Discussion Paper No. 12-056

Terms-of-Trade and the Funding of Adaptation to Climate Change and Variability

An Empirical Analysis

Oliver Schenker and Gunter Stephan

Zentrum für Europäische
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Centre for European
Economic Research

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Non-technical summary

Regional economies significantly diverge in their exposure as well as their capacity to adapt to climate change and variability. Between 1984 and 2004, if measured in percent GDP, costs of climate impacts were three times smaller in high-income countries than in low- to middle-income ones, where 80 percent of the world population lives.

The COP17 meeting at Durban once again demonstrated that the world community presently is unable to establish an international agreement on greenhouse gas abatement, which extends the Kyoto Protocol. This makes adaptation an urgent option for insuring against the threat of global warming. However, adaptation to climate change is costly and many developing countries lack the financial, institutional and the human resources for coping effectively with climate change.

Fairness and equity are major arguments why the industrialized countries should assist the developing countries. But there are further ones. Adaptation can help to ensure that the developing countries remain partners for economic growth, global governance and international trade. In particular, adaptation can moderate the terms-of-trade effects of climate related events as for example the one observed in 2008. After six years of drought Australia's rice production collapsed almost completely. Combined with other factors this caused a doubling of the world market price of rice, which led to panicked hoarding and violent protests. Indeed, even if free trade can curb climate change impacts, output losses in one single country might cause rising world market prices and the resulting terms-of-trade effects can pertain to real income losses in almost any country.

This paper analyses the interrelationship between international trade, regional adaptation and North-to-South transfers for funding adaptation within the framework of a dynamic computable general equilibrium model, where impacts of climate change depend on changes in precipitation and temperature. If all regions, even the least developed ones, own the necessary resources for adapting optimally to climate change and variability, by mid-century less than 10% of the regions' GDP would be invested for avoiding almost 40% of climate change damages. In absolute terms global adaptation expenditure would account to more than 85 billion US$ by 2050. This has measurable effects on the regions' competitiveness as well as on the terms-of-trade. If, however, the developing world does not own sufficient resources for adapting optimally to climate change, as is to expected, funding of adaptation, which is an element of international climate policy, can make sense from an economic perspective. In particular the Hicks-Kaldor criterion is fulfilled as aggregated welfare gains at least compensate the costs of providing financial assistance for adaptation.

Das Wichtigste in Kürze

Die Exposition, wie auch die Möglichkeiten, sich an den Klimawandel anzupassen, variieren signifikant zwischen verschiedenen Ländern. Zwischen 1984 und 2004 waren die Kosten aus Klimaschäden in Industrieländern dreimal kleiner als in Schwellen- und Entwicklungsländern, in denen 80 Prozent der Weltbevölkerung leben.

Die Klimakonferenz Ende 2012 in Durban, Südafrika, hat einmal mehr gezeigt, dass die Weltgemeinschaft derzeit nicht in der Lage ist, sich auf ein Abkommen zur Reduktion der weltweiten Treibhausgasemissionen, dass über die Ziele des Kyoto-Protokolls hinausgeht, zu einigen. Das macht Anpassung zu einer wichtigen Handlungsoption, um sich gegen die Bedrohungen des Klimawandels zu schützen. Diese Anpassungsmaßnahmen sind allerdings mit Kosten verbunden und vielen Entwicklungsländern fehlen die finanziellen und institutionellen Ressourcen.

Gerechtigkeitsüberlegungen sind wichtige Argumente, warum die Industrie- die Entwicklungsländer unterstützen sollten, aber nicht die einzigen. Die Finanzierung von Anpassungsmaßnahmen hilft sicherzustellen, dass die Terms-of-Trade Effekte des Klimawandels reduziert werden und die Entwicklungsländer so Handelspartner der Industriestaaten bleiben können. Ein Ereignis aus Jahre 2008 zeigt das exemplarisch: Infolge einer sechsjährigen Dürre kam die australischen Reisproduktion fast vollständig zum Erliegen. Gemeinsam mit anderen Faktoren führte das zu einer Verdoppelung des Reispreises auf dem Weltmarkt, was zu Panikkäufen und gewalttätigen Protesten in mehreren Entwicklungsländern führte. Auch wenn Freihandel helfen kann, die Effekte des Klimawandels zu dämpfen, zeigt dieses Beispiel, dass Produktionsrückgänge in einem einzelnen Land zu steigenden Weltmarktpreisen und die daraus folgenden Terms-of-Trade Effekte zu realen Einkommensverlusten führen können.

Dieses Papier analysiert die Beziehung zwischen internationalem Handel, regionaler Anpassung und Nord-Süd-Transfers zur Finanzierung von Anpassung mit Hilfe eines dynamischen berechenbaren allgemeinen Gleichgewichtsmodelles. Unter der Annahme, dass all Regionen, sogar die ärmsten, die nötigen Ressourcen besäßen, sich optimal an den Klimawandel anzupassen, müsste in der Mitte des 21. Jahrhunderts weniger als 10% des BIP einer Region dafür aufgewendet werden, um fast 40% der zu erwartenden Schäden des Klimawandels zu vermeiden. In absoluten Zahlen entsprächen die globalen Anpassungskosten zur Mitte des Jahrhunderts ungefähr 85 Milliarden US Dollar. Das würde einen messbaren Effekt auf die Wettbewerbsfähigkeit und die Terms-of-Trade einer Region haben. Wenn nun wie zu erwarten die Entwicklungsländer nicht über die nötigen Ressourcen verfügen, kann die Finanzierung von Anpassungsmaßnahmen durch die Industriestaaten aus ökonomischer Sicht Sinn machen. Für gewisse Transferbeträge ist das Hicks-Kaldor Kriterium, d.h. die aggregierten Wohlfahrtsgewinne erlauben eine Kompensierung der Finanzierungskosten, erfüllt.

Terms-of-Trade and the Funding of Adaptation to Climate Change and Variability. An Empirical Analysis.

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Abstract

This paper analyses the interplay between international trade, regional adaptation and North-to-South transfers for funding adaptation within the framework of a dynamic computable general equilibrium model, where impacts of climate change depend on changes in precipitation and temperature. If all regions, even the least developed ones, own the necessary resources for adapting optimally to climate change and variability, by mid-century less than 10% of the regions' GDP would be invested for avoiding almost 40% of climate change damages. This has measurable effects on the regions' competitiveness as well as on the terms-of-trade. If, however, the developing world does not own sufficient resources for adapting optimally to climate change, as is to expected, funding of adaptation can make sense from an economic perspective. In particular the Hicks-Kaldor criterion is fulfilled as aggregated welfare gains at least compensate the costs of providing financial assistance for adaptation.

Keywords: funding of adaptation, climate change, international trade, multi-regional dynamic CGE model

JEL-Classification: C68, D58, F18, Q56, Q54

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1 Introduction

Regional economies significantly diverge in their exposure as well as their capacity to adapt to climate change and variability.[1] Between 1984 and 2004, if measured in percent GDP, costs of climate impacts were three times smaller in high-income countries than in low- to middle-income ones, where 80 percent of the world population lives (see Burton et al., 2006). This has several reasons: First, developing countries are mostly located in tropical and subtropical latitudes, where climate events such as heat waves and drought periods are more severe than in the North. Second, much of their national income is generated in climate-sensitive sectors like agriculture and tourism. Finally, population growth and the expansion into high-hazard zones increased the number of people at risk of climate change disruption.

The COP17 meeting at Durban once again demonstrated that the world community presently is unable to establish an international agreement on greenhouse gas abatement, which extends the Kyoto Protocol. This makes adaptation an urgent option for insuring against the threat of global warming. However, adaptation to climate change is costly and many developing countries lack the financial, institutional and the human resources for coping effectively with climate change. Stern (2006) calculates that adaptation costs worldwide account to 4 up to 37 billion US$ annually. The World Bank (2007) estimates that 10 to 40 billion US$ are needed per year. The UNFCCC (2007) finally projects that by 2030 annual adaptation costs will be in the order of 46 to 171 billion US$. Thereby, 28 to 67 billion US$ are attributed to the developing countries.

Fairness and equity are major arguments why the industrialized countries should assist the developing countries. But there are further ones. Adaptation can help to ensure that the developing countries remain partners for economic growth, global governance and international trade. In particular, adaptation can moderate the terms-of-trade effects of climate related events as for example the one observed in 2008. After six years of drought Australia's rice production collapsed almost completely. Combined with other factors this caused a doubling of the world market price of rice, which led to panicked hoarding and violent protests. Indeed, even if free trade can curb climate change impacts, output losses in one single country might cause rising world market prices and the resulting terms-of-trade effects

[1] Exposure depends on climatic conditions and the wealth of a society. Capacity is a society's ability to adapt to climatic conditions, either by reducing harm, or exploiting beneficial opportunities, or both, which again depends on the society's wealth, education and institutions.

can pertain to real income losses in almost any country.[2]

This is a problem for the poorest. These countries do not own the necessary resources for coping with the risks of climate change. Last but not least for that reason several funds have been established for supporting adaptation in these countries: the Least Developed Countries Fund, which should support the 49 least developed countries, the Special Climate Change Fund, which provides financial assistance to all developing countries, and, based on Article 12 of the Kyoto Protocol, the Adaptation Fund. Finally, the Green Climate Fund was established at the recent COP17 meeting, through which 100 billion US$ annually should be provided for mitigation and adaptation in developing countries.

Contrary to mitigation adaptation is highly diverse. Adaptation includes the implementation of new management practices but also the investment into the protection of infrastructure. Some has the character of a private, some of a local public good. Some involves public and some private institutions. This explains why our knowledge on how to incorporate adaptation into integrated assessment models (IAM) of climate change still is rudimentary (Agrawala et al., 2011, Patt et al, 2010). Today, there are two approaches mainly: Bosello et al. (2010) view adaptation as anticipatory measure, which requires the accumulation of adaptation capital stocks. Examples are the building of dikes for flood protection. In contrast de Bruin et al. (2009) consider adaptation as reactive measure, which is effective almost immediately. Typically, this applies to agriculture, where climate impacts can be moderated through changing crops or adjusting planting and harvesting times.

Our analysis focuses on reactive adaptation. First, we are interested in the interplay between adaptation and international trade rather than the timing of costs and benefits of adaptation. Second, reactive adaptation is of particular importance in case of agriculture, which is an important source of the developing countries' national income. McCarl (2007) estimates that within the next twenty years 5 to 12 billion US$ have to be invested annually into adaptation for counterbalancing most of climate change impacts on agriculture. This indicates that the developing countries are especially vulnerable to climate change and might become even more vulnerable without sufficient investment into adaptation.

This paper analyzes the interrelationship between climate change adaptation, terms-of-trade and adaptation funding. It applies MITACC, a dynamic computable general equilibrium Mod-

[2] Schenker (2010) shows that in countries like the US, where market impacts are moderate, a significant fraction of climate change related costs results from terms-of-trade deterioration.

el for evaluating International Trade and regional Adaptation to Climate Change. Section 2 introduces the key features of the model. In particular, it explains at some detail, how adaptation is made explicit in MITACC. Section 3 discusses the numerical specification of MITACC, and Section 4 introduces the scenarios upon which our counterfactual analysis is based. Results of the calculations are presented in Section 5. Section 6 concludes.

2 Key Features of the Model[3]

Many of the basic ideas and numerical parameters, which are used for the purpose of MITACC, are taken from the RICE (Nordhaus, 2010) and MERGE (Manne et al., 1995) IAM as well as from Schenker (2010). In common with these models MITACC provides a reduced-form description of the regional economies, international trade and impacts of climate change. In contrast to the former ones MITACC combines a detailed representation of the regions' ability to adapt to climate change with a top-down perspective on the remainder of the regional economies.

2.1 A Short Overview

The world economy is divided into nine regions (see Appendix, Table 1), which are linked through trade in commodities and capital flows. Some regions like Europe (EUR) or North America (NAF) are characterized by relatively high wealth and low vulnerability to climate change. Others such as Sub-Sahara Africa (SAF) or South Asia (SOA) are less developed, but highly vulnerable. Each region is viewed as if a single agent maximizes the discounted utility of consumption over time. The time horizon exceeds through 2075 and time periods are five years in lengths. Each region produces two categories of commodities in two corresponding sectors: (1) vulnerable, which refers to the aggregate of goods and services, which are produced in climate vulnerable sectors such as agriculture, fishery, forestry and tourism, (2) non-vulnerable, which denotes the aggregate output of sectors, which are almost insensitive to climate change like industrial manufacturing or financial services.

Production of both vulnerable and non-vulnerable commodities is modeled through nested constant elasticity of substitution (CES) functions. Inputs into regional production are capital, labor and intermediate goods, which are region-specific and produced through inputs of vulnerable and non-vulnerable. Labor is mobile across sectors, but not across regions. Capital is traded on open international markets, which allows for shifting capital to regions with highest

[3] A full description of the model as well as a copy of the GAMS code is available upon request.

marginal returns. The regions' output of vulnerable and non-vulnerable can be used domestically and/or exported. We abstract from trade distortions, but apply Armington's (1968) assumption that imports and domestic products are imperfect substitutes.

IAM typically express market impacts of climate change as percentage effects of total GDP (see Mastrandrea, 2010). In contrast, MITACC uses sector-specific impact functions. Since by definition climate change affects the production of vulnerable goods only, impacts materialize as changes in output of vulnerable commodities. I.e., at any period *t* only the fraction $V_r(t)$

$$V_r(t) = 1/\big(1 + ND_r(t)\big) \quad (1)$$

of gross production of vulnerable is at disposal in region *r*. Net-impacts $ND_r(t)$ are market impacts, which can be observed and which depend, as discussed below, on regional gross damages (output changes in absence of adaptation), regional adaptation and adaptation costs.

2.2 Making Adaptation Explicit

Impacts of climate change can be reduced through adaptation, which, however, creates costs. In RICE damages, costs and benefits of adaptation are blended into a single number. However, for formulating adaptation as decision variable both have to be made explicit. Therefore, following de Bruin et al. (2009) net-impacts $ND_r(t)$ are separated into its constituent elements by assuming: (1) gross impacts as well as costs and benefits of adaptation are independent and separable of each other, (2) all can be expressed in units of vulnerable goods. More precisely, let $GD_r(t)$ denote gross impacts, i.e. the impacts in absence of adaptation, and let $0 \leq A_r(t) \leq 1$ denote endogenously chosen adaptation, which is measured as fraction of gross damages avoided. Then in region *r* at time *t* net-damages

$$ND_r(t) = (1 - A_r(t))GD_r(t) + AC_r\big(A_r(t)\big) \quad (2)$$

are the sum of adaptation costs $AC_r(A_r(t))$ and residual damages $(1 - A_r(t))GD_r(t)$.

Costs of adaptation are assumed to strictly increase with the level of adaptation

$$AC_r(A_r(t)) = \gamma_r A_r(t)^{\beta_r}, \quad (3)$$

where γ_r is the price per unit of adaptation, expressed in terms of output of vulnerable. $\beta_r > 1$ determines the curvature of the adaptation cost function. Note, the decision for adapting optimally is solely determined by gross impacts $GD_r(t)$ and the parameters of the adaptation cost function. Neither regional income nor output matters.

3 Calibration

3.1 Climate Data

Two variables are important for the assessment of climate impacts on vulnerable sectors such as agriculture. These are changes in temperature and precipitation. We use data provided by the global climate model ECHAM5 (Roeckner et al., 2005). The ECHAM5 simulations, which are based on the IPCC SRES A1B emission scenario (Nakicenovic and Swart, 2000), deliver monthly averages of both variables at a spatial resolution of about 200 km. Through aggregating these data to annual mean temperature and precipitation per region we observe that by mid-century the former Soviet Union (GUS) and North America (NAF) must await an increase of average surface temperature of about 3°C to 3.5°C.[4] Middle East and North Africa (MEN) as well as Sub Saharan Africa (SAF) should anticipate an additional warming of about 2.3°C, whereas for Oceania (OCE) only a moderate temperature increase of about 1.6°C is projected.

Projections on precipitation are more uncertain and trends are not as linear as in case of temperature. In South Asia (SOA) for example precipitation will raise by 4% only, whereas North America (NAF) and GUS might expect an increase of approximately 8% to 11%. An exception is Middle East and North Africa (MEN), which is already a dry region and must face a further decline in precipitation.

3.2 Climate Impacts

Most Integrated Assessment models view net-impacts as function of temperature change only. However, production in sectors such as agriculture is exposed to changes in both temperature and precipitation. Now, since agriculture is the most important among vulnerable sectors, to construct the sectoral impact function let us rely on the climate response function as established by Mendelsohn and Schlessinger (1999) and refined by Cline (2007).

The climate response function is a quadratic combination of temperature and precipitation and

[4] In polar regions temperature increase will be higher than in lower latitudes. Since these regions are sparsely populated, climate impacts on these regions are probably overestimated.

determines net revenues per hectare.[5] Taking the total differential gives for each region r and period t

$$(4) \qquad \widehat{ND}_r(t) = 116dT_r(t) - 9.9T_r(t)dT_r(t) + 0.47dP_r(t),$$

where $\widehat{ND}_r(t)$ denotes output changes, hence market impacts, which are determined by regional surface temperature $T_r(t)$ and marginal changes in regional temperature $dT_r(t)$ and precipitation $dP_r(t)$.

Function (4) is derived from statistical estimates based on results of a crop model and a linear-programming model of US farms. The latter includes adaptation measures like changing crop mixes, fertilizing and irrigation. Consequently, $\widehat{ND}_r(t)$ must be interpreted as net-impact, which implicitly includes adaptation. However, for decomposing net-impacts into costs of adaptation and residual damages (see Section 2.2) information about gross-impacts and adaptation is needed. We assume that the functional forms of gross-impacts and net-impacts are identical, i.e.,

$$(5) \qquad GD_r(t) = \alpha_{1,r}\, dT_r(t) - \alpha_{2,r}T_r(t)dT_r(t) + \alpha_{3,r}dP_r(t).$$

The impact coefficients $\alpha_{1,r}, \alpha_{2,r}, \alpha_{3,r}$ are then determined together with the adaptation cost parameters γ_r and β_r through calibration (see Appendix, Table A1). To this end a model is constructed (see de Bruin et al., 2009), which minimizes the discounted squared difference between the impacts $\widehat{ND}_r(t)$, as given by Cline (2007), and net-impacts $ND_r(t)$, which include explicitly made optimal adaptation.

3.3 Economic Data

Anthropogenic greenhouse gas emissions drive climate change. Although strongly depending on economic development, for the purpose of our analysis emissions and climate change are exogenously given. Projections are taken from the SRES A1B emission scenario (Nakicenovic and Swart, 2000), which is the mostly used IPCC emission scenario and predicts an atmospheric CO2 concentration of about 550 ppm by 2050.

[5] Mendelsohn and Schlessinger (1999) and Cline (2007) take CO2 fertilization effects on agriculture into account. Recent studies, however, show that these are smaller and more uncertain than previously thought (see Lee et al., 2011). They are neglected therefore.

Regional outputs, production structures, consumption and investment, factor endowments and trade flows are calibrated with GTAP 7.1 data (Narayanan and Walmsley, 2008). This data base provides a consistent representation of the 2004 world economy and contains information on trade and production for 113 regions and 57 commodities, which are aggregated accordingly. Elasticities of substitution are also taken from the GTAP 7 data base (see Appendix, Table A2). For consistency growth rates from IPCC SRES are used.

4 Scenarios

Four scenarios are discussed in the following. The first one is called BASE. It serves as reference scenario and assumes that the world economy develops without being affected by climate change. The second scenario is called TUMB. It reflects what might happen, if there are climate impacts as projected by the ECHAM5 simulations, but agents behave as “dump farmers”. I.e., global warming distresses the regional economies, but agents do not respond and hence do not invest into adaptation. This is not a realistic assumption, but allows assessing the effectiveness of adaptation.

The third scenario is called AUTO. As mentioned earlier, adaptation can create benefits, which are private to the single regions. Therefore self-interest suggests that some adaptation is made autonomously. AUTO considers the situation, where all regions own the necessary resources for optimally and autonomously investing into adaptation. Note, since in our framework adaptation is the only possibility to respond to climate change and benefits of adaptation are private to the single regions, AUTO establishes a Pareto-efficient solution.

Generally it is expected that the developing world does not own sufficient resources for optimally adapting to the risks of climate change, and hence, that North-to-South transfers for financing adaptation are necessary. FUND, which is the short-cut of the fourth scenario, supposes that Europe (EUR), North America (NAF) and Oceania (OCE) steadily increase their financial contributions to Sub-Sahara Africa (SAF), South America (SAM) and South Asia (SOA), until they hand over 0.1% of their GDP from 2050 onwards. This would imply transferring 33 billion US$ annually, which is at the low end of what the UNFCCC (2007) has calculated. However, since we abstract from investment into climate resilient infrastructure, these resources should cover a significant part of the developing countries’ adaptation expenditures in the vulnerable sector. It is further assumed that funds are equally shared among the recipient regions and that they are used for adaptation only. In order to abstract from crowding-out effects funded regions do not autonomously invest into adaptation.

5 Results from Numerical Simulations

5.1 TUMB: climate impacts, but no adaptation

Without investment into adaptation, MITACC predicts that under ECHAM 5 A1B assumptions and compared to BASE climate change will cause losses in the production of vulnerable, which by mid-century aggregate to 4.5% of the Gross World Product. Losses are not equally distributed across regions. The higher is a region's exposure to climate change, the higher are the impacts on agriculture and other vulnerable sectors. And the larger is the share of vulnerable sectors, the higher will be the welfare effects.

As Figure 1 shows, compared to BASE Oceania's (OCE) output of vulnerable is reduced by more than 50% under TUMB assumptions. In Sub-Saharan Africa (SAF), South America (SAM) and South Asia (SOA) a cut-back of 69%, 64% and 28%, respectively, is expected. The former Soviet Union (GUS) and North America (NAF), however, can extend the production of vulnerable by 13% and 11%, respectively. In these regions agriculture can benefit from global climate change. And since these regions produce a significant portion of world's food supply, agricultural production world-wide will decline by only 5.1% in 2050.

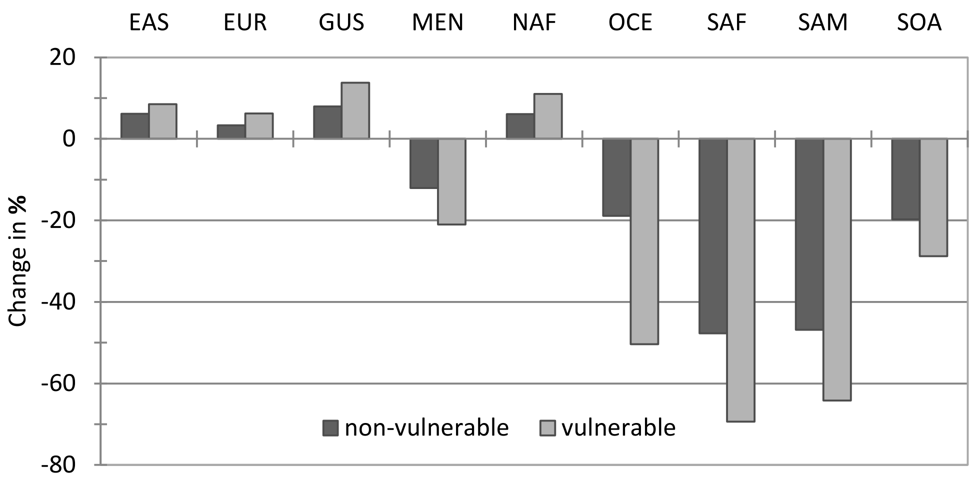

Figure 1: Effects of climate change on regional outputs by 2050 (in % compared to BASE)

By definition the production of non-vulnerable such as personal computers is not directly affected by climate change. Nonetheless, indirect impacts can be important. In Sub-Sahara Africa (SAF) and South America (SAM), where vulnerable production heavily declines, a cut-back of non-vulnerable outputs by almost 50% is observed. Therefore these regions cannot compensate the shortfall of vulnerable production through selling more non-vulnerable, which makes the argument that shifting agricultural production towards north could be a kind of climate change adaptation (see Juliá and Duchin, 2007) a questionable one.

Interregional reallocation of production and international competitiveness go hand in hand. Obviously, countries with highest exposure to climate change will face the largest losses in competitiveness. As the Revealed Comparative Advantage (RCA) Index (Balassa, 1965) indicates, in South America (SAM) and Oceania (OCE) the competiveness of vulnerable production is reduced by 10% and 7%, respectively. Regions, which are confronted with negligible climate change impacts like East Asia (EAS), realize small gains in competitiveness. Closely related are changes in terms-of-trade. Highly affected regions such SAM or SAF face significant terms-of-trade deterioration (11% and 8%), whereas regions such as GUS, where impacts are either negligible or positive, slightly improve their terms-of-trade.

5.2 AUTO: climate change and autonomous adaptation

Assume for a moment that all regions autonomously and optimally adapt to climate change. That means, each region r chooses a level of adaptation, such that marginal damages equal marginal adaptation costs, hence (see conditions (2) and (3))

$$A_r(t) = \left(\frac{GD_r(t)}{\gamma_r \beta_r}\right)^{\frac{1}{\beta-1}}. \tag{6}$$

By comparing AUTO and TUMB consequences of optimal adaptation become obviously. The necessary expenditure (see Table 1) spreads from almost zero (EAS) to more than 8% of regional GDP in Oceania (OCE), Sub-Saharan Africa (SAF) and South America (SAM). This mainly follows from high exposure and the economic size of vulnerable production. In absolute terms, investment into adaptation is highest in SAM. It accounts to almost 30 billion US$ by 2050, which is almost twice as much as North America (NAF) has to spend on optimal adaptation and is still 10 times higher than Europe's adaptation expenditure.

Moderating climate change affects the production of both vulnerable and non-vulnerable. Relative to TUMB, the former Soviet Union (GUS) and South America (SAM) can increase the outputs of vulnerable by 21% and 18%. Simultaneously, outputs of non-vulnerable are extended by 12% and 10%, respectively (see Figure 2). In Europe (EUR) and East Asia (EAS) outputs of both vulnerable and non-vulnerable will slightly be reduced.

Region	Adaptation Costs by 2050 % of GDP	Billion US $	Adaptation Level % of Gross Impacts
EAS	0.04	0.919	6.62
EUR	0.18	2.947	12.81
GUS	4.86	9.218	22.86
MEN	0.87	2.806	14.71
NAF	1.34	17.429	14.44
OCE	8.18	6.699	27.03
SAF	8.15	10.535	32.84
SAM	8.87	29.802	36.87
SOA	1.00	7.404	14.420

Table 1: Costs and benefits of autonomous adaptation by 2050 (Adaptation levels are expressed as fraction of damages avoided in the vulnerable sector.)

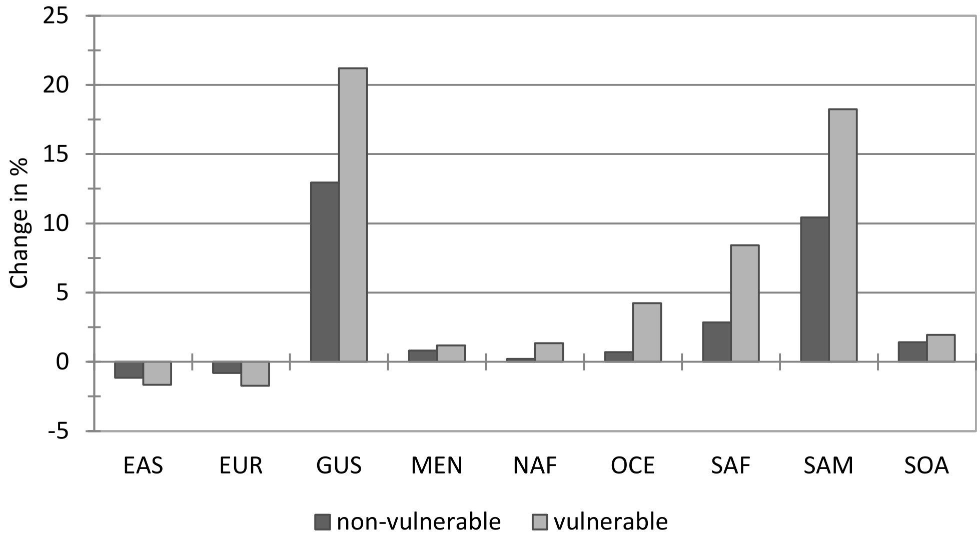

Figure 2: Change in sector outputs by 2050 (in % relative to TUMB)

This indicates that adaptation takes influence on the regions' comparative advantage. However, since a region's competitiveness is driven by several factors like for example differences in cost-efficiency of adaptation, effects are not always clear and might differ by sector. For example, optimal adaptation increases South America's (SAM) competitiveness in the production of vulnerable (see Figure 3). The less exposed East Asia (EAS) loses competitiveness both in vulnerable and non-vulnerable, while Sub-Sahara Africa (SAF), which is one of the regions with the largest exposure, loses competitiveness in vulnerable production, but wins in non-vulnerable.

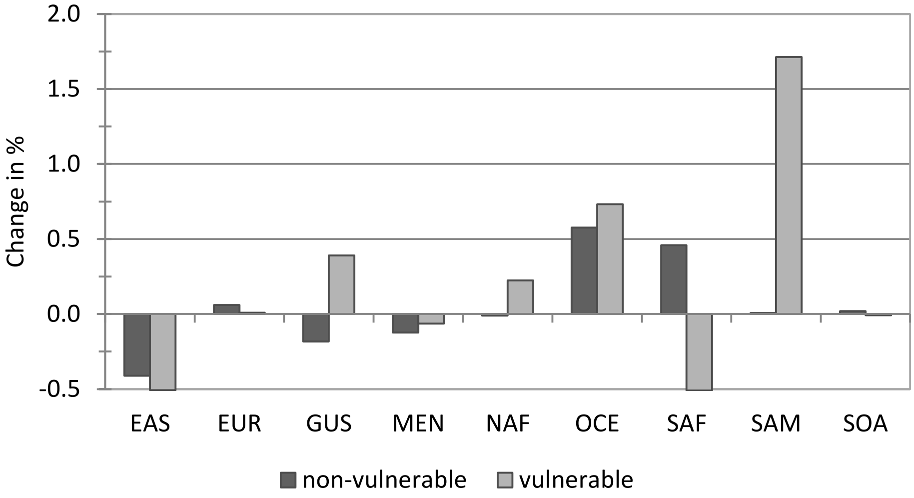

Figure 3: Percentage change in Revealed Comparative Advantage (RCA) by 2050 (relative to TUMB)

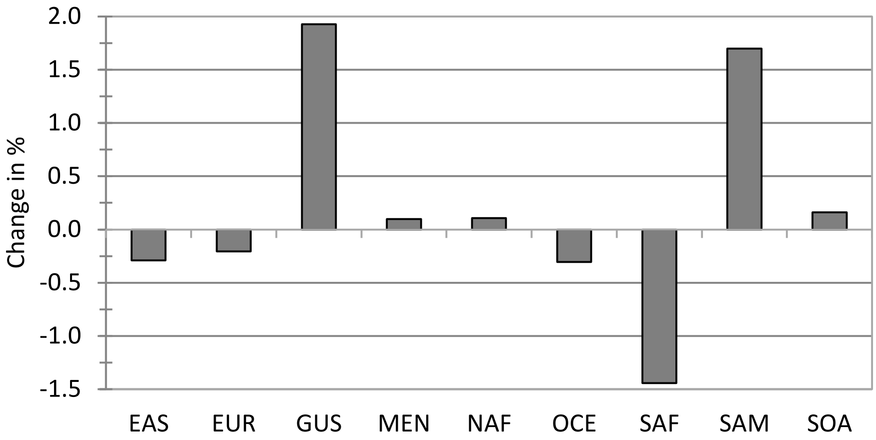

Figure 4: Percentage change in terms-of-trade by 2050 (relative to TUMB)

This is also reflected by changes in terms-of-trade (see Figure 4). While GUS and SAM can improve their terms-of-trade through adaptation, Sub-Sahara Africa (SAF) loses even more ground on the international markets.

5.3 FUND: climate impacts and the funding of adaptation

As described FUND assumes: (1) Europe (EUR), Oceania (OCE) and North America (NAF) support adaptation in Sub-Sahara Africa (SAF), South America (SAM) and South Asia (SOA). (2) Starting in 2015 from 0.0125% of their GDP the donors linearly increase their contributions, until these reach 0.1% in 2050. (3) Funds are equally shared among the recipients.

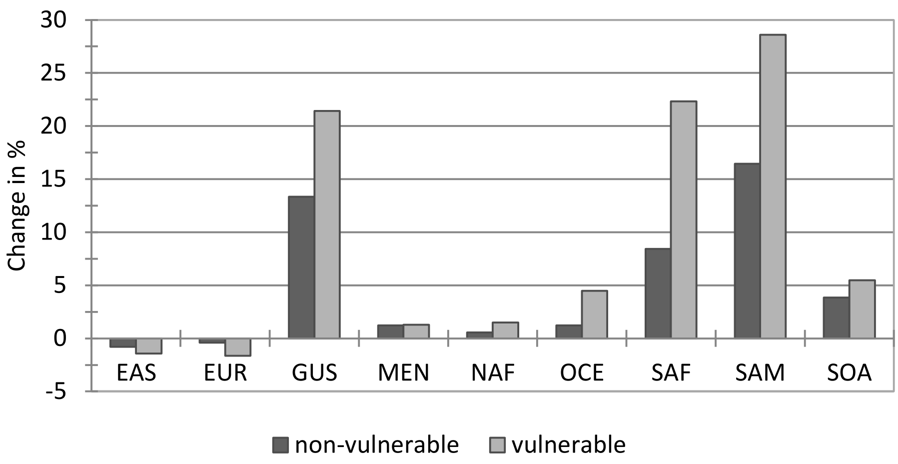

Figure 5: Effect on sector outputs by 2050 (in percent relative to TUMB)

Figure 5 shows the effects of funding adaptation on regional production (as the percentage differences in sector outputs between FUND and TUMB). All funded regions can profit in both vulnerable and non-vulnerable outputs.

Recall that within our approach AUTO describes a Pareto-optimal scenario. Hence AUTO sets a benchmark for the performance of FUND, where all regions autonomously invest into optimal adaptation except for SAF, SAM and SOA, which receive financial assistance.

	Adaptation Costs by 2050		**Adaptation Level**
Region	**% of GDP**	**Billion US $**	**% of Gross Impacts**
EAS	0.04	0.921	6.62
EUR	0.18	2.950	12.81
GUS	4.86	9.235	22.86
MEN	0.87	2.809	14.71
NAF	1.34	17.457	14.44
OCE	8.18	6.716	27.03
SAF	*8.61*	*11.172*	*33.31*
SAM	*3.30*	*11.172*	*28.73*
SOA	*1.53*	*11.172*	*16.40*

Table 2: Costs and benefits of funding adaptation by 2050 (regions in italics receive funding)

By comparing Tables 1 and 2 it becomes obvious that virtually no differences exist between AUTO and FUND except for the funded countries. In case of Sub-Sahara Africa (SAF) funded adaptation is close to optimality. South America (SAM) is under-supplied financially, while South Asia (SOA) is over-funded. Consequently, since the funding is completely invested into adaptation, adaptation in both cases is sub-optimal. This must have effects on the regions' terms-of-trade and Relative Comparative Advantage (RCA).

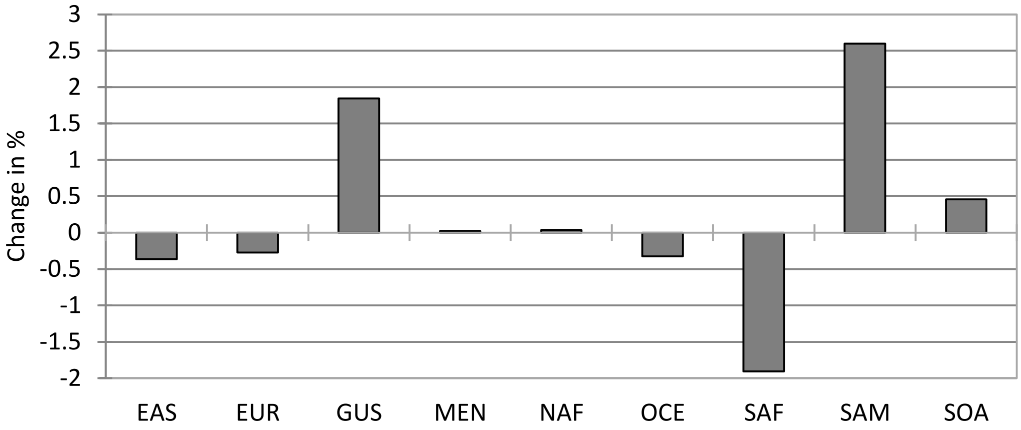

Figure 6: Changes in terms-of-trade through adaptation funding in 2050 (in % relative to TUMB)

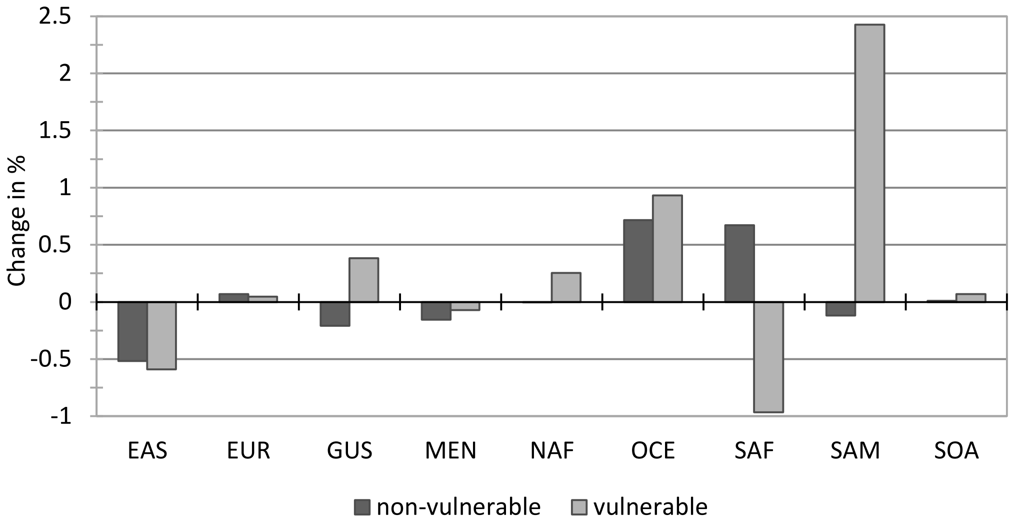

Figure 7: Change in Relative Comparative Advantage by 2050 (relative to TUMB)

As in AUTO South America (SAM) and South Asia (SOA) profit from terms-of-trade improvements through adaptation, while Sub-Sahara Africa (SAF) loses (compare Figure 4 and 6). Similarly, the donor regions EUR (-0.27%) and OCE (-3.2%) have to cope with loses in terms-of-trade, while NAF more or less stays unchanged. However, the effects are more pronounced than in AUTO. The same applies, if changes in RCA (relative to TUMB) are considered (compare Figures 3 and 7). There are slight differences in the order of magnitude, but effects point into the same direction.

Overall the results indicate that no qualitative differences between AUTO and FUND exist and that the quantitative differences are rather minor. Intuitively this is not surprising. AUTO defines a Pareto-efficient solution, but might require significant financial resources, which exceed the abilities of the poorest. FUND is an adaptation scenario, where policy has decided on supporting adaptation in the least developed countries through North-to-South transfers. As such FUND approaches AUTO, but does not grant a Pareto-efficient allocation of adaptation.

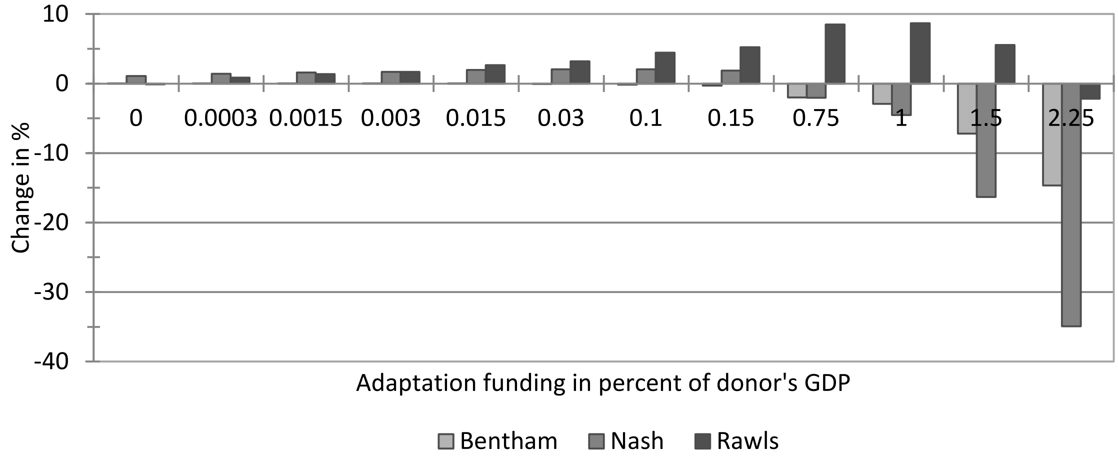

Figure 8: Percentage change in social welfare (FUND to TUMB) for different welfare aggregation criteria

This immediately raises the question of the rational for funding adaptation in the developing world? According to the Hicks-Kaldor criterion this is the case, if aggregated welfare gains at least compensate the costs. Figure 8 shows that, depending on the aggregation criteria, funding adaptation by spending 0.1% of the industrialized regions' GDP could turn out beneficial globally. However, Figure 8 also shows that depending on the welfare criteria funding levels exist, above which funding adaptation is counterproductive. If a Bentham principle through summing up the regions' welfare is applied, the beak-even level is relatively small (0.003%). A Nash welfare aggregation scheme, where individual welfare levels are multiplied with each other, would support a funding below 0.3% and under Rawls, where aggregated welfare correspond to the loss of the most affected agent, even a funding of 1% of GDP would be justified. This shows that, depending on the social welfare function, funding of adaptation in the developing world could be welfare improving and be justified under the Hicks-Kaldor criterion.

6 Conclusions

In 2011 the COP meeting at Durban failed to establish an international agreement on greenhouse gas abatement, which extends the existing Kyoto Protocol. This directed attention on adaptation, which consists of measures for reducing the follow-up costs of climate change. This paper uses MITACC, a dynamic computable general equilibrium model, where impacts of climate change and variability depend on changes both of temperature and precipitation, for analyzing the interplay between international trade, regional adaptation and the North-to-South funding of adaptation. If all regions, even the least developed ones, would own the necessary resources for adapting optimally to climate change, by mid-of-the-century at maximum 10% of the domestic GDP would be invested into adaptation for avoiding almost 40% of climate change induced damages. In absolute terms global adaptation expenditure would account to more than 85 billion US$ by 2050, where 47.741 billion should be invested in SAF, SAM and SOA. This is significantly above Stern's (2006) estimates but in the middle of the range the World Bank (2007) has projected.

Without North-to-South transfers the least developed regions won't own the necessary resources for optimally adapting to climate change and variability. Transfers are typically determined through policy negotiation and cannot be expected being efficient. Nonetheless, if sufficiently high, they could allow for approaching a Pareto efficient allocation of adaptation. As is usual in case of transfers, adaptation funding affects world trade and regions' relative comparative advantage. Now, since adaptation immediately reduces the negative impacts of climate change on the production of vulnerable, one would expect that the most affected regions of the South could profit from funding adaptation. However, since the effects of adaptation and its funding on international trade and production depend on the regional differences in the adaptation cost curves, the results are by no means clear-cut. For example, while South America (SAM) can increase its comparative advantage in the production of vulnerable, Sub-Sahara Africa (SAF) has to cope with a deterioration of its competitiveness in vulnerable on the one hand, but can increase its competitiveness in non-vulnerable on the other.

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Appendix

Region	Countries covered	α_1	α_2	α_3	γ	β
Oceania (OCE)	Aus, Nzl,	3.209	0.275	0.013	5.653	3.238
East Asia (EAS)	Chn, Jpn, Kor, Twn	0.068	0.006	0.002	6.756	3.604
South Asia (SOA)	Ind, Idn, Mal, Tha, …	0.140	0.012	0.005	5.623	3.629
North America (NAF)	Usa, Can, Mex	0.520	0.045	0.002	8.234	3.319
South America (SAM)	Bra, Arg, Col, Ven, …	1.532	0.107	0.007	5.162	4.051
Europe (EUR)	EU27, Swi, Nor, Cro, …	0.128	0.014	0.009	5.956	3.938
Former SU (GUS)	Rus, Rest of GIS	0.984	0.084	0.004	6.499	3.318
Middle East (MEN)	Tur, Mor, Rest of ME, …	0.103	0.009	0.042	12.412	3.790
Sub-Sahara Africa (SAF)	Zaf, Tan, Zwe, …	1.177	0.087	0.059	6.653	3.955

Table A1: Regional disaggregation, calibrated impact and adaptation cost parameter

Elasticities of substitution	Value
Aggregate commodities to GDP	0.2
Capital – labor in vulnerable	1.09
Capital - labor in non-vulnerable	1.29
KL – intermediates in vulnerable	Leontief
KL – intermediates in non-vulnerable	Leontief
Armington vulnerable	2.16
Armington non-vulnerable	2.57
Intertemporal elasticity of substitution	1

Table A3: Elasticities of substitution