countries may help to solve this problems. But the industrialized regions should also recognize that if they were still interested in an further integration of world trade, the increasing inequality due to climate change impacts may increase the difficulties in finding a compromise since the interests are even more disperse than without climate change.

We highlighted in this study the link between costs of climate change and international trade. But there are still a lot of open questions and therefore should his complex be examined deeper in further research. The interaction of climate and trade policy may be of special interest in the light of future climate and trade negotiations, especially due to the fact of congruence of Annex B countries of the Kyoto treaty and groups of common interests in international trade. And since the divergence in capital accumulation is one of the main drivers for the changes in competitivness, the consideration of capital mobility between the regions may affect this result.

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