Trade and Specialization in Integrated Assessment Models

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Abstract

Within this paper, we discuss applications of the hybrid model REMIND-R in a climate policy context. The regional specification of mitigation costs is analyzed in the context of globalization where regions are linked by global markets for emission permits, goods and several resources. Trade is modeled in REMIND-R as a control variable based on a dynamic Heckscher-Ohlin model with mobile capital. Resulting trade patterns are challenged by empirical observations. Based on different concepts (trade costs, time preferences, technologies) we attempt to reconcile model results and the empirics. While, in general, regional mitigation costs are quite insensitive to the trade-related adjustments, for single regions, like Russia, significant changes can be demonstrated.

keywords: climate policy, trade costs, international trade

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1 Introduction

The overview of mitigation analysis in the Third Assessment Report of the IPCC indicates at least three crucial factors in determining economic costs of climate policy strategies: 1) baseline development in the absence of climate policy, 2) the number and type of mitigation options considered in the analysis and 3) the way technological change is handled. The relevance of international trade is not addressed. Different studies (Springer, 2002, Böhringer and Rutherford, 2004, Leimbach et al. 2008), however, demonstrate that trade-related first order impacts (in particular reduced rents from trade in fossil fuels) determine the mitigation costs of several regions. Moreover, from a more theoretical point of view Copeland and Taylor (2005) had shown, that results from environmental economics that are valid in closed economies, are false or need serious amendments in a world with international trade.

In policy assessment, CGE models are powerful and preferred tools to incorporate trade based on the Heckscher-Ohlin type model. However, standard CGE models exhibit recursive dynamics with limited capability to represent investment and trade decisions in an intertemporal framework which seems to be more adequate for the long-term climate change issue. We follow the alternative approach of dealing with international trade in an economic growth model type.

In this paper, we discuss the implications of including trade into the hybrid model REMIND-R (Leimbach et al., 2008). With this Integrated Assessment model we investigate, on the one hand, the relevance of effects known from theory like specialization, factor price equalization (Stiglitz, 1970), home bias ((Obstfeld and Rogoff, 2000), terms-of-trade effects (Galor and Lin, 1994), and the Lucas-Paradox (Lucas, 1990). On the other hand we analyze the results against the background of empirical observations. We use REMIND-R to run climate policy simulations with specific settings of the trade system (e.g. considering trade in primary energy carriers but not in secondary energy). We discuss the resulting trade patterns and highlight mitigation cost implications of various assumptions on the trade system design.

The paper is structured as follows. In section 2, we present the trade module of REMIND-R and its integration in an intertemporal welfare-maximizing model framework. Laying open the nature of trade as control variable and the meaning of the intertemporal budget constraint is crucial. First results in analyzing a climate policy scenario are discussed in section 3. The analysis is based on model runs with the default model version. It turns out that the trade flow volumes are overestimated by this model when compared with empirical data. Therefore we conducted experiments with model versions that are revised in two directions. First, we include trade costs for primary energy carriers in order to adjust energy trade flows. Second, we changed our assumptions on the regional time preferences and the dynamics of efficiency growth in order to adjust the macroeconomic trade pattern as represented by the current accounts. The set up and the evaluation of these model experiments are discussed in section 4. Section 5 ends with some conclusions.

2 The trade module of REMIND-R

REMIND-R is a novel multi-regional hybrid model used to assess climate policies. Mitigation costs estimates are based on technological opportunities and constraints in the development of new energy technologies. Most essential, technological change in the energy sector is embedded in a macroeconomic environment that by means of investment and trade decisions governs regional development until 2100.

REMIND-R couples an economic growth model with a detailed energy system model and a simple climate model (see Figure 1)[1]. The individual regions are coupled by means of a trade module.

The current version of REMIND-R includes eleven world regions:

1. USA - USA
2. EUR - EU27
3. JAP - Japan
4. CHN - China
5. IND - India
6. RUS - Russia
7. AFR - Sub-Saharan Africa (incl. Republic of South Africa)
8. MEA - Middle East and North Africa
9. LAM - Latin America

[1]For a detailed technical description of REMIND-R we refer to http://www.pik-potsdam.de/research/research-domains/sustainable-solutions/remind-code-1

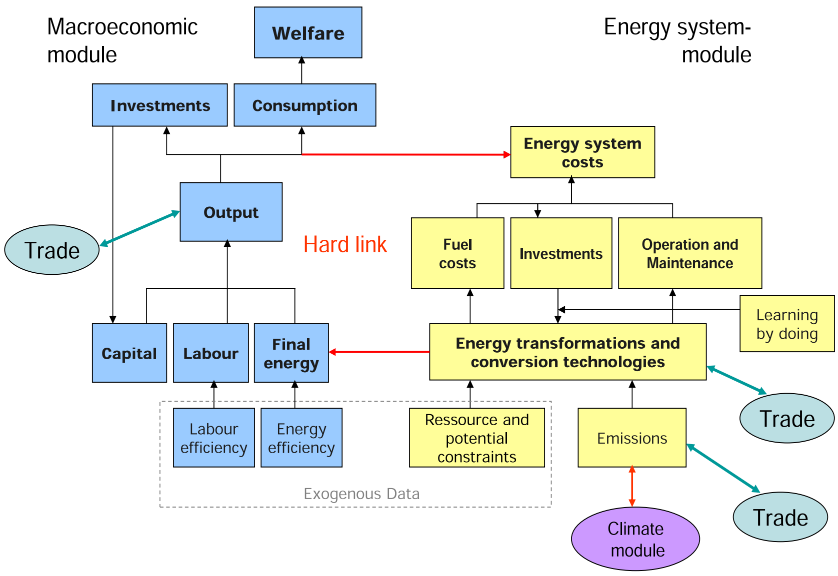


Figure 1: Structure of REMIND-R

10. OAS - Other Asia (Central and Pacific Asia)
11. ROW - Rest of the World (Canada, Australia and Rest of Europe).

The world-economic dynamics over the time horizon 2005 to 2100 is simulated by means of the macro-economy module in REMIND-R. The time step is five years. Each region is modeled as a representative household with a utility function $U(r)$ that depends upon the per capita consumption. With assuming the intertemporal elasticity of substitution of per capita consumption to be close to 1 it holds:

$$U(r) = \sum_{t=t_0}^{T} \left(\Delta t \cdot e^{-\zeta(t-t_0)} L(t,r) \cdot \ln \left(\frac{C(t,r)}{L(t,r)} \right) \right) \quad \forall r. \tag{1}$$

$C(t,r)$ represents consumption in time-step t and region r, $L(t,r)$ represents labor (equivalent to population) and ζ the pure rate of time preference[2]. It is the target of REMIND-R to maximise a global welfare function W that results as a weighted sum of the regional utility functions:

[2]We assume a pure rate of time preference of 3% for the simulation experiments presented in later sections.

$$W = \sum_r \left(w(r) \cdot U(r) \right). \quad (2)$$

The model REMIND-R calculates a pareto-optimal solution that corresponds with a global planner solution and/or a cooperative solution. With this approach, it is guaranteed that the necessary emission reductions are carried out cost-efficiently and that all trade interactions are directed at increasing welfare in general and lowering mitigation costs in particular.

In following the classical Heckscher-Ohlin (HO) and Ricardian model, trade between two regions is induced by differences in factor endowments and technologies. In REMIND-R, this is supplemented by the possibility of intertemporal trade. Another reason of trade which is based on increasing returns to scale with monopolistic competition is not considered here. In REMIND-R, capital mobility and trade in capital, represented by trade in the composite good, causes factor price equalization and guarantees an intertemporal and interregional equilibrium. Trade is modeled in the following goods:

- Coal
- Gas
- Oil
- Uranium
- Composite good (aggregated output of the macro-economic system)
- Permits (emission rights)

With $X_j(t,r)$ and $M_j(t,r)$ as export and import of good j of region r in period t, the following trade balance equation holds:

$$\sum_r (X_j(t,r) - M_j(t,r)) = 0 \quad \forall\, t, j \quad (3)$$

Trade represents a control variable. This provides a big challenge. A procedure of reconciling trade decisions of actors (i.e. regions), each of them maximizing their own welfare, is needed. In searching for the respective equilibrium solution we apply the Negishi-approach (cf. Manne and Rutherford, 1994; Leimbach and Toth, 2003). In this iterative approach, the objective functions of the individual regions are merged to a global objective function by means of welfare weights w (cf. eq. 2).

A distinguished pareto-optimal solution, which in the case of missing externalities also corresponds to a market solution, can be obtained by adjusting the welfare weights according to the intertemporal trade balances $B^i(r)$:

$$B^i(r) = \sum_t \sum_j \left(p^i_j(t) \cdot [X^i_j(t,r) - M^i_j(t,r)] \right) \quad \forall\, r, i \tag{4}$$

where i represents the iteration index which is skipped from the equations above and $p^i_j(t)$ represents world market prices derived as shadow prices from eq. 3. With a new set of weights

$$w^{i+1}(r) = f(w^i, B^i(r)) \quad \forall\, r, i \tag{5}$$

we compute a new solution from which we derive $B^{i+1}(r)$. It holds that

$$\mid B^{i+1}(r) \mid \;\; < \;\; \mid B^i(r) \mid \quad \forall\, r, i \tag{6}$$

and

$$\lim_{i \to \infty} B^i(r) = 0 \quad \forall\, r, \tag{7}$$

i.e. the intertemporal trade balance has to converge to zero for each region. Hence, the higher the intertemporal trade balance deficit of a region, the more the welfare weight needs be lowered to induce exports from this region to other regions.

The trade pattern that will result from model runs is highly impacted by the intertemporal trade balance constraint. Each export of the composite good qualifies the exporting region for a future import (of the same present value), but implies for the current period a loss of consumption. Trade with emission permits works similarly to goods trade. Emission rights are distributed free of charge according to the given allocation rule. The revenues from the sale of emission rights prove completely advantageous for the selling regions in the way that it generates entitlements for future re-exports of permits or goods. Each unit of CO_2 emitted by combusting fossil fuels $E(t,r,c)$ using technology c needs to be covered by emission certificates (either allocated $Q(t,r)$ net of exports $X_P(t,r)$ or imported $M_P(t,r)$):

$$\sum_c E(t,r,c) \leq Q(t,r) - X_P(t,r) + M_P(t,r) \quad \forall\, t, r. \tag{8}$$

3 Trade-related impacts on mitigation costs

For the subsequent analysis we apply the unrevised model version. We define a climate policy scenario that is based on the target of stabilizing the atmospheric CO_2 concentration at 450 ppm. While assuming a cooperative world, REMIND-R is run in the cost-effectiveness mode when it is used for climate policy simulations, i.e. the stabilization target is integrated into the model by an additional constraint.

In the analysis of how and at which costs the stabilization target can be achieved, we apply an international cap & trade system based on the contraction & convergence principle. In such a system, tradable emission rights will be allocated to the individual regions as of 2010. The endogenously determined global emission reduction path represents the world-wide available amount of emission rights.

Results from the policy scenario are compared to that of a reference scenario, also called business-as-usual (BAU) scenario. In the reference scenario, we simulate a development as if climate change has no economically and socially important impacts.

The pursued stabilization scenario requires a fast and drastic decrease of emissions. Global energy-related CO_2 emissions have to be reduced by almost 50% until 2050 (see Figure 2).

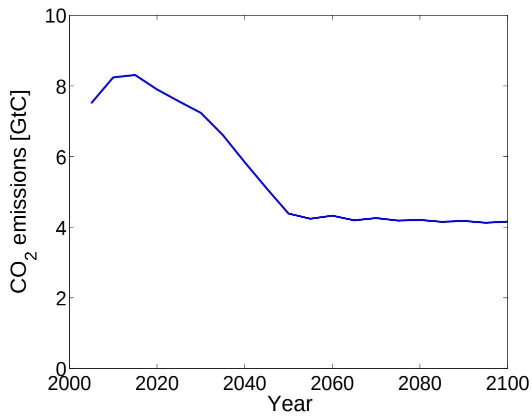


Figure 2: Global CO_2 emissions in policy scenario

Global average mitigation costs of the policy scenario, measured as consumption losses relating to the reference scenario, amount to around 0.6%. Global GDP losses are of the same magnitude. Regional mitigation costs, however, are quite different. Figure 3 provides an overview of the average regional mitigation costs.

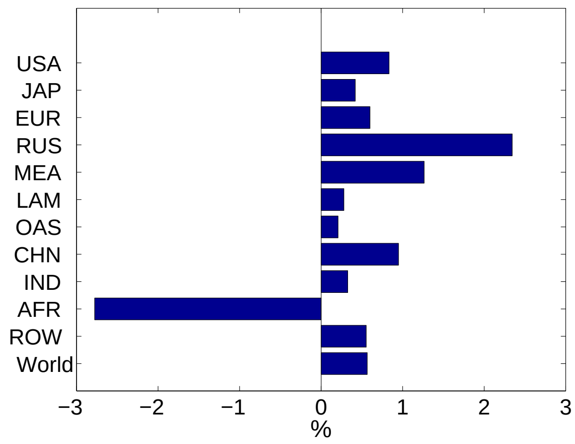


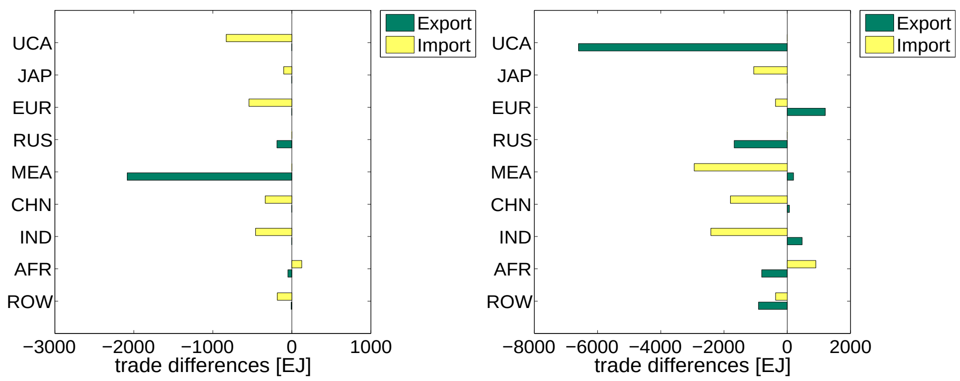
Figure 3: Average mitigation costs

Russia and MEA have to bear the highest costs (around 2.3% and 1.3%, respectively). The reconstruction of the global energy system reduces part of the possible rents of those regions whose revenues are to a large part derived from selling fossil resources. In contrast, Africa benefits. This is mainly due to revenues from selling emission permits, but also from uranium exports. In contrast to the prices of fossil fuels, the price of uranium increases in the policy scenario compared to the reference scenario. The developed countries use the option of emissions trade and buy permits in considerable amounts. This import, however, is on a value basis hardly visible in the current account.

Apart from significant changes on the energy resource market and the carbon market, the overall trade structure changes only slightly between the BAU scenario and the policy scenario in all regions.

In Figure 4, resource trade differences (in physical units cumulated over the century) between the policy scenario and the reference scenario are shown. Negative values represent less trade (either imports or exports) in the policy scenario. In general, trade in fossil resources decreases and trade in uranium increases.

Trade in coal is most significantly reduced in the policy scenario compared to the reference scenario. This is shown in Figure 5. In the reference scenario trade in coal rises quickly, whereas gas trade decreases and oil trade remains almost constant. In the policy scenario, there is a shift from coal to gas trade in the first decades. Due to the better CO_2 balance, compared to the other fossil energy sources, natural gas is used to a higher extent in the policy scenario in the short-term. Trade in coal increases as of 2050, when the diffusion of the carbon capture and sequestration technology revitalizes the use and the international trade of coal. The reduced demand on coal, oil and gas is mainly at the expense of Russia, ROW and MEA.



(a) Oil

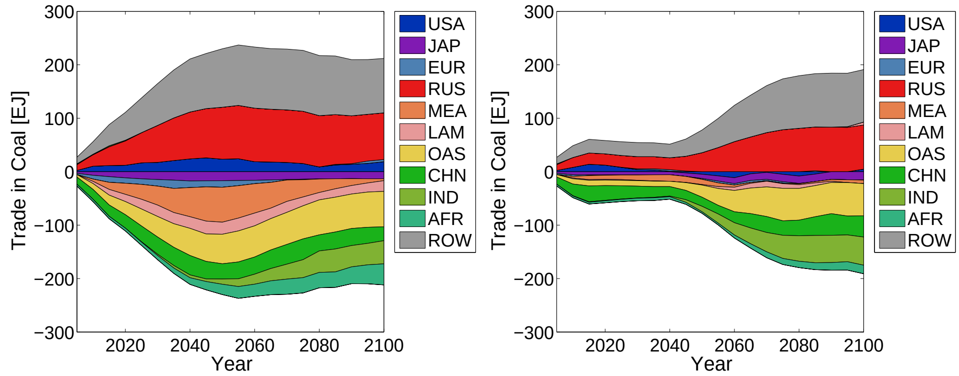
(b) Coal

Figure 4: Differences in trade between policy scenario and reference scenario

In line with demand changes on the resource markets we see changes in prices. The prices of coal, oil and gas in the policy scenario are significantly lower than in the reference scenario Worsened terms-of-trade can clearly be expected for the exporters of fossil fuels. Less export revenues have to be compensated by less imports of goods which limits consumption. MEA and Russia are most strongly affected, as resource exports bear a high share in their current accounts.

Gains and losses from emissions trading, changes in the energy resource market and price-induced terms-of-trade effects have a substantial impact on the mitigation costs.

However, for the regions with high shares in resource trade, mitigation costs could be overestimated by the model due to the fact that the reference scenario accounts for too optimistic trade volumes. This issue will be addressed in the next section.



(a) Reference scenario

(b) Policy scenario

Figure 5: Trade of coal differentiated by regions

4 Specialization patterns and empirics

This section describes activities and preliminary results that are subject of ongoing research. The major problem in dealing with trade as a control variable in a Heckscher-Ohlin-type trade model and in an intertemporal framework is the specialization pattern. Goods are exchanged between regions until either factor prizes are equalized or complete specialization is reached. An international trade pattern arises that is characterized by oversized trade flows. We tackle this problem separately for the energy trade part and the capital/composite goods trade part.

4.1 The impact of trade costs in energy trading

From our analyses it turns out that in a normative framework assuming a completely integrated world energy market, we have a strong specialization effect. Consequently, trade flows are much higher than what can be observed empirically. With respect to energy trade this in particular applies to trade in gas and coal; e.g. the simulated gas exports from MEA and coal exports from Russia exceed empirical values (in 2005) by more than 100 %. We approach this problem by accounting costs for physical trade of fossil primary energy carriers.

Using preliminary trade cost estimates, which differ across traded resources and regions, we are able to partially reconcile model outputs with empirical data for the base year. The inclusion of trade costs causes slight shifts in the mitigation strategies and costs. In particular, the high mitigation costs of Russia decline.

In this paper, we restrict the analysis of trade costs on the transport of fossil primary energy carriers (natural gas, crude oil, and coal). In REMIND-R, exports and imports are subject to a trade balance (see eq. (3)); the exchange can thus be viewed as a common pool supplied by exports and drained by imports. We keep this basic framework but augment it by the following approach: Trade costs are accounted on the balance of the importing regions by imposing financial costs (e.g., costs to finance the transportation infrastructure) and energetic losses (e.g., leakage during transport) on energy imports. Specific trade costs, i.e. the financial costs and energetic losses per unit of imported energy, reflect the average transport distance to reach the respective importer. Financial costs, represented by the product of specific costs $\gamma(r,e)$ and imports $M_E(t,r,e)$ of fossil resource *e*, are deduced from the importing region's GDP:

$$\begin{aligned} Y(t,r) - X_G(t,r) + M_G(t,r) = C(t,r) &+ I(t,r) + G(t,r) \\ &+ \sum_e \gamma(r,e) M_E(t,r,e) \qquad \forall\, t,r \end{aligned} \tag{9}$$

The GDP *Y(t,r)* of region r, augmented by composite goods imports $M_G(t,r)$, and net of total energy system costs *G(t,r)* and energy trade costs, is allocated to consumption *C(t,r)*, macroeconomic investments *I(t,r)* and composite goods export $X_G(t,r)$.

Energetic losses reduce the import amount $M_E(t,r,e)$ by a factor $\tau(r,e) < 1$ before it enters the importer's energy system. For primary energy consumption *P(t,r,e,c)* of fossil resources holds:

$$\sum_c P(t,r,e,c) = F(t,r,e) - X_E(t,r,e) + (1 - \tau(r,e)) M_E(t,r,e) \quad \forall\, t,r \tag{10}$$

F(t,r,e) represents fossil fuel extraction and $X_E(t,r,e)$ represents the resources export.

We adopt specific trade costs from Takeshita et al. (2006), pp. 290-294, and estimations on transport distances (see table 1). Takeshita et al. (2006) report specific trade costs (both financial costs and energetic losses) of various transport modes and energy carriers. They distinguish cost components dependent and independent of distance. Costs for the liquefaction of natural gas for LNG transport

REGION	Natural Gas distance [km]	Natural Gas costs [$/GJ]	Natural Gas losses [%]	Oil distance [km]	Oil costs [$/GJ]	Coal distance [km]	Coal costs [$/GJ]
USA	10000	1.2283	9.3	9000	0.1784	9000	0.7858
JAP	9000	1.1499	9.1	9000	0.1784	8000	0.7404
EUR	4000	0.7582	8.1	4000	0.1068	8000	0.7404
RUS	-	0	0	-	0	-	0
MEA	-	0	0	-	0	4000	0.5589
LAM	6000	0.9149	8.5	6000	0.1354	6000	0.6497
OAS	7000	0.9933	8.7	7000	0.1498	4000	0.5589
CHN	7000	0.9933	8.7	7000	0.1498	4000	0.5589
IND	3000	0.6799	7.9	3000	0.0924	4000	0.5589
AFR	-	0	0	-	0	5000	0.6043
ROW	-	0	0	-	0	-	0

Table 1: Trade cost parameters and the underlying estimations of import distances. No costs are assigned to exporters of the respective fossil energy carrier. Note: USA is an exporter of coal in the empirical statistics; however, it would become an importer during the model's time horizon if we do not assign trade costs for the USA. ROW is an importer of gas, but we assume zero costs as it is difficult to estimate a distance for this spatially highly distributed region. Numbers are adopted from Takeshita et al. (2006), pp. 290-294.

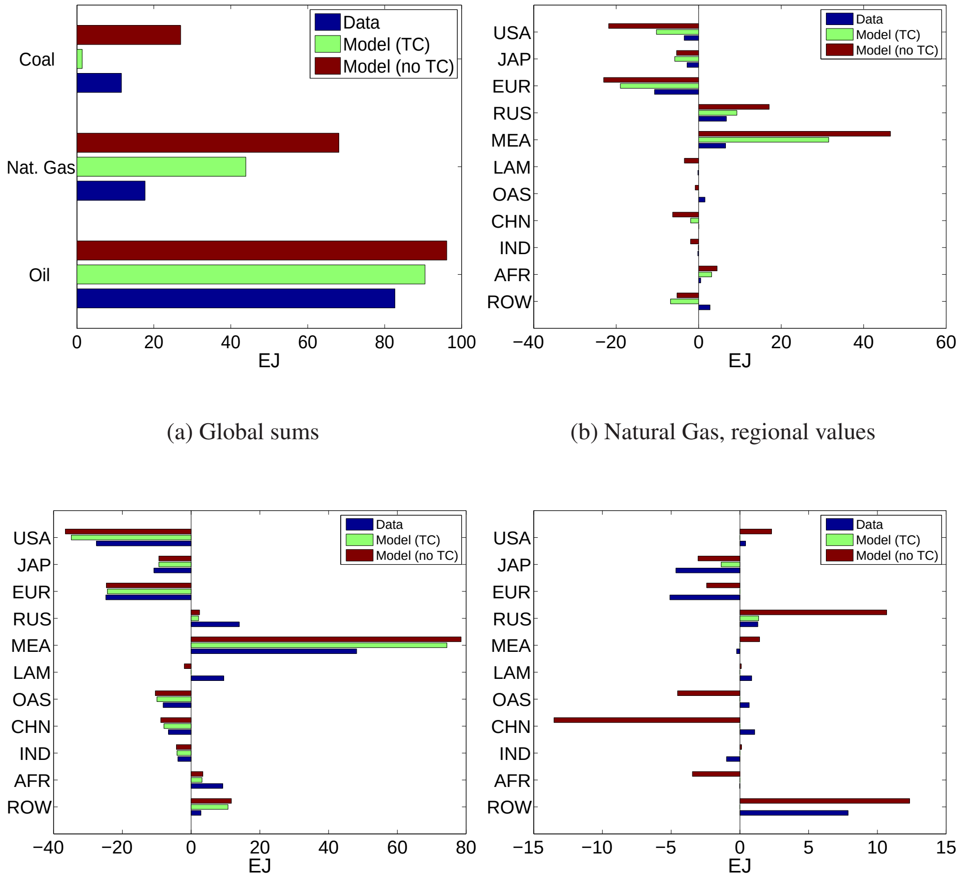
is an example of distance independent costs. We assume that the most efficient transport mode on long distances is chosen: Natural gas is transported via LNG tanker, which affords additional liquefaction and regasification facilities causing additional costs. For details on our additional assumptions see the appendix. It turns out that energetic losses of coal and oil transport by ship or tanker are relatively small and can be neglected. In contrast, energetic losses of natural gas transport are significant. They can mostly be attributed to own consumption for the liquefaction process. Further literature review is required to estimate the uncertainty in the specific trade cost parametrization applied in our study. We suppose that our specific coal trade costs (about a third of the value of the transported coal) are close to the upper bound of uncertainty.

Our analysis is structured as follows: First, we compare empirical data of trade flows in the year 2005 (IEA 2007a, IEA 2007b) with model results in our default scenario (no trade costs, ”no TC”), and with our revised scenario (trade costs included, ”TC”). We ask whether the gap between trade patterns empirically observed and trade patterns calculated by the model can be reduced by accounting for trade costs, and, if so, to which extent. Next, we examine trade pattern changes over the period 2005-2050.

In the year 2005, the global trade volumes of all fossil energy carriers are significantly lower (see Figure 6) in the revised scenario than in the default scenario. In case of natural gas and oil, the gap between default scenario and data is halfway closed in the revised scenario. Consideration of coal trade costs leads to a collapse of the world coal market.[3]

Concerning the trade specialization, real world exporters are generally also exporters in the model for natural gas and oil. Natural gas exports of MEA and RUS and imports of USA and EUR are reduced in the revised scenario. The decrease in global oil trade coincides mainly with reduced exports of the main exporter MEA. In case of coal, only JAP and RUS trade in the model, in contrast to empirical data. For Europe and ROW current trade flows are underestimated by the model. Nevertheless, for most regions (in particular Russia, China and OAS) unrealistic huge trade volumes are corrected. In the mid-run to long-run China can be expected to be a major importer as simulated in all model scenarios (see Figure 5). Yet it is an exporter of coal in the empirical data, in spite of its limited reserves, which are currently overexploited.

[3]The regional coal consumption is the same, but importers prefer domestic sources in the revised scenario.



(a) Global sums

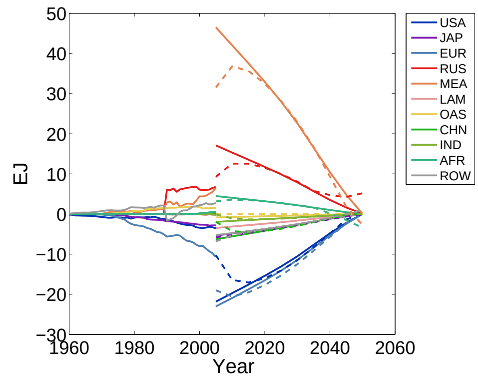
(b) Natural Gas, regional values

(c) Oil, regional values

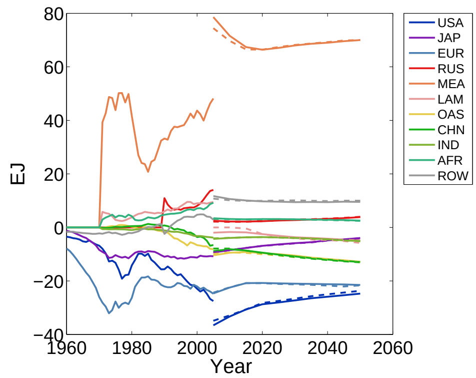
(d) Coal, regional values

Figure 6: Trade flows in the year 2005, comparison of empirical data to model results with and without trade costs (TC). Regional values <0 are imports, values >0 are exports.

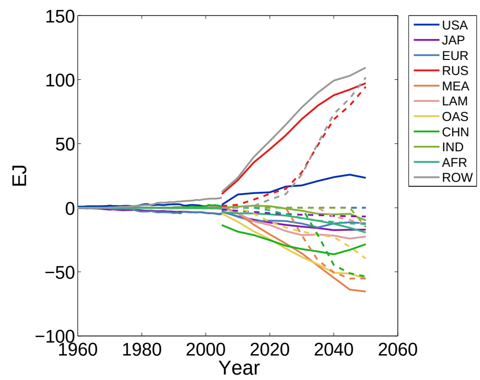
Now, we turn to the effect of trade costs on trade flows until 2050 (see Figures 7 for business as usual and 8 for the climate policy case). Natural gas trade is affected most in the first model years and in the policy scenario also towards the mid of the century. The influence on oil trade is relatively low. Coal trade is significantly attenuated until about 2025 by trade costs, when trade volumes in the baseline scenario of the revised version return to values comparable to current empirical values. In this scenario, the increase in coal trade is postponed by about two decades. Coal is thus more affected by trade costs than oil and natural gas. In general, we find that (likewise our analysis for the year 2005) major exporters remain exporters over the observed model period in all scenarios. The most prominent exception is USA, which is a prominent coal exporter in the default scenario, but not in the revised scenario.



(a) Natural Gas

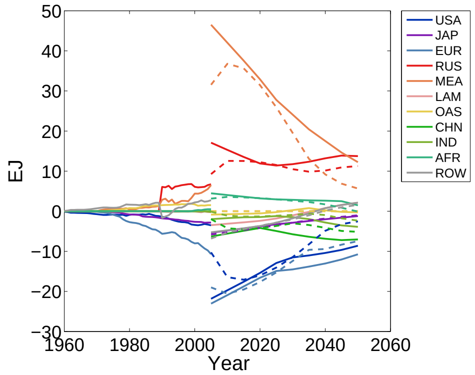


(b) Oil

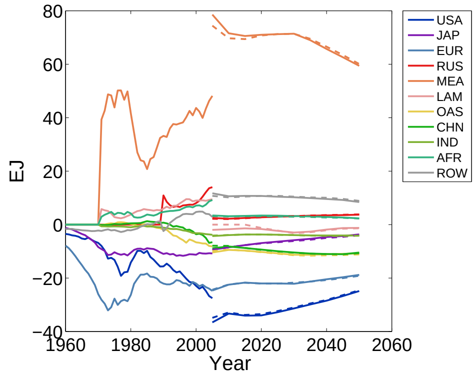


(c) Coal

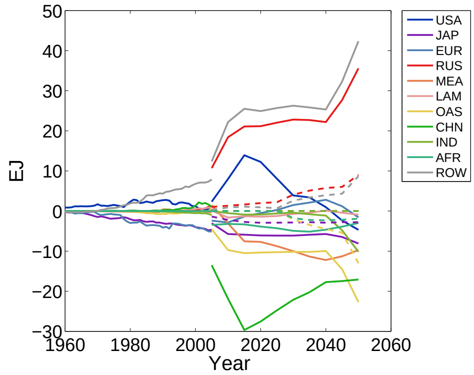
Figure 7: Trade flows, comparison of empirical data (1960-2005, solid lines) to model results (2005-2050) in the default scenario (no trade costs, solid lines) and in the revised scenario (with trade costs, dashed lines), both in the business as usual case. Values <0 are imports, values >0 are exports.



(a) Natural Gas



(b) Oil



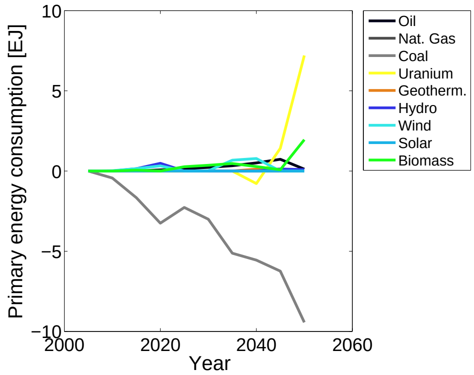
(c) Coal

Figure 8: Trade flows, comparison of empirical data (1960-2005, solid lines) to model results (2005-2050) in the default scenario (no trade costs, solid lines) and in the revised scenario (with trade costs, dashed lines), both in the climate policy case. Values <0 are imports, values >0 are exports.

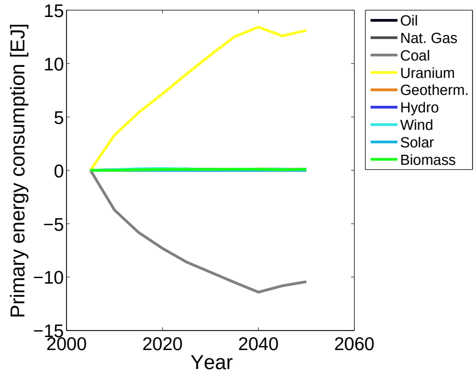
In accordance with reduced trade volumes, regional primary energy consumption patterns change when trade costs are imposed. The effect is most significant for coal (see Figure 9): In EUR and JAP, two major importers of fossil energy carriers, coal consumption decreases by up to approx. 10 EJ/a in 2050, if trade costs are assigned. On the other hand, RUS and ROW as the major coal exporters react to the decreased global coal demand in the revised scenario by consuming a higher amount of coal domestically.

These results reflect the so-called home bias in trade (Obstfeld and Rogoff, 2000): Due to trade costs, both exporters and importers consume a larger share of their endowment domestically rather than trading it. Specialization declines.

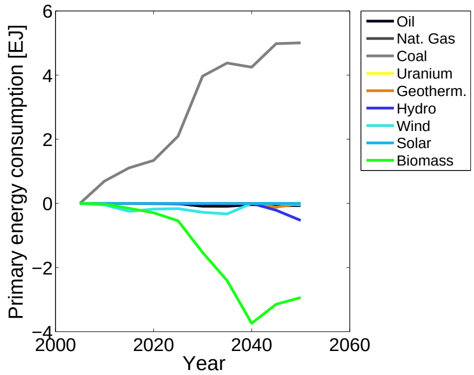
Global and regional mitigation costs are not altered drastically by trade costs (see Figure 10). The global value remains almost unchanged. However, in the regional distribution, mitigiation costs of major exporters (MEA, RUS, ROW) decrease, and the costs of two major importers (EUR, USA) increase. The effect for MEA, RUS and ROW is more pronounced. Exporters of fossil energy carriers face a huge devaluation of their factor endowment by the implementation of a climate target, along with reduced export prices. If trade costs are imposed (both in the business as usual and climate policy case), the amount of rents to get lost is reduced. The reduced mitigation benefits of AFR are due to a reduced demand for their excess emission permits as a consequence of a reduced fossil energy usage by fossil importing regions.



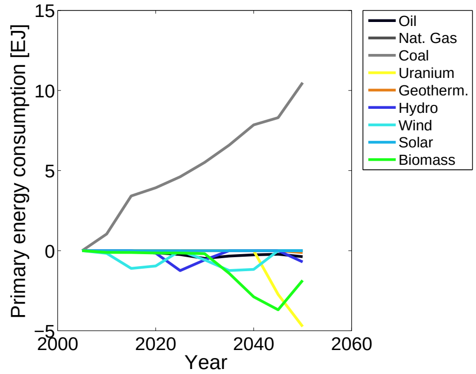
(a) Europe



(b) Japan



(c) Russia



(d) Rest of the World

Figure 9: Primary energy consumption difference of the revised scenario minus the default scenario. Positive values indicate an increase of consumption when TC are added. Both experiments: business as usual.

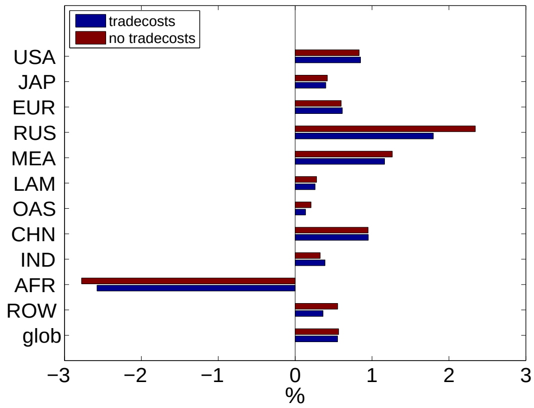


Figure 10: Regional mitigation costs in the default scenario (without trade costs) and the revised scenario (with trade costs)

4.2 Time preferences, productivity differences and trade

With respect to trade in the composite good, which dominates the current account of most regions, there is a general pattern in REMIND-R. Developed countries are exporters first and importers later. The opposite applies to the developing regions. The main drivers behind this pattern are productivity differentials, preferences and the intertemporal budget constraint.

The composite good represents consumption goods and investment goods simultaneously. Hence they can be expected to flow either into regions with higher marginal utility of consumption (consumption good effect) and/or into regions with higher marginal productivity (investment good effect). Both is the case. Due to the impact of the intertemporal budget constraint, trade patterns turn around later when differences in marginal utilities and productivities have declined. However, while this is in accordance with the theory, empirics show a slightly different picture. This applies to the level of trade. Simulated current accounts deviate by an order of magnitude for several regions. But it also applies to the direction of trade. The latter is known as the Lucas Paradox (Lucas, 1990). This effect is most significant for China and the USA. High trade deficits and trade surpluses, respectively, are simulated for these regions in the model experiments, as discussed in section 3.

We make numerical experiments aiming at harmonizing simulated volumes of trade flows with empirically reported numbers. A first conceptual approach in correcting the trade flow level is to capture the home bias effect (cf. Obstfeld and Rogoff, 2000). Most standard CGE models apply Armington elasticities to model the home bias. While capturing the home bias is suited to adjust the level of trade flows, it is not likely to help in tackling the Lucas Paradox. We, therefore, followed another approach that similar to the Armington elasticities take influence on regional preferences, but is more radical.

We started from the assumption that causation of international trade is given by regional differences either in factor endowments, technologies or preferences. Both latter drivers rendered to be suited elements for trade flow adjustments. In case of preferences, we recognize that the savings behavior is not unique in the world. Differences are rooted in the stage of economic development and in socioeconomic and cultural characteristics of respective regions. In an economic growth model the savings behavior is best modeled by the pure rate of time preference. Therefore, we refrain from the original model assumption of equal time preferences and tested the impact of their regional differentiation [4]. We, however, assume that the preferences remain constant over time in each single region.

With respect to technological differences, we make use of the combined impact of the intertemporal trade balance and the investment good effect. This can be expressed as the ratio of the intertemporal productivity slope. In REMIND-R, this relates to the set up of the exogenous efficiency growth parameters of the CES-nested production function. Each production function calculates the amount of output, $V(t,r,v_{out})$, from the associated factor input amounts $V(t,r,v_{in})$ according to the elasticity of substitution and the efficiency $A(t,r,v_{in})$. It holds:

$$V(t,r,v_{out}) = \left(\sum_{M_{CES}} \left(A(t,r,v_{in}) \cdot V(t,r,v_{in})\right)^{\rho(r,v_{out})} \right)^{1/\rho(r,v_{out})} \qquad \forall\, t,r,v_{out}. \tag{11}$$

The list M_{CES} assigns the correct input types v_{in} to each output v_{out}. To describe the general efficiency growth path $g(t,r,v_{in})$ of a production factor v_{in}, we specify an initial growth rate $p_s(t,r,v_{in})$ and a transition $p(r,v_{in})$ to a final

[4] The assumption of interacting representative agents with different time preferences is quite uncommon in standard economic theory (Lengwiler, 2005). The majority of theoretical literature discusses the existence of different preferences in the context of individuals or agents that represent less than entire world regions.

growth rate $p_l(t, r, v_{in})$. The efficiency development is calculated by

$$A(t, r, v_{in} = A(t-1, r, v_{in} \cdot (1 + g(t, r, v_{in})) \quad \forall\, t, r, v_{in}, \tag{12}$$

with

$$\begin{aligned} g(t, r, v_{in}) &= p_l(t, r, v_{in}) \\ &+ [(p_s(t, r, v_{in}) - p_l(t, r, v_{in})) \cdot e^{(-p(r, v_{in}) \cdot (t - t_0))}] \quad \forall\, t, r, v_{in}. \end{aligned} \tag{13}$$

For all energy production factors, efficiency growth rates are defined in relation to labour productivity changes. For the purpose of adjusting the trade pattern, the ratio between p_s and p_l is crucial.

Table 2 shows the default parameter setting of REMIND-R. The common time preference is 3% and initial growth rates are chosen based on empirical data which, however, differ by source and by the time span that is taken as the basis.

In the revised version industrialized regions face a higher time preferences compared to the default version, with the highest value of 4.5% for the USA. We assume a lower time preference for developing regions with high saving rates, particularly fast growing regions like China and India. The adjustment of the efficiency parameters follows two basic pattern: increasing the initial growth rate (in range of empirically plausible values) and decreasing or keeping constant the long-term growth rate or vice versa. The former applies to the USA and Europe, the latter to the emerging economies China, India and OAS. For all other regions, parameters have not changed, except Japan, for which the starting as well as the long-term growth rate was slightly increased. The concrete parameters of the revised version are shown in Table 3.

REGION	time preference	p_s	p_l	p
USA	0.03	0.021	0.012	0.05
JAP	0.03	0.011	0.012	0.04
EUR	0.03	0.018	0.012	0.015
RUS	0.03	0.029	0.017	0.027
MEA	0.03	0.044	0.0138	0.029
LAM	0.03	0.04	0.0184	0.025
OAS	0.03	0.04	0.02	0.02
CHN	0.03	0.086	0.018	0.04
IND	0.03	0.062	0.019	0.019
AFR	0.03	0.038	0.02	0.027
ROW	0.03	0.026	0.018	0.02

Table 2: Parameters of default model version

REGION	time preference	p_s	p_l	p
USA	0.045	0.025	0.01	0.03
JAP	0.04	0.014	0.013	0.021
EUR	0.04	0.022	0.012	0.02
RUS	0.02	0.029	0.017	0.027
MEA	0.03	0.044	0.0138	0.029
LAM	0.025	0.04	0.0184	0.025
OAS	0.02	0.035	0.025	0.02
CHN	0.015	0.05	0.02	0.015
IND	0.015	0.055	0.019	0.019
AFR	0.03	0.038	0.02	0.027
ROW	0.03	0.026	0.018	0.02

Table 3: Parameters of revised model version

This parameter transition from the default to the revised REMIND-R version influences the whole economy, in particular the regional GDP and consumption paths. As known from the theory, a higher time preference results in a short-term increase and a long-term decrease of consumption linked to a lower GDP path. This pattern holds for Europe and the USA, indicating dominance of the preference effect over the impact of the increased starting efficiency growth rates (see Figure 11). An opposite pattern occurs for most other regions, especially for India and OAS. Remarkable is the behavior of China. This is the only region, which changes the direction of the GDP difference between the default and revised version over the time horizon. A higher GDP path in the first half of the century is followed by a lower one in the second half. The second part is in contrast of what one would expect from the direct effect of the lower time preference rate and the higher long-term efficiency growth rates. It can only be explained by shifts in the trade pattern.

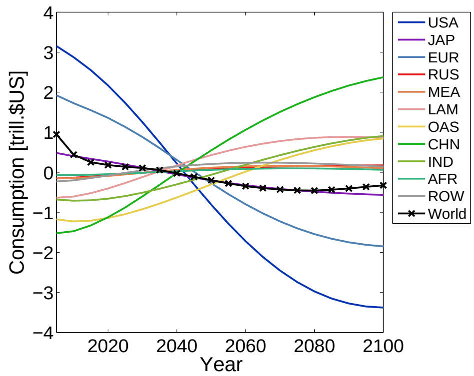


Figure 11: Consumption differences between default and revised version

In analyzing trade pattern changes, we first focus again on the base year 2005. Figure 12 shows the difference of trade in the composite good between the default and the revised version for all regions in 2005. Positive values indicate more export/import in the revised REMIND-R version, while negative values denote less import/export in the revised compared to the default version. The change in efficiency growth parameters and time preference rates results in less export of the composite good in the industrialized regions USA, Japan and Europe. At the same time, developing regions like MEA, LAM, OAS, China, India and Africa import less composite goods in the revised compered to the default version. Overall, this is a drastic reduction in the trade volumes, but as we will show later, this provides an improved correspondence to empirical data.

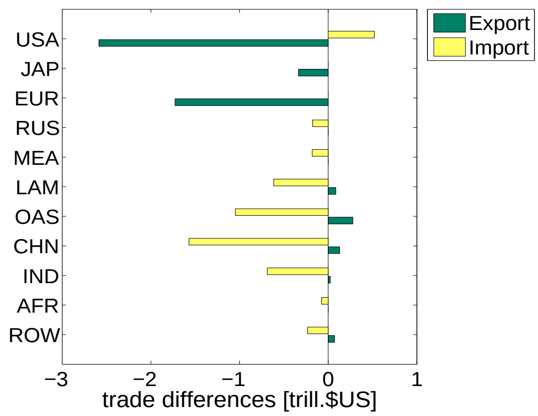
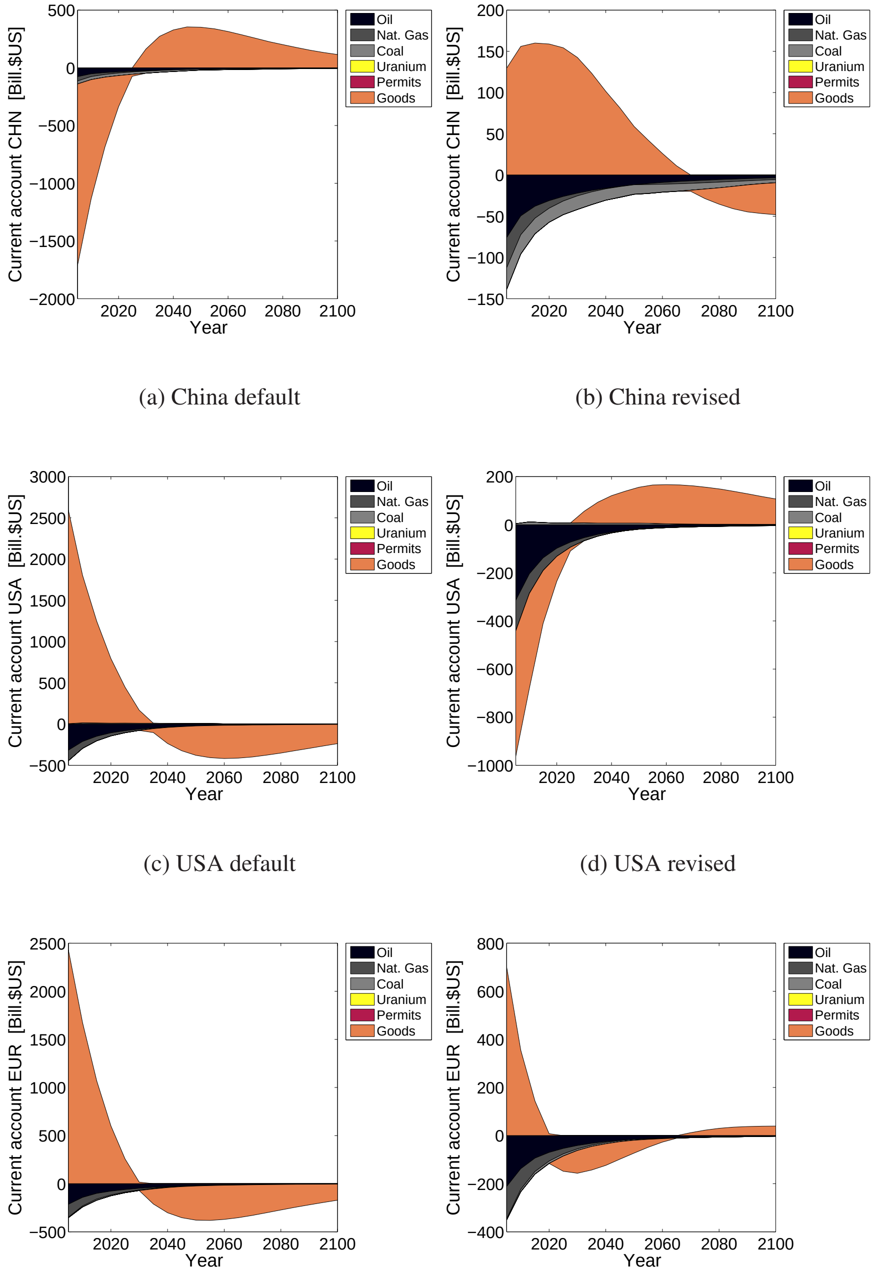


Figure 12: Trade differences between default and revised version

We now look at trade pattern changes as documented in the simulated current accounts. The change between the default and revised version is most obvious for particular regions. The current accounts in the default and the revised version are compared for the regions China, USA and Europe in Figure 13. In the default version China imports a large amount of the composite good in the first time periods and gets later an exporter. This trade structure, which is for the initial period contradictory to empirical results, changes in the revised version of REMIND-R. China exports goods until 2070 and gets afterwards an importer of composite goods. Similar improvement is achieved for the trade behavior of the USA. The unrealistic default result of having a trade surplus in the beginning of the century changes to the opposite.

Figure 13 presents results from the respective BAU scenarios. The trade pattern represented by the current accounts does not change qualitatively in the respective policy scenarios. However, due to the lower overall trade level, climate policy induced changes in the trade of primary energy carriers and emission permits gain importance.

Exemplary for all regions, we provide evidence of the improved correspondence of the model results with empirical data for the regions China, USA and Europe in Figure 14. Our model results for the time horizon 2005-2100 are compared to empirical current account data (WDI, 2005) for 1960-2003. In contrast to the energy trade data which show a more stable pattern, the current accounts are subject to significant short-term changes. Hence, there is no need for the model to meet empirical data of a single year. However, we aimed at bringing the initial level of the simulated current accounts into the empirically given range. Moreover, sustained trade deficits and surpluses as e.g. for USA and China should be reproduced. Figure 14 demonstrates that the revised version of REMIND-R meet these targets and provides more realistic trade pattern.



(a) China default

(b) China revised

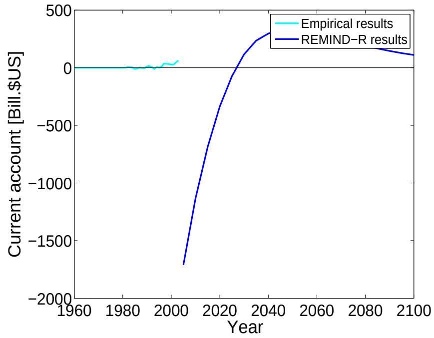
(c) USA default

(d) USA revised

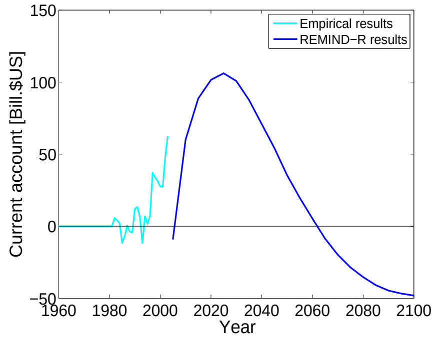
(e) Europe default

(f) Europe revised

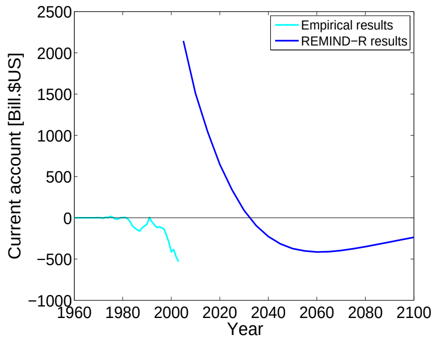
Figure 13: Current account of China, USA and Europe from default and revised BAU scenario



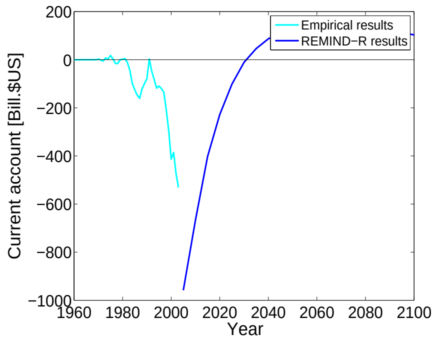
(a) China default



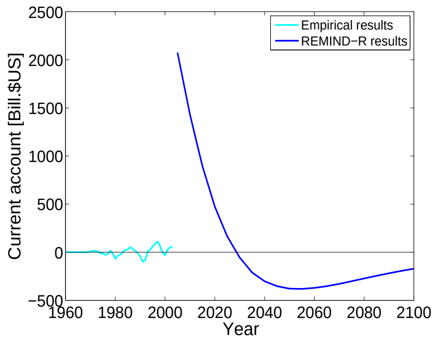
(b) China revised



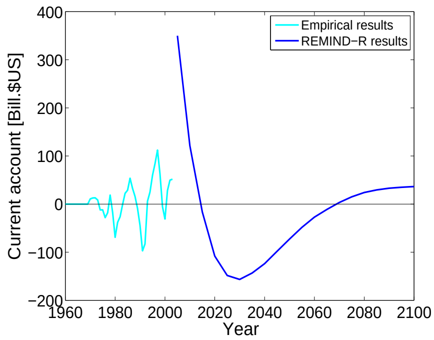
(c) USA default



(d) USA revised



(e) Europe default



(f) Europe revised

Figure 14: Current account of China, USA and Europe of default and revised version; Empirival data based on WDI (2005)

Finally, we want to discuss the impacts of the parameter adjustment on the mitigation costs. There is no clear-cut indication of the impact direction. Mitigation costs of USA and Europe are affected differently, although their parametrization was altered in the same direction. The same holds for China and India. China and Russia, regions with high mitigation costs, are negatively affected. Global mitigation costs slightly increase (by 0.04 percentage points), which might be due to the slight upward shift of the growth trajectory. It is known that higher economic growth (if not associated by an according improvement of the energy efficiency) increases the mitigation gap and hence the mitigation costs.

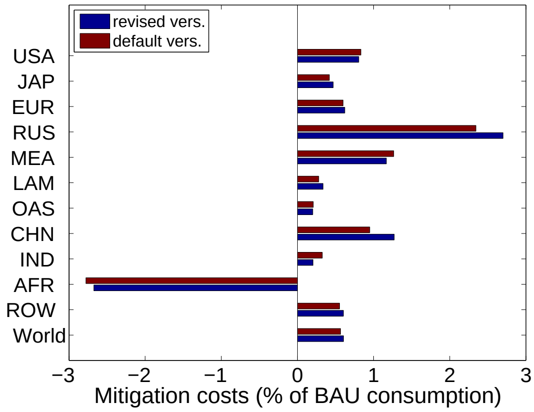


Figure 15: Regional mitigation costs in the revised and default policy scenario

5 Conclusions

This paper discussed trade-related issues in climate policy modeling. The trade module of the hybrid IA model REMIND-R, which is used for climate policy analysis, was subject of investigation. Improvements of this model along theoretical lines and empirical data are suggested and tested. Less specialization, a home bias, and consequently a trade pattern that is in much better correspondence with the empirics result from our experiments. While energy trade flows are controlled by the inclusion of empirically estimated trade costs, trade in the composite good is controlled by altered assumptions on the regional preferences and technologies. By means of the latter, we were able to resolve the Lucas Paradox.

While the impact of the model adjustments on the trade pattern is remarkable, mitigation costs change only slightly. The general conclusion from REMIND-R policy experiments hold: a 450ppm CO_2 stabilization target can be achieved by global cost of around 0.6% of global world product. Russia faces the most significant changes of mitigation costs. In the presence of energy trade costs, mitigation costs decrease due to a lower amount of energy trade revenues that potentially could be lost in the policy scenario. This is mainly linked to the correction of coal exports from which Russia benefit to a higher extent in the BAU scenario. However, changes in the macroeconomic parameters drive Russia's mitigation cost changes in the opposite direction, hence, offset the first effect partially. A likewise offset of mitigation cost changes apply to USA, Japan, LAM, India and ROW. Europe and Africa are twice slightly negatively affected.

The mitigation costs impact of changes in the macroeconomic pattern are different for similar regions that were subject to similar changes. This indicates a complex feedback pattern which includes terms-of-trade effects that demand for further research.

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6 Appendix

Deriving specific trade cost parameters from Takeshita et al. (2006), pp. 290-294, requires additional assumptions:

Transport modes and facilities: Natural gas is transported via LNG tanker (rather than by pipeline) which is more efficient on longer distances. The tanker is assumed to travel 1000km per day. Liquefaction and regasification facilities are assumed to have a lifetime of 25 yrs. Required electric power for liquefaction is assumed to be produced from the treated natural gas with a thermal efficiency of 0.38. Costs of LNG tanker transport, liquefaction and regasification add up to total natural gas trade costs. Crude oil is transported via tanker (rather than by pipeline). Coal is transported by ship (rather than by rail).

Transport distances: Distances are estimated as the direct line between pairs of representative sites in the respective regions. Cities chosen for distance estimation are New York (USA), Tokyo (JAP), Berlin (EUR), Novosibirsk (RUS) as most fossil reserves of Russia are located in the north of Sibiria, Riad (MEA), Sao Paolo (LAM), Jakarta (OAS), Shanghai (CHN), Bombay (IND), Lagos (AFR), and Calgary, Sydney or Kapstadt (ROW) depending on the energy carrier and assumed trade partner. Furthermore, we need to make assumptions on the origin of exports for each importer to derive distances. In case of OECD regions, we consider empirical values of current import origins. For natural gas and oil, we choose MEA as the origin of imports into JAP, CHN, and IND and determine the respective distances accordingly. MEA or RUS is the origin of imports into EUR and OAS (same distance). LAM imports from AFR. MEA is the origin of natural gas and oil imports into USA. However, parts of the oil imports come from Canada (ROW), so the distance MEA - USA is reduced by 10 % in case of oil. For coal, RUS is the origin of imports into MEA, CHN, IND, and USA. JAP and OAS import coal from ROW (Australia), LAM and AFR from ROW (South Africa). EUR imports coal partly from ROW (South Africa) and RUS, so a distance inbetween is chosen. Please note that these attributions are used only to specify trade cost parameters. They do not contradict the concept of a global trade balance for each tradable good.

It should be noted that transport mode and distance assumptions are optimistic regarding the cities chosen for distance estimation. Distances might by significantly longer in reality, and less efficient transport modes might be chosen partly due to geographical or political barriers. E.g., coal exports from RUS to IND will probably not use a ship for the direct way from Novosibirsk to Bombay.