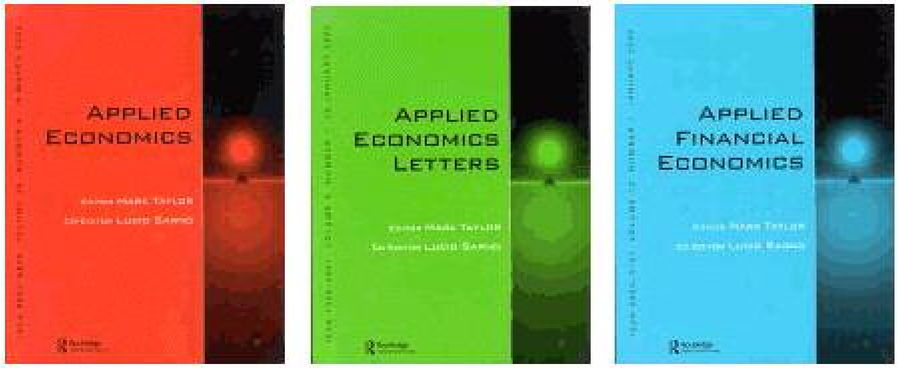

Burden Sharing in a Greenhouse: Egalitarianism and Sovereignty Reconciled

Journal:	*Applied Economics*
Manuscript ID:	APE-04-0210
Journal Selection:	Applied Economics
Date Submitted by the Author:	30-Nov-2004
JEL Code:	D58 - Computable and Other Applied General Equilibrium Models < D5 - General Equilibrium and Disequilibrium < D - Microeconomics, F42 - International Policy Coordination and Transmission < F4 - Macroeconomic Aspects of International Trade and Finance < F - International Economics, Q43 - Energy and the Macroeconomy < Q4 - Energy < Q - Agricultural and Natural Resource Economics
Keywords:	climate policy, economic welfare, international equity, emissions trading, computable general equilibrium modeling

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Abstract

The allocation of emission entitlements across countries is the single most controversial issue in international climate policy. Extreme positions within the policy debate range from entitlements based on current emission patterns (sovereignty) to entitlements based on equal-per-capita allocations (egalitarianism). This paper shows that gradual convergence from sovereignty towards egalitarianism could provide a pragmatic solution to the equity debate: When combined with international emissions trading, the convergence approach stands out for offering the developing countries substantial incentives for participation in the international greenhouse gas abatement effort without imposing excessive burdens on the industrialized countries.

Key words: climate policy, economic welfare, international equity, emissions trading, computable general equilibrium modeling.

JEL classification: D58, F42, Q43

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1. Introduction

Climate change due to anthropogenic greenhouse gases has emerged as one of the most important issues facing the international community. Greenhouse gases - particularly fossil fuel-based carbon dioxide emissions - are accumulating in the atmosphere as a result of human activities, and the ongoing increase in greenhouse gas concentrations is expected to raise the global average temperature and cause other changes to the climate. Global consensus exists that climate change represents a significant potential threat requiring a considerable reduction of greenhouse gas emissions in the long term (IPCC 2001).

Given the public good character of the global atmosphere and the inherent free-riding incentives, greenhouse gas reduction cannot be achieved without international cooperation, to be codified in a long-term international policy agreement. Reaching such an agreement is, however, crucially dependent on solving the fundamental issue of burden sharing: how shall abatement duties - or likewise emission entitlements - be allocated across countries? This issue has already dominated previous climate negotiations and proved extremely difficult to solve even though the overall abatement targets under discussion were very moderate in comparison with the long-term requirements considered here.

Proposals on the allocation of emission entitlements can be grouped in terms of two main focal principles (Grubb 1995): Egalitarianism (equal-per-capita allocation) and sovereignty (allocation related to the status quo). The equal-per-capita allocation corresponds to the justice principle of "equality of resources", suggesting that all human beings should be entitled to an equal share of the atmospheric resource. It is the fair division criteria most often cited in the literature (see Bertram 1992, Kverndokk 1995). At the opposite end of the spectrum, a strict status-quo allocation - proportionate to current emissions - has been considered in the literature (see e.g. Young and Wolf 1992). According to this view, current emissions would constitute a status-quo right established by past usage and custom.

Egalitarianism and sovereignty mark the range of positions held by the players in international climate diplomacy. Many developing countries have emphasized that acceptance of any emission constraint can be expected only if emission rights are allocated on an equal-per-capita basis (Rose et al. 1998). From the perspective of the industrialized countries, however, equal-per-capita entitlements would imply a tremendous deviation from current emission patterns and - if applied on short notice - induce potentially large adjustment costs in countries with currently high per capita emissions.

Given the discrepancy of positions held, the ultimate question arises as to if and how they can be reconciled.[1] A natural way of reconciliation could involve the idea of convergence, allowing for gradual adjustment from current emission patterns towards a terminal point where future entitlements to emit will have become proportional to population. The global emission budget in such a scenario would have to be continuously reduced, in line with the climate protection requirements mentioned above.[2]

Notwithstanding the comparative philosophical appeal of the three approaches to greenhouse burden sharing, the prospects for a broader political agreement on any one approach will ultimately depend on their economic implications in terms of the magnitude and distribution of adjustment costs across regions.[3] However, the cost assessment is a complex task. Apparently, the costs of emission abatement depend not only on the profile of emission entitlements as such but also on whether emission entitlements are tradable or not. In addition, emission constraints do not only trigger adjustment effects in the energy system but have implications for all - domestic and international - markets.

The acceptability of alternative burden sharing schemes thus cannot be assessed at “face value” but requires a consistent and comprehensive representation of market interactions. To this end, we use an intertemporal multi-region computable general equilibrium model of the world economy. Each of the three greenhouse burden sharing schemes is examined for the case with and without emissions trading among the regions. The main conclusion emerging from our numerical simulations is that the convergence approach coupled with emissions trading has considerable comparative virtues with respect to broader political acceptability by offering the developing countries economic incentives for participation in the international greenhouse gas abatement effort without imposing excessive burdens on the industrialized countries. Changes in international prices, i.e. the terms of trade, turn out to be an important determinant for the distribution of adjustment costs. Because of terms-of-trade effects, some regions may experience significant economic losses even under entitlement allocation rules which impose no binding emission constraint on them.

[1] As Hahn and Stavins (1995) note, several criteria may need to be combined in order to create international consensus on emissions allocations.

[2] Formulations such as this have been discussed independently by Grubb and Sebenius (1992), Shue (1993) and Welsch (1993).

[3] Our evaluation deliberately neglects the benefits from global warming mitigation, since benefit estimates are highly uncertain at the global and regional level (see Tol 2002 for a recent survey on assessment methods and estimates). The large uncertainties on the benefits from greenhouse gas abatement (i.e. external cost estimates for global warming) are reflected in the climate policy debate: Long-term emission reduction objectives are not the outcome of a cost-benefit analysis but based on recommendations from natural science on tolerable emission levels (see section 2.A).

The economic implications of various emission entitlement schemes have been subject to numerical analysis in several studies (see Rose et al. 1998 for a literature review), employing different methodological frameworks. Some studies fully neglect terms-of-trade effects (e.g. Kverndokk 1993) or fail to capture important intertemporal responses in savings and investment to emission constraints (e.g. Rose et al. 1998). Other studies (see Manne and Richels 1995 or Nordhaus and Boyer 1999) shift the focus from differentiated cost analysis under exogenous global emission ceilings to cost-benefit analysis, thereby deriving optimal abatement paths based on highly stylized integrated assessment models. None of the previous studies provide a rigorous quantitative comparison of the three greenhouse gas entitlement schemes which have been found focal in the burden sharing debate and which we address in this paper.

The paper is organized as follows. In section 2, we provide the definition of the alternative policy-relevant abatement scenarios. In section 3, we give a brief non-technical summary of an intertemporal multi-sector, multi-region computable general equilibrium framework that we use for the economic impact assessment or our alternative burden sharing rules. In section 4, we first present the implications of the different entitlement rules for per capita endowments and cutback requirements across major world regions; we then provide a detailed discussion of results complemented by sensitivity analysis. In section 5, we draw policy conclusions.

2. Modeling of Burden Sharing Rules

A. Design of Abatement Policies

Presuming that uncertain future outcomes of climate change could be extreme and irreversible, risk aversion justifies the adoption of a precautionary approach rather than hinging on cost-benefit analysis (see e.g. Gollier et al. 2000). In this vein, the United Nations Framework Convention on Climate Change (UNFCCC) aims at establishing an ample margin of safety based on recommendations from natural science on "tolerable" emission levels. The UNFCCC's stated goal is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC 1992, Article 2).

To comply with such stabilization targets, the Intergovernmental Panel on Climate Change (IPCC), which serves as the scientific advisory board to the UNFCCC, postulates reductions of global carbon emissions till 2100 by up to 50 percent below current levels (IPCC 2001). We take this to mean that emissions till 2050 are to be reduced by roughly 25 percent and that this target is to be attained by gradual adjustment of global emissions over the period 2010 to 2050. The choice of 2010 as the starting year for global emission reduction reflects the understanding that some time will be needed to achieve such a substantial international agreement and that its provisions will not enter into force instantaneously.[4]

We consider three emission entitlement rules for allocating the global emission budget. Each of these rules is combined with two alternative assumptions on the tradability of emission rights yielding six scenarios to be examined.

The emission entitlement rules are defined as follows:

SOVEREIGNTY: The global carbon resource is distributed across regions in proportion to their business-as-usual emissions in 2010.

EGALITARIANISM: The global carbon resource is distributed across regions in proportion to their respective population.

CONVERGENCE: Starting from 2010, where business-as-usual emission patterns define the emission entitlement, *CONVERGENCE* warrants a gradual convergence of emission entitlements over the specified time horizon towards equal-per-capita rights (see section 2B.).

Concerning the tradability of emission rights, we distinguish between two abatement regimes which capture the extreme points of where-flexibility in international carbon abatement policy:[5]

NoTrade: The carbon limits strictly apply at the country level. In other words, countries are not allowed to buy or sell emission permits on international markets. All emission reductions must take place domestically.

Trade: Emission rights can be traded across borders. There are no restrictions to the eligibility of trading partners and the magnitude of emission trade.

B. *Definition of Global Emission Trajectory*

Having stated the basic distribution rules for emission entitlements, we next define the global carbon emission constraint over time.

The global emission trajectory over the adjustment period is obtained by merging the global reduction target for 2050 with the idea of convergence of per capita entitlements

[4] With respect to the Kyoto Protocol – the sole international climate policy agreement so far – it is commonly perceived that the current round covering the period 2008-2012 will accomplish very little in terms of global emission reductions (see Buchner et al. 2002 or Springer 2002 for surveys).

[5] An alternative form of flexibility, so-called when-flexibility, is disregarded in this paper. When-flexibility entails the banking and borrowing of carbon emission rights. A recent analysis of when-flexibility in greenhouse gas abatement is provided by Stephan and Müller-Fürstenberger (2004).

towards the target year. This yields a gradual adjustment in both total emissions and in the distribution of emission rights across countries.

In formal terms, the convergence idea warrants that the per capita emission rights of country *i* in year *t*, $z_i(t)$, are a weighted average of business-as-usual per capita emissions in 2010 and the uniform per capita right $\bar{z}$ valid in 2050:

$$z_i(t) = \frac{40-(t-2010)}{40} \cdot z_i(2010) + \frac{(t-2010)}{40} \cdot \bar{z}.$$

The total carbon limit $LIMIT_i(t)$ for a country in a certain year is obtained by multiplying the per capita emission right by the country's population $POP_i(t)$ in that year:[6]

$$LIMIT_i(t) = z_i(t) \cdot POP_i(t).$$

Adding the carbon limits across countries defines the global carbon limit over the time horizon. We impose this global emission trajectory also on the scenarios *SOVEREIGNTY* and *EGALITARIANISM* to assure consistent comparison of alternative carbon entitlement rules. Under *SOVEREIGNTY*, the given global carbon budget at any point in time will be distributed across regions in proportion to their 2010 emission levels, whereas under EGALITARIANISM the carbon emissions will be allocated proportional to the regions' projected population figures.

3. Method of Assessment

A. Basic Model Features

Carbon abatement policies do not only cause direct adjustments on fossil fuel markets but produce indirect spillovers to other markets which in turn feed back to the economy. In a world that is increasingly integrated through trade, policy-induced adjustments of domestic production and consumption patterns will also influence international prices, i.e. the terms of trade, via changes in exports and imports. General equilibrium provides a comprehensive framework for studying price-dependent market interactions; the simultaneous explanation of the origination and the spending of income of economic agents allows to address both, economy-wide efficiency as well as equity implications of policy intervention. Therefore, computable general equilibrium models have become a central method for the assessment of the economy-wide impacts of emission policies on resource allocation and the associated implications for incomes of economic agents (see e.g. Weyant 1999).

Beyond the consistent representation of market interactions as well as income and expenditure flows, climate policy analysis often calls for an explicit dynamic framework since

[6] Of course, in implementing this formula, it is important to use population projections fixed ex ante, in order to avoid incentives for population growth.

policy intervention applies over longer time periods. To build dynamic features in the modeling of the economic behavior of households and firms requires an assumption on the degree of foresight of the economic agents. In a deterministic setting, the only consistent approach is to assume that agents in the model know as much about the future as the modeler: Agents have rational (intertemporal) expectations and consistently anticipate all current and future prices (Manne and Richels 1992).

Against this background, we use an intertemporal multi-sector multi-region computable general equilibrium model of global trade and energy use (see Böhringer and Rutherford 2001) for the quantification of regional adjustment costs under our different abatement policy scenarios. For the sake of brevity, we abstain from presenting a detailed specification of the model algebra (incl. parameterization) and restrict ourselves to a non-technical summary.[7]

B. Economic Structure

Our model divides the global economy into 10 geopolitical regions which are linked through bilateral trade flows. The economic structure of each region consists of 4 production sectors (1 non-energy macro good sector and 3 fossil fuel sectors) whose outputs are demanded by intermediate production, exports, investment and final consumption. Table 1 gives an overview of the regional and sectoral disaggregation.

Table 1: Model dimensions (sectors, factors, and regions)

PRODUCTION SECTORS	REGIONS
Energy	North America (USA and Canada)
Coal	Western Europe
Gas	Pacific OECD (Japan, Australia, New Zealand)
Oil	Other Pacific Asia*
Non-Energy	Former Eastern Bloc
Non-energy macro good aggregate	China
PRIMARY FACTORS	India
Labor	Middle East and North Africa
Capital	Latin America**
Fossil-fuel resources (for coal, oil, and gas)	Sub-Saharan Africa

* Indonesia, Malaysia, Philippines, Singapore, Thailand, Taiwan, Republic of Korea

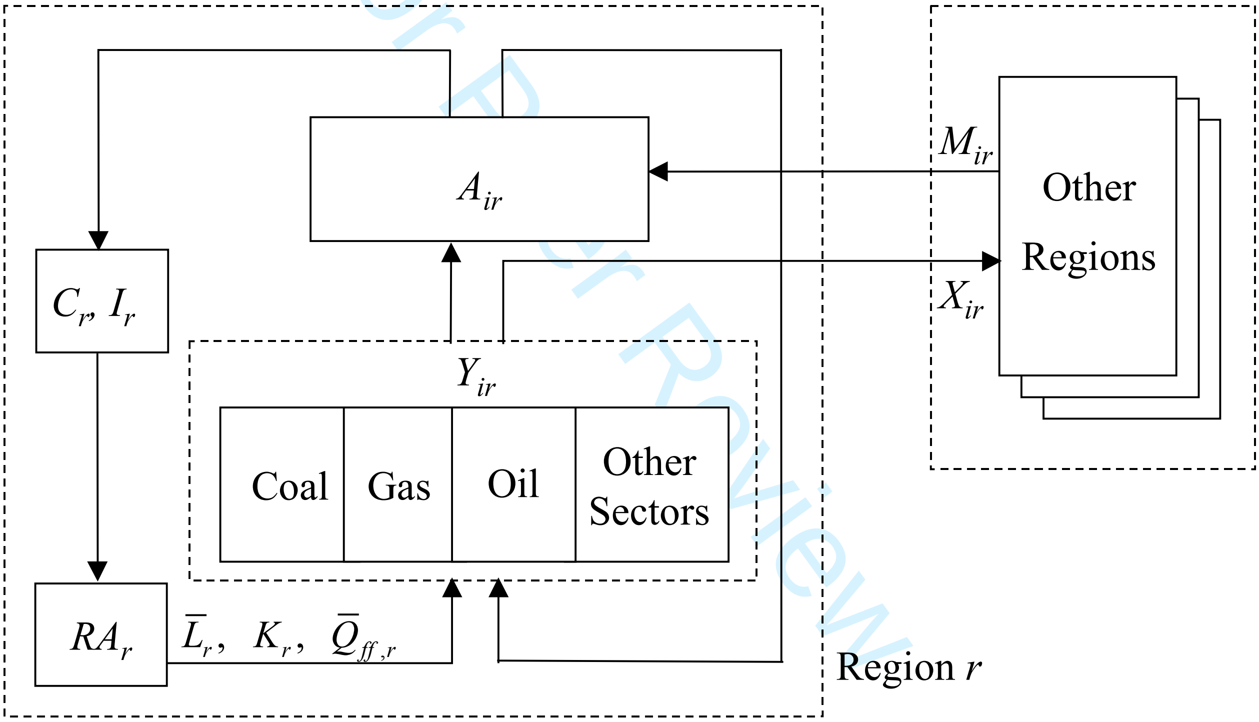
** Mexico, Argentina, Brazil, Chile, Rest of South America

[7] The interested reader can download this information from ftp://ftp.zew.de/pub/zew-docs/div/entitlements.pdf

Figure 1 lays out the diagrammatic structure of the model's single-period sub-module. Primary factors of a region *r* include labor $\overline{L}_r$, capital K_r and resources of fossil fuels $\overline{Q}_{ff}$ ($ff \in$ {coal, gas, oil}). The specific resource used in the production of coal, gas, and oil results in upward sloping supply schedules consistent with exogenous fossil fuel supply elasticities.

Production Y_{ir} of commodities *i* in region *r*, other than primary fossil fuels, is captured by aggregate production functions which characterize technology through substitution possibilities between various inputs. Nested constant elasticity of substitution (CES) cost functions with several levels are employed to specify the KLEM substitution possibilities in domestic production sectors between capital (*K*), labor (*L*), energy (*E*) and non-energy intermediate inputs, i.e. material (*M*).

Figure 1: Structure of the single period sub-module



Final aggregate consumption demand C_r of the representative agent RA_r in each region is given as a CES composite which combines consumption of an energy aggregate with a non-energy consumption bundle. The substitution patterns within the non-energy consumption bundle as well as the energy aggregate are described by nested CES functions.

All goods used on the domestic market in intermediate and final demand correspond to a so-called Armington good (Armington, 1969), i.e., a CES composite A_{ir} of the domestically produced variety and a CES import aggregate M_{ir} of the same variety from the other regions.

Domestic production either enters the formation of the Armington good or is exported to satisfy the import demand of other regions.

Endowments of labor and the specific resources are fixed exogenously. Within any time period, we assume competitive factor and commodity markets such that prices adjust to clear these markets.

In each region, there are backstop technologies for producing the industrial energy aggregate and the household energy aggregate. The carbon-free backstop, represented as a carbon sequestration activity that requires inputs of the non-energy macro good, establishes an upper bound on world fossil fuel prices. Carbon emissions are associated with fossil fuel demand in production and final consumption.

In the dynamic model setting, the representative household in each region chooses to allocate lifetime income, i.e. the intertemporal budget, across consumption in different time periods in order to maximize lifetime utility. In each period, the agent faces the choice between current consumption and future consumption, that is purchased via savings. Investment takes place as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by a uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and marginal utility of a unit of consumption is equalized within and across countries. Capital stocks evolve through constant geometric depreciation and new investment.

C. Calibration

As is customary in applied general equilibrium analysis, the model is based on economic transactions in a particular benchmark year. Benchmark data determine parameters of the functional forms from a given set of benchmark quantities, prices, and exogenous elasticities taken from the literature. With respect to benchmark prices and quantities, we employ the GTAP-4 database which provides detailed input-output tables as well as bilateral trade flows for 50 commodities and 45 regions for the year 1997 (McDougall et al. 1998).

A key feature of any long-term burden-sharing rule is the extent to which it binds economies in the future: The magnitude of adjustment costs to exogenous emission constraints crucially depends on the business-as-usual (*BaU*) characteristics of economies over time. We calibrate the model's economies to official *BaU* projections on GDP and fossil fuel production (IIASA 1998) and a common 5% net rate of return on capital in all countries. Population statistics across regions are based on the World Population Prospects (UN 1996).

The number of regions and time periods incorporated in our model represent a compromise between a desire for greater geographical detail and a longer-term horizon on the one hand and practical limitations for solution time and data requirements on the other hand.

4. Implications of Burden Sharing Rules

Even though burden sharing rules will ultimately be assessed on the basis of their endogenous economic consequences, the distribution of emission entitlements and cutback requirements implied by these rules play an important role in international climate negotiations. We therefore start the presentation of results by discussing these more immediate implications. This will be followed by a discussion of the economic effects. Finally, we present sensitivity analysis regarding the robustness of our central policy insights.

A. Emission Entitlements and Cutback Requirements

Table 2 reports the per capita endowments for the three entitlement rules across the ten world regions represented in our numerical CGE model.

We first consider the actual emission profile as of 2000. It shows a tremendous dispersion, ranging from 0.21 tons per capita for Sub-Saharan Africa to 5.23 tons per capita for North America.

In the scenario *SOVEREIGNTY*, the regional per capita emission rights by 2050 range from 0.06 tons for Sub-Saharan Africa to 3.27 tons for North America, i.e. a North American's emission rights exceed those of an African by more than a factor of 50. This ratio for 2050 is more than twice the current ratio. In general, the *SOVEREIGNTY* allocation rule implies a further increase of the already large differences of per capita emissions between industrialized and developing countries. The reason for this result is the strong population growth projected for many of the developing countries, especially in Africa and the Middle East.

The *EGALITARIANISM* scenario entails that the current differences in per capita emissions be abolished within less than 10 years, i.e. by 2010. This scenario implies that the developing regions get emission rights in excess of their current emissions, while industrialized countries face drastic domestic cutback requirements or else - under tradability - must buy substantial amounts of emission rights. As the extreme example, an African by 2010 would have the right to emit five times as much as she or he currently does whereas a North American would be entitled to emit less than the fifth part of current emissions.

These figures illustrate the potential drawbacks of both the *SOVEREIGNTY* and the *EGALITARIANISM* scenarios. While the former places a huge long-term burden on the developing countries, the latter confronts the industrialized countries with tremendous short-term adjustment requirements. The *CONVERGENCE* rule avoids these drawbacks. In this scenario, all regions, except for Africa and India, are facing decreasing per capita emission rights in the long term, but the time path entails neither abrupt changes in the beginning nor huge inequalities towards the end.

Table 2: Per capita emission endowments for alternative entitlement rules (in tons of carbon)

	2000	2010	2020	2030	2040	2050
Scenario *SOVEREIGNTY*						
Sub-Saharan Africa	0.21	0.19	0.14	0.11	0.08	0.06
China	0.72	0.78	0.66	0.56	0.47	0.39
India	0.22	0.23	0.19	0.16	0.13	0.10
Latin America	0.58	0.61	0.50	0.41	0.33	0.27
Middle East and North Africa	0.55	0.51	0.37	0.27	0.20	0.15
North America	5.23	5.84	5.11	4.43	3.84	3.27
Pacific OECD	2.87	3.32	3.05	2.78	2.47	2.16
Other Pacific Asia	0.68	0.71	0.60	0.50	0.41	0.34
Former Eastern Bloc	1.83	2.06	1.81	1.56	1.32	1.10
Western Europe	2.75	3.23	2.97	2.70	2.38	2.07
All regions (WORLD)	1.07	1.11	0.91	0.75	0.60	0.48
Scenario *EGALITARIANISM*						
All regions (WORLD)	s. above	1.11	0.91	0.75	0.60	0.48
Scenario *CONVERGENCE*						
Sub-Saharan Africa	0.21	0.20	0.27	0.34	0.41	0.48
China	0.72	0.83	0.74	0.66	0.57	0.48
India	0.22	0.23	0.29	0.36	0.42	0.48
Latin America	0.58	0.60	0.57	0.54	0.51	0.48
Middle East and North Africa	0.55	0.52	0.51	0.50	0.49	0.48
North America	5.23	5.66	4.36	3.07	1.78	0.48
Pacific OECD	2.87	3.26	2.56	1.87	1.18	0.48
Other Pacific Asia	0.68	0.73	0.67	0.60	0.54	0.48
Former Eastern Bloc	1.83	2.10	1.70	1.29	0.89	0.48
Western Europe	2.75	3.15	2.48	1.82	1.15	0.48
All regions (WORLD)	1.07	1.11	0.91	0.75	0.60	0.48

Table 3 summarizes the effective cutback requirements by region compared to their *BaU* emissions over the time horizon. Negative entries indicate that the respective emission constraint is not binding.

In the *SOVEREIGNTY* scenario, all regions face binding carbon constraints from 2020 onwards. The percentage cutback rates are rather uniform across regions because differences in emission entitlements closely reflect the differences in *BaU* emissions. By 2050, cutback rates are between 59 and 64 percent.

Table 3: Effective cutback requirements (% from *Business-as-Usual*)

	2010	2020	2030	2040	2050
Scenario *SOVEREIGNTY*					
Sub-Saharan Africa	-	23	39	51	61
China	-	26	42	55	64
India	-	23	39	51	60
Latin America	-	21	38	50	59
Middle East and North Africa	-	22	40	52	61
North America	-	20	37	50	61
Pacific OECD	-	21	38	52	63
Other Pacific Asia	-	24	41	53	62
Former Eastern Bloc	-	25	43	55	63
Western Europe	-	21	37	50	61
Scenario *EGALITARIANISM*					
Sub-Saharan Africa	-469	-392	-331	-269	-215
China	-34	4	28	46	58
India	-384	-269	-190	-130	-85
Latin America	-86	-47	-16	8	26
Middle East and North Africa	-115	-89	-63	-44	-26
North America	80	85	89	92	94
Pacific OECD	66	76	83	88	92
Other Pacific Asia	-53	-14	14	32	46
Former Eastern Bloc	47	63	73	80	84
Western Europe	65	75	82	87	91
Scenario *CONVERGENCE*					
Sub-Saharan Africa	-	-44	-95	-151	-215
China	-	22	37	49	58
India	-	-18	-38	-59	-85
Latin America	-	8	16	22	26
Middle East and North Africa	-	-5	-9	-17	-26
North America	-	30	55	76	94
Pacific OECD	-	33	58	77	92
Other Pacific Asia	-	17	30	39	46
Former Eastern Bloc	-	31	54	70	84
Western Europe	-	32	57	75	91

Under *EGALITARIANISM*, by contrast, cutback rates are much more dispersed. Some regions are not facing binding constraints at all, but are entitled to emit more than they are expected to under *BaU*. This is the case for Africa, India, and the Middle East over the whole time horizon and for China, Latin America and Other Pacific Asia over the first few decades.

In the *Convergence* scenario, the cutback rates by 2050 are the same as in the *Egalitarianism* case, but different at earlier dates. Africa, India, and the Middle East again have abundant emission rights over the entire time horizon, but the percentage of unused rights in the first decades is much smaller than under *Egalitarianism*. For China, Latin America, and Other Pacific Asia no abundant rights occur at all.

At the global level, surplus carbon rights under *Egalitarianism* as well as *Convergence* imply that emissions by 2050 are roughly 10 percent below the IPCC target (see Figure 2).

The occurrence of unused emission rights under the *Egalitarianism* scheme and, to a lesser extent, under the *Convergence* scheme is likely to increase the global economic adjustment costs as compared to the *Sovereignty* scheme, unless emission rights are internationally tradable (i.e. surplus emission rights will be sold). Conversely, the economic benefit from tradability can be expected to be more pronounced under *Convergence* and, particularly, under *Egalitarianism* than under *Sovereignty*. We will return to this logic below.

Figure 2 visualizes the global carbon trajectories for the *BaU* case in comparison to the overall carbon entitlements (LIMIT) and the actual emission path for the *NoTrade* case under scenarios *Sovereignty*, *Egalitarianism,* and *Convergence*.

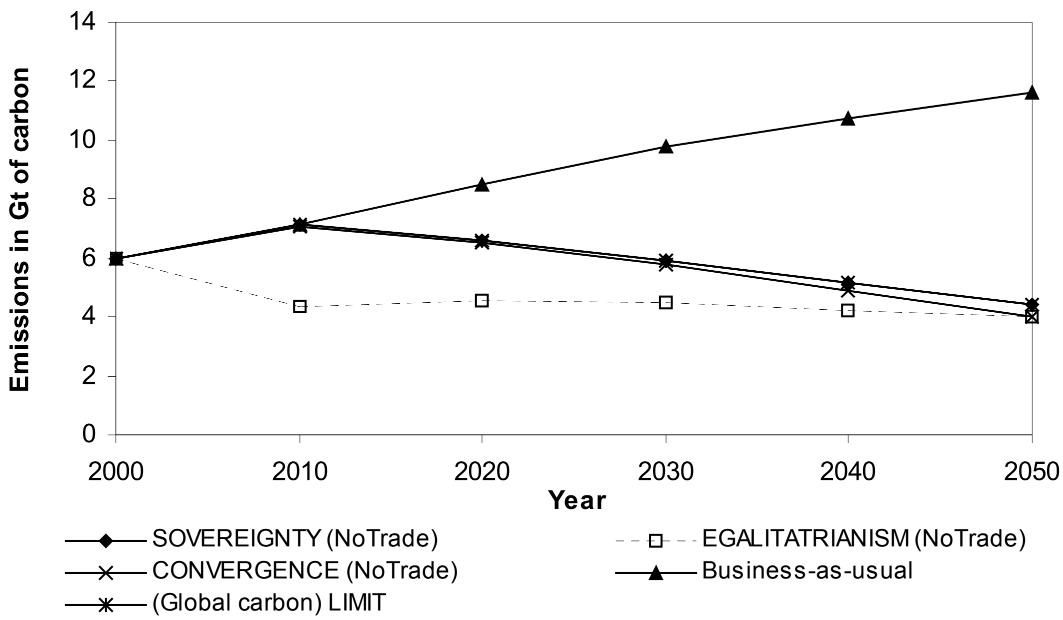


Figure 2: Carbon emission trajectories

Under *BaU*, global emissions increase from roughly 6 Gt carbon in 2000 to 11.5 Gt carbon in 2050. The *BaU* trajectory is in line with the IIASA A1 reference scenario (IIASA 1998) that serves as our baseline for the business-as-usual development of world economies. By 2050, the global carbon limit of 4.4 Gt as suggested by the IPCC is more than 60 percent below *BaU* emissions which makes clear the dramatic adjustment requirements towards less carbon-intensive production and consumption patterns.[8] For *SOVEREIGNTY*, there are no surplus emission rights in the *NoTrade* case. The *SOVEREIGNTY* trajectory, therefore, coincides with the LIMIT trajectory.

B. Abatement Costs

Apart from the ease of carbon substitution reflected in the regions' technologies and preferences, there are two important factors that determine the adjustment costs for a particular region.

The first of these factors is the reduction target, i.e. the effective cutback requirements relative to the *BaU* path of emissions: Larger cutback requirements in carbon emissions as a percentage of *BaU* emissions ceteris paribus lead to larger abatement costs.

The second factor are the trade characteristics: The change in international prices induced by emission constraints on open economies implies an indirect secondary burden or benefit for all open economies which can significantly alter the primary economic implications of the domestic abatement policy (Böhringer and Rutherford 2002). Depending on its initial trade patterns a region will gain or lose from these international spillovers, i. e. changes in its terms of trade.

With respect to carbon abatement and our sectoral disaggregation, it is useful to distinguish spillovers from fossil fuel markets on the one hand and from non-energy markets on the other hand. As to spillovers on fossil fuel markets, a larger cutback in global fossil fuel consumption due to stringent global carbon emission constraints depresses the international prices of fossil fuels providing benefits to fuel importers and losses to fuel exporters. As to spillovers on non-energy markets, countries are able to pass on an increase in production costs to other countries due to product heterogeneity in trade of the non-energy macro good. Whether a country will experience a terms-of-trade loss or gain on the macro good markets depends on its initial trade shares and elasticities (of export supply and import demand) as well as differences in the cost changes of macro good production induced by the abatement scenario.

Terms-of-trade effects explain why a country can experience a welfare loss even if it does not face a binding emission constraint, as is the case for some countries in our

[8] Similar cutback requirements of 65 % compared to the global *BaU* 2050 emission levels have been postulated by a recent EU policy study in order to meet the EU's long-term climate policy objective to prevent global mean temperature rising by more than 2°C over pre-industrial levels (Criqui et al. 2003).

EGALITARIANISM and CONVERGENCE scenarios. They can also influence considerably the primary benefits from international emissions trading.

Bearing in mind these central determinants of abatement costs, we now turn to the interpretation of simulation results. For the *NoTrade* case, the effective cutback requirements determine the level of *marginal* abatement costs across regions that are depicted in Figures 3 - 5. For each entitlement scenario, we have grouped the countries into sellers and buyers with the price trajectory for globally tradable permits (labeled WORLD) as a reference line to explain their trading position from the *NoTrade* perspective. The marginal abatement costs under *NoTrade* and, hence, the distribution of buyers and sellers of emission rights, if trade got implemented, is much influenced by the entitlement rule.

In the *SOVEREIGNTY* case, the dispersion of marginal abatement costs across regions is relatively moderate. The reason is that the *SOVEREIGNTY* allocation rule preserves to a larger extent the differences in *BaU* emission demands across regions leading to relatively uniform percentage cutback requirements as a central determinant of marginal abatement costs. The narrow range of marginal abatement costs across regions under *SOVEREIGNTY* explains why emissions trading provides rather small savings in global abatement costs. The group of permit buyers only emits 4 percent more than they would under *NoTrade* whereas the group of permit sellers just emits 6 percent less as compared to the *NoTrade* case.

In the *EGALITARIANISM* scenario, marginal abatement costs are much more dispersed. Industrialized countries face relatively high effective abatement requirements and, therefore, substantial marginal abatement costs. On the other hand, developing countries get either imposed rather modest abatement requirements or do not face any binding emission constraint over the whole time horizon (regions Africa, India, and Middle East). Emissions trading under *EGALITARIANISM*, thus, induces large changes in the regional pattern of emissions compared to purely domestic abatement. While the group of permit buyers increases emissions by more than the double of their aggregate *NoTrade* emission level, the group of sellers only emits roughly 70 percent of their *NoTrade* emissions.[9]

The same range of marginal abatement costs by 2050 and the same buyer-seller configuration as in the *EGALITARIANISM* scenario arise in the *CONVERGENCE* scenario. The implications of emissions trading on the regional reallocation of emissions are, however, significantly less pronounced than in the *EGALITARIANISM* case:

[9] Note that the large increase of emissions within buyer regions is not only accommodated by additional reduction efforts on behalf of the seller regions but also by the use of previous surplus emissions in particular from developing regions Africa, India, and the Middle East.

Figure 3: Marginal abatement costs under *NoTrade* for scenario SOVEREIGNTY

a: permit seller regions b: permit buyer regions

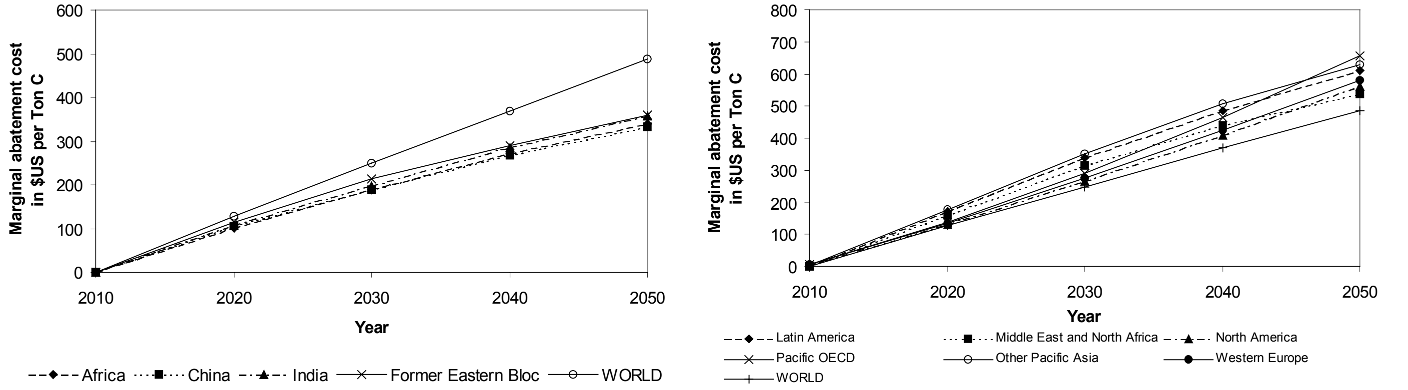
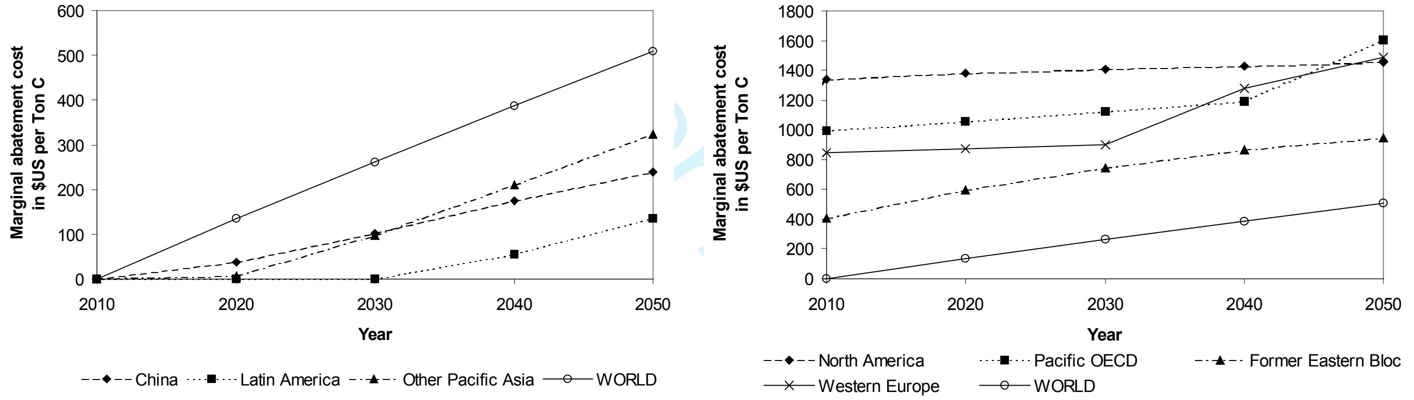


Figure 4: Marginal abatement costs under *NoTrade* for scenario EGALITARIANISM

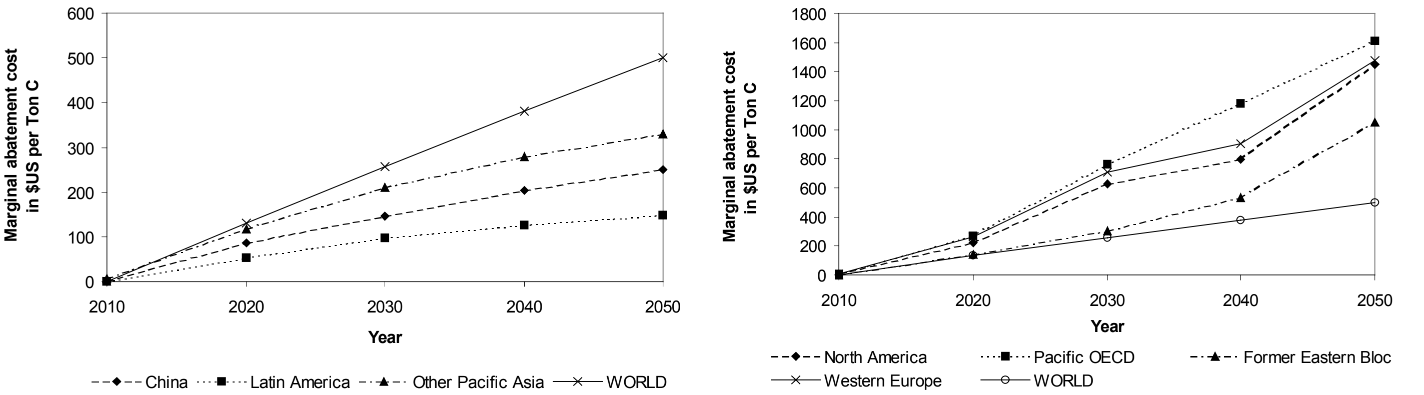
a: permit seller regions b: permit buyer regions



N.B.: India, Middle East, and Africa are seller regions under *Trade* without any binding carbon constraint (i.e. carbon tax) under *NoTrade*

Figure 5: Marginal abatement costs under *NoTrade* for scenario CONVERGENCE

a: permit seller regions b: permit buyer regions



N.B.: India, Middle East, and Africa are seller regions under *Trade* without any binding carbon constraint (i.e. carbon tax) under *NoTrade*

The possibility to buy cheaper abatement abroad makes the group of permit buyers emit 1.3 as much as they would under *NoTrade* whereas the group of permit sellers decreases emissions to roughly 80 percent of their *NoTrade* emission level.

Table 4 reports the total adjustment costs that arise from carbon abatement under the various emission entitlement schemes for the *NoTrade* and *Trade* case (measured by the Hicksian equivalent variation (*HEV*) in lifetime income discounted to the year 2000).

Table 4: HEV in lifetime income (% change from *BaU*) – *NoTrade* versus *Trade*

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Sub-Saharan Africa	-2,26	-2,09	-2.73	20.72	-1.74	14.24
China	-2,90	-2,08	-2.44	0.23	-2.35	-0.74
India	-1,75	-1,71	0.23	21.56	0.16	15.15
Latin America	-1,21	-1,17	-1.56	0.98	-0.90	0.30
Middle East and N. Africa	-2,28	-2,02	-4.20	3.23	-2.60	2.03
North America	-0,80	-0,83	-6.71	-2.89	-2.64	-2.16
Pacific OECD	-0,35	-0,40	-2.51	-1.19	-1.17	-0.96
Other Pacific Asia	-0,50	-0,67	-0.12	0.64	-0.04	0.17
Former Eastern Bloc	-3,30	-2,92	-13.84	-9.06	-7.82	-6.97
Western Europe	-0,37	-0,40	-3.05	-1.37	-1.34	-1.10
WORLD	-0,85	-0,83	-3.99	-0.77	-1.82	-0.75

In the *SOVEREIGNTY* scenario without emissions trading, all countries face a binding emission constraint and experience a loss in welfare which ranges from 0.37 percent for Western Europe and Pacific OECD to more than 3 percent for the Former Eastern Bloc. Differences in welfare losses not only depend on differences in the cutback requirements as reported in Table 3 but also on implied terms-of-trade effects. On a worldwide scale, the welfare loss amounts to 0.85 percent. Under *Trade,* the global welfare loss remains more or less unchanged (0.83 percent): Since the dispersion of abatement costs is not very large under the *SOVEREIGNTY* scheme, the overall benefits from lower abatement costs arising under *Trade* are relatively small.[10] Nevertheless, countries with large losses under *NoTrade*, i.e. the Former Eastern Bloc and China, now fare significantly better. On the other hand, the welfare losses of Pacific OECD, Western Europe, North America, and, particularly, Other Pacific

[10] Copeland and Taylor (2000) show in a theoretical model that uniform emission reductions across countries (*SOVEREIGNTY*) can yield a globally efficient allocation in the absence of permit trading when there is free trade in goods. The mechanism is similar to the substitutability of factor movements for goods trade, known from trade theory. Because the general-equilibrium marginal cost of cutting back on emissions is a function of the set of goods produced, trade-related substitution across dirty and clean goods shifts the marginal abatement cost curve in for some countries and out for others. This effect can be so complete that trade in goods alone can equalize marginal abatement costs across countries. In addition, even disregarding these effects, Karp and Liu (2001) find that under uniform emission reductions the welfare gains from permit trading may be rather small.

Asia get enhanced which indicates that emissions trading does not produce a Pareto improvement over *NoTrade* for the *SOVEREIGNTY* scenario.

The result that emissions trading does not lead to a Pareto improvement is a clear instance of terms-of-trade effects: Although it is known that - in the absence of second-best effects - emissions trading must improve *global* efficiency, there is - a priori - no guarantee that *every* region will benefit from emissions trading. The reason behind this ambiguity are changes in the terms of trade which - contrary to the wide-spread partial equilibrium approach in environmental policy analysis - are taken into account in our general equilibrium framework.[11] In the *SOVEREIGNTY* scenario under *Trade*, portions of the abatement burden are shifted to countries which are major suppliers of import goods for Other Pacific Asia, Pacific OECD, North America, and Western Europe. The import prices of the latter countries increase. This more than offsets their primary benefit from emissions trading due to reduced direct abatement costs.

The welfare effects are much different when we consider the *EGALITARIANISM* scheme. The main finding is that, in the absence of emissions trading, the global welfare cost is higher than that under *SOVEREIGNTY* by almost a factor of five. This is the result of two partial effects. First, even though the global carbon cap is the same as under *SOVEREIGNTY*, the respective region-specific cap is not binding for some of the developing countries. Consequently, the *effective* global carbon emissions are lower under *EGALITARIANISM* than under *SOVEREIGNTY*, and the global economy faces a stronger adjustment requirement. Second, cutback rates under *EGALITARIANISM* are high for the industrialized regions, even in the short term, requiring large structural adjustments. This implies very high costs for the industrialized world as compared to the *SOVEREIGNTY* scheme where emission entitlements deviate much less from the *BaU* emission requirements.

A striking insight is that Africa and the Middle East, although not facing binding emission constraints over the entire time span, experience significant welfare losses which even exceed their adjustment costs in the apparently more restrictive *SOVEREIGNTY* case. The reason is again to be found in terms-of-trade effects: The imports of these countries become more expensive because of high abatement costs in the supplier countries; in addition, reduced

[11] Copeland and Taylor (2000) show that trade in pollution permits affects goods prices in such a way that at least one country's terms of trade are worsened. As a result, a permit buyer can lose from permit trade via a terms of trade deterioration even if all countries benefit from carbon trade in terms of reduced direct compliance costs. Secondary terms-of-trade effects thus offset or enhance the primary benefit from trading carbon across domestic borders. Obviously, the prospects that the unambiguous primary gains from emissions trading dominate the ambiguous secondary terms-of-trade effects depend on the initial permit allocation. The more countries deviate in marginal abatement costs for the *NoTrade* case, the higher are the global efficiency gains and - ceteris paribus - the associated gains at the country level.

import demand by the industrialized world, whose economic activity and income drops substantially, exerts a downward pressure on the prices of exports from Africa and the Middle East (for the latter, in particular, revenues from fossil fuel exports decline). India, on the other hand, perceives terms-of-trade gains, mainly due to reduced expenditure for fossil fuel imports.

Given the large divergence of marginal abatement costs across countries under the *EGALITARIANISM* scheme, emissions trading offers huge benefits. When moving from *NoTrade* to *Trade*, the global welfare loss drops from almost 4 percent to 0.77 percent.[12] In addition, emissions trading is Pareto improving under the *EGALITARIANISM* scheme. As *EGALITARIANISM* entails large cross-country differences in marginal abatement costs, the primary efficiency gains from emissions trading are high enough to more than outweigh potentially negative terms-of-trade effects. In addition, emissions trading now implies that all of the developing regions (including China) actually *gain* from climate change mitigation, i.e. they improve their economic welfare considerably beyond *BaU* levels.[13] For OECD regions (North America, Western Europe and Pacific OECD) and the Former Eastern Bloc international emissions trading reduces adjustment costs but still leaves them with significant welfare losses. In fact, the losses of industrialized countries for *EGALITARIANISM* under *Trade* are much higher than those for *SOVEREIGNTY* under *NoTrade*.

Considering the *CONVERGENCE* entitlement scheme under *NoTrade*, we find the global welfare loss to be much more moderate than under the more extreme *EGALITARIANISM* allocation but still more than double the *SOVEREIGNTY* value. The welfare implications for India, Africa, and the Middle East again reveal the importance of international spillovers. Although these regions do not have to undertake domestic abatement, they are affected by abatement action in other countries through changes in international market prices. While India slightly gains from international spillovers, Africa and the Middle East suffer from abatement elsewhere. As under *EGALITARIANISM*, the Former Eastern Bloc and North America again have the strongest losses in welfare, but these losses are now much lower because of less stringent effective cutback requirements.

If the *CONVERGENCE* entitlement scheme is combined with emissions trading, we find that the global welfare loss is reduced by half. Emissions trading is again *universally* beneficial as

[12] Note that the global welfare loss for emissions trading under *EGALITARIANISM* as well as under *CONVERGENCE* is now smaller than under *SOVEREIGNTY* due to income effects incorporated in the general equilibrium framework.

[13] Note that some of these regions do not exploit their carbon budget to the full extent under *NoTrade.* Their (shadow) price of emission rights increases dramatically from zero in the *NoTrade* case to the world market permit price under *Trade*. In other words: Their abundant emission rights under *NoTrade* become a valuable international resource which provides them with substantial additional net income.

compared to the *NoTrade* case, which means that under *CONVERGENCE* the primary efficiency gains from emissions trading are still high enough to more than outweigh negative terms-of-trade effects for individual regions. Similar to emissions trading under the *EGALITARIANISM* entitlement scheme, the developing regions (except for China) improve their economic welfare beyond *BaU* levels whereas the industrialized world face distinctly smaller adjustment costs.

C. *Sensitivity Analysis*

In order to assess the robustness of our findings with respect to uncertainties in the parameterization space we have performed sensitivity analysis with respect to changes in various key assumptions: (i) long-term emission reduction target, (ii) energy demand responsiveness, (iii) oil price responsiveness, (iv) trade impacts (ease of substitution for the traded macro-good), and (v) discount rate.

Details of these calculations are provided in the download. We find that all of our insights based on the central case estimates case remain robust. Application of the sovereignty principle (*SOVEREIGNTY*) without where-flexibility imposes particularly high welfare losses on the low developed regions. Emissions trading offers only very limited potential for alleviating their burdens. In addition, emissions trading fails to yield a Pareto improvement over the *NoTrade* case. Application of the egalitarian principle (*EGALITARIAN*), unless coupled with emissions trading, entails global welfare costs several times higher than those encountered under the other entitlement rules. While emissions trading under the *EGALITARIAN* scenario provides huge cuts in global welfare costs, it entails large welfare gains for developing countries relative to the doing-nothing (*BaU*) case. Application of the convergence principle (*CONVERGENCE*) combined with international emissions trading attenuates the magnitude of global income redistribution: Developing countries have a strong incentive to join a global emission control scheme whereas the burden on the industrialized countries may not be perceived as excessively high. Moreover, under less ambitious emission reduction targets than considered in the central case, *CONVERGENCE* combined with emissions trading may deliver an improvement over *BaU* even for the geopolitically important transition region China.

5. Conclusions

One of the most controversial choice issues facing the world community is the allocation of abatement duties across countries to achieve the reduction in global greenhouse gas emissions recommended by the science of climate change. In this paper, we have investigated the economic impacts of three alternative emission entitlement schemes (*SOVEREIGNTY*, *EGALITARIANISM*, and *CONVERGENCE*) that stand out in the international climate-change related burden sharing debate.

In assessing our simulation results, it can be concluded that *SOVEREIGNTY* without where-flexibility imposes particularly high welfare losses on the low developed regions Africa, China, India, and the Middle East. Emissions trading offers only very limited potential for alleviating their burdens. In addition, emissions trading is in this case not universally (Pareto) superior to a *NoTrade* regime and may therefore be rejected by several regions. Overall, *SOVEREIGNTY* can, thus, be perceived as unacceptable to the developing countries independent of the degree of where-flexibility.

Concerning the *EGALITARIANISM* scheme, the most outstanding result is that, unless coupled with emissions trading, it entails global welfare costs several times higher than those encountered under the other entitlement rules. The extreme dispersion of marginal abatement costs implied by the *EGALITARIANISM* arrangement offers a large potential for cost reduction by means of international emissions trading. The latter will cut global welfare costs by 80 percent and would provide a Pareto improvement over the corresponding *NoTrade* case. *EGALITARIANISM cum* emissions trading, however, induces a pronounced dichotomy between the developing countries and the industrialized countries in that the former experience welfare gains relative to the doing-nothing (*BaU*) case, whereas the latter must carry the burden not only of climate change mitigation but also of large-scale global income redistribution.

In the *CONVERGENCE* scenario, it is still true that most developing countries experience a welfare gain relative to *BaU* if emission entitlements are tradable, but the net transfers involved are much smaller. Emissions trading entails a reduction in global welfare costs by more than half[14] and is universally superior to the *NoTrade* case. The chief virtue of the *CONVERGENCE cum* emissions trading arrangement is that it offers the developing countries a substantial incentive for participation in the international climate change mitigation effort.[15] By contrast, *SOVEREIGNTY* entails a further reduction of the already low income of the developing countries (including China). *EGALITARIANISM*, on the other hand, either implies - in

[14] It should be recalled, however, that part of the cost reduction under *CONVERGENCE* for the *Trade* case arises because the global carbon budget is partly unused in the absence of emissions trading. This qualification concerning the virtues of emissions trading applies a fortiori in the *EGALITARIAN* case. We maintain, however, that the acceptability of carbon abatement arrangements rests basically on their economic implications, unless the predefined global carbon constraint is violated.

[15] Hahn and Stavins (1995) note that developing countries will have little incentive to participate in an international agreement unless they see clear economic benefit from doing so.

the *NoTrade* case - tremendous global inefficiency, or huge levels of trade in emission rights with associated very large "North-South" transfers.

From a policy point of view, we conclude that gradual convergence from sovereignty towards egalitarianism could provide a pragmatic solution to the equity debate: When combined with international emissions trading, the convergence approach stands out for offering the developing countries substantial incentives for participation in the international greenhouse gas abatement effort without imposing excessive burdens on the industrialized countries. The convergence approach coupled with unrestricted where-flexibility should therefore play an important role in international climate change policy.

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Burden Sharing in a Greenhouse: Egalitarianism and Sovereignty Reconciled

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Downloadable Appendix

(ftp://ftp.zew.de/pub/zew-docs/div/entitlements.pdf)

Appendix A: Algebraic Model Description

This appendix presents the algebraic equilibrium conditions of our intertemporal multi-region, multi-sector general equilibrium model designed to investigate the economic implications of alternative long-term emission entitlement schemes.

The following key assumptions apply for the "generic" model:

- Output and factor prices are fully flexible and markets are perfectly competitive.
- Labor force productivity increases at an exogenous growth rate (Harrod-neutral technological progress).
- In equilibrium, there is a period-by-period balance between exports from each region and global demand for those goods. The model adopts the Armington assumption for export and import markets of a non-energy macro good to differentiate between commodities produced for the domestic market, the export market and the import market. Fossil fuels are treated as perfect substitutes on international markets.
- In each region, a representative consumer (likewise the social planner) maximizes the present value of lifetime utility subject to (i) an intertemporal balance of payments constraint, (ii) the constraint that the output per period is either consumed (incl. intermediate demand and exports) or invested, and (iii) the equation of motion for the capital stock, i.e. capital stocks evolve through depreciation and new investment. This renders the optimal level of consumption and investment over time.
- The agents have an infinite horizon, and their expectations are forward looking and rational. To approximate an infinite horizon model with a finite horizon model we assume that the representative consumer purchases capital in the model's post-horizon period at a price which is consistent with steady-state equilibrium growth (terminal condition).

The model is formulated as a system of nonlinear inequalities using GAMS/MPSGE (Rutherford 1999) and solved using PATH (Dirkse and Ferris 1995). The inequalities correspond to the three classes of conditions associated with a general equilibrium: (i) exhaustion of product (zero-profit) conditions for constant-returns-to-scale producers, (ii) market clearance for all goods and factors, and (iii) income balance for the representative consumers in each region.

The fundamental unknowns of the system are three vectors: activity levels (production indices), non-negative prices, and consumer incomes. In equilibrium, each of these variables is linked to one inequality condition: an activity level to an exhaustion of product constraint, a commodity price to a market clearance condition, and a consumer income variable to an income definition equation. An equilibrium allocation determines production, prices and incomes.

In the following algebraic exposition, the notation Π^X is used to denote the zero-profit function of activity *X*. Formally, all production activities exhibit constant returns to scale, hence differentiating Π^X with respect to input and output prices provides compensated demand and supply coefficients, which appear subsequently in the market-clearance conditions. All prices are expressed as present values.

A.1 *Exhaustion of Product Conditions*

Macro Good Production

Aggregate output in region *r* describes the supply of the non-energy macro good to the domestic market and export market. A separable nested constant elasticity of substitution (CES) cost function is employed to specify the substitution possibilities between capital (*K*), labor (*L*) and an energy composite (*E*). At the top level, a constant elasticity describes the substitution possibilities between the energy aggregate and the aggregate of labor and capital. At the second level capital and labor trade off with a unitary elasticity of substitution. On the output side, production is split between goods produced for the domestic market and goods produced for the export market according to a constant elasticity of transformation. The (intra-period) zero-profit condition for the production of the macro good is:

$$\Pi_{rt}^{Y} = (\theta_r^X p_{rt}^{X^{1+\eta_r}} + (1-\theta_r^X) p_{rt}^{1+\eta_r})^{\frac{1}{1+\eta_r}} - \left[\theta_r^{EY} (\frac{p_{rt}^{EY}}{\beta_{rt}})^{1-\sigma_r^{KLE}} + (1-\theta_r^{EY}) \left(w_{rt}^{\alpha_r} v_{rt}^{1-\alpha_r} \right)^{1-\sigma_r^{KLE}} \right]^{\frac{1}{1-\sigma_r^{KLE}}} = 0$$

where:

p_{rt}^X output price of macro good produced in region *r* and period *t* for export market,

p_{rt} output price of macro good produced in region *r* and period *t* for domestic market,

p_{rt}^{EY} price of industrial energy aggregate for macro good production in region *r* and period *t*,

w_{rt} wage rate in region *r* and period *t*,

v_{rt} rental price of capital services in region *r* and period *t*,

θ_r^X benchmark share of exports in macro good production of region *r*,

θ_r^{EY} benchmark share of industrial energy aggregate in macro good production of region *r*,

α_r benchmark share of labor in value-added of macro good production in region *r*,

η_r elasticity of transformation between production for the domestic market and production for the export market of region *r*,

σ_r^{KLE} elasticity of substitution between the energy aggregate and value-added in production for region *r*,

β_{rt} exogenous energy efficiency improvement index, which measures changes in technical efficiency for region *r* in period *t*,

and

Y_{rt} associated dual variable which indicates the activity level of macro good production in region *r* and period *t*.

Fossil Fuel Production

The production of fuels requires inputs of domestic supply (macro good) and a fuel-specific factor which can be thought of as a sector-specific resource.[1] The zero-profit condition has the form:

$$\prod\nolimits_{rt,ff}^{F} = p_t^{ff} - \left[\theta_r^{ff} {q_{rt}^{ff}}^{1-\sigma_r^{ff}} + (1-\theta_r^{ff}) {p_{rt}^{A}}^{1-\sigma_r^{ff}}\right]^{\frac{1}{1-\sigma_r^{ff}}} = 0 \qquad ff \in \{\text{COA,OIL,GAS}\}$$

where:

p_t^{ff} world market price of fossil fuel *ff* in period *t*,

q_{rt}^{ff} price of fuel-specific resource for production of fossil fuel *ff* in region *r* and period *t*,

p_{rt}^{A} Armington price of macro good in region *r* and period *t*,

θ_r^{ff} benchmark share of fuel-specific resource for fossil fuel production in region *r*,

σ_r^{ff} elasticity of substitution between the fuel-specific resource and non-energy inputs in fossil fuel production of region *r*,

and

$F_{rt,ff}$ associated dual variable which indicates the activity level of fossil fuel production *ff* in region *r* and period *t*.

[1] A constant returns to scale production function with convex levelsets exhibits decreasing returns to scale in *remaining* factors when one or more inputs are in fixed supply. We exploit this result in representing a decreasing returns to scale function through a constant returns to scale activity which uses the fuel-specific factor.

The value of the elasticity of substitution σ_r^{ff} between non-energy inputs and the fuel-specific resource determines the price elasticity of fossil fuel supply ε_r^{ff} at the reference point, according to the relation:

$$\varepsilon_r^{ff} = \sigma_r^{ff} \frac{\theta_r^{ff}}{1-\theta_r^{ff}}.$$

Armington Production

Inputs of the macro good into energy production, investment demand and final consumption are a composite of a domestic and imported variety which trade off with a constant elasticity of substitution. The corresponding zero profit condition for the production of the Armington good is given by:

$$\prod_{rt}^{A} = p_{rt}^{A} - \left[\theta_r^A \, p_{rt}^{1-\sigma_r^A} + (1-\theta_r^A)\left[\left(\sum_s \theta_{sr}^M \, p_{st}^{X\;1-\sigma_r^M} \right)^{\frac{1}{1-\sigma_r^M}} \right]^{1-\sigma_r^A} \right]^{\frac{1}{1-\sigma_r^A}} = 0$$

where:

θ_r^A benchmark share of domestic macro input into Armington production in region *r*,

θ_{sr}^M benchmark share of imports from region *s* (aliased with index *r*) in total macro good imports of region *r*,

σ_r^A Armington elasticity of substitution between domestic macro good and imported macro good aggregate for region *r*,

σ_r^M elasticity of substitution between macro good imports for region *r*,

and

A_{rt} associated dual variable which indicates the activity level of Armington production in region *r* and period *t*.

Production of the Industrial Energy Aggregate

Energy inputs to the macro production are a nested separable CES aggregation of oil, gas and coal. Gas and oil trade off as relatively close substitutes in the lower nest of the energy composite; at the next level the oil and gas composite combines with coal at a lower rate. The zero-profit condition for the production of the industrial energy aggregate is:

$$\prod_{rt}^{EY} = p_{rt}^{EY} - \{\theta_r^{COA}(p_t^{COA} + pcarb_{rt}CO2_{COA})^{1-\sigma_r^{COA}} + (1-\theta_r^{COA})$$

$$[\theta_r^{OIL}(p_t^{OIL} + pcarb_{rt}CO2_{OIL})^{1-\sigma_r^{LQ}} + (1-\theta_r^{OIL})(p_t^{GAS} + pcarb_{rt}CO2_{GAS})^{1-\sigma_r^{LQ}}]^{\frac{1-\sigma_r^{COA}}{1-\sigma_r^{LQ}}}\}^{\frac{1}{1-\sigma_{COA}}} = 0$$

where:

$pcarb_{rt}$ carbon price in region *r* and period *t*,

$CO2_{ff}$ physical carbon coefficient for fossil fuels,

θ_r^{COA} benchmark share of coal input into industrial energy aggregate of region *r*,

θ_r^{OIL} benchmark share of the oil input into the gas and oil composite of industrial energy production in region *r*,

σ_r^{COA} elasticity of substitution between coal and the gas and oil composite in industrial energy production of region *r*,

σ_r^{LQ} elasticity of substitution between gas and oil in industrial energy production of region *r*,

and

EY_{rt} associated dual variable which indicates the activity level of industrial energy aggregate production in region *r* and period *t*.

Production of the Household Energy Aggregate

Energy demanded by the household is a CES aggregate of fossil fuels. The zero-profit condition for the production of the household energy aggregate has the form:

$$\prod_{rt}^{EC} = p_{rt}^{EC} - \left(\sum_{ff}\theta_{r,ff}^{EC}(p_t^{ff} + pcarb_{rt}CO2_{ff})^{1-\sigma_r^{EC}}\right)^{\frac{1}{1-\sigma_r^{EC}}} = 0$$

where:

p_{rt}^{EC} price of household energy aggregate for region *r* and period *t* ,

$\theta_{r,ff}^{EC}$ benchmark share of fossil fuel input *ff* in the household energy aggregate of region *r*,

σ_r^{EC} elasticity of substitution between fossil fuel inputs within the household energy aggregate,

and

EC_{rt} associated dual variable which indicates the activity level of household energy aggregate production in region *r* and period *t*.

Production of the Household Consumption Aggregate

In final consumption demand the household energy aggregate trades off with the macro good at a constant elasticity of substitution:

$$\prod_{rt}^{C} = p_{rt}^{C} - \left(\theta_r^C \, p_{rt}^{A^{1-\sigma_r^C}} + (1-\theta_r^C)\, p_{rt}^{EC^{1-\sigma_r^C}} \right)^{\frac{1}{1-\sigma_r^C}} = 0$$

where:

p_{rt}^{C} price of household consumption aggregate for region *r* and period *t*,

θ_r^C benchmark share of macro good into aggregate household demand of region r,

σ_r^C elasticity of substitution between macro good and energy aggregate in household consumption demand of region r,

and

C_{rt} associated dual variable which indicates the activity level of household consumption in region *r* and period *t*.

Backstops for Industry and Household Energy Aggregate

For each region there is a carbon-free backstop for the industrial energy aggregate and the household aggregate. This backstop is available in infinite supply at a price which is calculated to be a multiple of the macro good price. Below, we take explicit account of the non-negativity constraint for backstop production:

$$\prod_{rt}^{\tau} = p_{rt}^{\tau} - a_r^{\tau}\, p_{rt}^{A} \leq 0 \qquad \tau \in \{BC, BY\}$$

where:

p_{rt}^{τ} price of energy backstop for industry (τ = BY) or household (τ = BC) ,

a_r^{τ} multiplier of the macro good price index for industrial energy backstop (τ = BY) or household energy backstop (τ = BC),

and

BY_{rt} ,BC_{rt} are the associated dual variables which indicate the activity levels of backstop energy production in region *r* and period *t* for industries or households.

Capital Stock Formation and Investment

An efficient allocation of capital, i.e. investment over time assures the following intertemporal zero-profit conditions which relates the cost of a unit of investment, the return to capital and the purchase price of a unit of capital stock in period t:[2]

$$\Pi_{rt}^{K} = p_{rt}^{K} - v_{r}^{\tau} - (1-\delta)\, p_{r,t+1}^{K} = 0$$

and

$$\Pi_{rt}^{I} = p_{r,t+1}^{K} - p_{rt}^{I} = 0$$

where:

P_{rt}^{K} value (purchase price) of one unit of capital stock in region r and period t,

δ_r depreciation rate in region r,

p_{rt}^{I} cost of a unit of investment in period t which in our case equals p_{rt}^{A},

and

K_{rt} associated dual variable, which indicates the activity level of capital stock formation in region r and period t,

I_{rt} associated dual variable, which indicates the activity level of aggregate investment in region r and period t.[3].

A.2 Market Clearance Conditions

Labor

The supply-demand balance for labor is:

$$\bar{L}_{rt} = Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial w_{rt}}$$

where:

$\bar{L}_{rt}$ exogenous endowment of time in region r and period t.[4]

Capital

The supply-demand balance for capital is:

$$K_{rt} = Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial v_{rt}}$$

---

[2] The optimality conditions for capital stock formation and investment are directly derived from the maximization of lifetime utility by the representative household taking into account its budget constraint, the equation of motion for the capital stock and the condition that output in each period is either invested or consumed. Note that in our algebraic exposition we assume an investment lag of one period.

[3] As written, we have taken explicit account of the non-negativity constraint for investment.

[4] Time endowment grows at a constant rate g, which determines the long-run (steady-state) growth rate of the economy.

Fuel-Specific Resources

The supply-demand balance for fuel-specific resources is:

$$\overline{Q}_{rt}^{ff} = F_{rt,ff} \frac{\partial \Pi_{rt,ff}^{F}}{\partial q_{rt}^{ff}} \qquad ff \in \{COA, OIL, GAS\}$$

where:

$\overline{Q}_{rt}^{ff}$ exogenous endowment with fuel-specific resource *ff* for region *r* and period *t*.

Fossil Fuels

The supply-demand balance for fossil fuels is:

$$\sum_r F_{rt}^{ff} = \left(\sum_r EY_{rt} \frac{\partial \Pi_{rt}^{EY}}{\partial (p_t^{ff} + pcarb_t CO2_{ff})} + EC_{rt} \frac{\partial \Pi_{rt}^{EC}}{\partial (p_t^{ff} + pcarb_t CO2_{ff})} \right) \qquad ff \in \{COA, OIL, GAS\}$$

Macro Output for Domestic Markets

The market clearance condition for the macro good produced for the domestic market is:

$$Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial p_{rt}} = A_{rt} \frac{\partial \Pi_{rt}^{A}}{\partial p_{rt}}$$

Macro Output for Export Markets

The market clearance condition for the macro good produced for the export market is:

$$Y_{rt} \frac{\partial \Pi_{rt}^{Y}}{\partial p_{rt}^{X}} = \sum_s A_{st} \frac{\partial \Pi_{st}^{A}}{\partial p_{st}^{X}}$$

Industrial Energy Aggregate

The market clearance condition for the industrial energy aggregate is:

$$EY_{rt} + BY_{rt} = EY_{rt} \frac{\partial \Pi_{rt}^{EY}}{\partial p_{rt}^{EY}}$$

Household Energy Aggregate

The market clearance condition for the household energy aggregate is:

$$EC_{rt} + BC_{rt} = EC_{rt} \frac{\partial \Pi_{rt}^{EC}}{\partial p_{rt}^{EC}}$$

Armington Aggregate

The market clearance condition for Armington aggregate is:

$$A_{rt} = Y_{rt}\frac{\partial\,\Pi^{Y}_{rt}}{\partial\ p^{A}_{rt}} + C_{rt}\frac{\partial\,\Pi^{C}_{rt}}{\partial\ p^{A}_{rt}} + I_{r}\frac{\partial\,\Pi^{I}_{rt}}{\partial p^{A}_{rt}} + BY_{rt}\frac{\partial\,\Pi^{BY}_{rt}}{\partial p^{A}_{rt}} + BC_{rt}\frac{\partial\,\Pi^{BC}_{rt}}{\partial p^{A}_{rt}}$$

Household Consumption Aggregate

The market clearance condition for the household consumption aggregate is:

$$C_{rt} = D_{rt}$$

where:

D_{rt} uncompensated final demand which is derived from maximization of lifetime utility (see below).

A.3 Income Balance of Households

Consumers choose to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. The representative agent in each period solves:

$$\text{Max}\ \sum_{t}\left(\frac{1}{1+\rho_r}\right)^{t} u_r(C_{rt})$$

$$\text{s.t.}\ \sum_{t} p^{C}_{rt}C_{rt} = M_r$$

where:

u_r instantaneous utility function of representative agent in region *r*,

ρ_r time preference rate of representative agent in region *r*,

and

M_r lifetime income of representative agent in region *r*.

Lifetime income *M* is defined as:

$$M_r = p^{K}_{r0}\overline{K}_{r0} + \sum_{t} w_{rt}\overline{L}_{rt} + \sum_{ff} q^{ff}_{rt}\overline{Q}^{ff}_{rt}$$

$$+\sum_{t}\sum_{ff} pcarb_{rt}CO2_{ff}\left(EY_{rt}\frac{\partial\Pi^{EY}_{rt}}{\partial(p^{ff}_{t} + CO2_{ff}\ pcarb_{rt})} + EC_{rt}\frac{\partial\Pi^{EC}_{rt}}{\partial(p^{ff}_{t} + CO2_{ff}\ pcarb_{rt})}\right)$$

where:

$\overline{K}_{r0}$ initial capital stock in region *r*.

With isoelastic lifetime utility the instantaneous utility function is given as:

$$u_r(C_{rt}) = \frac{C_{rt}^{1-\frac{1}{\mu_r}}}{1-\frac{1}{\mu_r}}$$

where:

μ_r constant intertemporal elasticity of substitution.

The uncompensated final demand function D_{rt} is then derived as:

$$D_{rt}(p_{rt}^C, M) = \frac{(1+\rho_r)^{-t\mu_r}}{\sum_t (1+\rho_r)^{-t^{\mu_r}} p_{rt}^{C^{1-\mu_r}}} \frac{M}{p_{rt}^{C^{\mu_r}}}$$

A.4 Terminal Constraints

The finite horizon poses some problems with respect to capital accumulation. Without any terminal constraint, the capital stock at the end of the model's horizon would have no value and this would have significant repercussions for investment rates in the periods leading up to the end of the model horizon. In order to correct for this effect we define a terminal constraint which forces terminal investment to increase in proportion to final consumption demand:[5]

$$\frac{I_{Tr}}{I_{T-1,r}} = \frac{C_{Tr}}{C_{T-1,r}}.$$

A.5 Summary of Key Elasticities

Table A.1 summarizes the central values for key elasticities employed for the core simulations.

Table A1: Overview of key elasticities

Type of elasticity	Description	Central Value
Armington elasticity of substitution (σ_r^M, σ_r^A)	Degree of substitutability	
	• Between macro imports from different regions	2
	• Between the import aggregate and the domestically produced macro good	1
Armington elasticity of transformation (η_r)	Degree of substitutability between macro good produced for the domestic market and macro good destined for the export market	2

[5] This constraint imposes balanced growth in the terminal period but does not require that the model achieves steady-state growth.

Price elasticity of fossil fuel supply (ε_r^{ff})	Degree of response of international fossil fuel supply to changes in fossil fuel price	1 (coal), 4 (gas) 8 (oil)
Elasticity of substitution between non-energy and energy composite in production (σ_r^{KLE}) and final demand (σ_r^{C})	This value increases linearly over time between a short-run value of 0.2 and the long-run value of 0.8 to reflect empirical evidence on differences between short-run and long-run adjustment costs (Lindbeck, 1983)	0.2 (short run: 2000) 0.8 (long run: 2050)
Interfuel elasticity of substitution (σ_r^{ff})	Degree of substitutability between fossil fuels (fuel switching)	0.5 (final demand) 2[a],1[b] (industry)

[a] between oil and gas [b] between coal and the oil-gas aggregate

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Appendix B: Sensitivity Analysis

To evaluate the sensitivity of our results, we have run additional simulations for alternative assumptions on (i) long-term emission reduction targets, (ii) energy demand responsiveness, (iii) oil price responsiveness, (iv) trade impacts (ease of substitution for the traded macro-good), and (v) discount rate. We find that all of our insights based on the central case simulations remain robust. This section reports the detailed quantitative welfare impacts expressed as Hicksian equivalent variation (HEV) in income (% present value of *BaU* consumption).

B.1 Long-term Emission Reduction Target:

The central case global emission reduction target in 2050 amounts to more than 60 % of the *BaU* emission level. In the sensitivity analysis, we investigate less ambitious cutback requirements of 50 %, 40 %, and 30 % global emission reduction in 2050 vis-à-vis the *BaU* emission level.

B.2 Energy Demand Responsiveness

The adjustment costs of emission constraints depend on the ease of substitution between energy and other factors in production and consumption. The end-use demand elasticity determines how total energy demand responds to increases in the price of energy in both the short- and long-run. The substitution elasticity between energy and other factors (i.e. the implicit energy demand elasticity) rises linearly over time between a lower short-run value and a higher long-run value to reflect empirical evidence on differences between short-run and long-run adjustment costs. In the sensitivity analysis, we reset the short-run value (central case: 0.2) to 0.1 (low) and 0.5 (high), respectively.

B.3 Oil Price Responsiveness

The supply elasticity for oil determines how its price responds to changes in the demand for crude oil. The lower the supply elasticity is, the more responsive the price of oil to a change in the demand for oil is. For a given reduction in global crude oil demand, the price drops more for lower elasticity values than it does for higher values. Increasing the price response (decreasing the supply elasticity), thus, causes oil exporting nations to suffer more when a carbon abatement policy is enacted. Conversely, higher price responses (lower supply elasticities) lead to greater benefits for oil importing countries. In the sensitivity analysis, we halve (low) or double (high) the central case value of 8.

B.4 Trade Impacts (Armington Elasticity)

Non-energy macro goods are treated as imperfect substitutes with substitution possibility between the domestically produced good and the import aggregate from other regions being characterized by a constant (Armington) elasticity of substitution. The Armington elasticities together with the respective bilateral trade shares, are important determinants for the region-specific terms-of-trade effects on the non-energy market. In the sensitivity analysis, we decrease or increase the central case Armington elasticities (central case values: 2 - between macro imports from different regions; 1 - between the import aggregate and the domestically produced macro good) to assess the robustness of our results concerning trade impacts (terms-of-trade effects) on non-energy markets.

B.5 Discount Rate

The discount rate as the pure rate of time preference between current and future consumption determines the intertemporal allocation of consumption. In equilibrium, the representative agent in each region is indifferent between consuming one unit of consumption today or consuming the value of one unit of consumption that is adjusted for time preference tomorrow. In the sensitivity analysis, we decrease or increase the discount rate vis-à-vis the central case value (5 %) by 0.25 %.

Table B.1: Sensitivity to emission reduction target in 2050

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
50 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.75	-1.51	-2.67	17.26	-1.68	12.15
China	-1.97	-1.39	-1.76	0.59	-1.59	-0.16
India	-1.11	-0.76	-0.02	19.34	-0.07	13.84
Latin America	-0.76	-0.73	-1.49	1.03	-0.8	0.51
Middle East and N. Africa	-1.56	-1.38	-3.99	2.89	-2.43	1.97
North America	-0.45	-0.48	-6.47	-2.14	-2.46	-1.59
Pacific OECD	-0.19	-0.23	-2.35	-0.87	-1.03	-0.7
Other Pacific Asia	-0.22	-0.35	-0.05	0.71	0.07	0.36
Former Eastern Bloc	-2.03	-1.8	-12.01	-6.83	-6.28	-5.23
Western Europe	-0.16	-0.19	-2.86	-0.99	-1.18	-0.77
WORLD	-0.51	-0.49	-3.76	-0.42	-1.61	-0.41
40 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.39	-1.23	-2.62	14.4	-1.64	10.29
China	-1.38	-1.03	-1.39	0.63	-1.16	0.02
India	-0.74	-0.48	-0.11	17.08	-0.14	12.31
Latin America	-0.5	-0.48	-1.49	0.97	-0.8	0.56
Middle East and N. Africa	-1.11	-0.99	-3.84	2.53	-2.3	1.81
North America	-0.27	-0.28	-6.28	-1.64	-2.3	-1.22
Pacific OECD	-0.11	-0.14	-2.25	-0.67	-0.94	-0.53
Other Pacific Asia	-0.07	-0.18	-0.06	0.69	0.09	0.42
Former Eastern Bloc	-1.26	-1.12	-10.82	-5.27	-5.34	-4.02
Western Europe	-0.06	-0.07	-2.71	-0.74	-1.05	-0.57
WORLD	-0.31	-0.3	-3.59	-0.23	-1.47	-0.23
30 % global emission reduction in 2050 from *BaU* level						
Sub-Saharan Africa	-1.07	-0.97	-2.56	11.63	-1.58	8.43
China	-0.91	-0.74	-1.16	0.6	-0.87	0.14
India	-0.47	-0.28	-0.18	14.51	-0.2	10.53
Latin America	-0.33	-0.31	-1.48	0.87	-0.8	0.54
Middle East and N. Africa	-0.76	-0.68	-3.72	2.13	-2.17	1.57
North America	-0.15	-0.15	-6.09	-1.24	-2.16	-0.91
Pacific OECD	-0.05	-0.07	-2.14	-0.5	-0.85	-0.39
Other Pacific Asia	0.01	-0.07	-0.11	0.63	0.05	0.42
Former Eastern Bloc	-0.7	-0.62	-9.8	-3.93	-4.54	-2.98
Western Europe		-0.01	-2.59	-0.54	-0.94	-0.41
WORLD	-0.18	-0.17	-3.45	-0.1	-1.35	-0.11

Table B.2: Energy demand responsiveness – short-run substitution elasticities (σ_r^{KLE} , σ_r^C)

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low substitution elasticity (0.1)						
Sub-Saharan Africa	-2.26	-2.13	-2.78	21.85	-1.74	14.58
China	-3.01	-2.21	-2.49	0.42	-2.41	-0.73
India	-1.83	-1.75	0.23	22.52	0.16	15.45
Latin America	-1.22	-1.19	-1.59	1.1	-0.9	0.33
Middle East and N. Africa	-2.27	-2.05	-4.27	3.48	-2.57	2.11
North America	-0.81	-0.84	-7.36	-3.08	-2.72	-2.24
Pacific OECD	-0.37	-0.41	-2.76	-1.27	-1.21	-1
Other Pacific Asia	-0.54	-0.72	-0.12	0.72	-0.05	0.18
Former Eastern Bloc	-3.51	-3.21	-14.63	-9.41	-8.04	-7.15
Western Europe	-0.38	-0.4	-3.37	-1.47	-1.4	-1.14
WORLD	-0.88	-0.85	-4.34	-0.81	-1.88	-0.78
High substitution elasticity (0.5)						
Sub-Saharan Africa	-2.24	-2.03	-2.67	18.99	-1.75	13.65
China	-2.7	-1.77	-2.36	0.07	-2.24	-0.65
India	-1.62	-1.62	0.22	20.18	0.16	14.67
Latin America	-1.18	-1.11	-1.53	0.83	-0.9	0.28
Middle East and N. Africa	-2.28	-1.93	-4.12	2.9	-2.64	1.93
North America	-0.8	-0.83	-5.79	-2.62	-2.55	-2.06
Pacific OECD	-0.32	-0.38	-2.14	-1.09	-1.11	-0.9
Other Pacific Asia	-0.45	-0.59	-0.12	0.56	-0.01	0.19
Former Eastern Bloc	-2.91	-2.35	-12.22	-8.45	-7.38	-6.59
Western Europe	-0.36	-0.4	-2.58	-1.25	-1.28	-1.04
WORLD	-0.82	-0.78	-3.48	-0.71	-1.76	-0.7

Table B.3: Oil price responsiveness – oil supply elasticity (ε_r^{oil})

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low responsiveness – high oil supply elasticity (16)						
Sub-Saharan Africa	-2.12	-2.05	-2.4	20.84	-1.56	14.13
China	-2.86	-2.1	-2.39	0.16	-2.33	-0.79
India	-1.8	-1.81	0.15	21.51	0.14	15.07
Latin America	-1.09	-1.05	-1.32	0.98	-0.72	0.34
Middle East and N. Africa	-1.87	-1.67	-3.44	3.4	-2.08	2.23
North America	-0.83	-0.85	-6.71	-2.82	-2.65	-2.12
Pacific OECD	-0.37	-0.42	-2.53	-1.2	-1.19	-0.96
Other Pacific Asia	-0.55	-0.72	-0.25	0.57	-0.12	0.11
Former Eastern Bloc	-3.13	-2.77	-13.34	-8.85	-7.48	-6.77
Western Europe	-0.39	-0.41	-3.05	-1.39	-1.35	-1.11
WORLD	-0.84	-0.82	-3.94	-0.75	-1.79	-0.73
High responsiveness – low oil supply elasticity (4)						
Sub-Saharan Africa	-2.43	-2.14	-3.13	20.69	-1.94	14.39
China	-2.95	-2.07	-2.48	0.28	-2.38	-0.69
India	-1.64	-1.56	0.52	21.66	0.32	15.32
Latin America	-1.38	-1.33	-1.8	0.93	-1.06	0.22
Middle East and N. Africa	-2.93	-2.6	-5.5	2.89	-3.47	1.64
North America	-0.77	-0.8	-6.71	-2.95	-2.63	-2.19
Pacific OECD	-0.32	-0.37	-2.48	-1.18	-1.14	-0.95
Other Pacific Asia	-0.43	-0.62	0.09	0.72	0.09	0.24
Former Eastern Bloc	-3.57	-3.18	-14.46	-9.43	-8.29	-7.31
Western Europe	-0.34	-0.38	-3.04	-1.36	-1.34	-1.08
WORLD	-0.87	-0.84	-4.06	-0.8	-1.86	-0.77

Table B.4: Sensitivity to Armington elasticities (σ_r^M, σ_r^A)

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low Armington elacticities (0.75; 1.5)						
Sub-Saharan Africa	-2.4	-1.91	-3.79	22.05	-2.27	15.17
China	-2.97	-1.69	-3.24	1.56	-2.62	0.25
India	-1.74	-0.96	-0.88	22.96	-0.46	16.57
Latin America	-1.29	-1.18	-2.34	1.22	-1.23	0.46
Middle East and N. Africa	-2.41	-2	-5.46	3.47	-3.2	2.2
North America	-0.8	-0.84	-6.65	-2.98	-2.63	-2.21
Pacific OECD	-0.31	-0.41	-2.53	-1.23	-1.15	-0.98
Other Pacific Asia	-0.54	-0.62	-0.74	1.22	-0.34	0.57
Former Eastern Bloc	-3.28	-2.93	-14.1	-9.05	-7.86	-6.9
Western Europe	-0.35	-0.41	-3.03	-1.44	-1.32	-1.14
WORLD	-0.85	-0.8	-4.19	-0.69	-1.9	-0.67
High Armington elacticities (1.5; 3)						
Sub-Saharan Africa	-2.15	-2.22	-1.83	19.72	-1.25	13.54
China	-3.05	-2.62	-2.13	-0.99	-2.39	-1.68
India	-1.83	-2.21	0.85	20.79	0.62	14.15
Latin America	-1.15	-1.14	-0.93	0.78	-0.61	0.18
Middle East and N. Africa	-2.18	-2.02	-3.13	3.04	-2.03	1.9
North America	-0.81	-0.81	-6.74	-2.8	-2.63	-2.11
Pacific OECD	-0.39	-0.4	-2.49	-1.16	-1.18	-0.94
Other Pacific Asia	-0.53	-0.7	0.26	0.22	0.13	-0.11
Former Eastern Bloc	-3.34	-2.92	-13.48	-9.09	-7.78	-7.04
Western Europe	-0.39	-0.39	-3.07	-1.32	-1.36	-1.06
WORLD	-0.87	-0.86	-3.84	-0.84	-1.76	-0.81

Table B.5: Sensitivity to discount rate

	Scenario *SOVEREIGNTY*		Scenario *EGALITARIANISM*		Scenario *CONVERGENCE*	
	NoTrade	*Trade*	*NoTrade*	*Trade*	*NoTrade*	*Trade*
Low discount rate (4.75 %)						
Sub-Saharan Africa	-2.44	-2.21	-2.89	22.14	-1.9	15.6
China	-3.12	-2.24	-2.61	0.11	-2.54	-0.85
India	-1.88	-2.2	0.25	22.58	0.18	16.25
Latin America	-1.3	-1.27	-1.64	1.04	-0.97	0.35
Middle East and N. Africa	-2.44	-2.17	-4.39	3.4	-2.8	2.2
North America	-0.86	-0.89	-6.84	-3.09	-2.84	-2.35
Pacific OECD	-0.37	-0.42	-2.57	-1.27	-1.25	-1.04
Other Pacific Asia	-0.53	-0.73	-0.1	0.68	-0.02	0.2
Former Eastern Bloc	-3.52	-3.11	-14.48	-9.66	-8.44	-7.52
Western Europe	-0.4	-0.43	-3.13	-1.47	-1.45	-1.19
WORLD	-0.92	-0.9	-4.1	-0.84	-1.97	-0.81
High discount rate (5.25 %)						
Sub-Saharan Africa	-1.17	-1.11	-1.52	20.5	-0.58	14.2
China	-2.29	-1.55	-1.82	0.7	-1.74	-0.24
India	-0.11	0.36	1.36	23.08	1.38	16.55
Latin America	-0.89	-0.86	-1.16	1.17	-0.53	0.51
Middle East and N. Africa	-2.34	-2.16	-3.88	2.86	-2.43	1.67
North America	-1.53	-1.55	-7.23	-3.49	-3.22	-2.8
Pacific OECD	-0.85	-0.9	-2.93	-1.64	-1.61	-1.42
Other Pacific Asia	1.05	0.88	1.43	2.15	1.51	1.69
Former Eastern Bloc	-3.7	-3.38	-13.76	-9.15	-7.94	-7.15
Western Europe	-2.77	-2.78	-5.48	-3.66	-3.7	-3.4
WORLD	-1.72	-1.69	-4.78	-1.64	-2.62	-1.61