Intertemporal trade and the Integrated Assessment of climate change mitigation policies

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Abstract

Within this paper, we discuss problems of integrating intertemporal trade into an economy-energy-environment model. Modeling intertemporal trade provides additional flexibility in achieving economic development as well as environmental sustainability targets, that likely corresponds to real-world flexibility. However, based on simulations with an economic growth model in an environment of free trade and perfect competition, model output is challenged by empirical data. This paper demonstrates how, based on trade-theoretical concepts, model results and empirical data are reconciled with each other and the Lucas-Paradox can be resolved. Within a climate policy context, the question arises to what extent climate policy assessments are sensitive against the integration of intertemporal trade and the way intertemporal trade is modelled. From simulation results it transpires that global and regional mitigation costs are quite insensitive to the inclusion of intertemporal trade.

JEL classification: D90, F11, F18, Q54, Q55
keywords: climate policy, international trade, time preference, Lucas Paradox

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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. In the economic literature, however, increasing attention has been given recently to the interaction of international trade and climate change (e.g. Copeland and Taylor, 2005; Weber and Peters, 2009). Different studies (e.g. Böhringer and Rutherford, 2004; Springer, 2002; Leimbach et al. 2010a) demonstrate that trade-related impacts (in particular reduced rents from trade in fossil fuels and revenues from the permit market) determine the mitigation costs of several regions.

In mitigation 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.

Within Integrated Assessment (IA) models centered around an economic growth model, e.g. RICE (Nordhaus and Yang, 1996) and MERGE (Manne et al., 1995), a composite good exists that aggregates the majority of each countries' tradeable goods. Commonly, trade in the composite good balances trade in energy resources and emission permits. Capital inflows and current account deficits do not occur in such a setting when intertemporal trade is not modeled. Intertemporal trade is meant as trade between a good today against a good of the same type in the future. The possibility of intertemporal trade in Integrated Assessment models is hardly addressed since Nordhaus and Yang (1996) - on the one hand, because of the numerical demands on solving large-scale models with intertemporal trade, on the other hand, because of the peculiarity of resulting trade flow patterns. However, intertemporal trade (and therefore the possibility of current account deficits) significantly contributes to the growth dynamics of the world economy. This paper aims to renew the discussion and to highlight the role that intertemporal trade and trade-related assumptions play in mitigation cost assessments.

Based on the application of the IA model REMIND-R (Leimbach et al., 2010b), we investigate the implications of intertemporal trade and the relevance of effects known from theory like specialization, factor price equalization (Stiglitz, 1970), and the Lucas-Paradox (Lucas, 1990). In particular, we analyze model results against the background of empirical observations. In a model with perfect competition and free trade, simulated trade flows may deviate in an order of magnitude from empirically obeserved data. Ten Raa and Mohnen (2001) report this for a multi-product model. With the intertemporal dimension of trade as modeled by REMIND-R a similar effect can be observed.

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 analyze the reaction of a stylized economic growth model on the introduction of intertemporal trade analytically. In section 3, we present the trade module of the large-scale Integrated Assessment model 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. A comparison of empirical data and model outcomes from REMIND-R simulations is discussed in section 4. By means of differentiated regional time preferences trade flows are contained and redirected and the Lucas-Paradox is resolved. The implication of modelling intertemporal trade and of the way intertemporal trade is modeled on the mitigation costs is investigated in section 6. We end with some conclusions.

2 Trade in an economic growth model

What drives trade in an economic growth model? In order to answer this question based on simple analytical reasoning, we consider a single-factor, two-country economic growth model. Both countries produce just one composite good. Utility U is a function of consuming this good over a time $t = 0, ..., T$. The representative agents of each country have no preferences on consuming domestic compared to foreign goods. In this setting, trade is only meaningful as intertemporal trade which can simultaneously be conceived as capital trade or as borrowing and lending (cf. Obiols-Homs, 2011). This yields the following optimization problem for each country i=1,2:

$$max \int_{t=0}^{T} e^{-\rho_i t} U_i(C_i(t))dt \tag{1}$$

$$s.t. \quad C_i(t) = f(A_i(t), K_i(t)) - I_i(t) - X_i(t) \tag{2}$$

$$\dot{K}_i(t) = I_i(t) + (1 - \delta)K(t) \tag{3}$$

$$\dot{D}_i(t) = X_i(t) + r(t) \cdot D_i(t) \tag{4}$$

$$D_i(T) = 0. \tag{5}$$

$$\dot{K}_i(T) = 0. \tag{6}$$

C_i, A_i, K_i, I_i, X_i and D_i represent consumption, total factor productivity, capital, investments, net exports, and net foreign assets, respectively. f is a neo-classical constant-return-to-scale production function. Utility is discounted based on the pure rate of time preference ρ, capital is depreciated with the rate δ, and net foreign assets yield interest by the amount $r \cdot D_i$. Eq. (5) ensures that all debts are cleared, i.e. all accumulated current account deficits are balanced at the end of the time horizon.

From the economic theory we know that for the marginal product of capital at the optimum growth path it holds (Cass, 1965):

$$f'(\hat{K}_i(t)) = \rho + \delta. \tag{7}$$

In an open economy with unrestricted capital trade the marginal products in each region converge to each other:

$$f'(\hat{K}_1(t)) = f'(\hat{K}_2(t)). \tag{8}$$

In following the classical Heckscher-Ohlin (HO) and Ricardian model (Flam and Flanders, 1991), trade between countries (or regions) is induced by differences in three economic fundamentals - factor endowments (K), technologies (A) and preferences (ρ). While this was originally derived from a two-product static case, it can analogously be applied to a multi-product case (cf. Ten Raa and Mohnen, 2001) and to the one-product intertemporal case. The present study investigates the latter. We are interested in the transitional effects and in the resulting trade patterns that not only take into account that marginal products of capital can be equalized by initial trade shocks but also that the trade interaction is only completed if initial export (import) is balanced by future import (export) as ensured by eq. (5).

We explore the impact of regional differences of the three fundamentals sequentially. Besides the respective difference, regions are assumed to be symmetric. Common properties of neoclassical welfare and production functions hold. Due to diminishing marginal productivity, a higher capital endowment within region 1 results in an initial trade flow from region 1 to region 2. Hence, region 1 accumulates net foreign assets:

$$K_1(0) > K_2(0) \Rightarrow f'(K_1(t)) < f'(K_2(t)) \Rightarrow D_1(t) > D_2(t). \tag{9}$$

The trade flow shifts later. Region 2 exports the composite good to meet eq. (5).

We yield the opposite trade pattern for differences in the technology (i.e. differences in the total factor productivity) which directly provide deviations of $f'(K_1)$ and $f'(K_2)$.

$$A_1(t) > A_2(t) \Rightarrow f'(K_1(t)) > f'(K_2(t)) \Rightarrow K_1(t) > K_2(t) \Rightarrow D_1(t) < D_2(t). \tag{10}$$

Convergence of marginal productivities can only be achieved by increasing the capital stock of region 1 by means of imports. In both previous cases, trade is induced as part of an instantaneous transition towards a new steady state (in particular an optimal capital output ratio).

Beyond that, directed trade can be triggered by differences of productivity growth in the following way:

$$\begin{aligned} \dot{A}_1(t) > \dot{A}_2(t) \Rightarrow \frac{f'(K_1(t))}{f'(K_2(t))} > \frac{f'(K_1(t-1))}{f'(K_2(t-1))} \Rightarrow \\ \frac{K_1(t)}{K_2(t)} > \frac{K_1(t-1)}{K_2(t-1)} \Rightarrow D_1(t) < D_2(t). \end{aligned} \tag{11}$$

Laterally reversed to the trade pattern induced by comparative advantages in a static multi-product world, capital flows towards the more productive country in times when productivity differences are expected to be highest and towards the less productive country otherwise.

Finally, with respect to differences in preferences we refer to eq. (7). According to this optimality condition, a higher marginal product of capital for the region with the higher time preference (i.e. region 1) can be assumed. This again implies transitional trade flows from region 2 to region 1:

$$\rho_1 > \rho_2 \Rightarrow f'(K_1(t)) > f'(K_2(t)) \Rightarrow K_1(t) > K_2(t) \Rightarrow D_1(t) < D_2(t). \quad (12)$$

In an open economy with perfect international capital market, the neoclassical model predicts that capital moves quickly to equalize marginal products. This can lead to huge initial capital flows. Though, the extent of capital flows depends on the instance of regional differences. If differences in endowments, technologies and preferences induce trade in opposite directions, initial capital flows will be contained. However, in Integrated Assessment models this is hardly the case. The standard assumptions are equal preferences, and capital endowments and technology differences that imply capital flows from North to South.

Within subsequent analyses with REMIND-R it turns out that differentiating the time preferences is effective in containing initial trade flows. However, the assumption of interacting representative agents with different time preferences is not common in standard economic theory (Lengwiler, 2005). The majority of the relevant literature examines the existence of different preferences in the context of individuals or agents that represent less than countries or entire world regions. Apart from that, Barro et al. (1995) bring forward the argument of different preferences when explaining growth patterns of countries. They, furthermore, introduced human capital to a allow for an imperfect capital mobility. In this framework only the accumulation of physical capital can be financed by borrowing.

The assumption of regional differentiated time preferences rates can be combined with the assumption of either being constant or varying over time. While the former is consistent with the hypothesis that successive generations are motivated by the same system of preferences (Ramsey, 1928), it creates another unappealing characteristic. If agents discount future utility and use different constant discount rates, then, at any future state, all the capital will be owned by agents with the lowest discount rate (Barro et al., 1995; Bliss, 2004).

Optimal growth with endogenously determined rates of time preferences is examined by Das (2003) and Uzawa (1996). Das (2003) adopts the idea that the time preference varies with increasing income. While previous theoretically based argumentation is in favor of increasing marginal impatience, as it ensures stability of the steady state, Das (2003) demonstrates that a stable steady state can also be consistent with decreasing marginal impatience.

While use of both regionally differentiated and time-variant rates of time preferences is not common in Integrated Assessment modeling (Hof et al., 2010), theoretical literature provides sound foundation for experiments based on such kind of assumptions.

3 The trade module of REMIND-R

REMIND-R is a 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 Fig. 1)[1]. The individual regions are coupled by means of a trade module.

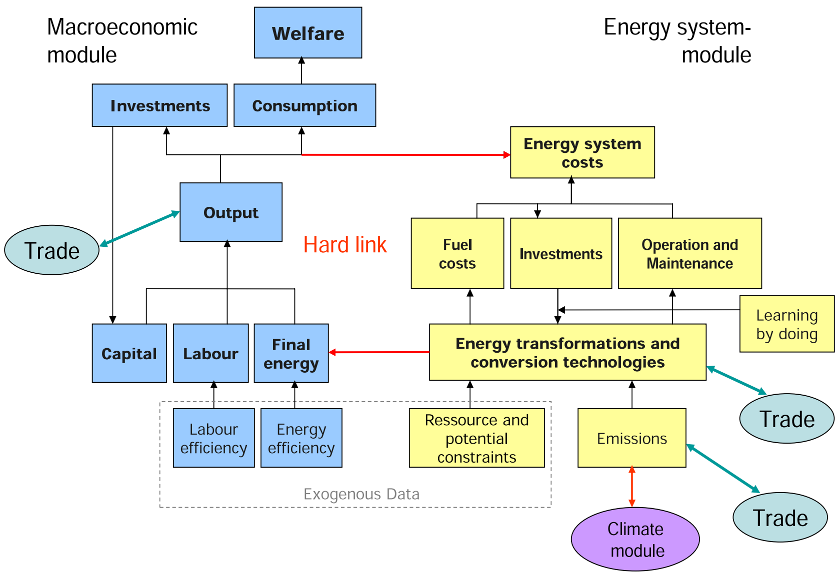


Figure 1: Structure of REMIND-R

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

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

1. USA - USA
2. EUR - EU27
3. JPN - Japan
4. CHN - China
5. IND - India
6. RUS - Russia
7. AFR - Sub-Saharan Africa (excl. Republic of South Africa)
8. MEA - Middle East and North Africa
9. LAM - Latin America
10. OAS - Other Asia (Central and Pacific Asia)
11. ROW - Rest of the World (Canada, Australia, South Africa 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:

$$U(r) = \sum_{t=t_0}^{T} \left(\Delta t \cdot e^{-\zeta(t-t_0)} L(t,r) \cdot \ln \left(\frac{C(t,r)}{L(t,r)} \right) \right) \quad \forall r. \tag{13}$$

$C(t,r)$ 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].

In the original version of REMIND-R, trade between regions is induced by differences in factor endowments and technologies. This is supplemented by the possibility of intertemporal trade. Capital mobility, 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:

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

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

There is no bilateral trade, but export in and import from a common pool. 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:

$$\sum_r (X_j(t,r) - M_j(t,r)) = 0 \quad \forall\, t, j \tag{14}$$

Both trade variables represent control variables. A procedure of reconciling trade decisions of actors (i.e. regions) 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 W by means of welfare weights w:

$$W = \sum_r (w(r) \cdot U(r)) \tag{15}$$

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 $B^i(r)$:

$$B^i(r) = \sum_t \sum_j \left(p_j^i(t) \cdot [X_j^i(t,r) - M_j^i(t,r)]\right) \quad \forall\, r, i \tag{16}$$

where i represents the iteration index which is skipped from the equations above and $p_j^i(t)$ represents world market prices derived as shadow prices from eq. 14. With a new set of weights

$$w^{i+1}(r) = f(w^i, B^i(r)) \quad \forall\, r, i \tag{17}$$

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

$$\mid B^{i+1}(r) \mid \;<\; \mid B^i(r) \mid \quad \forall\, r, i \tag{18}$$

and

$$\lim_{i \to \infty} B^i(r) = 0 \quad \forall\, r, \tag{19}$$

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 its welfare weight needs to be lowered to induce exports from this region to other regions.

The trade patterns 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 commodity 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 $M_P(t, r)$):

$$\sum_c E(t, r, c) \leq Q(t, r) - X_P(t, r) + M_P(t, r) \quad \forall\, t, r. \tag{20}$$

4 Simulation results vs. empirical data

Despite of its complexity, REMIND-R behaves like the stylized economic growth model as introduced in section 2 concerning intertemporal trade. The intertemporal trade balance (eq. 16) and its terminal condition (eq. 19) take effect like the net foreign asset constraints (eq. 4 and 5) in the stylized growth model. The intertemporally traded composite good represents consumption goods and investment goods simultaneously. Hence it 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. In preliminary simulations with REMIND-R, an international trade pattern arises that is characterized by oversized trade flows compared to empirically observed figures. This is illustrated for the USA in Fig. 2. As we did not restrict trade flows by artificial bounds, productivity differences between regions are equalized quickly by capital trade (i.e., trade in the composite good). This leads to initial spikes in current account balances and an overestimation of trade flows (cf. Nordhaus and Yang, 1996). Ten Raa and Mohnen (2001) report on deviations in the same order for a free trade model based on the economic fundamentals only. However, while this is in accordance with the theory, empirics show a slightly different picture.

Deviations form the empirics does not only apply to the level of trade but also to the direction of trade - capital is flowing from North to South in the model. This 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 (cf. Fig. 2).

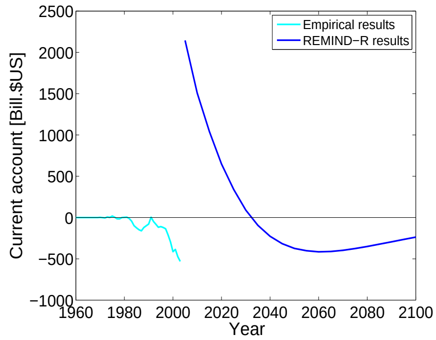


Figure 2: Current account of USA; empirical data are based on WDI (2005), simulated data on unadjusted model version

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, which request for a shift in the direction of trade. 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 - as demonstrated in section 2 - 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 linked to the pure rate of time preference. We refrain from the original model assumption of equal time preferences and tested the impact of their regional differentiation. Though, we assume that the preferences remain constant over time in each single region to maintain intergenerational consistency, while recognizing a long-term regional spread in consumption growth rates (cf. discussion in section 2).

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 slopes (cf. (11)). In REMIND-R, this relates to the set up of the exogenous efficiency growth parameters of the CES-nested production function, in particular the growth of labor efficiency. However, the range of potential variation is restricted. According to common knowledge the general pattern of productivity growth exhibits high growth rates for countries like China and other emerging economies, constant growth rates for developed countries and in the long run converging but still somewhat higher growth rates of the devoloping countries.

Overall, the adjustment of the time preferences is the dominant effect. Table 1 shows the original and the adjusted set of time preferences assumed in REMIND-R.

In the revised version industrialized regions face a higher time preferences compared to the unadjusted 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.

This parameter transition from the unadjusted 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. This pattern holds for Europe and the USA (see Fig. 3). An opposite pattern occurs for most other regions. While the changes in the growth pattern are substantial, consumption in the most impatient region (i.e. USA) is still growing until 2100. This put the theoretical finding that in the long-run the agent with the lowest discount rate owns all capital into perspective.

Like CGE models, growth models use base year data in order to calibrate model parameters (e.g. distribution and efficiency parameters of the CES production function). This ensures that the model generates correct GDP figures in the base year.

REGION	SRTP (original)	SRTP (adjusted)
USA	0.03	0.045
JAP	0.03	0.04
EUR	0.03	0.04
RUS	0.03	0.02
MEA	0.03	0.03
LAM	0.03	0.025
OAS	0.03	0.02
CHN	0.03	0.015
IND	0.03	0.015
AFR	0.03	0.03
ROW	0.03	0.03

Table 1: Parameters of unadjusted model version

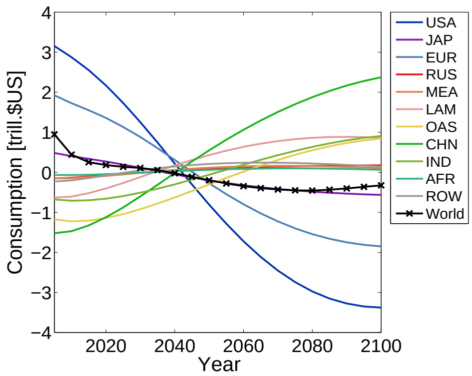
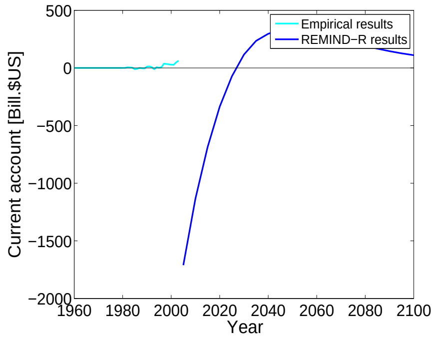


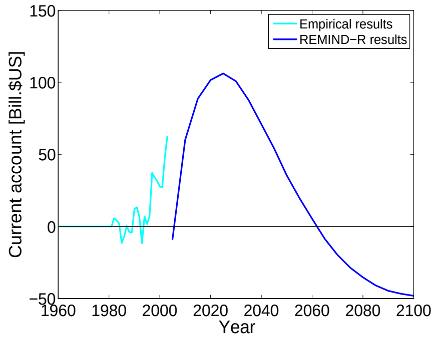
Figure 3: Consumption differences between unadjusted and revised version (net present value)

Other economic figures like investments and trade represent free variables or control variables. Deviation between simulated and empirically observed values for those figures are likely to appear, but should ideally be kept to a minimum. Consequently, these deviations represent an evaluation criterion.

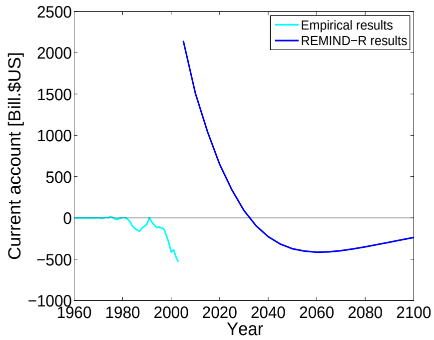
For the two most extreme examples - USA and China - Fig. 4 put together model results for the time horizon 2005-2100 and empirical current account data (WDI, 2005) for 1960-2003. In general, the current accounts are subject to significant short-term changes. Hence, there is no need for the model to meet empirical data of a single year. However, simulated figures within the initial periods are expected to be in a broadly defined empirical range. While this holds for the revised model version, for the unadjusted model version it holds not. Moreover, with the revised model version sustained trade deficits and surpluses as empirically observed for USA and China are reproduced, hence the Lucas-Paradox is resolved.



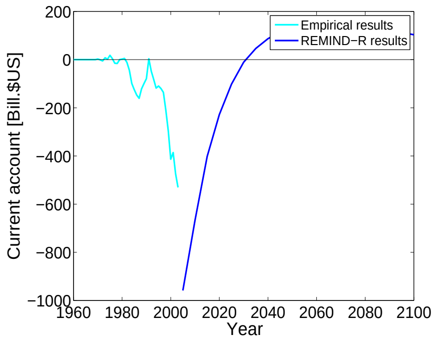
(a) China unadjusted



(b) China revised



(c) USA unadjusted



(d) USA revised

Figure 4: Current account of China and USA of unadjusted and revised version; Empirical data based on WDI (2005)

Fig. 5 shows how this change in the trade pattern, represented by the trade flows in the base year, also applies for other regions. 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 unadjusted version. Mainly driven by a change in regional time preference rates initial exports and imports decrease. The former applies to the developed world regions for which the time preference rates were increased, while the latter applies to the developing regions for which the preference rates were lowered. For a number of regions (e.g. USA, CHN, OAS) initial trade changes the direction. Overall, this provides an improved correspondence to empirical data for the revised model version.

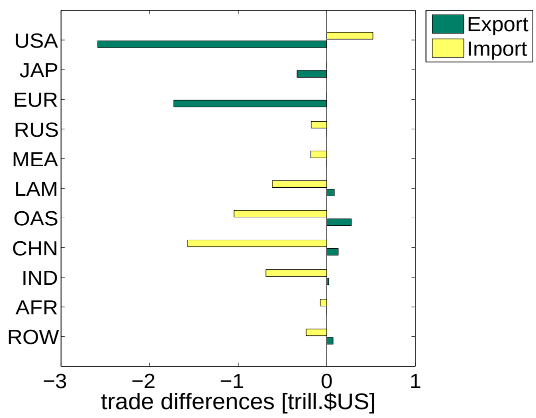
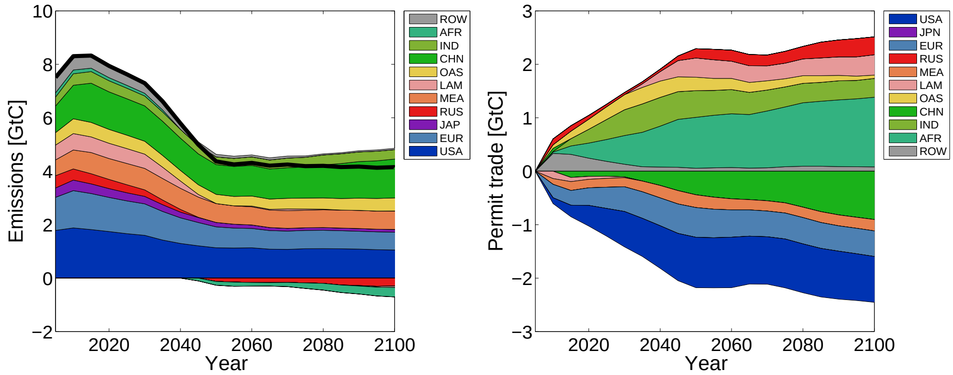


Figure 5: Trade differences between unadjusted and revised version in 2005 (composite good only)

5 Climate policy analysis

In this section, we want to discuss the impacts of intertemporal trade on the assessment of mitigation policies represented by an international cap-and-trade system which aims at stabilizing the atmospheric greenhouse gas concentration at 450 ppm CO_2. First, we analyze some results from policy scenarios based on the revised model version as discussed in the previous section. REMIND-R simulates a cooperative solution that includes a globally optimal emission reduction path. The international burden sharing of the reduction efforts is based on an initial allocation of emission permits which follows the contraction & convergence rule, i.e transition from grandfathering to equal per capita allocation (cf. Meyer, 2000).

Fig. 6(a) shows the global emission reduction path and its regional decomposition. In order to keep the 450 ppm (CO_2 only) stabilization scenario, the global emission path has to be turned around soon. Furthermore, CO_2 emissions have to be reduced by almost 50% until 2050. Although their population share is decreasing, the developed world regions keep their share on global emissions. This is linked to substantial imports of emission permits (see Fig. 6(b)). Africa becomes the major seller of permits. This generates revenues that make Africa better off in the policy scenario than in the baseline scenario and is demonstrated by negative mitigation costs - measured as consumption losses relative to the respective baseline - in Fig. 7. Africa reduces its own use of emission permits by using carbon capturing and sequestration technologies which in combination with the use of biomass generates negative emissions as of 2040 (cf. Fig. 6(a)). While this on the one hand also applies to Russia, this region suffers on the other hand from a loss of revenues on the fossil fuel markets which results in highest mitigation costs for Russia. Global average mitigation costs are around 0.6% of baseline consumption.



(a) CO_2 emissions (b) Permit trading

Figure 6: Energy-related CO_2 emissions (solid black line indicates global emissions) and permit trade structure (positive values indicate sellers of permits)

The regional share on global mitigation costs depends on the allocation of emission permits, the availability and adaptability of low-carbon energy technologies and the current carbon intensity of the respective economies. It is, however, quite robust with respect to the implementation of intertemporal trade.

Overall, the integration of intertemporal trade as well as the adjustments aiming at containing intertemporal trade have only a moderate impact on the mitigation costs (see Fig. 7). Global mitigation costs (averaged over time) differ by a maximum of 0.04 percentage points between the unadjusted and the revised scenario. The most significant change is that China in the scenario with a higher discount rate cannot afford in the long run to buy emission permits of more than 0.25 GtC due to the accumulated current account deficits in the initial periods. In consequence, mitigation costs slightly increase. With respect to the changes of regional mitigation costs, no clear-cut indication of the impact direction of the adjustments between the model variants with intertemporal trade can be given. 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.

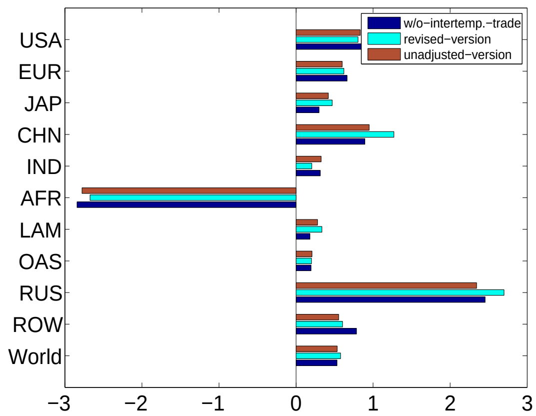


Figure 7: Regional mitigation costs in the revised and unadjusted policy scenario

Somewhat surprisingly, there is also only a small difference between the scenarios with and without intertemporal trade. There are two effects that actually can be expected to occur. On the one hand, with excluding intertemporal trade, the economic growth path potentially slows down if there is a shortage of capital in some regions. This would result in a lower emission path in the baseline of the scenario that excludes intertemporal trade and consequently in a smaller mitigation gap. Lower mitigation costs can be expected. On the other hand, the possibility of intertemporal trade helps in mitigation policies. Restructuring the energy systems towards a carbon-free system requires capital that in several world regions cannot completely be allocated domestically. Intertemporal trade, which represents consumption and investments financed from abroad, offers this flexibility.

Neither of these two effects has a significant impact. Initial factor endowments are close to their optimal mix. Therefore trade flows are primarily induced by the consumption effect that includes a welfare-increasing redistribution of global GDP but has no sustainable GDP growth effect. Furthermore, within the mitigation scenario, perfect foresight lowers the benefits of additional capital mobility.

This conclusion is supported by a carbon price path that is nearly the same for the scenarios with and without intertemporal trade (see Fig. 8). The availability of foreign capital does not change the price signal and hence the domestic investment strategy in building up low carbon technologies. However, intertemporal trade and capital mobility may gain importance in scenarios that request for higher emission reduction efforts (cf. Leimbach, 2010a).

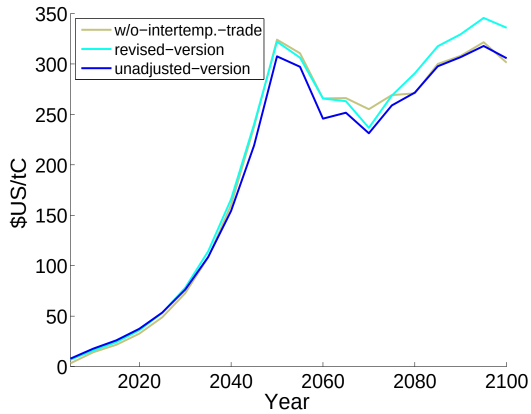


Figure 8: Carbon prices

6 Conclusions

Trade-related issues in climate policy modeling are discussed in this paper. The trade module of the hybrid IA model REMIND-R, which is used for climate policy analysis, was the subject of investigation. Trade in the composite good is controlled by altered assumptions on the regional preferences and technologies. By means of them, simulated trade and capital flows could be brought into better correspondence with empirical data. Moreover, we were able to tackle the Lucas Paradox by generating capital flows from South to North in a neoclassical growth model.

In applying the model for a stylized climate policy analysis, it turns out that the impact of the way we model intertemporal trade is small. While the impact of the model adjustments on the trade pattern is remarkable, global and regional 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 the global world product.

Mitigation cost differences are in particular small between scenarios with and without intertemporal trade. There is neither a dominant baseline effect (additional GDP growth due to the availability of foreign capital) nor a dominant mitigation effect. Trade flows primarily represent a welfare-increasing redistribution of global GDP without a sustainable growth effect.

While it is impossible to match empirical data with a model that excludes intertemporal trade and therefore the possibility of current account deficits, the question arises if this imprecision is tolerable in face of the slight differences in the key assessment variables and in return for the reduced numerical complexity. Future research has to explore whether there is a larger impact of intertemporal trade in model settings with externalities, market imperfections and limited anticipation of shocks.

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