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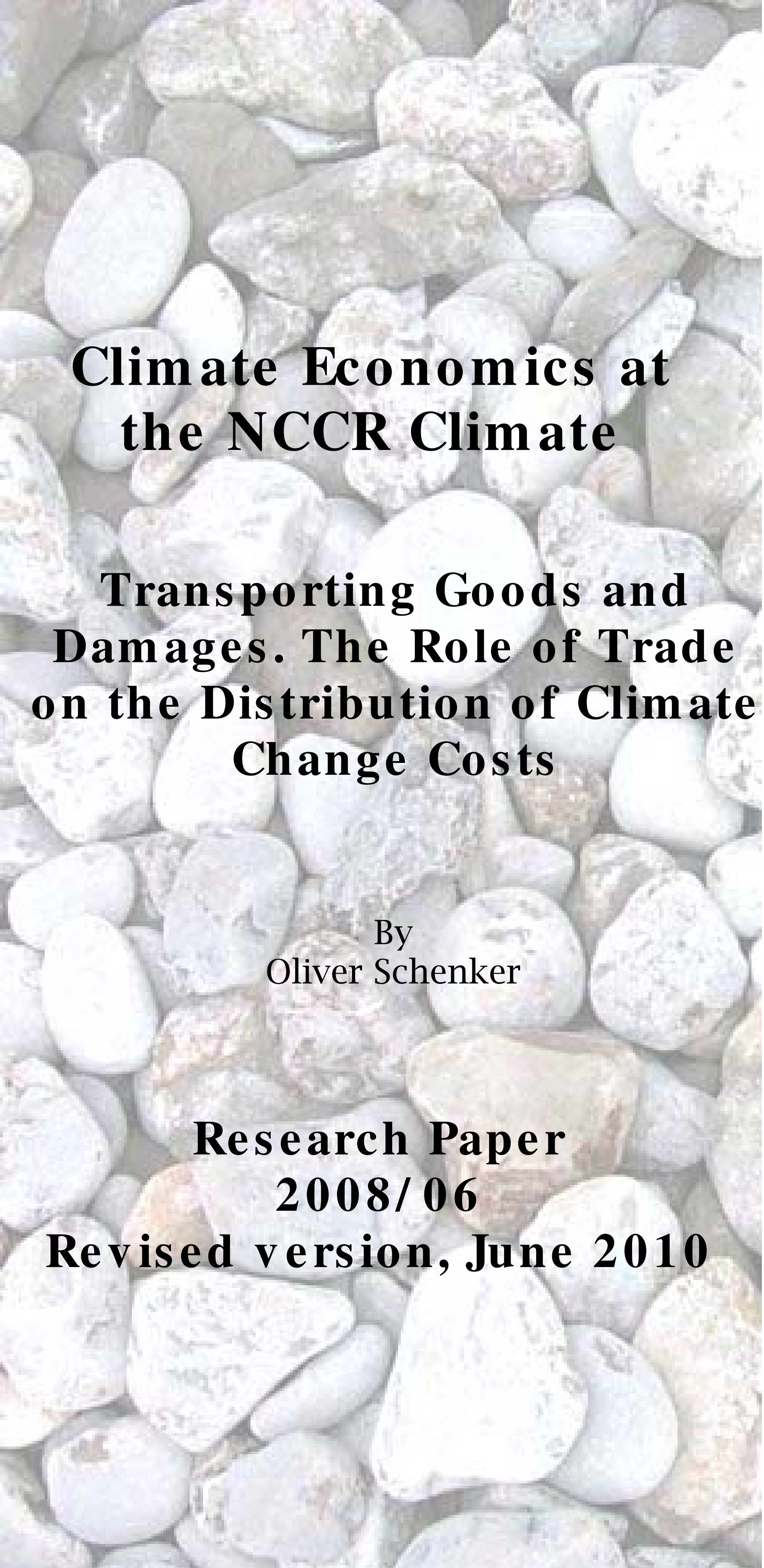

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Oliver Schenker

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Oliver Schenker*

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Abstract

Impacts from climate change vary significantly across world regions. Whereas regions in tropical and subtropical areas will sufer severely from the effects of climate change, are the impact estimates for regions in more northern latitudes relative moderate. But regions can not be considered as independent from each others exposure. In this paper we examine the spillover of climate change impacts between regions through international trade within a climate sensitive, dynamic CGE model with international trade. Under the emission scenario SRES A1B we observe at the end of the twenty-first century regional losses between 2 and 13 % GDP relative to a scenario without climate change. By means of a decomposition method we show that such a spillover of damages through international trade has a significant influence, positive or negative, on the total costs of climate change for a region. For regions with low exposure to climate change and high adaptive capacities, spillover effects are responsible for a third of total costs from climate change.

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

JEL-Classification: C68, D58, F47, O41

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1 Introduction

There is no doubt that global climate is changing. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) provides striking evidence that during the last century the world's surface temperature has increased by 0.6 ℃ in average, and concludes that a further increase by additional 1.4 to 5.8 ℃ must be expected by 2100 (IPCC 2007b).

Today, the impact which 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 multiple socio-economic effects, which might range from merely inconvenient to disastrous. For example, Stern (2006) has estimated that the world economy might suffer losses in the order of 5-7% GDP annually, if global average temperature rises by 5-6 ℃ until 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 the middle of the present century.

However, regions are not equally exposed to environmental and societal impacts from global warming. As shown by Bättig, Wild, and Imboden (2007), the magnitude and direction of precipitation and temperature changes and the probability of extreme weather differ significantly across countries. Whereas countries near the equator are heavily exposed to changes in climatic conditions and variability, the exposure of countries in higher latitudes is much smaller. This is illustrated by Figure 1, which shows the Climate Change Index by Bättig, Wild, and Imboden (2007) per country. This index summarizes annual temperature and precipitation change, as well as the incidence of extreme events as expected from data of global circulation models for the period 2071-2100.

Beside the geographic location, a region's exposure to climate change depends on its abilities to adapt, which in turn depends on the societies' institutions, the level of education and economic wealth (see Brooks, Adger, and Kelly (2005)). Most studies argue that less developed countries in low latidues are more sensitive with respect to climate change and variability (IPCC 2007a) than developed regions, which mostly have the capacity to adapt their economic and social structures at least in parts to the expected climate change disruptions.

Tol, Downing, Kuik, and Smith (2004) discern between four categories of countries depending on their exposure to climate change and variability as well as on the adaptive capacities. The first one covers highly vulnerable countries like Bangladesh, one of the poorest countries in the world and heavily exposed to sea level rise and cyclones. The second category includes countries such as Namibia with low adaptive capacities as well, but which are not exposed to the risks of climate change to the same extent. Countries like Australia and the United States belong to a third category and are characterized by a high ability to adapt to climate impacts. Finally, the last category comprehends countries with high adaptive capacities and low impacts. Examples are countries from

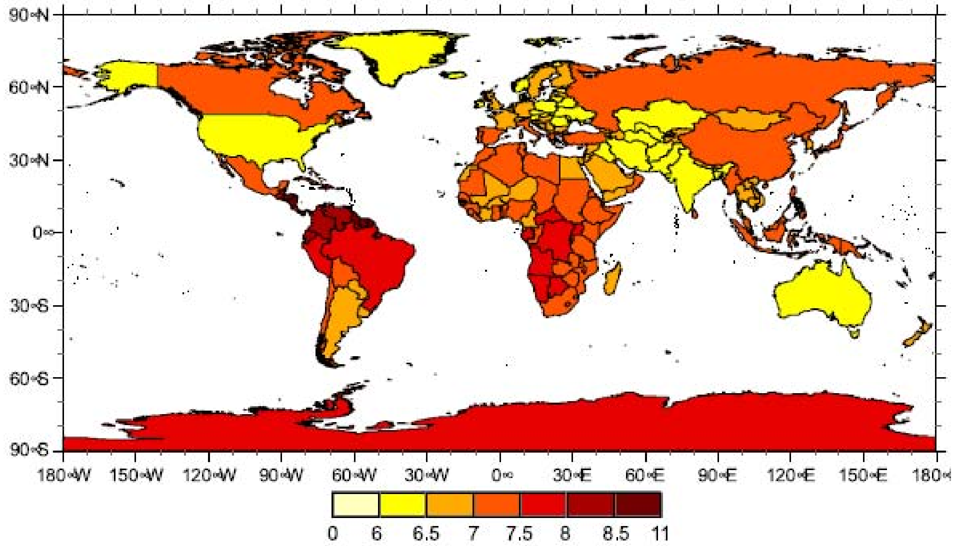

Figure 1: Climate Change Index on country-level for the period of 2071 - 2100. The Climate Change Index is the weighted mean of four indicators: (i) changes in annual temperature, (ii) changes in annual precipitation, (iii) changes in extreme temperature events, and (iv) changes in extreme precipitation events. Source: Bättig et al. (2007)

the northern hemisphere such as Norway and Canada.

As this classification indicates, both the exposure to climate change as well as the ability to adapt, are unevenly distributed across countries. And in most cases, regions which are expected to suffer from severe impacts of climate change, are the ones with low adaptive capacities.

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 prices in international markets and hence on Terms of 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.

Hurricane Katrina provides one of the most striking examples of how damages, which occur in one region, spillover into others. Katrina directly caused total damages of 81 billion U.S. Dollars (in prices of 2005) on property in the regions Mississippi, Louisiana and Alabama (Blake, Rappaport, and Landsea 2007). The massive disruption of oil production and processing in the Gulf of Mexico has led to a shortage in gasoline supply. During the week after the storm, U.S. gasoline prices jumped up by as much as 60 cents per gallon (New York Times, 04.09.2005), and in the United Kingdom gasoline prices rose by 3-4 pence per liter in the aftermath of the hurricane (BBC News, 02.09.2005). British consumers and firms, far away from the Gulf of Mexico, were confronted with higher energy costs, at least in the short run.

There is also empirical evidence that climate shocks affect the exports of a country. A recent paper by Jones and Olken (2010) has estimated the effects of climate shocks on the annual growth rate of exports. Their results show that in poorer, more vulnerable countries the annual growth rate of exports is reduced by 2 to 5.7 percentage points if the annual average temperature is increased by 1 ℃. Obviously this must have an effect also on the importing country.

It is the purpose of this paper (i) to explore both, qualitatively and quantitatively, direct and spillover effects of climate change for regional economies and (ii) to examine how the comprehension of trade changes the distribution of climate related costs and benefits.

To capture the distinction between conventional climate impacts, as used in most existing impact studies (e.g. Mendelsohn, Morrison, Schlesinger, and Andronova (2000)), and effects which are caused by international trade, we use the following definitions: *Direct effects* are impacts of climate change on the regional economy. The resulting costs and benefits are bore in the region which was hit by the climate impact. *Spillover effects* are effects of climate change, which affect welfare in regions different from the one, where the impact has occurred. They materialize in terms of trade effects, i.e. changing relative prices of commodities or factors in international trade.[1]

Discerning between direct and spillover effects is of particular importance for the assessment of climate related costs and benefits for small open economies. For countries which are classified by Tol, Downing, Kuik, and Smith (2004) as countries with low impacts and high adaptive capacities it might happen that spillover effects will dominate the market costs of climate change in the country itself.

For assessing these effects, both quantitatively and qualitatively, we develop a multi-sector, multi-regional, dynamic computable general equilibrium (CGE) model, where the future climate is exogenously given by data from global circulation models.[2] To estimate regional impacts we slightly modified the damage function of Nordhaus and Boyer (2000). Although the formulation has some serious shortcomings, due to it's simplicity it is still used often. This allows to compare our results with other studies.

To assess how the different regional impacts of climate change affect international trade and to which extend impacts spillover into other regions, we apply a decomposition method for general equilibrium effects. This allows to calculate the individual contribution of a region's climate impact on the total costs of climate change for other regions. The decomposition of impacts shows that spillover effects are responsible for about 20-30% of the total climate costs for regions which are provided with high capacities to

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[1] Note that our analysis neglects non-market damages such as amenity value losses from biodiversity, etc. because non-market damages are by definition damages which are not treated by the economic system itself. Such non-market damages will therefore not transmitted by changes in economic institutions as prices, but uses rather different channels as the media, etc.

[2] Since we are not interested in optimal policies with respect to GHG emissions we abstain from closing the carbon cycle and a subsequent cost-benefit analysis of this issue.

adapt and are less exposed to climate change.

Several studies in the field of business cycle analysis examine the transmission of economic shocks from one country to another. Examples are Frankel and Rose (1998) and Baxter and Kouparitsas (2005), who examine the comovement of business cycles of different regions due to a contagion by international trade and factor movement. They find evidence that increased trade between a pair of countries increases the magnitude of transmission of productivity shocks between this two countries. Kose and Yi (2006) then reproduce these effects in a real business cycle model. This spillover of shocks has the same cause and the transmission flows in the same channel as in our model, although our model differs from their model with respect to time horizons and the inclusion of monetary markets.

The rest of the paper is organized as follows: Section 2 explains the mechanism of this spillover effects with an Edgeworth-Box representation at hand. Section 3 discusses (i) the expected impacts of climate change on different world regions, and (ii) explains, how climate change impacts are integrated in the economic model. Section 4 describes the model which is based on a dynamic general equilibrium representation of the world economy. Section 5 presents the results of our numerical simulations. The decomposition of the costs into direct and spillover effects is explained in Section 6. Finally, Section 7 concludes.

2 Spillover Effects: An Illustration

To get some intuition let us briefly discuss the role of spillover effects in the framework of a pure exchange economy as shown in Figure 2. There are two countries, N and S, and the two commodities, x and y, denote the total endowment of good 1 and 2, respectively. S owns the fraction γ (λ) of the total amount of y (x). The remaining endowment $(1-\gamma)$ and $(1-\lambda)$, respectively, are in the property of N. Without trade allocation a will be realized. If there is trade between the both regions, allocation b is attainable, which is Paretosuperior.

Now let us assume that there is a negative asymmetric shock such that S looses half its initial endowments. If, as in Figure 2, S has a high share of the initial endowment in y, y becomes scarce, and hence, more expensive. The terms of trade are worsen from N's perspective, i.e, N now gets less in exchange for a unity of commodity 1 and benefits from trade are lower. Compared to the situation *ex ante*, although not directly affected, N suffers welfare losses because of terms of trade effects resulting from the impact in S.[3]

Figure 2 also shows N's maximum costs resulting from those spillover effects. In case of a total extinction of country S, country N would fall back to the welfare level as in

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[3] Note that also positive spillovers from a negative shock in the economy of the trading partner are possible. If 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 unaffected country. The additional purchasing power would make the not affected country better off.

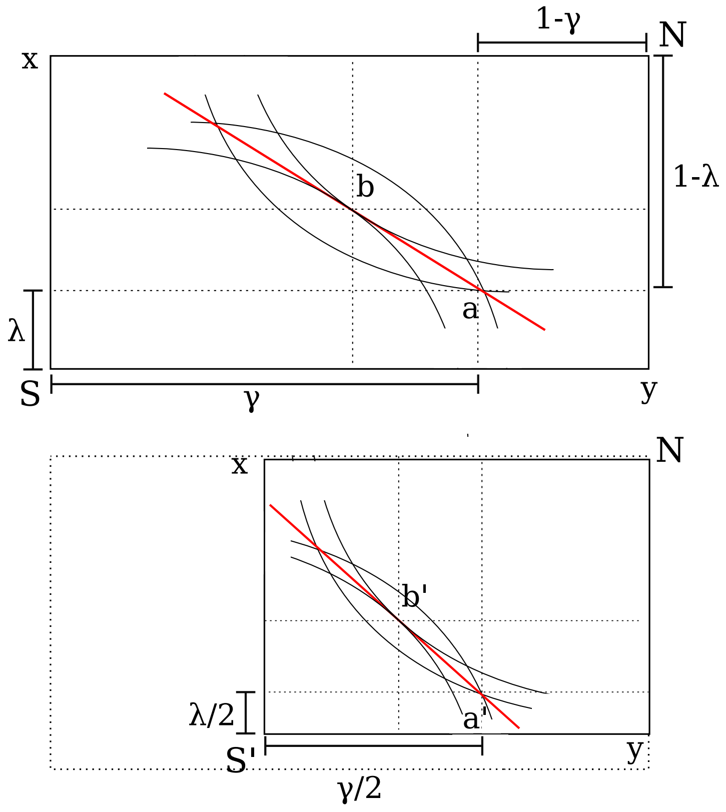

Figure 2: The Edgeworth box above shows the situation before the shock. In the figure below S has lost half of his output after the shock.

autarky. In this case, maximum spillover costs are equal to total benefits from trade.

But this is only one side of the coin. While N has to bear a part of the costs of the shock on S, S profits from bilateral trade. Since the terms of trade effect favors the affected country S, its welfare losses from the negative shock are dampened. From the perspective of S, international trade reduces effective costs from climate change and can therefore be considered as an implicit adaptation measure.

3 Estimating Impacts from Climate Change

Whereas the natural sciences behind climate change are relatively clear and robust, estimates of the socio-economic impacts of climate change are still characterized by a significant degree of uncertainty. Jamet and Corfee-Morlot (2009) identify four reasons, why this is the case: First, projections about the development of greenhouse gas emissions depend among others on population as well as on economic growth, technological progress and policy interventions, which are all difficult to estimate. Second, we do not fully understand all geophysical and ecological feedbacks, e.g. how sensitive the sea level responds to global temperature changes is highly debated. Third, the risk of abrupt and irreversible impacts, as for example a breakdown of ocean currents or an abrupt melting of large ice shields in polar regions, cannot be quantified. Finally, the aggregation of global impacts with an uniform metric is still an open issue, in particular since impacts have to be aggregated along three dimensions: across different sectors, which requires a common measure such US \$, across regions, which raises the question of equity, and over time, where the role of discounting is in debate.

Today, sophisticated climate models are available, but the complexities and computational demands prevent their direct application in integrated assessments analysis. Therefore there is a need to develop proxies to transfer the climate scientists' knowledge into the economic analysis of the greenhouse effect. A proxy for capturing the socio-economic impacts of climate change, typically used in most integrated assessment models and global impacts studies, is the so-called damage function. Generally, these functions are simplified and are calibrated only at two points: (1) the status quo, and (2) the impact of a doubling of the pre-industrial CO_2 concentration in the atmosphere. Moreover, these estimates are mostly based on U.S. data. To estimate climate change impacts in other world regions, these estimates will be simply extraoplated.[4]

Although we are fully aware that the choice of the impact function is crucial for the outcome of a cost assessment of climate change, we resort to the impact and damage

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[4] Not surprisingly, impacts differ largely in existing studies. Mendelsohn, Morrison, Schlesinger, and Andronova (2000) estimate that for a 3 ℃ increase of global mean temperature global costs and benefits almost offset each other, Tol (2002) predicts losses of about 1 per cent of annual Gross World Product (GWP). Nordhaus and Boyer (2000), which include the willingness to pay to avoid catastrophic impacts, forecast costs of about 3 per cent of GWP. The Stern Review (2007) reports a loss of about one per cent of GDP per capita. For a broader discussion of impact estimates in the integrated assessment literature see Stern (2007), Smith, Schellhuber, and Mirza (2001), and Jamet and Corfee-Morlot (2009).

sub-model of the *R*egional Dynamic Integrated Climtate Economy (RICE) framework (Nordhaus and Boyer (2000)) for four reasons: (1) it includes a wide range of affected sectors, (2) it captures regional differences in adaptive capacity, (3) it is transparent in the aggregation of damages, and (4) it is relatively easy to adapt to our needs. Nevertheless, the comparison with simulation results of different impact modules would give additional insights about the sensitivity of our results. We leave that open for future work.

The RICE damage assessment captures both market and non-market damages (which we neglect as described for the subsequent analysis). Market damages can be expressed in terms of a national accounting system. They include impacts of climate change on the agricultural sector, on coastal resources, on forestry, energy- and water systems, on construction, on fisheries, and on certain settlements, which can not be protected from climate change.

Additionally, Nordhaus and Boyer (2000) use information from expert interviews about the likelihood of occurrence of catastrophic events at a certain temperature increases to calculate the willingness to pay to avoid such catastrophic damages. The resulting insurance premia are significant for some regions. For example, India, that will suffer from a potential shift in monsoon pattern, or the European countries, which face a potential change in the thermohaline circulation, are willing to pay about 2% of GDP to avoid this risks. This inclusion of catastrophic events is the main reason for the significant larger impacts for temperatures above 2 ℃ compared to other impact assessment studies.

3.1 Climate Data

To estimate the future climate impacts, we require information about future temperature changes. For that we use temperature data generated by the general circulation model (GCM) ECHAM5 (Roeckner, Bauml, Bonaventura, et al. 2005), which has contributedimporant findings for the recent fourth assessment report (AR4) of the *Intergovernmental Panel on Climate Change* (IPCC) (IPCC 2007b, ch.10). The resolution of ECHAM5 is about 200 km, which is detailled enough to calculate average temperature changes for the world regions in our model.

The ECHAM5 model provides average monthly surface temperature data for every grid point at the time periods 2011-2030, 2046-2065, and 2080-2099. Temperature anomalies are calculated relative to the mean of the period 1961-1990.[5] We aggregate annual mean temperature anomalies for every region and assume a lineary temperature increase linearly between the declared periods.[6]

The main driver of the atmospheric warming are antropoghenic greenhouse gas emissions. Although strongly depending on economic developments, emission scenarios are exogenously given in our model. However, since we are not interested in optimal mit-

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

[6] See Table 3 in the Appendix for regional mean temperatures in 2100.

igation policies, such a cost-effectiveness approach is justifiable. The future emission projections, which serve as input for the GCM-data used in our model, are given by IPCC SRES scenario A1B (Nakicenovic and Swart 2000), the most prominent scenario in IPCC AR4. But note thate these scenarios do not consider explicit policy actions to mitigate greenhouse gas emissions.

The highest temperature increase is observed in polar regions. The large mean temperature increase in Russia and in North America can be explained mainly through the accelerated warming in northern parts of the respective countries. [7]

Apart from polar regions are he highest increase in regional temperature (about 5.5 ℃ in 2100) expected in South Asia. For Europe the expected temperature rise will be approximately 4.5 ℃. In areas, which already today face high average temperatures such as Sub-Sahara Africa, temperatures will disproportionately increase by 5.2 ℃. On average the world temperature will rise 4.22 ℃ relative to the control period. The relative low increase is caused by the slower warming of the inertial ocean surface.

3.2 Calibrating the Damage Function

We divide the world into regions which differ with respect to the exposure to in international trade and the exposure to the risks of climate change. Therefore our model slightly differs from RICE. First, in contrast to RICE, which discerns between eight regions, our model distinguishes between fifteen regions. Table 3.2 shows the regional aggregation. Second, whereas in RICE regional impacts are related to global mean temperature change, we use differentiated temperature estimates for every region.

To calculate climate impacts we distinguish between impacts depending on regional temperature changes and impacts, which are caused by global scale changes. For each region r the aggregated impact at date t is represented by the sum of two quadratic functions. For an explanation remember that climate impacts on agriculture, forestry and fisheries, on energy- and water supply, in outdoor recreation, in settlements, and in human health are primarily driven by changes in regional temperature. But sea level rise is caused by temperature changes in polar regions as well as by the expansion of warmer water, which depends on air temperature over the ocean. Therefore global mean temperature change is viewed as main causer for this global scale processes.

For calibrating the regional damage functions we neglect non-market damages. Instead we concentrate the analysis only on impacts from market based sectors, which are calibrated by data from the RICE model. That means in particular that a 2.5 ℃ average warming would imply in the agricultural sector impacts, which range from benefits of 0.87 % GDP in GUS to annual costs of 0.5 % in Southern Europe. If global mean temperature raises by 6 ℃ this could cause severe impacts on coastal infrastructure. The studies considered in Nordhaus and Boyer (2000) estimate costs of 3.3 % GDP for

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[7] The Arctic regions in those countries are sparsely populated and of less economic importance, but our economic data, which is aggregated on a county-level, does not allow to control for with-in country heterogenity. We thus potentially overestimate economic damages in this two large countries.

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 1: The regional aggregation of the model.

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, which is included in the impact assessment of the RICE model, is not a clear-cut market damage, since the costs caused by such events are not totally captured by national accounting systems and have also a non market component. But we argue that the predominant part of the costs from catastrophic events is reflected in economic terms and should be included in such an analysis. Compared to other global impact studies the comprehension of catastrophic impacts causes significant higher damages in European regions and in South Asia. The catastrophic events which cause this high costs, are in the case of Europe the potential shutdown of the thermohaline circulation and the increased probability of a significant shift in the monsoon patterns in South Asia. To avoid this risk in case of a 6 °C warming, the two regions would be willing to pay an insurance premium of 13 and 15 % GDP, according to Nordhaus and Boyer (2000).

Summarizing the results from above, the climate-damage relationship used in the economic analysis can be described as follows:

$$D_{r,t} = \theta_r^1 \Delta RT_{r,t} + \theta_r^2 (\Delta RT_{r,t})^2 + \theta_r^3 \Delta GT_t + \theta_r^4 (\Delta GT_t)^2. \tag{1}$$

At date t region r has to cope with economic costs from climate change $D_{r,t}$. These damages are a quadratic function of the regional temperature change relative to pre-industrial times, $\Delta RT_{r,t}$, plus the change in the global mean temperature, ΔGT_t. The coefficients θ_r^j, $j \in \{1,2\}$ ($j \in \{3,4\}$) capture the economic sensitivity to regional (global) mean temperature changes.

Note that the different European regions have identical damage coefficients, since the impact data from Nordhaus and Boyer (2000) does not allow to distinguish between different European regions. This does not imply, however, that damages in a particular point in time are equal since temperature changes may differ.

4 The Economic Model

To analyze how climate change affects international trade and to isolate direct from spillover effects we develop a multi-commodity, multi-region dynamic general equilibrium model of the world economy. The time horizon covers a period of 100 years. The model starts in the year 2010 and the results are reported every 10 years. Each region is viewed as being homogeneous and acts as if it is represented by a representative agent, who maximizes intertemporal welfare. Changes of the global climate is given for the regional decision makers, and hence, the adaption of trade patterns, investments and production decisions are the only options to minimize costs from those impacts.

At each point in time there are five commodities, which are traded on open international markets. These are (1) agricultural products ($A_{r,t}$) such as crops, wheat, but also outputs from forestry and fishery, (2) basic material ($B_{r,t}$), which covers labor intensive produced goods like clothes, (3) high value goods ($H_{r,t}$), which are capital intensive manufacturing goods such as machinery and motor vehicles, (4) services ($S_{r,t}$) like health, transport and financial services, and (5) fossil fuels($F_{r,t}$). For the composition of the commodity classes see Table 4 in the Appendix.

Further inputs into regional production are capital, labor and renewable energy, which are, however, not traded internationally. The model is formulated as a mixed complementarity problem (MCP) with the GAMS software package (Rutherford 1995). Many other prominent models in this field are formulated as non-linear programs and use through an iterative method defined weights in the objective function. The formulation as a MCP allows to abstain from those error-prone iterative algorithms.

4.1 Production and International Trade

Production is highly aggregated. For the sake of simplicity we assume that (1) all regions have access to the same production technologies, and (2) there is no technological change. The production of all goods are characterized by constant elasticities of substitution (CES). All production functions are homogeneous of degree one.

In each region a specific macro-good $Y_{r,t}$ is produced with two aggregates of inputs: a composite good $G_{r,t}$, which aggregates total regional demand of A, B, H, S and energy $E_{r,t}$ with

$$Y_{r,t} = \Omega_{r,t}(\theta_r^Y E_{r,t}^{\rho_Y} + (1-\theta_r^Y) G_{rt}^{\rho_Y})^{1/\rho_Y}, \tag{2}$$

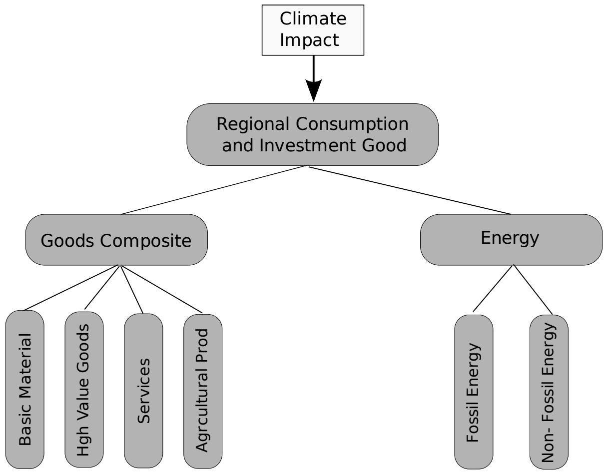

Figure 3: Regional gross production $Y_{r,t}$ is an aggregate of a composite good and energy. Goods are traded internationally and energy is based on international traded fossil energy and non-traded non-fossil energy.

where $\Omega_{r,t} = 1/(1 + D_{r,t})$ is the regional climate damage factor. $\Omega_{r,t}$ captures the economic costs of climate change as described in the chapter before. The higher damages $D_{r,t}$ are, the smaller is the net output of a region. Figure 3 shows the top-level of the production structure.

The net macro output $Y_{r,t}$ can be consumed $C_{r,t}$, invested in regional capital stock $I_{r,t}$ or used as an input in the production of traded commodities $IM_{r,t,i}$. Hence, the following market clearance condition has to hold for the macro good:

$$Y_{r,t} = C_{r,t} + I_{r,t} + \sum_i IM_{r,t,i},\ \forall i \in \{A, B, H, S\}. \tag{3}$$

Further inputs into the production of commodity i are capital and labor. Figure 4 explains the basic production structure of the model. The produced output of good i then can be exported and/or used domestically. Imports and the domestically used outputs serve then as inputs in the regional macro production.

Since all regions use the same production technology, the rationale for trade are (1) differences in factor endowments and (2) different exposure to climate impacts. The first rationale refers to a Heckscher-Ohlin type of trade whereas the second is based on classical Ricardian considerations of comparative advantages.

We assume non-perfect substitutability between domestic and foreign goods of the same variety (Armington 1968). This assumption is assumed for all traded commodities except for the fossil energy market. For this highly standardized good we suppose perfect homogeneity and hence a common world market price.

The model abstracts from explicit trade distortions. Neither transportation costs nor an explicit modeling of tariffs or export subsidies are considered in the model. We further do not allow for imbalances in trade balances.

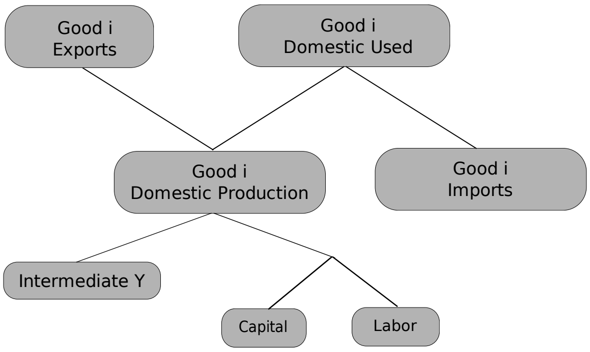

Figure 4: Capital, labor and the macro good $Y_{r,t}$ serve as inputs for the production of good i. A fraction of the production of commodity i is then exported to foreign. The remaining share together with imports enter in turn in the macro good production.

4.2 Intertemporal Utility Optimization

To determine optimal consumption and investment trajectories we use a Ramsey approach. More precisely, in each region r a representative agent maximizes a constant intertemporal elasticity of substitution utility function (CIES).

$$U_r = \sum_{t=2010}^{2100} (\frac{1}{1+\delta})^{-t+1} \frac{C_{r,t}^{1-\sigma} - 1}{1-\sigma}, \tag{4}$$

where δ describes the discount rate and σ refers to the inverse of the intertemporal elasticity of substitution. From period t to period $t+1$ households face the following budget constraint:

$$p_{r,t}^{Y}(C_{r,t} + I_{r,t}) = w_{r,t}\overline{L}_{r,t} + rk_{r,t}K_{r,t} + p_t^F \overline{F}_{r,t} \ , \tag{5}$$

thus expenditures for consumption and investment expressed in prices of the macro good, $p_{r,t}^{Y}$, have to be equal to capital and labor income, where $w_{r,t}$ and $rk_{r,t}$ denote the wage and rental rate of capital, respectivly, plus the rent from selling the endowment of fossil energy on the international market $p_t^F \overline{F}_{r,t}$.

Note that production factors are only mobile within but not across regions[8] and the capital stocks depreciate at a constant rate, which is identical for all regions.

4.3 Calibration of the Economic Model

The economic growth rate is one of the main drivers of the future emissions of greenhouse gases and strongly influence expected climate change. To assure that the temperature change, which is the trigger for impacts, is consistent with the greenhouse gas emission

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[8] Although the consideration of factor mobility might be important to map the whole magnitude of spillover effects, we neglect the possibility of foreign direct investments in this paper. Allowing production factors to move in regions which are less exposed to climate change might be an efficient type of adaptation. Since we focus on the examination of the principal mode of action of spillover effects, we let the question about the consequence of factor mobility open for further research.

trajectory and the respective extensiveness of the economy, exogenous growth rates are taken from the IPCC SRES emission scenario A1B.

Since the time horizon of the model is finite, whereas the maximizing household mimic as if his horizon would be infinite, problems related to end of time effects may appear. To avoid this problems we apply the methods suggested by Lau, Pahlke, and Rutherford (2002).

Finding realistic elasticities of substitution is a difficult and often unsatisfied challenge. Difficult because the choice can strongly influence the results. Unsatisfying because not enough empirical evidence exits, which would help to choose the 'right' elasticity, especially over such a long time horizon. Nevertheless, Armington elasticities are taken from Gallaway, McDaniel, and Rivera (2003). Other elasticities such as the elasticity of substitution between capital and labor in the different sectors are taken from Okagawa and Ban (2008) and Kemfert and Welsch (2000). In section 5.3 will we conduct a comprehensive sensitivity analysis of the chosen parameter values.

The regional economies and their trade patterns are calibrated with data from the GTAP6 project (Dimaranan 2006).

5 Counterfactual Analysis

The climage change costs of a region are defined as the difference between the outcome of the *baseline* scenario with no climate induced impacts and the outcome of a scenario with climate induced impacts as described above. We call the climate change scenario *A1B* with respect to the corresponding emission scenario.

5.1 The Costs of Climate Change

The comparision of the two simulations shows that climate change causes significant costs for the world economy in the long run. Figure 5 illustrates the differences in main indicators between the two scenarios. We observe a slightly higher Gross World Product (GWP) in *A1B* compared to *baseline*, but from 2035 onwards adverse impacts from climate change increase. In 2100, annual losses from climate change account for 4 per cent of the *baseline* GWP. The positive effect on GWP during the first third of the twenty first century can be explained by two reasons: on the one hand, a small warming causes benefits in some regions due to increases in agricultural productivity. On the other hand, regions accumulate more capital in the beginning to smooth consumption over time and damp larger impacts in later periods.[9]

The negative impacts of climate change in later periods depend on several factors. First, the average temperature at the end of the century in the different regions is by 4 ℃ up to almost 7 ℃ higher than today. According to our calibrated climate damage

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[9] Note that this additional capital accumulation is an implicit kind of adaptation against damages in later periods from climate change. Obviously, the size of this effect depends on the supposed discount rate.

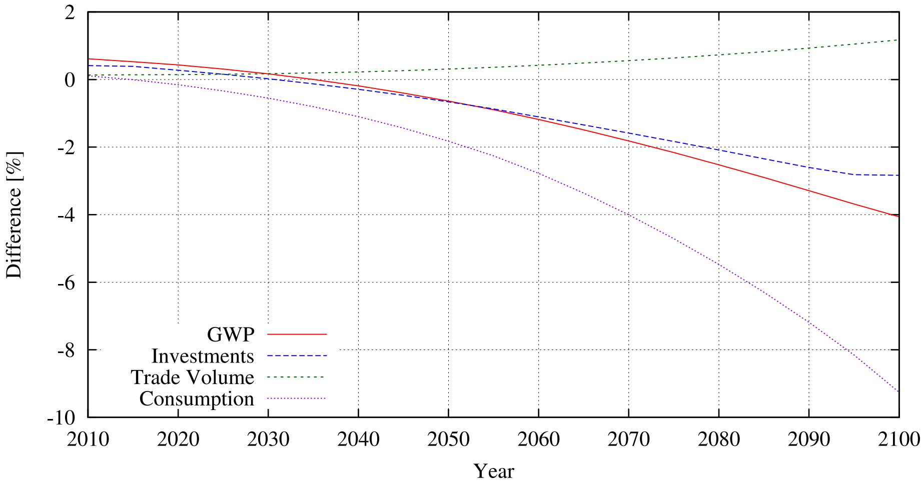

Figure 5: Changes in GWP, aggregated investments, trade volume, and consumption relative to the baseline scenario.

function such a warming would cause an annual loss of GDP between 1 and 9.2 %. But this neglects the inherent economic dynamics of the process. As pointed out by Fankhauser and Tol (2005) two types of "horizontal linkages" are relevant for the assessment of climate induced economic costs. If a constant saving rate is assumed, a climate induced output loss leads to a reduction of savings and investments since less capital is accumulated, and hence, output is lower. In a Ramsey-Cass-Koopmans model, such as the one used here, a second effect matters since forward-looking agents anticipate future climate costs and adapt saving decisions. Thus, savings may increase to compensate losses in future income or may decrease as damages reduce capital productivity.

A comparison of both investment trajectories shows evidence for both cases. In the first thirty years of the simulation period, the sum of regional investments is slightly higher in *A1B* compared to *baseline* to compensate future shortfalls and to profit from productivity gains, which come along with a moderate warming.

A further factor which affects climate change induced costs are the so called intermediate effects (Stern 2007, p.152). The production of most goods uses intermediate goods as inputs and when these inputs already are affected by climate change, damages in one sector can multiply damages in others. Impacts in the water sector for example may amplify impacts in agriculture. The model capture this characteristic by the use of net (affected) GDP as an intermediate input in the sectoral production.

Since climate change is exogenous the only adjustment mechanism besides changes in capital accumulation is trade between the different severly affected regions. As pointed out by Juliá and Duchin (2007), increasing world trade might be an efficient adjustment strategy for agriculture and probably also for other affected sectors. Our model resultat give an indication for this argument. The global trade volume, which is defined as the sum of all exports relative to GWP increases with increasing global warming. This adjustment of regional sectoral production reduces the total costs from climate change

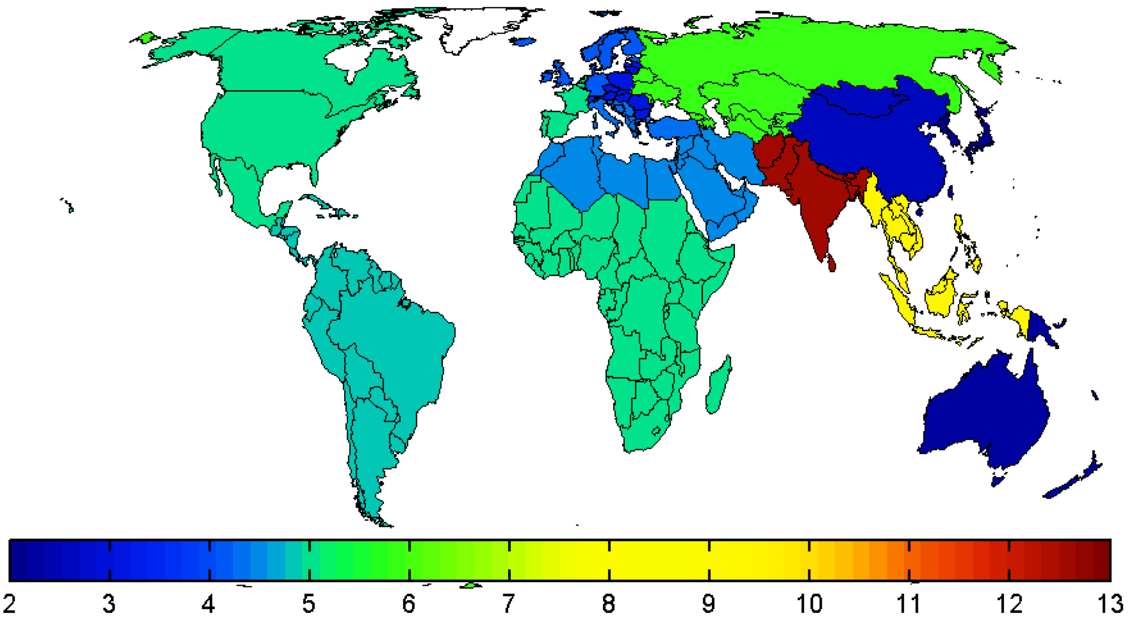

Figure 6: Regional Costs from Climate Change in 2100 in percent of GDP relative to the baseline scenario, $\Delta GDP_{r,2100} = -100 \times \frac{Y^{A1B}_{r,2100} - Y^{B}_{r,2100}}{Y^{B}_{r,2100}}$.

impacts. But these costs are not uniformly distributed among regions. Figure 6 shows large differences in regional damages. East Asia looses only about 2 % of GDP compared to *baseline*, whereas South Asia has to cope with costs of 12.5 %. Global warming lowers GDP for the different European regions from 3 to 5 %, whereas NAFTA has to bear costs of 5 % of GDP from climate change in 2100. Note that in absolute terms the loss in NAFTA is larger than the loss in South Asia. An aggregated view substantially underestimates the costs from climate change for poorer regions. But the less developed regions in Sub-Sahara Africa, South - and South-East Asia and partly South America, the regions with that have contributed the least to the anthropogenic greenhouse gas emissions are the most affected regions from climate change.

5.2 Trade Impacts of Climate Change

The regional differences in exposure to climate impacts causes differences in the regions productivity and therefore have may influence the competitivness of a region. To examine the effects on competitiveness in more detail, we calculate the Revealed Comparative Advantage (RCA) index as introduced by Balassa (1965). In his most simple form the index is defined as

$$RCA_{r,i} = \frac{X_{r,i}}{\sum_i X_{r,i}} / \frac{\sum_r X_{r,i}}{\sum_r \sum_i X_{r,i}}, \qquad (6)$$

where $X_{r,i}$ denotes the region r's exports of commodity i. If the RCA is greater (smaller) than unity, the region has a comparative (dis)advantage in the production of

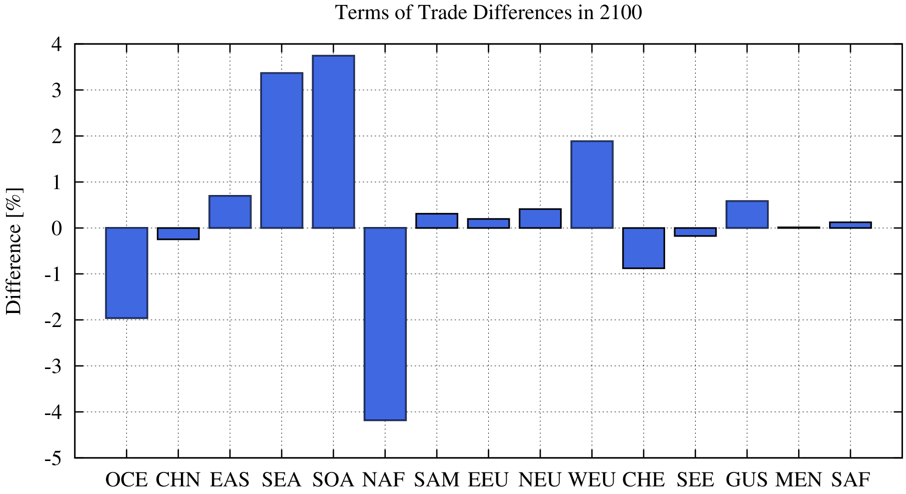

Figure 7: Percentage change in Terms of Trade comparing baseline and A1B in 2100.

the respective commodity.

The analysis shows that existing comparative advantages are not reversed under climate change, but rather reinforced (see Table 5 in the Appendix). The regional competitiveness in commodity production seems to be relativly persistent. South Asia, which has already a comparative advantage in agriculture, can increase its advantage within that sector. Since South Asia is one of the most exposed regions to climate change, it cannot accumulate capital at the same rate as other regions and hence, cannot compete in more capital intensive sectors. It can be seen in Table 5 that generally less affected regions gain market shares in capital intensive sectors, whereas the relativly more affected regions gain competitiveness in labor intensive sectors. And since the more affected regions are almost identical to the developing regions with low capital stocks, a reinforcing of existing patterns of trade is the consequence.

In the trans-boundary transmission of climate change costs, changes in Terms of Trade (ToT) play the decisive role. As shown in the simple Edgeworth-box example above (see Figure 2), divergent output shocks influence the ToT, defined as the price of a country's exports relative to imports. Commodities from regions which are more affected will become more scarce. This raises the price of exports relative to the price of imports. The less affected region thus gets less in exchange for the exported commodity. Hence its ToT are decreasing, whereas the ToT of the stronger affected region are increasing. Figure 7 depictes the percentage change in ToT, comparing both scenarios in the year 2100. As explained above, the geographic pattern of climate change impacts reinforces the production allocation in the world economy. Due to climate damages agricultural production in less capitalized economies decreases and prices increase relatively to capital intensive goods. Hence capital abundant and less affected regions such as NAFTA have to cope with a deterioration of ToT, whereas stronger affected regions such as South and South East Asia profit from improved ToT.

This shows that international trade may lead to a more equal sharing of the unequal

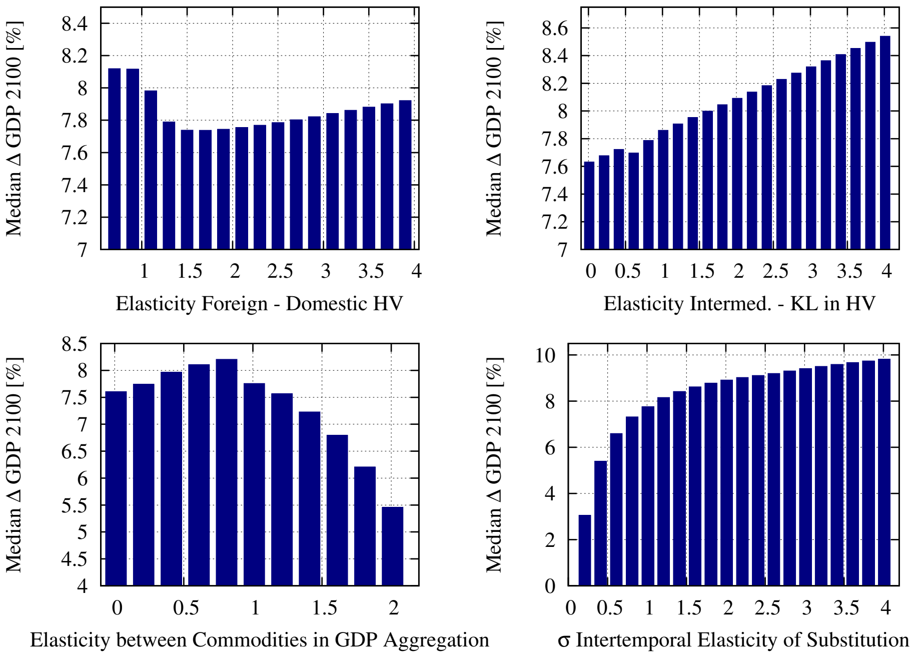

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Figure 8: Sensitivity analysis. All graphs show the median loss in regional GDP in the year 2100 due the climate change relative to the baseline scenario.

distribution of climate impacts among world regions. The stronger affected regions can shift a fraction of their market damages to the less affected trading partners, since the unequal exposure causes a change in ToT in favor of the stronger affected regions.

We will discuss the policy implications of these results more in detail in the concluding section of this paper. In the next section of the paper we will decompose the partition of the total costs of climate change in direct and spillover effects. This will indicate how relevant such trade induced spillover effects are for an accurate assessment of climate change costs.

5.3 Sensitivity Analysis

But first we will examine the parameter sensitivity of the model with respect to a region's total costs from climate change. We have done a careful sensitivity analysis for all crucial parameters in the model. The model responds quit robust on parameter changes. In general, assuming an complementary or a nearly perfect substitution relationship in the CES production functions change the total costs in terms of GWP just about 1.5 percentage points.

Figure 8 presents four exemplary cases. The panel in the top-left shows the by climate change induced median loss in regional GDP in the year 2100 for a different Armington elastcities of subsitution between domestic and foreign high value goods. Climate change costs are high for very low elasticities, decreases for medium parameter values and does slightly increase again. But the differences between different parameter values are moderate.

If we compare different elasticities in the aggregation of the commodities as in the panel in the bottom left, it is obvious that higher elasticities reduce climate change costs. A higher elasticity allows for more flexibility in consumption and hence, a better adapation of trade patterns to minimize costs from climate change.

As shown in the panel in the bottom right of figure 8 causes an increase in intertemporal elasticities of subsitution σ significant increases of losses. Since a higher σ allows for a better subsitutionability between the consumption of different periods it reduces the necessity to invest capital and maintain the economy under such unfavorable circumstances such as in the *A1B* scenario in the year 2100. Hence, the differences between climate change and the baseline case are rather increased.

6 Decomposition of Climate Change Impacts

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

General equilibrium modeling has the advantage of being more realistic with respect to the functionality of the economy, but has the disadvantage that many processes happen simultaneous. Positive or negative feedback cause an amplification or a reduction of an exogenous shock. If simultaneously different shocks take place, an assignment of the economic impact of a certain shock is challenging. Several methods have been developed to overcome this problem.

For differentiating between domestic impacts on the one hand and foreign ones on the other we apply a method, which was suggested by Harrison, Horridge, and Pearson (2000). It is in the nature of the problem that climate impacts happen simultaneously in different regions. In a *ceteris paribus* examination one regional climate impact would shock the system after another. And hence, the magnitude of a shock impact depends on the sequence of his incidence. For example the impact of climate change in NAFTA on East Asia's ToT depends on whether South Asia's climate impact are already taken into account or not. But with n regions, $n!$ different sequences of shocks are possible. To overcome this problem Harrison, Horridge, and Pearson present a generic decomposition method which is independent from the order of shocks. Their method calculates the contributions of a single shock on the examined variable such that the rate of change across all exogenous shocks is kept constant.

The original decomposition procedure by Harrison, Horridge, and Pearson (2000) was implemented in GEMPACK: Böhringer and Rutherford (2004) have developed an implementation for CGE models in GAMS. The approach of Böhringer and Rutherford needs a repeated solving of the model to evaluate the necessary derivatives numerically, which makes the decomposition procedure relative CPU time intensive.

Since we use a multi-period model, from a theoretical point of view one should calculate the contribution of the climate impact of a certain region and at a certain time period on current and future time periods in all other regions. Because of reasons for computational efficiency we simplify the decomposition and consider only the contribution of a specific regional impact on the same period on other regions. To do that we use a static version of the dynamic trade model, which is able to replicate the periodic equilibria of the dynamic model.

The application of the above explained decomposition technique shows that because of international trade regional climate impacts can affect the welfare of economies which are geographically far away from the location where the impact occurs. We show this exemplary with the decomposition of general equilibrium effects from regional climate impacts in the year 2100.

Figure 9 shows the difference in discounted regional GDP between the *baseline* and *A1B* scenario and the respective contribution of direct and spillover effects to the total difference in percent of baseline GDP. As we have seen in the last section, climate costs are unequal distributed among regions. The same holds for the distribution of spillover and direct impacts. There seems to be no clear relationship between the magnitude of direct and spillover effects. South East Asia and South Asia, the two regions which have to cope with the largest impacts, profit differently from the spillover effects and their integration into international trade. Whereas South East Asia is able to reduce climate costs by about 15 % due to improved Terms of Trade, South Asia is not able to profit from this channel. The ability to profit from spillover effects depends on (1) the demand for commodities for which the affected region has a comparative advantage and (2) on the state and ability of the trading partners to buy the supplied goods.

There seems to be also evidence for our hypothesis that in the case of countries which have higher adaptive capacities and are less exposed to direct impacts, such as most developed regions, spillover impacts are responsible for a significant part of total climate costs. In all European regions apart from Eastern Europe and in NAFTA the fraction of spillover impact on total climate costs is about one third. The decomposition of the general equilibrium effects shows that direct impacts alone explain only a part of the total costs from climate impacts a region has to cope with. It is therefore necessary for an accurate assessment of a region's climate costs to incorporate the effects on trade from differences in the climate impact exposure.

7 Concluding Remarks & Policy Implications

We have showed in a general equilibrium model and with regional climate scenarios that costs from global climate change are not uniformly distributed among regions. Whereas regions in higher latitudes have at the end of the century between 2 - 3 % less GDP compared to a situation without climate change, South Asian regions have to cope with a loss in GDP in the range of 10 and 12 %. This heterogeneity influences also regional competitiveness and Terms of Trade.

We are able to show that linkages from international trade matter for an accurate

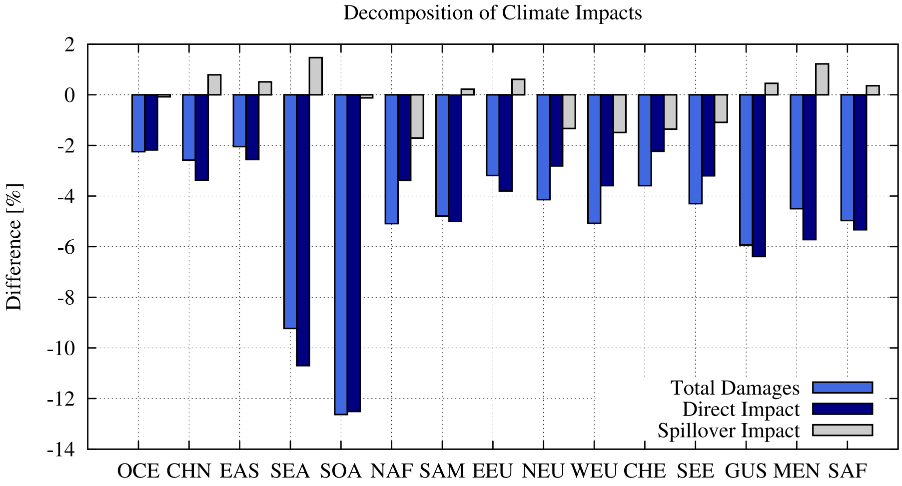

Figure 9: Total costs, direct and spillover effects of climate change in percent of baseline GDP.

assessment of the climate costs. Since the today less developed regions will be harder affected from environmental changes, imbalances in regional competitiveness will be pronounced. The main driver for the changing competitiveness is the impact of climate change on capital accumulation. Hence the largest changes in the competitiveness are observed in capital intensive goods. Regions, which start already with higher capital stocks and are relatively less affected by global warming, such as most of the OECD countries, gain competitiveness in this commodities. Contrary developing countries are only able to compete in labor intensive goods such as agriculture. Our results therefore contradicts results from partial equilibrium studies of the agricultural market as in Juliá and Duchin (2007), which suggest that climate change is not a problem for total agricultural supply, since production will shift towards North. Since trade balances have to be equalized, the South is compelled to produce labor intensive commodities whereas the North has still a comparative advantage in the production of capital intensive goods. From that perspective trade is not an effective moderator of differences in climate change impacts. Due to that argument, Cline (2007) argues that the notion that trade will greatly reduce losses from climate change has a “let them eat cake” flavor.

Our analysis shows further that climate change also slows or reverses the convergence process between developing and developed regions, which contradicts the assumed regional convergence in most of the IPCC emission scenarios.

The linkages between different affected regions through international trade cause spillover effects, which may affect regional welfare. To identify the magnitude 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 might be relative severe. Due to gains in Terms of Trade, most developing regions with higher exposure to climate change impacts benefit from better ToT, whereas in in the case of most European regions and

NAFTA spillover effects are responsible for a third of expected total costs from climate change. This shows that for an accurate cost assessment this international dimension has to be included. But by the same token it should also be mentioned that a towards more protectionism oriented trade policy in the less affected regions can not reduce welfare losses from climate change, since it just would voluntary abandon welfare gains from trade, which are by definition greater than the spillover effects. Since international trade causes an efficient allocation of production factors and dampens global costs of climate change, it is rather appropriate to fortify efforts for stronger multilateral trade agreements.

This study shows that the two topics climate change and international trade should be discussed in a common context to accuratly assess the costs of climate change for a specific region. The nexus between trade and costs of climate change 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 reduce spillover costs for regions, which are less affected by direct impacts. Since the divergence in capital accumulation is one of the main drivers for the changes in competitiveness, a further facilitation of capital mobility between regions may help to reduce the problem as well.

We highlight in this study the link between the costs of climate change and international trade. But there are still a lot of open questions and hence this complex deserves to be examined more in detail in further research. Better knowledge about the sectoral impacts of climate change for example might help to get a sharper picture about the impacts of climate change on international trade and production patterns. The comprehension of newer theories of international trade may also generate additional insights for such second order consequences of climate change.

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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 2: Estimated coefficients of the damage function. Based on data of Nordhaus and Boyer (2000).

A Appendix

Region	ΔT
Switzerland	4.75
China	5.33
East Asia	4.23
South East Asia	3.98
South Asia	5.57
NAFTA	5.76
South America	4.60
Oceania	4.57
Sub-Sahara Africa	5.25
MENA	5.06
GUS	6.88
Eastern Europe	4.62
Northern Europe	4.86
South & Southeastern Europe	4.63
Western Europe	4.41
World Average	4.22

Table 3: Average regional annual temperature anomaly in 2100 in degree Celsius. Calculations based on ECHAM5 A1B.

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 4: Sectors in the model and the assigned goods

Sector	A		B		H		S	
Region	*Base*	*A1B*	*Base*	*A1B*	*Base*	*A1B*	*Base*	*A1B*
CHE	0.19		0.44		0.99		1.46	
CHN	0.64	+ .01	2.12	+ .01	0.94		0.65	
EAS	0.35		1.06	+ .01	1.45		0.41	
EEU	0.73		1.38		0.88	- .01	1.08	
GUS	1.35	+ .01	2.75	- .01	0.52		0.86	
MEN	1.55	+ .02	1.39		0.87		0.89	
NAF	0.89	+ .02	0.60	+ .03	1.03	+ .01	1.17	+.04
NEU	0.71	- .02	0.48	- .01	0.93		1.42	+.02
OCE	3.53	+ .03	0.83	+ .02	0.45	+ .01	1.36	-.01
SAF	3.33	+ .03	1.94	- .02	0.65		0.59	
SAM	3.78		1.64		0.63		0.65	
SEA	1.37	+ .02	1.11	- .03	1.28	- .01	0.44	+.02
SEE	0.63		1.02	- .01	0.73		1.50	-.01
SOA	1.98	+ .08	2.93	- .08	0.52	- .01	0.64	+.01
WEU	1.00	- .03	0.51		0.87	- .01	1.43	+.03

Table 5: Values in column *Base* show the Revealed Comparative Advantage for the year 2100 under the baseline scenario. Column *A1B* shows the change in the RCA index caused by climate change. If cells are empty no significant change was observed.