E. World Economic Impacts of the Kyoto Protocol

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1. Introduction

The Kyoto Protocol entails quantified emissions limitations and reduction objectives for industrialized (Annex B) countries (UN, 1997). Signatory countries are now obligated to adjust their production and consumption patterns through appropriate policy measures such that domestic emission levels get in line with the mandated emission constraints. Adjustment of economic activities in larger open economies such as the industrialized regions are likely to affect international prices via changes in export and import quantities. For example, large reductions in the demand for oil by industrialized countries may drive down international oil prices, which is beneficial for oil importing countries but harmful for oil exporters.

Assessing the potential economic impacts of the Kyoto Protocol the present paper focuses on two closely related questions: Do terms of trade effects matter for the economy-wide costs on individual countries? If so, which countries will gain and which countries will lose from international spill-overs?

In our empirical analysis we find that emission restrictions for Annex B countries as mandated under the Kyoto Protocol will not only affect abating industrialized countries but also trigger significant international spill-over effects to non-abating developing countries. In general, industrialized countries are able to pass on part of their domestic adjustment costs to their trading partners in the developing world by demanding fewer exports and shifting the terms of trade against the latter.

Our results are based on simulations with a dynamic multi-sectoral model for the global economy incorporating bilateral trade between eleven major world regions. Section 2 describes our modeling framework. Section 3 presents the details of the Kyoto abatement scenario and the interpretation of quantitative results. Section 4 concludes.

2. Analytical Framework

2.1 Model Characteristics

The analytical framework is an intertemporal computable general equilibrium model for the global economy which is based on the International Impact Analysis Model (IIAM) developed by BERNSTEIN, MONTGOMERY and RUTHERFORD (1997). The current model features 11 regions (countries) which are linked through bilateral trade flows. The economic structure of each region consists of 4 production sectors (1 non-energy sector and 3 fossil fuel sectors) whose outputs are demanded by intermediate production, exports, investment and a representative consumer. Table E1 gives an overview of the regional and sectoral aggregation, which is based on GTAP data for 26 regions and 38 sectors (McDOUGALL, 1995). Producers and representative consumers behave according to the competitive paradigm, in the sense that they take market prices as given. Consumption and investment decisions are based on rational point expectations of future prices. The representative agent for each region maximizes lifetime utility from consumption which implicitly determines the level of savings. Entrepreneurs choose investment in order to maximize the present value of their firms (production sectors). We provide a non-technical description of the intertemporal multi-sector, multi-region model.[1]

Production

In each region production of the non-energy macro good is captured by an aggregate production function which characterizes technology through transformation possibilities on the output side (between production for domestic and export markets) and substitution possibilities on the input side (between alternative combinations of inputs). On the output side production is split between goods produced for the domestic markets and goods produced for the export market subject to a constant elasticity of transformation. On the input side capital, labor and an energy aggregate of fossil fuels trade off with a constant elasticity of substitution. Production of the energy aggregate is described by a CES function which reflects substitution possibilities for different fossil fuels (i.e., coal, gas, and oil). Fossil fuels are produced from fuel-specific resources and the non-energy macro good subject to a CES technology. The elasticity of substitution between the resource input and non-energy inputs is calibrated to match a given price elasticity of supply. Depletion leads to rising fossil fuel prices at constant demand quantities but the relationship between depletion rates, fossil energy stocks and fuel production is not incorporated (i.e. the model has no stock accounting of fossil fuels).

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[1] An algebraic model summary can be obtained from the authors on request.

Tab. E1: Overview of Sectors and Countries/Regions

Sectors		Regions	
Label	Long name	Label	Long name
COL	coal	ASIA	India and other Asia (Republic of Korea, Indonesia, Malaysia, Philippines, Singapore, Thailand, China, Hong Kong, Taiwan)
GAS	natural gas	CNA	Canada, New Zealand, Australia
OIL	crude oil	CHN	China
MACRO	non-energy macro good aggregate	EU15	European Union (European Union 12, Austria, Finland, Sweden)
		JPN	Japan
		LSA	Latin America (Mexico, Argentina, Brazil, Chile, Rest of Latin America)
		MIDE	Middle East and North Africa
		REC	Russia , Eastern and Central European Countries
		ROW	Other countries
		SSA	Sub Saharan Africa
		USA	United States of America

Source: data base, GTAP 3.0; see McDOUGALL (1995)

Household Behavior

In each region a representative household chooses to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. In each period households face the choice between current consumption and future consumption, which can be purchased via savings. That is, consumption and the level of savings are endogenously determined in each period. The trade-off between current consumption and savings is given by a constant intertemporal elasticity of substitution. Households demand an aggregate consumption good, which is a CES composite of the non-energy macro good and a household-specific energy aggregate.

Investment

Managers of the firms invest 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 a unit of consumption is equalized within and across countries.

International Trade

Following ARMINGTON (1969), domestic, imported and exported varieties of the non-energy goods are distinguished by origin. The Armington aggregation function provides a constant elasticity of substitution between domestic and imported varieties for the non-energy good for all buyers in the domestic market. With respect to trade in energy, fossil fuels are treated as perfect substitutes, which implies that we use net trade data with no cross-hauling. International capital flows reflect borrowing and lending at the world interest rate, and are endogenous subject to an intertemporal balance of payments constraint: there is no change in net indebtedness over the entire model horizon.

Carbon Emission Restrictions

A system of emission permits is used to impose emission limits on certain countries. In the baseline, where no reduction targets apply, all countries dispose of abundant emission rights such that their (shadow) price is zero. In the abatement counterfactual countries subject to emission limits are only endowed with rights up to the emission limit. Permit rights then become a scarce good with a positive price. In our simulations we assume that permits are tradable within a country such that the marginal costs of abatement are equalized across domestic sources. The permit price is then equivalent to the domestic carbon tax which would be necessary to achieve the given emission limit. Revenues from permits or likewise carbon taxes are refunded lump-sum back to the representative consumer in the abating country.

2.2 Parametrization

Benchmark data are used to calibrate parameters of the functional forms from a given set of quantities, prices and elasticities. Data stems from three different sources which need to be reconciled to yield a consistent benchmark data set:

- *GTAP database* (McDOUGALL, 1995). GTAP includes detailed input-output tables for 38 sectors in 30 regions and a world trade matrix with bilateral trade flows for all sectors and regions.
- IEA energy balances and energy prices/taxes (IEA, 1992). IEA provides statistics on physical energy flows and energy prices for industrial and household demands.
- *DOE/IEA* (DOE, 1995). DOE/IEA makes projections on the future development of world GDP and fossil fuel production differentiated by countries.

We replace GTAP's aggregate input-output monetary values for energy supply and demand with physical energy flows and energy prices as given in IEA's energy statistics. This "bottom-up" calibration of energy demands and supplies yields sector-specific and energy-specific CO_2 coefficients. The advantage is that marginal abatement cost curves and hence the cost evaluation of emission constraints are based on actual energy flows rather than aggregate monetary data, which strengthens the credibility of the quantitative results.

A steady-state growth path in which all physical quantities grow at an exogenous rate often underlies calibration of a dynamic model in applied CGE analysis.[2] However, we want to incorporate exogenous baseline assumptions as reported in *DOE* on non-uniform growth rates for GDP and fossil fuel production across countries. We employ autonomous energy efficiency improvement (AEEI) factors which scale energy demand functions in order to match GDP forecasts with the energy production projections.[3] The exogenous assumptions on fossil fuel production for the baseline imply a reference emission level for the world as a whole. At the country level the baseline emission trajectory determines the extent to which potential reduction obligations with respect to a reference year (in our case: 1990) bind in the future.[4] In the baseline world carbon emissions grow from 6 billion metric tons in 1990 to more than 11 billion metric tons by the year 2030. This is roughly consistent with the carbon emission projections of the IPCC reference scenario for medium economic growth (IPCC, 1997). Table E2 summarizes the central values for key elasticities employed for the core simulations.

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2 The virtue of the steady-state calibration is that the amount of exogenous information which goes beyond the explanatory scope of the model is kept at a minimum.

3 AEEI captures the rate of improvement in energy efficiency independent of price changes (see MANNE and RICHELS, 1994, for a survey of estimates).

4 See BÖHRINGER, JENSEN, RUTHERFORD, 1998 or BÖHRINGER, HARRISON, RUTHERFORD, 1997 on the importance of baseline assumptions for the magnitude and distribution of abatement costs.

Tab. E2: Overview of Key Elasticities

Type of elasticity	Description	Central Value
Armington elasticity of substitution	Degree of substitutability • between macro imports from different regions • between the import aggregate and the domestically produced macro good	 2 1
Armington elasticity of transformation	Degree of substitutability between macro good produced for the domestic market and macro good destined for the export market	2
Elasticity of fossil fuel supply	Degree of response of international fossil fuel prices to changes in fossil fuel	1 (coal), 4 (gas, oil)
Elasticity of substitution between non-energy and energy composite in production and final demand	This value increases linearly over time between a short-run value and the long-run value to reflect empirical evidence on differences between short-run and long-run adjustment costs (LINDBECK, 1983)	0.25-0.5 (Annex B), 0.20-0.4 (non-Annex B)
Interfuel elasticity of substitution	Degree of substitutability between fossil fuels (fuel switching)	0.5 (final demand) 2[a],1[b] (industry)

between oil and gas

b) between coal and the oil-gas aggregate

3. The Kyoto Protocol: Abatement Scenario and Computational Results

3.1 Abatement Scenario

Under the Kyoto Protocol industrialized (Annex B) countries have committed themselves to reduce greenhouse gas emissions on average by 5.2% below 1990 levels over the period 2008 - 2012.[5] Table E3 gives the commitments for the industrialized countries or regions as represented in our analytical framework.

[5] No emission limits apply so far to developing countries.

Tab. E3: Quantified Emissions Limits Under the Kyoto Protocol (UN, 1997)

Country or Region	Label	Commitments (Percentage of 1990 Base Year Greenhouse Gas Emissions)
Canada, New Zealand, Australia[a]	CAN	99
European Union	EU15	92
Russia, Eastern and Central European Countries[b]	REC	98.3
Japan	JPN	94
New Zealand	NZL	100
United States of America	USA	93

a) The reduction commitments of Canada (94), New Zealand (100) and Australia (108) are weighted based on the individual 1990 emission levels.

b) The effective reduction rate for REC is derived from the individual commitments of countries belonging to the REC region.

Reduction rates differ across signatory countries. At the domestic policy level governments are free to choose the policy instrument (e.g., emission taxes, command and control measures, voluntary agreements) in order to meet their emission reduction target. In principle the Kyoto Protocol includes the option for emission trading among industrialized countries. The negotiations on the institutional framework for emission trading have been postponed to follow-up conferences. Given the disagreement between the EU and the US on the scope of permissible trade it is uncertain whether operational rules will be in effect in the near future.[6]

For our abatement scenario we adopt the country-specific reduction targets as stated in the Kyoto Protocol and apply these targets to carbon dioxide, which is the most important greenhouse gas. With respect to the carbon emission trajectory until 2010 we assume that emission constraints for signatory countries are in effect from 2000 onwards and entail a linear cut-back of 1990 emission levels to the respective Kyoto reduction target by 2010. Governments in abating countries apply carbon taxes sufficient to meet their exogenous emission reduction profile over time. Revenues are recycled lump-sum to the representative agent in each region. After 2010 we require industrialized Annex B countries to keep their carbon emissions constant at 2010 levels. Due to the unresolved issue of the scope of emission

[6] A major concern of the EU is that "idle" emission rights (so-called hot air) in particular from REC will be used by other industrialized countries such that emission trading actually increases total emissions from industrialized countries as compared to those in the no trade case.

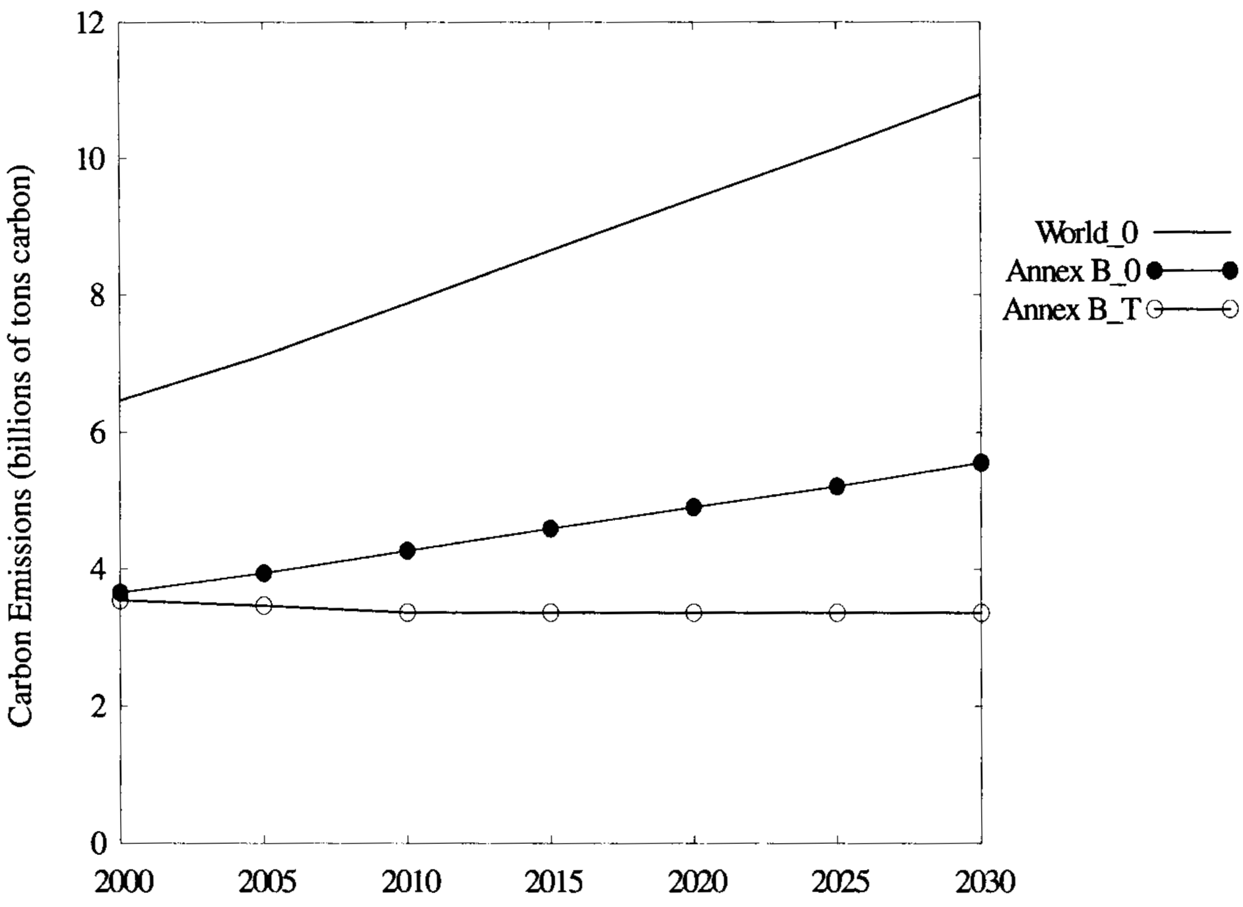
trading we assume that there will be no (substantial) trade in permits between Annex B countries. For non-Annex B countries there are no emission constraints.

As is customary in general equilibrium analysis, the scenario evaluation is based on the comparison of alternative equilibria. The economic implications of implementing the Kyoto Protocol are reported with reference to the business-as-usual case where no carbon constraints apply.

Figure E2 illustrates that the Kyoto abatement scenario imposes significant cuts in fossil fuel use for the industrialized world as compared to the baseline.

Industrialized countries in aggregate must reduce carbon emissions by roughly 20 % from baseline levels in 2010 to comply with the Kyoto Protocol (2010). Keeping emissions at this target afterwards imply a drop of baseline emissions of up to 40 % in 2030.

Fig. E1: Baseline Emissions for the World and Annex B Countries as well as Target Emission Trajectory for Annex B Countries



3.2 Quantitative Results

Column A of Table E4 reports the total welfare effects across regions associated with the implementation of our abatement scenario.

The welfare figures convey two broad insights. First, complying with the Kyoto targets and holding emissions constant thereafter involves significant economic costs for abating Annex B countries. Second, the actions of Annex B countries produce substantial spill-overs to non-Annex B countries.

Both results do not come as a surprise. The emission reduction targets for industrialized countries restrict fossil fuel use as compared to the baseline and imply that primary factors are employed less productively. The productivity loss associated with fuel shifting or energy savings translates into a welfare reduction. Constraints on economic activities in industrialized countries spill-over to non-Annex B countries via changes in the export and import levels which are accompanied by changes in international prices. *Terms of trade* can be used to determine whether a country will benefit or lose from the change in international prices. Terms of trade are measured as the ratio in value terms of a country's exports to its imports. A positive change in the terms of trade then means that the country has to export less for a given amount of imports, hence the country experiences a welfare gain from the change in international prices. The sign and the magnitude of the terms of trade effect for open economies depend on the initial trade patterns and the changes in international prices induced by the policy interference (here: carbon taxes). The welfare losses for non-Annex B countries as listed in Column A indicate that the terms of trade for developing countries deteriorate. The developing countries are adversely affected by reduced economic activity in the industrialized world. In order to better understand the key determinants of the aggregate policy effect we employ the decomposition method as described in BÖHRINGER and RUTHERFORD (1999). This decomposition allows for a break down of the aggregate economic effect into a domestic policy effect (i. e., domestic adjustment abstracting from changes in international prices) and international spill-overs (i. e., changes in the terms of trade).

Tab. E4: Welfare Implications of the Kyoto Protocol (in % Hicksian equivalent variation in lifetime income from baseline)

	A Full Policy Effect	B Domestic Policy Effect	C Fossil Fuel Price Effect	D (= A - B) Full Terms of Trade Effect
ASIA	-0.15		0.10	-0.15
CHN	-0.72		-0.40	-0.72
CNA	-0.38	-0.15	-0.22	-0.23
EU15	-0.13	-0.20	0.09	0.07
JPN	-0.02	-0.13	0.09	0.11
LSA	-0.14		-0.09	-0.14
MIDE	-0.59		-1.12	-0.59
REC	-0.35	-0.41	-0.12	0.06
ROW	-0.06		0.16	-0.06
SSA	-0.34		-0.44	-0.34
USA	-0.31	-0.34	0.01	0.03

Key:

A: Aggregate welfare effect accounting for changes in international prices for all traded goods

B: Partial welfare effect neglecting changes in international prices (i.e., keeping international prices fixed at the baseline level)

C: Secondary burden or benefit due to changes in fossil fuel prices only (i.e., keeping the international prices of the non-energy macro good fixed at the baseline level)

D: Secondary burden or benefit due to changes in international prices

Domestic policy effect

The domestic policy effect (see column B of Table E4) reflects the economic implications of carbon constraints in industrialized countries assuming that international prices are unaffected from the domestic tax policy. As expected, the welfare impact of domestic emission abatement is negative. The magnitude of the welfare loss associated with the domestic abatement policy depends on a number of factors such as the effective reduction requirement with respect to the baseline, the level of pre-existing energy taxes, the initial energy (emission) intensity, and substitution elasticities. Figure E2 shows the marginal cost of abatement across Annex B countries. These costs are equivalent to the carbon tax rates which have to be charged in order to comply with the exogenous emission reduction target. The differences in the marginal abatement costs reflect the differences in the abatement requirements across countries. The larger the reduction target, the more costly it gets at the margin to substitute away from carbon. Figure E3 joint with Figure E2 illustrate this point. With respect to the baseline, the emission constraints on industrialized countries bind more and more over time, which implies rising marginal costs of abatement as low-cost options have already been exhausted.

International spill-overs

The welfare implications of spill-overs from domestic abatement to international markets at the single country-level (see column D of Table E4) depend on two major trade characteristics. First, the country's position on fossil fuel markets: whether the country is a net importer or a net exporter of fossil fuels. Second, the amount of non-energy trade a country conducts with Annex B and non-Annex B countries. The cut-back in fossil fuel demand imposed on Annex B countries depresses international fossil fuel prices (see Figure E5).

Fig. E2: Marginal Abatement Costs - Carbon Taxes (in dollars per ton carbon)

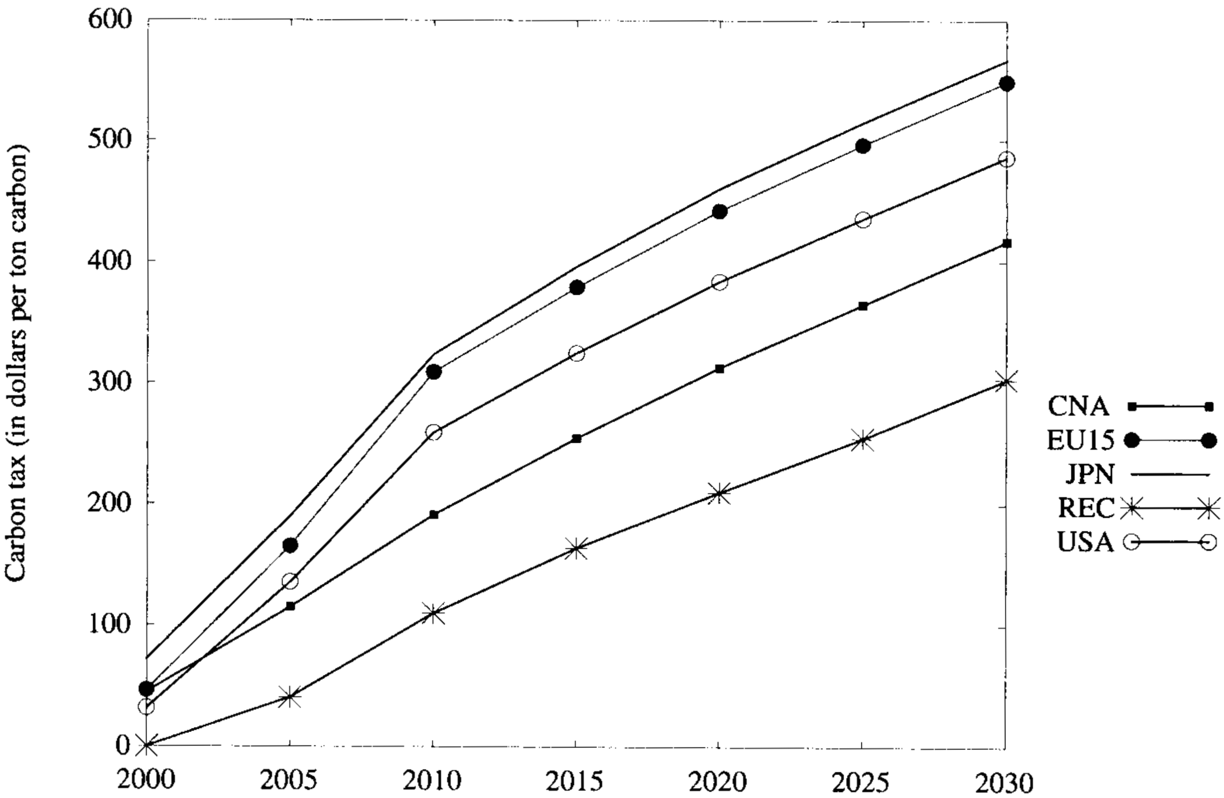


Fig. E3: Reduction Requirements in Carbon Emissions for Annex B Countries as Compared to Baseline

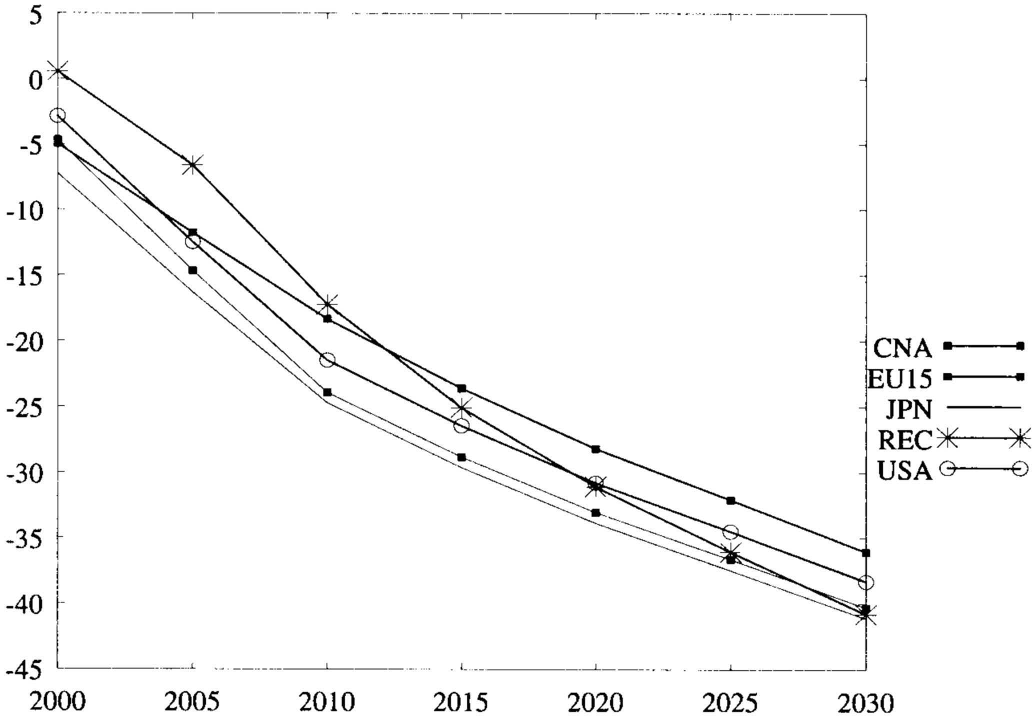
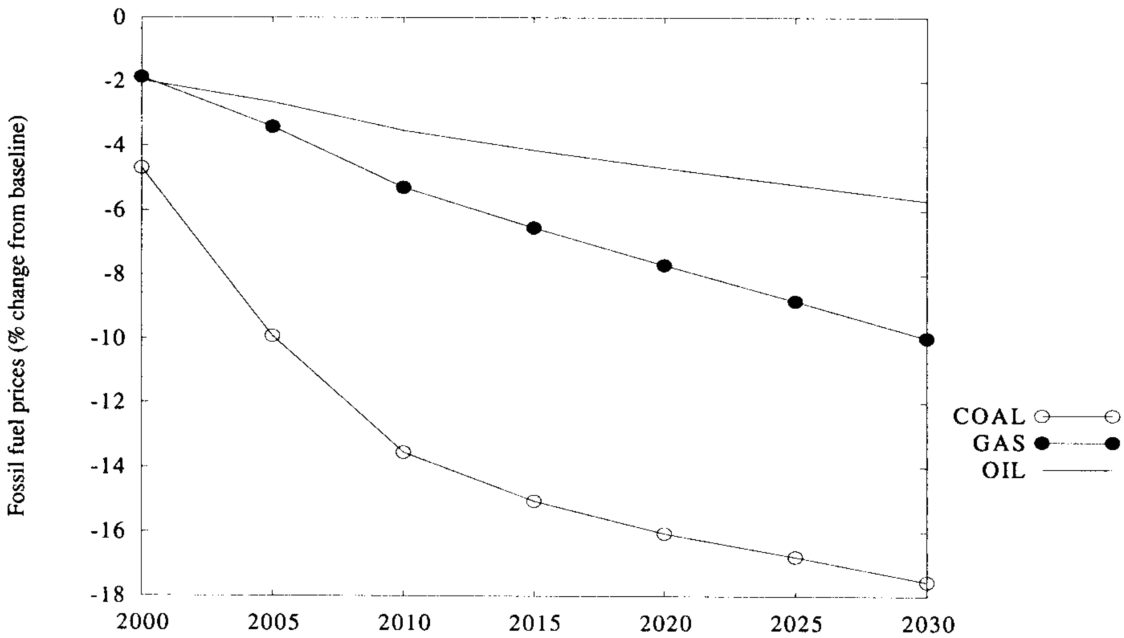


Fig. E4: Fossil Fuel Price Trajectory



This decrease in demand by industrialized countries is only partially offset by an increased demand in non-abating developing countries. With falling fuel prices, those countries which are fossil fuel importers gain while other countries which are net exporters lose. Column C of Table E4 presents the welfare implications of falling fossil fuel prices on the different countries or regions. MIDE as a large oil exporter is most adversely affected by the fall of the international oil price. CHN as a large coal exporter suffers from decreasing international coal prices. On the other hand, regions such as EU15 or JPN gain because fossil fuel imports get cheaper. For some countries, which are both net importers *and* net exporters of fossil fuels, the aggregate effect depends on export and import quantities as well as the relative changes in fossil fuel prices. The USA, for example, benefits more from smaller payments for oil and gas imports than it loses revenues from coal sales. CNA is a minor oil importer but exports large quantities of coal and gas which causes an aggregate loss from decreasing fossil fuel prices.

In the non-energy macro good market, abating countries lose competitiveness as compared to non-abating countries. Carbon emission constraints in abating countries drive up the price of their macro good relative to those of the macro goods from non-abating countries. As a consequence, exports of abating countries decline whereas exports of non-abating countries increase (see Figures E5 and E6).[7]

Nearly all abating industrialized countries are able to improve their terms of trade on the macro-good market. Due to product heterogeneity implied by the Armington assumption, abating countries can pass on the increase of higher production prices to trading partners. In other words, abating countries can offset part of the welfare loss induced by the domestic abatement policy through international market power. It should be noted that tax burden shifting occurs not only between abating and non-abating countries but also among abating industrialized countries, which are typically large trading partners. CNA is the sole industrialized region which suffers from a terms of trade loss on the macro good market.

As CNA has rather low carbon taxes and trades intensively with other abating countries, which adopt higher carbon taxes, it is rather a tax burden importer than a tax burden exporter. For non-abating countries the terms of trade effect depends on the extent to that the higher costs of imports from abating countries are offset by cost advantages on export markets and cheaper imports from other non-abating countries. CHN and ASIA suffer from a strong increase in import prices of their trading partner JPN, which levies very high domestic carbon taxes. ROW and LSA exhibit very large import shares from industrialized countries and therefore are

[7] Non-abating countries gain in export shares not only on the import markets of abating countries but also by displacing exports from abating countries to non-abating countries. They also displace Annex B exports with domestic production.

negatively affected from carbon taxes in the industrialized world. MIDE and SSA improve the terms of trade on the macro good markets as they gain significantly in competitiveness with respect to their main trading partner EU15.

Fig. E5: Exports of the Non-Energy Macro Good From Annex B Countries

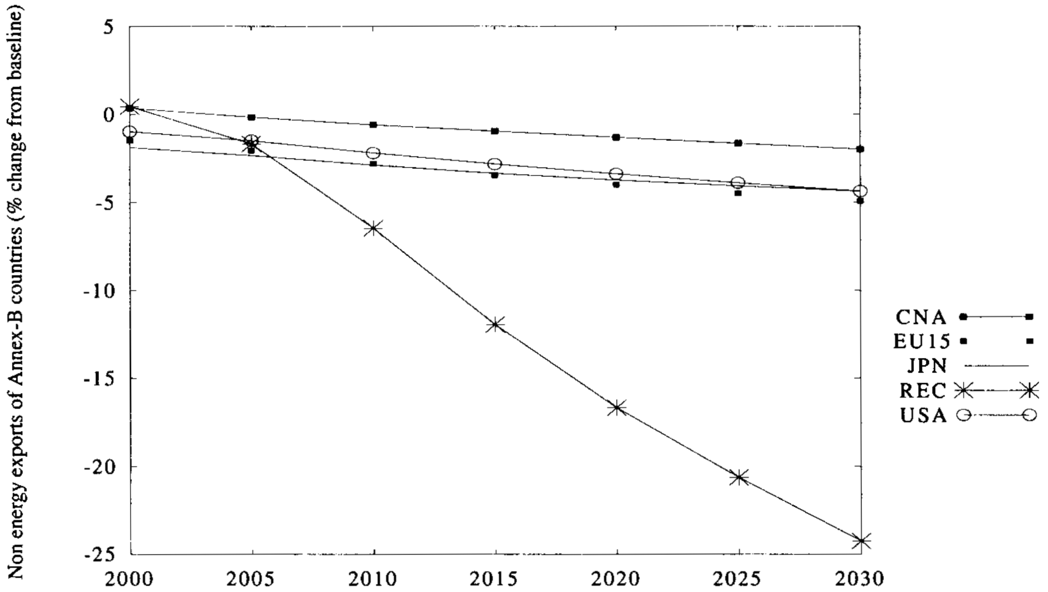
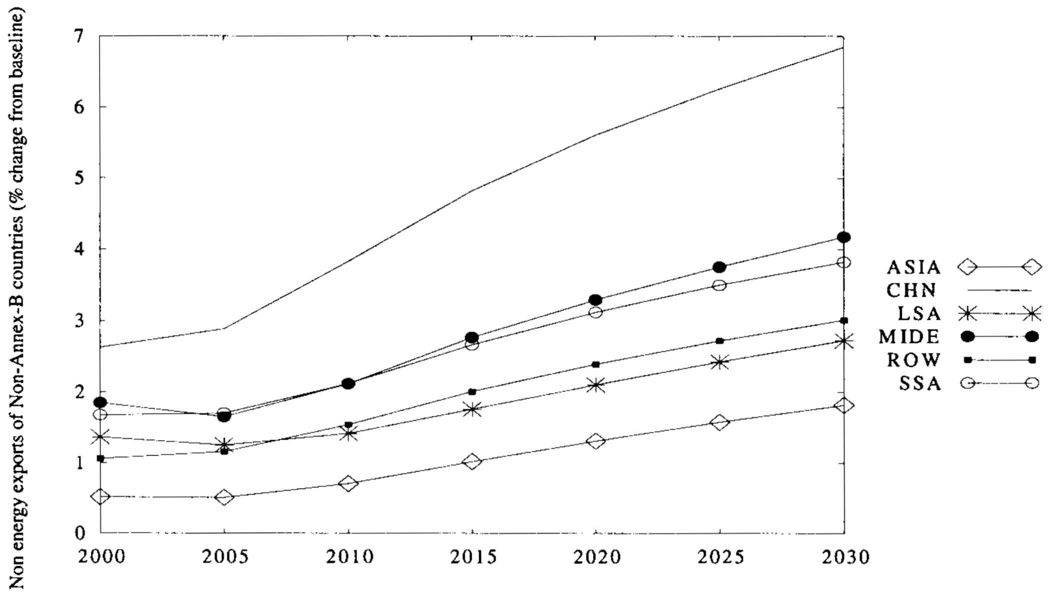


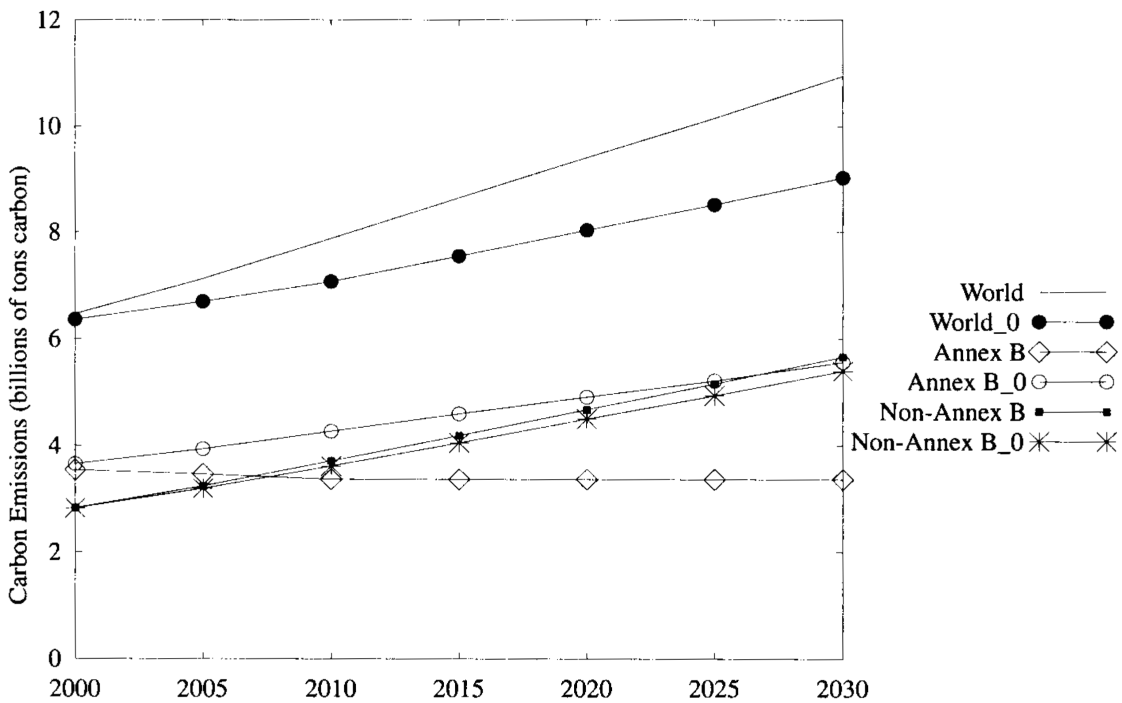
Fig. E6: Exports of the Non-Energy Macro Good From Non-Annex B Countries



Carbon emissions

Figure E7 depicts total carbon emissions differentiated by Annex B countries and non-Annex-B countries. For comparison we have added the respective baseline projections for carbon emissions. There are two important insights emerging from Figure E7. First, world carbon emissions still grow at a high rate even though industrialized Annex B countries stabilize their emission at 94.8% of 1990 emission levels from 2010 onwards. Second, leakage reduces global cost-effectiveness of unilateral abatement as energy-intensive production relocates from abating countries to non-abating countries with less carbon-efficient technologies. In fact, the leakage rate, measured as the ratio of the increase in the non-Annex B emission to the decrease in Annex B emissions, is more than 10%.[8]

Fig. E7: Carbon Emissions for the Abatement Scenario



World: world carbon emissions after implementation of the Kyoto Protocol
World_0: world baseline carbon emissions
Annex B: emissions of Annex-B countries after implementation of the Kyoto Protocol
Annex B_0: baseline carbon emission of Annex B countries
Non-Annex B: emissions of non-Annex-B countries after implementation of the Kyoto Protocol
Non-Annex B_0: baseline carbon emission of non-Annex B countries

[8] Leakage rates would potentially increase under a higher sectoral disaggregation where energy-intensive goods are treated as close substitutes in international trade. See BÖHRINGER, RUTHERFORD, VOß, 1998 or BÖHRINGER, 1998 for a discussion of the leakage problem and appropriate countermeasures such as tax exemptions or grandfathered permits.

4. Concluding Remarks

The major conclusion from our analysis with respect to future global warming negotiations is related to the issue of burden sharing between the industrialized and the developing world. Spill-over effects from carbon abatement in industrialized countries on non-abating developing countries are significant. As the induced welfare losses in developing countries are in the range of the adjustment costs in industrialized countries, *serious problems of fair burden sharing occur even without reduction obligations for the developing countries.* Although the Kyoto Protocol restricts carbon emissions by industrialized countries, global carbon emissions will still grow significantly for reasonable baseline assumptions of economic development and future fossil fuel consumption in non-abating developing countries. Given adverse international spill-over effects, much more stringent reduction targets on industrialized countries seems to be an adverse strategy for many developing countries as well. In this context, complementary analysis by HARRISON and RUTHERFORD (1998) indicates that emission trading (joint implementation) between signatory and non-signatory countries can relax significantly the problem of equitable burden sharing. Gains from trade in carbon abatement could be distributed as to mitigate the global equity problem that arises from unilateral abatement of the industrialized countries.

The present analysis could be extended in several ways to provide additional insights for alternative assumptions on the model structure, baseline projections, market mechanisms and abatement policy design:

- A more elaborate representation of the non-energy production side, in particular the distinction of traded carbon-intensive non-energy goods, would strengthen the credibility of estimates for terms of trade effects and carbon leakage rates.
- As has been demonstrated by BÖHRINGER, JENSEN and RUTHERFORD (1998) the baseline projections for future economic and emission growth have major implications on the magnitude and distribution of economic costs. It would be interesting to see how robust the qualitative results are with respect to significantly diverging baseline projections.
- In our simulations we have assumed that international markets for fossil fuels are competitive. Doubts remain whether large fossil fuel suppliers would accept that easily a major decrease in supply prices induced by energy taxation in the industrialized world. Additional simulations which account for a strategic response of fossil fuel suppliers (e.g. monopolistic cut-backs in fossil fuel production) could reveal how important the competitive paradigm is for our qualitative conclusions. A refined representation of fossil fuel markets would also call for the stock accounting of fossil fuels, i.e. an endogenous relationship between depletion rates, fossil energy stocks and fuel production.

- The simulations in this paper do not cover the possibility of permit trade (joint implementation). The literature on carbon trade points out large gains from permit trade (see e.g. DEAN, 1994 or WEYANT, 1997), in particular when developing countries are included. From a policy point of view, it would be important to show how the welfare implications of the Kyoto Protocol change when we allow for free trade in permits.

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