The Dismantling of a Breakthrough:
The Kyoto Protocol – Just Symbolic Policy!

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Abstract

We show that U.S. withdrawal from the Kyoto Protocol is straightforward under political economy considerations. The reason is that U.S. compliance costs exceed low willingness to pay for dealing with global warming in the U.S. The withdrawal had a crucial impact on the implementation design of the Protocol prior to its likely ratification at the end of 2002. Remaining non-EU Parties to the Kyoto Protocol gained veto bargaining power and, thus, were successful in asserting far-reaching concessions from the EU on sink credits and, in particular, on the tradability of emission rights. Taking these concessions into account, the Kyoto Protocol was essentially reduced to a symbolic treaty that codifies more or less business-as-usual emissions and makes compliance a rather cheap deal.

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1. Background

During the last decade, the issue of international cooperation in climate protection has received increasing attention in economic research. The main focus has been on the underlying economic incentives for sovereign states to enter into international environmental agreements. Since climate protection constitutes the problem of providing a global public good, it is faced with severe incentive problems for governments that try to maximize their net economic benefits. The game-theoretical literature has provided important insights into the difficulties of establishing effective and efficient cooperation on the provision of climate protection (see Finus (2001) and Schmidt (2001) for an overview).

Beyond the fundamental incentive problems of international cooperation, climate change policy has an important political economy dimension. In the standard political economy approach, any government is motivated by the objective of maximizing its political income, i.e. the probability of being re-elected. In order to be re-elected, the government must obey the preferences of the pivotal voter, who can be approximated by the median voter in a democracy. Thus, the national median voter imposes a restriction on what would be acceptable to a government in international environmental negotiations. Ultimately, one would expect a government only to enter into agreements that are acceptable to the median voter. From a political economy point of view, thus, the median voter's willingness to pay ultimately determines the outcome of international environmental negotiations. Surprisingly, this fact has been widely ignored in the literature (exceptions are Congleton (1992, 2001) and Vogt (2002)).

In this paper, we combine the simplistic public choice approach on the median voter's willingness to pay for climate protection with a computable general equilibrium (CGE) analysis of the costs of emission abatement to explain the effective outcome of the Kyoto Protocol. Our investigation rests to a large extent on the familiar techniques of cost benefit analysis. Since benefits from climate protection are supposed to be negligible for current generations and, hence, can be ignored in a political economy context, we base our analysis on estimates for the costs of implementing the Kyoto Protocol. These estimates are obtained from a large-scale computable general equilibrium (CGE) model of global trade and energy use. We interpret these numbers as measures for the required willingness to pay for having the Kyoto Protocol enacted. In a second step, we confront the required willingness to pay with actual willingness to pay in major signatory countries of the Protocol. The comparison of required and actual willingness to pay then allows us to infer whether the Protocol is likely to be ratified by those countries in the future or not. We do not claim to provide an exhaustive public choice model of climate policy, which would have to consider other important political economy aspects like impacts of special interest groups, too (Boom (2002a), Boom (2002b), Svendsen (1999), Dijkstra (1999)). However, we show that the median voter hypothesis is already sufficient in order to explain why the Kyoto Protocol has been reduced to what we call „symbolic policy“.

The Kyoto Protocol was negotiated in 1997 during the Third Conference of the Parties to the United Nations Framework Convention of Climate Change. The Climate Change Convention that has been adopted during the Rio Earth Summit in 1992 provides the institutional framework for international climate policy. It has been ratified by the vast majority of the world's states. Periodic meetings of these Parties to the Climate Change Convention – the so-called Conferences of Parties – should promote and review efforts to combat global warming. The Kyoto Protocol requires industrialized countries (as listed in its Annex B) to limit their emissions of greenhouse gases, most notably CO_2 from fossil fuel combustion.

Initially, the Kyoto Protocol was supposed to provide a large cutback in business-as-usual emissions for the developed world and, therefore, was celebrated as a breakthrough in international climate protection (Oberthür and Ott (1999)). Our CGE calculations confirm that the Kyoto treaty – in its original form – would have induced a substantial cutback in the developed world's business-as-usual emissions. However, it would also have imposed non-negligible costs for major signatory countries. The Kyoto conference in 1997 left open several crucial aspects of concrete implementation, especially with respect to credits for carbon sinks, i.e. forests and agricultural soils that store CO_2, and the question of full versus restricted tradability of emission rights across Annex B countries. Re-negotiations during the Sixth and Seventh Conferences of the Parties at Bonn (June 2001) and Marrakech (November 2001) led to a generous accounting of carbon sinks and unrestricted trade in emissions rights. In particular, free permit trade accommodates large cuts in overall compliance costs because Russia and the Ukraine can sell huge amounts of surplus emission rights (so called "hot air") which were ceded to them in the original Kyoto deal. We show that even under these relaxed constraints, the implementation of the Kyoto Protocol would still have been quite costly for the U.S. Since public opinion polls in the U.S. indicate a rather low willingness to pay for climate policy and re-negotiation leeway had been exhausted, the withdrawal of the U.S. government from the Kyoto Protocol in March 2001 does not come as a surprise from a political economy point of view.

Ironically, U.S. withdrawal can be regarded as the ultimate impetus for the ratification of the Kyoto Protocol. The reason is the so-called “double trigger”, which requires two conditions to be fulfilled before the Protocol will enter into force. Firstly, at least 55 Parties to the Convention must ratify the treaty by their national parliaments. Secondly, industrialized countries among ratifying Parties must represent at least 55 % of the total 1990 CO_2 emissions from this group. Since the U.S. is by far the biggest emitter of CO_2 among Annex B parties, ratification of the Kyoto Protocol after U.S. withdrawal requires approval of most of the remaining major industrialized countries. More specifically, it was no longer possible for the Kyoto Protocol to enter into force without the participation of Russia and the country group of Canada, Australia, New Zealand and Japan. After U.S. withdrawal, these countries used their veto bargaining power in the subsequent climate negotiations at Bonn and Marrakech to obtain far-reaching concessions from the European Union (EU) on the controversial issues of sink credits and emissions trading: The EU accepted the generous accounting of sink credits and unrestricted trade of “hot air” that it had heavily opposed in negotiations prior to U.S. withdrawal in order to save the Kyoto Protocol and to come up to its self-proclaimed leadership role in international climate policy. Our CGE simulation results show that these concessions reduce Kyoto to a symbolic treaty. Ratification of the treaty for the remaining Annex B countries now comes at virtually no economic cost, while environmental effectiveness is driven close to zero.

Several studies have already pointed out that the recent modifications to the Kyoto Protocol have substantially watered down its environmental effectiveness (see Buchner et al. (2001) for a synopsis). However, none of these studies takes a political economy perspective to explain the final outcome of the Kyoto negotiation process. Moreover, our quantitative estimates on the required willingness to pay for climate policies are based on an analytical framework that combines several important innovations, such as market power in permit trade or terms-of-trade effects.

The remainder of the paper is organized as follows. Section 2 presents cost estimates of implementing Kyoto in its original form. Section 3 explains the recent U.S. withdrawal from a political economy perspective. Section 4 explores the implications of U.S. withdrawal on the subsequent climate policy negotiations. Section 5 includes a sensitivity analysis of quantitative estimates with respect to uncertainties in the parameterization space. Section 6 concludes.

2. Emission Reduction Constraints and *Required* Willingness to Pay

In the Kyoto Protocol, industrialized countries have adopted quantified emission limitation and reduction objectives with reference to their 1990 emission levels (UNFCCC (1997)). The column labeled "Baseline Emissions - 1990" of Table 1 lists the historic emissions for all Annex B regions.

Table 1: Baseline emissions and emission reduction targets for Annex B regions[*]

Region	Baseline Emissions (MtC)[a]		Kyoto Targets (% vis-à-vis 1990)[b]		*Effective* Targets (%vis-à-vis 2010)		*Effective* Targets (MtC)	
	1990	2010	*OLD*	*NEW*	*OLD*	*NEW*	*OLD*	*NEW*
AUN	88	130	+6.8	+10.2	–27.7	–25.4	–36	–33
CAN	127	165	–6.0	+7.9	–27.7	–17.0	–46	–28
EUR	929	1041	–7.8	–5.2	–17.7	–15.4	–184	–160
JPN	269	331	–6.0	–0.8	–23.6	–19.4	–78	–64
CEA	301	227	–7.1	–3.9	+23.2	+27.5	+53	+62
FSU	1036	713	0.0	+6.4	+45.3	+54.6	+323	+389
Total US out[c]	2750	2607	–5.0	–0.5	+0.7	+3.8	+32	+166
USA	1347	1809	–7.0	–3.2	–30.8	–27.9	–556	–505
Total US in[d]	4097	4416	–5.0	–0.5	–11.9	–7.7	–525	–339

* For reasons of data availability, we apply the greenhouse gas reduction targets to CO_2 only, which is by far the most important greenhouse gas among industrialized countries.

Key: AUN – Australia and New Zealand, CAN – Canada, EUR - OECD Europe (incl. EFTA), JPN – Japan, CEA - Central and Eastern Europe, FSU - Former Soviet Union (incl. Ukraine).

[a] Based on IEO (2001): reference case [b] Estimates by the European Commission (Nemry 2001)

[c] Annex B without U.S. compliance (assuming full trade in "hot air")

[d] Annex B with U.S. compliance (assuming full trade in "hot air")

The reduction targets as originally foreseen by the Protocol are reported in the column labeled "Kyoto Targets - *OLD*". The column "Kyoto Targets - *NEW*" accounts for the softening of targets through credits for carbon dioxide sinks as agreed upon during the Seventh Conference of the Parties at Marrakech (see Nemry (2001)). Since credible data to measure effective sinks from forest management and agricultural activities vis-à-vis the business-as-usual is missing, sink credits under the Kyoto Protocol largely come down to ”creative accounting”.

The reduction targets with respect to 1990 apply to historic emission levels. Since these targets will not become legally binding before the Kyoto commitment period between 2008-2012, the appropriate reference for the *effective* cutback requirements are the business-as-usual (*BaU*) emissions during the commitment period. The column labeled “Baseline Emissions - 2010” reports the projected *BaU* emissions for the central year 2010 of the commitment period based on the reference scenario of the most recent International Energy Outlook (IEO 2001) by the U.S. Department of Energy. Except for the economies in transition, which include Central and Eastern Europe (CEA) as well as the Former Soviet Union (FSU), the Kyoto targets with respect to 1990 translate into much more stringent *effective* targets with respect to 2010, since industrialized countries are projected to have economic growth accompanied by a considerable increase in greenhouse gas emissions from fossil fuel combustion. Australia and New Zealand (AUN), for example, receive emission rights that are 6.8 % higher than their 1990 reference emission levels, but in 2010 they will nevertheless face an effective cutback requirement of 27.7 % vis-à-vis their projected *BaU* emissions. Apparently, the economies in transition have been endowed with emission entitlements under the Kyoto Protocol that are well in excess of their anticipated future *BaU* emissions. As will be elaborated below, the availability of these excess emissions will crucially affect the potential compliance costs of OECD countries under the Kyoto Protocol. The final column of Table 1 converts the effective targets from percentage terms into absolute units.

An assessment of Table 1 with respect to the implementation of the Kyoto Protocol in its original form (i.e. U.S. compliance and *OLD* targets) indicates that the Kyoto Protocol demands a substantial cutback of *BaU* emissions in the industrialized world. Even in the case of unrestricted Annex B trade in emission rights, which would allow for the full availability of “hot air“ from CEA and FSU, aggregate Annex B emissions are supposed to fall by 11.9 % as compared to *BaU* in 2010.

Given some indication of the voter's actual willingness to pay for climate protection, the key issue regarding political acceptance of the Kyoto Protocol are the compliance costs associated with the implementation of the Kyoto targets. These compliance costs can be interpreted as a rough proxy for the *required* willingness to pay to have the Kyoto targets enacted. To measure compliance costs, we employ an established computable general equilibrium model of world trade and energy use that simulates the economic adjustment costs to emission constraints. The general equilibrium approach provides a consistent and comprehensive framework for studying price-dependent interactions between the energy system and the rest of the economy. It has become the standard tool for the analysis of the economy-wide impacts of environmental policies on resource allocation and the associated implications for incomes of economic agents (see Conrad (1999, 2001))

The multi-sector, multi-region computable general equilibrium model underlying our analysis has been extensively used in the past to quantify the economic impacts of alternative greenhouse gas abatement strategies (see e.g. Böhringer (2000), Rutherford and Paltsev (2000), Böhringer (2002), Böhringer and Rutherford (2002)). In the standard model version, all factor and commodity markets are assumed to be competitive. Here we treat FSU as a monopolist on imperfectly competitive international permit markets (Westkog (1996)) due to its dominant supply position stemming from huge amounts of „hot air" (see Table 1). As a monopolist, FSU restricts permit supply by charging a mark-up over its marginal abatement cost (which is zero for „hot air") to maximize profits. Due to the lack of appropriate data, our policy simulations do not consider the possibility that Annex B countries can purchase emission rights through abatement projects in non-Annex B developing countries (the so-called Clean Development Mechanism). The latter would lower market power of the FSU. Furthermore, it should be noted that adjustment costs to emission constraints in our model are borne by a representative household in each region. Thus, we can not distinguish the incidence of abatement policies across different (interest) groups.

As is customary in applied general equilibrium analysis, the model is based on economic transactions in a particular benchmark year (1997 in our case). Benchmark data determine parameters of the functional forms from a given set of benchmark quantities, prices, and elasticities. With respect to benchmark quantities and prices, we employ the GTAP-EG database as described in Rutherford and Paltsev (2000). The magnitude and distribution of abatement costs associated with the implementation of the Kyoto emission constraints crucially depend on the *BaU* projections for gross domestic product, fuel prices, energy efficiency improvements, etc. In our comparative-static framework, we infer the *BaU* economic structure of the model's regions for the year 2010 using projections of the International Energy Outlook for growth in gross domestic product, fossil fuel production, and future energy prices. We incorporate autonomous energy efficiency improvement factors which scale energy demand functions to match the exogenous emission forecasts. In our simulations, we measure the economic and environmental consequences of abatement policies with respect to the *BaU* situation in 2010.

For the sake of brevity, we abstain here from presenting a detailed description of basic model assumptions, the model algebra, and the model parameterization. The interested reader can download this information from ftp://ftp.zew.de/pub/zew-docs/div/kp-polecon.pdf (see also Böhringer and Rutherford (2002) for a compact algebraic model formulation).

Table 2 summarizes the economic and environmental effects for two alternative designs of implementing Kyoto. Scenario *NTR_USin_OLD* considers the implementation of the Kyoto Protocol based on the original reduction targets (*OLD*), U.S. compliance (*USin*) and exclusively domestic action, i.e. no trade in emission rights (*NTR*). Obviously, emission constraints as originally mandated under the Kyoto Protocol induce non-negligible adjustment costs to OECD countries (see Weyant (1999) for similar results of previous model-based studies). The reason is that the emission targets, which are stated with respect to 1990, translate into much higher *effective* carbon reduction requirements with respect to business-as-usual emission levels during the Kyoto budget period between 2008-2012.

Without trade in emission rights, compliance to domestic emission constraints require substantial changes in the production and consumption patterns of OECD countries towards less carbon intensity, which induces a loss of productivity and real income (consumption). Adjustment costs – measured in percentage loss of *BaU* consumption – range from 0.17 % for EUR to 1.48 % for CAN, indicating regional differences in the effective cutback requirements, carbon intensities of economies, the ease of carbon substitution within production and consumption, and indirect losses or benefits through terms-of-trade effects. The latter are the reason why CEA and FSU as well as non-Annex B countries (ROW) are affected by abatement policies of trading partners even though they do not face a binding emission constraint. Terms-of-trade effects under the Kyoto Protocol work primarily through the decline of international fuel prices due to the drop in fossil energy demand: Net fuel importers such as CEA benefit from cheaper energy imports, while FSU and ROW, which are net fuel exporters, are negatively affected.

Table 2: Key economic and environmental impacts of implementing the Kyoto Protocol

Region		*NTR_USin_OLD:* No Trading (*NTR*), U.S. Compliance (*USin*), Original Targets (*OLD*)	*TRD_USin_NEW:* Trading (*TRD*), U.S. Compliance (*USin*), New Targets (*NEW*)
		Percentage change in private consumption relative to the business-as-usual 2010 projections	
AUN	Australia and New Zealand	-1.18	-0.63
CAN	Canada	-1.48	-0.50
EUR	Europe	-0.17	-0.10
JPN	Japan	-0.26	-0.06
CEA	Central and Eastern Europe	0.49	2.16
FSU	Former Soviet Union	-0.93	2.78
USA	USA	-0.51	-0.27
ROW	Rest of the World	-0.35	-0.13
TOTAL		-0.24	-0.06
		Private consumption change in $US\$_{97}$ per capita	
AUN	Australia and New Zealand	-114	-62
CAN	Canada	-162	-53
EUR	Europe	-23	-13
JPN	Japan	-53	-13
CEA	Central and Eastern Europe	8	36
FSU	Former Soviet Union	-12	34
USA	USA	-92	-49
ROW	Rest of the World	-3	-1
		Percentage change in global emissions relative to the business-as-usual 2010 projections	
TOTAL		-9.6	-4.4

As has been elaborated by Böhringer and Rutherford (2002), indirect terms-of-trade effects account for a substantial share of the total economic impact on abating countries. Direct abatement costs of CAN, for example, are significantly magnified by reduced revenues from fossil fuel exports. When we convert the percentage changes in consumption into equivalent payments per capita, the specific costs for abating OECD regions range from 23 US$/capita for EUR to 162 US$/capita for CAN. The compliance costs for the U.S. amounts to 92 US$.

Scenario *TRD_USin_NEW* provides cost estimates that account for the outcome of the Conferences of Parties at Bonn in June 2001 and Marrakech in November 2001: Besides the generous accounting of carbon sink credits (*NEW*), the Parties have agreed on unrestricted Annex B emissions trading (*TRD*). These modifications to the Kyoto Protocol substantially lower compliance costs. At the same time, environmental effectiveness of the Protocol drops from 9.6 % to 4.4 % of global emission reduction, in particular due to "hot air" trade. While sales of "hot air" provide substantial transfers to CEA and FSU, implementation of the Kyoto Protocol under *TRD_USin_NEW* would still impose a significant consumption loss for AUN, CAN and the USA with an annual per-capita cost of 62 US$ (AUN), 53 US$ (CAN) and 49 US$ (USA). We will use the cost figure for USA below in order to argue that sink credits and unrestricted emissions trading have not made the Protocol cheap enough for the U.S. to re-join.

3. The Rationale behind U.S. Withdrawal

We have argued that in a political economy context, governments will keep the preferences of their voters in mind. They will not agree upon treaties that would not find the support of the median voter at home. To investigate the prospects of greenhouse gas abatement policies, we must compare the *required* willingness to pay with the *actual* (revealed) willingness to pay for climate protection by the domestic median voter. The *required* willingness to pay for the U.S. as quantified in Table 2 appears substantial even for Kyoto in its re-negotiated form. This raises the question of whether *actual* willingness to pay for mitigating climate change in the U.S. ever reached such high levels.

Unfortunately, quantitative estimates of the demand for mitigating climate change are sparse in the literature. There are two established methods that could be used for measuring environmental preferences with respect to climate change.

First, one could try to estimate the demand for climate protection from some theoretical model, e.g. a public good model. This approach is taken by Murdoch and Sandler (1997a) for the case of ozone layer depletion where they perform regression analysis to demonstrate that the Montreal Protocol has not been an effective agreement but confirms the game-theoretic prediction of non-cooperative Nash behavior. A further study by Murdoch and Sandler (1997b) employs the same technique to derive the demand for cutbacks of sulfur emission showing that the Helsinki Protocol has not been an effective international environmental agreement. Finus and Tjøtta (2002) look at the Oslo Protocol, which also deals with sulfur emissions. Based on empirical data, they calibrate damage functions based on non-cooperative Nash behavior of countries (see also Mäler (1989)) and show that the effectiveness of the Oslo Protocol does not exceed the *status sine pacto*, i.e. a situation without such an agreement. However, these studies stand as rare attempts to measure environmental demand in the context of a global public good.

Second, one could try to detect voters' preferences by asking them directly, e.g. by using the framework of a contingent valuation study. This approach has also been used extremely rarely to determine the demand for climate protection - last but not least because of the large difficulties to value a highly abstract and invisible good "protection of the earth's climate", where the benefits are highly uncertain and may not arise until far in the future. We only know of one contingent valuation study in the context of climate change mitigation, which has been performed for Switzerland (see Ledergerber et al. (1994)).

Since empirical evidence from econometric and contingent valuation studies on the demand for climate protection is very scarce, it seems reasonable to revert to public opinion polls as reported in Tables 3 and 4 for the U.S. Some difficulties in interpretation arise with respect to the obscure category "neither willing nor unwilling". To our understanding, these respondents indicated that they do not want a change of the status quo. We therefore add them to those respondents that are opposed to higher taxes or cuts in their standard of living. The tables then clearly show that the vast majority of U.S. citizens is not willing to pay much higher taxes or to accept cuts in their standard of living in order to protect the environment. Moreover, this fraction of respondents rose from about 60 % in 1993 to about 70 % in 2000. Even if we skip the category "neither willing nor unwilling", the recent polls for 2000 report a distinct majority of people that are opposed to higher eco-taxes or income losses for the sake of the environment.

It must be conceded that the polls asked for the protection of the environment in general, and, therefore, are not specific to the problem of climate change. Yet, as we can see from Table 5, the topic "Environment " is strongly dominated by other issues like "Ethics", "Crime", or "Drugs".

Table 3: Acceptance of high eco-taxes

	U.S. 1993 (%)	U.S. 2000 (%)*
(1) Very willing	7.3	6.2
(2) Fairly willing	32.9	25.5
(3) Neither nor	20.4	27.0
(4) Fairly unwilling	25.8	19.3
(5) Very unwilling	13.6	22.1
Sum (4) and (5)	39.4	41.4
Sum (3), (4) and (5)	59.8	68.4

*own calculations based on unreleased raw data from ISSP (2000)

Question: *How willing would you be to pay much higher taxes in order to protect the environment?*

Source: ISSP (1993) and ISSP (2000)

Table 4: Acceptance of cuts in standard of living

	U.S. 1993 (%)	U.S. 2000 (%)*
(1) Very willing	6.2	5.5
(2) Fairly willing	27.9	23.9
(3) Neither nor	24.0	26.7
(4) Fairly unwilling	26.2	20.5
(5) Very unwilling	15.6	23.4
Sum (4) and (5)	41.8	43.9
Sum (3), (4) and (5)	65.8	70.6

*own calculations based on unreleased raw data from ISSP (2000)

Question: *How willing would you be to accept cuts in your standard of living in order to protect the environment?*

Source: ISSP (1993) and ISSP (2000)

Table 5: Ranking of different political topics in the U.S.

Problem	April 2000	January 2001
Ethics/ moral/ family decline/ Dishonesty/ lack of integrity	7	13
Education	11	12
Crime/ violence	12	9
Drugs	5	7
Health care	6	7
The economy (general)	4	7
Taxes	3	5
Poverty/ hunger/ homelessness	6	4
Environment/ pollution	2	2
Lack of military defense	1	2

Question: What do you think is the most important problem facing this country today?

Source: Gallup (2001, p.4)

Table 6: Ranking of different environmental topics in the U.S.

	May 1989	April 1990	April 1991	Oct 1997	April 1999	April 2000
Pollution of lakes, rivers and reservoirs	72	64	67		61	66
Contamination of soil and water by toxic waste	69	63	62		63	64
Air pollution	63	58	59	42	52	59
Loss of natural habitat for wildlife	58	51	53		49	51
Ocean and beach pollution	60	52	53		50	54
Damage to the ozone layer	51	43	49	33	44	49
Loss of tropical rain forests	42	40	42		49	51
Acid rain	41	34	34		29	34
Global warming	35	30	35	24	34	40

Question: I'm going to read you a list of environmental problems. As I read each one, please tell me if you personally worry about this problem a great deal, a fair amount, only a little, or not at all?
The table shows the percentage of respondents who worried a great deal.

Source: Gallup (2000, p.4)

Moreover, "global warming" is a very low ranking issue even on the environmental agenda (see Table 6 - entries show the percentage of respondents who "worried a great deal"). Hence, we may conclude that if willingness to pay for the protection of the environment as a whole is already low, it will be even lower for climate change protection in particular.

To make up for the lack of concrete contingent valuation studies on the willingness to pay of U.S. voters for climate protection, we revert to the estimates for Switzerland. Ledergerber et al. quantified the average willingness to pay of Swiss voters at 22 francs in 1994, which amounts to roughly 17 US$ in 1997. In the previous section, the *required* willingness to pay for the U.S. to re-join the Kyoto Protocol after sink crediting and emissions trading has been quantified at 49 US$ per capita (see column "*TRD_USin_NEW*" of Table 2). Taking into account that Switzerland stands out for high income and educational level (both of which show a positive correlation to the willingness to pay for climate protection), it seems safe to infer that U.S. willingness to pay will not exceed the Swiss willingness to pay by a factor of nearly 3.

The Bush administration obviously realized that compliance to Kyoto even in its "light" version would have imposed substantial costs on the U.S. economy and that additional negotiation to make the Protocol acceptable to the U.S. public was not possible. The two key issues of re-negotiation, sinks and tradability, had been already very stressed in the climate negotiations prior to U.S. withdrawal. There was no more leeway left to further lower the U.S. target. Realizing the discrepancy between required and actual willingness to pay for mitigating climate change, the U.S. withdrew.

In this context, it could be argued that, had Al Gore been elected President, he would not have backed out of the Kyoto Protocol given the same willingness to pay. However, irrespective of a democratic or republican presidency, the prospects for U.S. ratification of the Kyoto Protocol have been very small over the last years. In fact, prior to the Kyoto conference, the U.S. Senate has already unanimously passed the Byrd-Hagel resolution, which makes 'meaningful participation' of developing countries a *conditio sine qua non* for ratification of the Kyoto Protocol. The Senate made it clear that it will not accept any treaty on climate change 'unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period' (Oberthür and Ott (1999), p.70). The vast majority of the American public was supportive of the Senate's reservation on ratification of the Kyoto Protocol, as is indicated by Table 7.

Table 7: U.S. opinion on burden sharing

All countries the same changes	70 %
Developing countries less burden	19 %
Don't know	8 %
Both/ neither	3 %

Question: Some people say that since poorer countries did not cause much pollution, they should not have to bear as much of the burden in dealing with global warming. Others say that every country, rich or poor, should make the same changes in order to limit future global warming. Which of these views comes closer to your own?

Source: Princeton Survey Research/ Pew 1997, cited in: http://www.publicagenda.org/issues/angles_graph.cfm?issue_type=environment&id=93&graph=mp9.gif

A U.S. survey conducted by Wirthlin in September 1998 (Wirthlin (1998)) yields very similar results. When confronted with the statement: 'I do not support the Kyoto Protocol because it unfairly forces developed countries to reduce pollutants, while allowing other countries to continue polluting', 25 % of the respondents agreed strongly and 43 % told the interviewers they agreed somewhat. Only 30 % agreed to the following statement: 'It is only fair that undeveloped countries should not be held to the same pollution standards, since they still need to catch up with the rest of the developed countries' (Wirthlin (1998), p.6). In short, U.S. withdrawal from the Kyoto Protocol seems to have voter's support, not only under narrow willingness to pay considerations, but also under specific fairness perceptions.

As will be elaborated in the following section, US withdrawal had important consequences for the remaining Annex-B countries. Particularly, it led to a significant reduction of compliance costs for them. However, reduced compliance costs provide an important part of an explanation of bargaining and ratification behavior of remaining Annex-B countries but they are not the whole story. Additionally, one has to take into account the political circumstances in these countries.

As is clearly indicated by Table 8, public concern about climate change is somewhat higher in Canada, Australia and Japan than in the U.S. European citizens are highly concerned about the issue of global warming.

Table 8: Public Concern about climate change in different Annex B countries

	1998	2000
France	50.8	63.6
Germany	68.7	62.8
UK	50.0	60.7
Australia	53.7	49.0
Japan	47.1	45.5
Canada	43.5	44.6
USA	33.0	37.6

Question: How serious a problem do you consider each of the following environmental issues to be? Climate change or global warming.
The table shows the percentage of respondents who considered climate change to be „very serious“.

Source: International Environmental Monitor (1998, 2000)

Moreover, comparison of Table 9 with Table 5 indicates that the issue of „environmental quality“ ranks much higher even in Canada, Australia and Japan than in the U.S. These observations help to explain why the governments of these countries had some interest in achieving an international treaty on the climate issue and thus kept to the Kyoto Process while the U.S. withdrew.

Table 9: Ranking of "Environmental quality" in different Annex B countries

Australia			Canada			France		
	1998	2000		1998	2000		1998	2000
Unemployment	40.0	14.2	Economic problems	27.1	20.5	Unemployment	67.9	42.4
Environmental Quality	22.4	23.1	Unemployment	24.9	7.9	**Environmental quality**	6.5	14.4
Economic Problems	8.4	9.2	Political problems	5.4	8.1	Crime/ violence/moral decay	4.1	9.5
Health/ medical problems	7.0	3.7	Poverty	5.1	9.2	Poverty	2.8	2.7
Political problems	6.5	2.5	**Environmental quality**	5.1	5.8	Economic problems	2.7	4.6
Crime/ violence/moral decay	3.3	5.5	Crime/ violence/moral decay	5.1	9.8	Political problems	2.7	4.5
Substance abuse	2.8	4.5	Education/ Literacy	3.4	3.4	Immigration	2.3	2.6
Prejudice/ discrimination	1.3	1.8	Health/ medical problems	3.1	18.1			
			Social security	2.0	-			
			weather patterns	1.5	-			

United Kingdom			Germany			Japan		
	1998	2000		1998	2000		1998	2000
Unemployment	19.7	9.1	Unemployment	73.9	46.2	Economic problems	32.2	35.3
Crime/ violence/moral decay	12.3	14.3	**Environmental quality**	5.3	7.8	Political problems	14.4	9.4
Environmental Quality	11.3	9.2	Political problems	3.3	4.9	**Environmental quality**	10.9	13.4
Health/ medical problems	8.5	8.5	Social security	2.4	4.4	Education/ Literacy	8.6	5.1
Economic problems	8.1	4.9	Economic problems	1.8	7.3	Crime/ violence/moral decay	6.5	3.8
Poverty/ homelessness	7.4	8.2	Immigration	1.6	1.7	Social security	5.8	8.4
Education/ Literacy	6.0	2.9	Crime/ violence/moral decay	1.5	7.3	Unemployment	2.5	5.9
Social security	3.6	2.7	Prejudice/ discrimination	1.0	2.0	Health/ medical problems	1.3	1.4
Political problems	3.3	3.8						

Source: International Environmental Monitor (1998, 2000)

4. The Implications of U.S. Withdrawal

U.S. withdrawal had a major impact on the subsequent climate negotiations, since it gave veto bargaining power to important single countries in the climate talks. Due to the "double trigger" mechanism, entry into force of the Kyoto Protocol is no longer possible without participation of Russia and the country group of Canada, Australia, New Zealand, and Japan. All of these regions have expressed reluctance to agree to the Protocol without major revisions to its original amendments.

After years of tedious negotiations, U.S. withdrawal paved the way for the Bonn agreement of remaining Annex B countries on the final implementation of the Kyoto Protocol. The agreement at Bonn in June 2001 (which was confirmed at the Marrakech climate conference in November 2001) was the straightforward result of the altered bargaining situation. After

U.S. withdrawal, the remaining non-EU countries were able to obtain far-reaching concessions from the EU. The EU had always been very restrictive on the key issues of "sinks" and "tradability". With respect to the former issue, the EU had been demanding for a long time to exclude sinks as a means for the fulfillment of reduction targets in the first commitment period of the Kyoto Protocol between 2008-2012. With respect to the latter issue, it always favored strict caps on tradability to suppress trade in „hot air".

Table 10 provides quantitative evidence on the economic and environmental implications of U.S. withdrawal, sink credits and emissions trading.

Table 10: Economic and environmental impacts of implementing the Kyoto Protocol

Region	*NTR_USin_OLD*	*NTR_USout_OLD*	*NTR_USout_NEW*	*TRD_USout_NEW*
	Percentage change in private consumption relative to the business-as-usual 2010 projections			
AUN	-1.18	-1.09	-0.93	-0.29
CAN	-1.48	-0.62	-0.29	-0.13
EUR	-0.17	-0.24	-0.19	-0.06
JPN	-0.26	-0.34	-0.22	-0.05
CEA	0.49	0.27	0.22	0.75
FSU	-0.93	-0.69	-0.59	0.38
USA	-0.51	0.01	0.01	0.00
ROW	-0.35	-0.19	-0.15	-0.03
TOTAL	-0.24	-0.12	-0.09	-0.01
	Private consumption change in $US\$_{97}$ per capita			
AUN	-114	-107	-90	-28
CAN	-162	-68	-32	-15
EUR	-23	-31	-24	-8
JPN	-53	-67	-43	-9
CEA	8	4	3	12
FSU	-12	-9	-7	5
USA	-92	-	-	-
ROW	-3	-1	-1	-
	Percentage change in global emissions relative to the business-as-usual 2010			
TOTAL	-9.6	-2.8	-2.3	-0.7

Non-compliance of the U.S. without sink credits and for purely domestic abatement action (scenario *NTR_USout_OLD)* implies considerable adjustment costs to the remaining OECD regions, while the global environmental effectiveness compared to scenario *NTR_USin_OLD* drops by more than a factor of 3. In fact, due to U.S. withdrawal, EUR and JPN will face higher adjustment costs, since the drop in international fuel prices will be less pronounced. Contrary, exporters of fossil fuels like CAN, FSU and ROW are less adversely affected. Not surprisingly, sink credits – as captured in scenario *NTR_USin_NEW* – reduce the economic cost to Annex B countries. The one outliner is CEA that faces a small decrease in economic benefits since the relaxation of reduction targets to OECD countries lowers its comparative advantage in the production of energy-intensive goods. Global emission reduction declines to 2.3 %. Despite of sink credits, per-capita compliance costs for important industrialized countries such as CAN (32 US$), JPN (43 US$), and in particular AUN (90 US$) remain substantially above the estimates on willingness to pay for Switzerland. Scenario *TRD_USout_NEW* refers to the final outcome of the Kyoto re-negotiation process incorporating U.S. withdrawal, sink credits and unrestricted emissions trading. These modifications to the original Protocol have drastically reduced compliance costs with substantial consumption gains to CEA and FSU vis-à-vis the *BaU* situation. The downside is that the environmental effectiveness of the Protocol is driven close to zero because „hot air" from FSU and CEA can be fully traded (see also Böhringer (2002)).

Table 10 also provides interesting insights with regard to the self-declared "climate leadership" of the European Union. In a cross-country comparison of implementation costs, EUR ranks lowest. Willingness to pay for the implementation of the Kyoto Protocol in its original form would have required a willingness to pay which is five times higher in AUN (114 US$) and seven times higher in CAN (162 US$) than in EUR (23 US$). It is highly unlikely that willingness to pay in these countries would have ever reached such high levels. For the EU, it has been very easy to act as a protagonist of ambitious reduction targets, since the implied costs for the EU were relatively low.

In our political economy context, one can assert that U.S. withdrawal has significantly promoted the ratification of the Kyoto Protocol *because* it essentially reduces compliance for remaining Annex B countries to mere symbolic policy.

5. Sensitivity Analysis

Our quantitative estimates for the required willingness to pay presented in Tables 2 and 8 are based on central case elasticities. To evaluate the sensitivity of our model estimates to uncertainties in the parameterization space, we have performed 1000 Monte Carlo simulations. In each simulation, values for six elasticities (trade elasticities, energy demand elasticities and fossil fuel supply elasticities) that are key determinants for the economic adjustment costs to emission constraints were drawn from uniform probability distributions around the model central values (see download: Table A.1 in section A.7 of Appendix A).

Table 11 provides a statistical summary of results. For each of the scenarios, we have listed the core (central case) values together with the mean and the median as well as the 5 % quantile and 95 % quantile. The central case effects are close to the mean and median values. Based on our sample distribution, there is a 90 % probability that adjustment costs and global emission reduction lie between the values indicated by the 5 % and 95 % quantile. Although we observe some spread, particularly for the scenarios without emission trading that stand out for stronger overall adjustment effects, all of our insights based on the central case general equilibrium estimates remain robust even when we account for substantial uncertainty in the parameterization space.

Figures 1 and 2 visualize the dispersion of outcomes with respect to global emission reduction and the per capita consumption changes across regions. We have used box-plots to mark the range between the 5% quantile and the 95% quantile. In addition, we have entered the median values as well as the core simulation results.

From Figure 1 we see that the spread of environmental effects within each scenario is very small. The reason is straightforward. The main determinant for global environmental effectiveness in a given scenario are the region-specific emission reduction targets. Changes in elasticity values have only indirect implications for global emission reduction mainly via induced changes in leakage (see Felder and Rutherford 1993): Sub-global abatement of emissions leads to an increase in emissions in non-abating regions, reducing the global environmental effectiveness. Since leakage increases with the magnitude of unilateral reduction requirements as well as restrictions to permit trade, it is not surprising that the dispersions of outcomes is greatest for scenario *NTR_USin_OLD*.

Across all the scenarios, the median and core simulation results are very close. We can conclude that the distinct losses in global environmental effectiveness of the Kyoto Protocol when moving from scenario *NTR_USin_OLD* to scenario *TRD_USout_NEW* are very robust with respect to major changes in the parameterization of elasticities. As to per capita consumption changes, the variability of results with respect to changes in elasticities is more pronounced. The level of elasticity values directly affect the magnitude of economic adjustment costs.

Table11: Results of Monte Carlo simulation

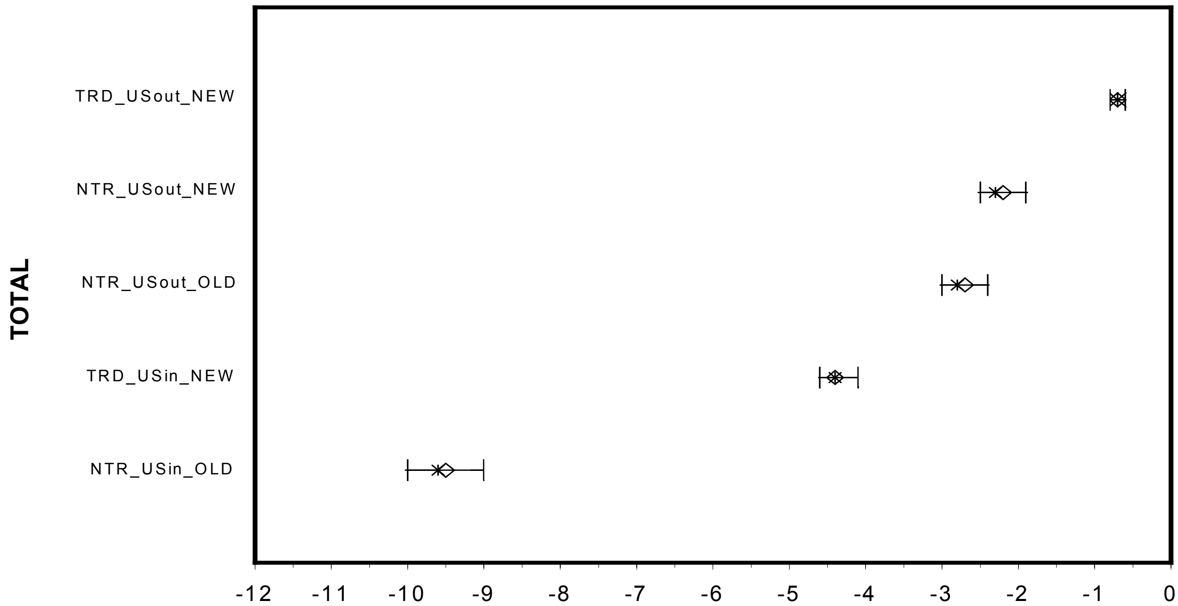
	NTR_USin_OLD					TRD_USin_NEW					NTR_USout_OLD					NTR_USout_NEW					TRD_USout_NEW				
	core value	mean	median	5% quantile	95% quantile	core value	mean	median	5% quantile	95% quantile	core value	mean	median	5% quantile	95% quantile	core value	mean	median	5% quantile	95% quantile	core value	mean	median	5% quantile	95% quantile
Percentage change in private consumption relative to the business-as-usual 2010 projections																									
AUN	-1.18	-1.16	-1.14	-1.38	-1.01	-0.63	-0.61	-0.60	-0.71	-0.53	-1.09	-1.07	-1.06	-1.30	-0.91	-0.93	-0.92	-0.91	-1.10	-0.78	-0.29	-0.27	-0.27	-0.33	-0.23
CAN	-1.48	-1.43	-1.42	-1.59	-1.31	-0.50	-0.48	-0.48	-0.54	-0.44	-0.62	-0.64	-0.63	-0.76	-0.55	-0.29	-0.29	-0.29	-0.32	-0.26	-0.13	-0.13	-0.13	-0.15	-0.12
EUR	-0.17	-0.19	-0.20	-0.23	-0.14	-0.10	-0.10	-0.10	-0.12	-0.08	-0.24	-0.26	-0.26	-0.29	-0.22	-0.19	-0.20	-0.20	-0.22	-0.17	-0.06	-0.06	-0.06	-0.07	-0.05
JPN	-0.26	-0.31	-0.31	-0.38	-0.21	-0.06	-0.08	-0.08	-0.10	-0.05	-0.34	-0.38	-0.39	-0.46	-0.28	-0.22	-0.25	-0.26	-0.30	-0.18	-0.05	-0.05	-0.05	-0.05	-0.04
CEA	0.49	0.50	0.50	0.29	0.73	2.16	2.02	1.98	1.39	2.86	0.27	0.30	0.30	0.16	0.45	0.22	0.24	0.24	0.12	0.36	0.75	0.67	0.64	0.46	0.95
FSU	-0.93	-0.88	-0.87	-1.04	-0.74	2.78	2.80	2.69	2.15	3.72	-0.69	-0.64	-0.63	-0.79	-0.53	-0.59	-0.54	-0.54	-0.67	-0.45	0.38	0.38	0.37	0.29	0.50
USA	-0.51	-0.56	-0.53	-0.78	-0.42	-0.27	-0.28	-0.27	-0.35	-0.23	0.01	0.01	0.01	0.00	0.03	0.01	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.01
ROW	-0.35	-0.31	-0.30	-0.42	-0.24	-0.13	-0.11	-0.11	-0.15	-0.09	-0.19	-0.17	-0.16	-0.23	-0.13	-0.15	-0.14	-0.13	-0.18	-0.11	-0.03	-0.03	-0.03	-0.04	-0.02
TOTAL	-0.24	-0.25	-0.25	-0.31	-0.21	-0.06	-0.06	-0.06	-0.06	-0.05	-0.12	-0.13	-0.13	-0.14	-0.12	-0.09	-0.09	-0.09	-0.10	-0.09	-0.01	-0.01	-0.01	-0.02	-0.01
Marginal abatement costs in US$$_{97}$ per ton of carbon																									
AUN	126	135	124	92	207	43	43	42	34	55	123	132	120	89	203	106	113	104	77	172	18	17	17	14	20
CAN	145	154	145	112	222	43	43	42	34	55	132	137	130	99	197	64	65	63	51	87	18	17	17	14	20
EUR	111	114	110	88	149	43	43	42	34	55	106	108	104	83	143	87	88	85	69	115	18	17	17	14	20
JPN	183	191	181	139	270	43	43	42	34	55	176	184	173	133	262	129	133	127	100	183	18	17	17	14	20
CEA	0	0	0	0	0	43	43	42	34	55	0	0	0	0	0	0	0	0	0	0	18	17	17	14	20
FSU	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
USA	156	170	156	114	271	43	43	42	34	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Private consumption change in US$$_{97}$																									
AUN	-114	-113	-110	-134	-99	-62	-59	-59	-69	-52	-107	-104	-103	-128	-86	-90	-89	-86	-107	-76	-28	-26	-28	-31	-21
CAN	-162	-155	-153	-174	-141	-53	-52	-53	-59	-47	-68	-70	-68	-82	-59	-32	-32	-32	-35	-29	-15	-14	-15	-15	-12
EUR	-23	-25	-26	-31	-18	-13	-13	-14	-16	-10	-31	-33	-34	-38	-29	-24	-26	-26	-29	-22	-8	-8	-8	-8	-7
JPN	-53	-61	-61	-76	-43	-13	-15	-15	-20	-10	-67	-76	-76	-91	-57	-43	-50	-51	-59	-35	-9	-10	-9	-10	-9
CEA	8	8	8	5	12	36	33	33	23	47	4	5	5	2	7	3	4	4	2	6	12	11	11	7	16
FSU	-12	-11	-11	-13	-9	34	34	33	27	46	-9	-8	-8	-10	-6	-7	-7	-6	-8	-5	5	5	4	3	6
USA	-92	-102	-96	-142	-76	-49	-50	-49	-63	-41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Percentage change in global emissions relative to the business-as-usual 2010 projections																									
TOTAL	9.60	9.51	9.50	9.00	10.00	4.40	4.39	4.40	4.10	4.60	2.80	2.71	2.70	2.40	3.00	2.30	2.22	2.20	1.90	2.50	0.70	0.69	0.70	0.60	0.80

For example, the choice of Armington elasticities and fossil fuel supply elasticities govern the terms-of-trade effects; substitution elasticities between energy and non-energy inputs in intermediate and final demand determine the ease of adjustment to emission constraints.

Moreover, it must be noted that Figure 2 presents absolute numbers, i.e. similar relative changes of results become more pronounced for scenarios that exhibit stronger economic adjustment for a specific country. Therefore, the range of outcomes is substantially broader for countries that face binding emission constraints under scenarios without emissions trading. If countries have no emission constraint and benefit from emissions trading (FSU and CEA), the opposite applies. For the USA, 90 % of the results within the scenario *TRD_USin_NEW* on per capita cost lie between 63 US$ and 41 US$. This provides a safe margin on the discrepancy between the *required* and the *actual* willingness-to-pay that underlies our reasoning on the U.S. withdrawal.

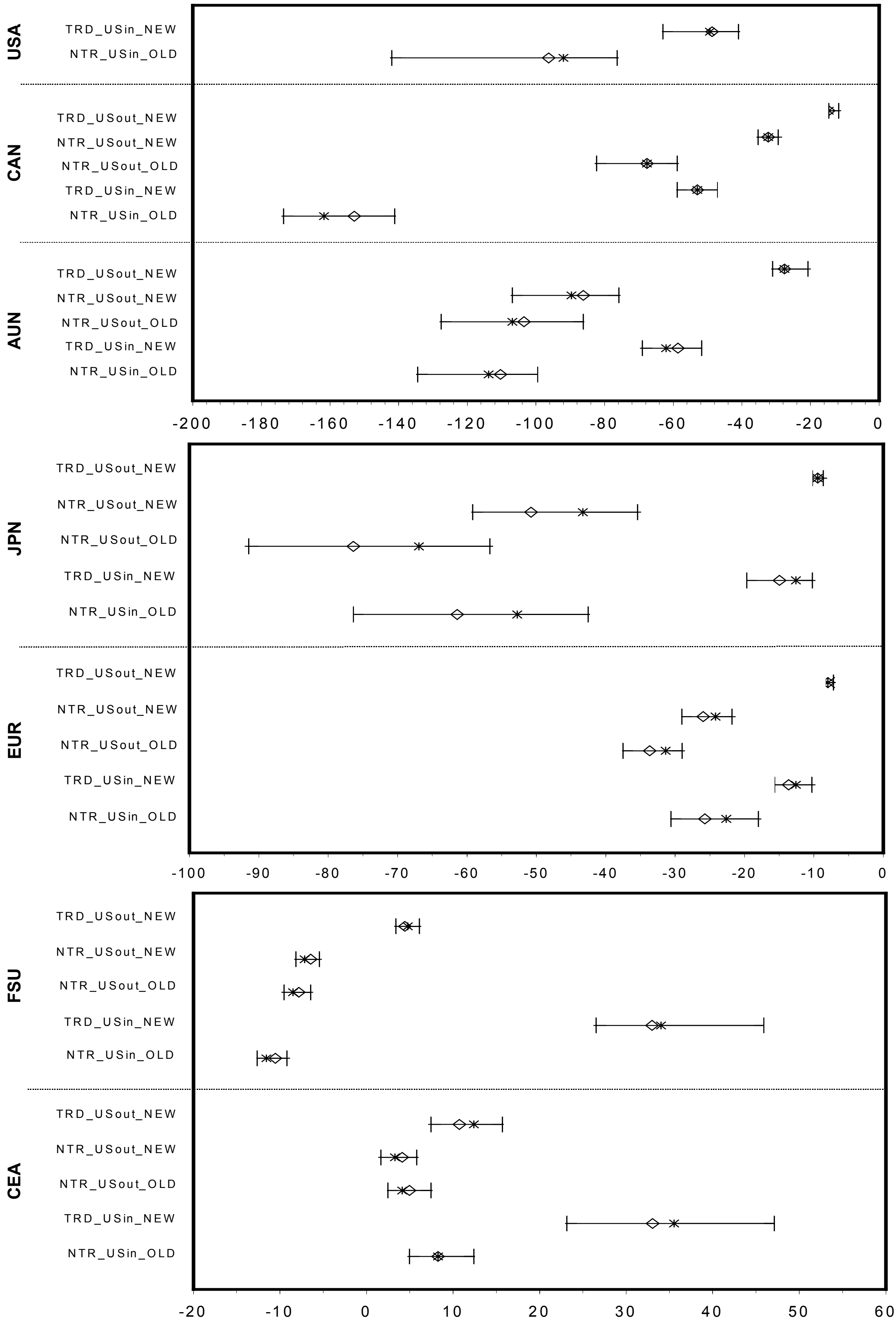
Across scenarios and regions, the core simulation results and the median values are pretty close. Keeping in mind that our box-plots represent a 90% probability of outcomes, the variability of results seems rather modest.

Figure 1: Global environmental effectiveness (% change vis-à-vis BaU emissions)



Key: | 5% and 95% quantile ◇ Median ⚹ Core value

Figure 2: Private consumption change in US$$_{97}$ per capita



Key: | 5% and 95% quantile ◇ Median ⋇ Core value

6. Conclusion

We tried to shed some light on recent developments in the climate change negotiations from a political economy point of view. We have shown that U.S. withdrawal from the Kyoto Protocol is straightforward given the potential compliance costs and the domestic voters' low willingness to pay.

U.S. withdrawal in 2001 had a major impact on the subsequent climate policy negotiations at Bonn and Marrakech since it endowed the remaining key Parties with veto bargaining power. Canada, Australia, New Zealand, Japan, and Russia were put into a position to achieve far-reaching concessions from the EU on carbon sinks and tradability of emission rights, particularly „hot air" trade from the Former Soviet Union. U.S. withdrawal, combined with sink credits and, in particular, unrestricted „hot air" trading, reduce the Kyoto Protocol to a symbolic treaty that codifies more or less business-as-usual emissions and makes compliance a rather cheap deal. This result fits into the literature on the effectiveness of international environmental agreements, which casts serious doubts whether such treaties go much beyond the state without any agreement (Murdoch and Sandler (1997a,b), Finus and Tjøtta (2002)).

We conclude that U.S. withdrawal, in fact, has led to a complete dismantling of the Kyoto Protocol that had once been celebrated as a breakthrough in climate protection.

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The Dismantling of a Breakthrough:
The Kyoto Protocol – Just Symbolic Policy!

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Downloadable Appendix

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

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Appendix A: Detailed Algebraic Model Description

This section outlines the main characteristics of a generic static general equilibrium model of the world economy designed for the medium-run economic analysis of carbon abatement constraints. It is a well-known Arrow-Debreu model that concerns the interaction of consumers and producers in markets. Consumers in the model have a primary exogenous endowment of the commodities and a set of preferences giving demand functions for each commodity. The demands depend on all prices; they are continuous and non-negative, homogenous of degree zero in factor prices and satisfy Walras' Law, i.e. the total value of consumer expenditure equals consumer income at any set of prices. Market demands are the sum of final and intermediate demands. Producers maximize profits given a constant returns to scale production technology. Because of the homogeneity of degree zero of the demand functions and the linear homogeneity of the profit functions in prices, only relative prices matter in such a model. Two classes of conditions characterize the competitive equilibrium in the model: market clearance conditions and zero profit conditions. In equilibrium, price levels and production levels in each industry are such that market demand equals market supply for each commodity. Profit maximization under a constant returns to scale technology implies that no activity does any better than break even at equilibrium prices. The model is a system of simultaneous, non-linear equations with the number of equations equal to the number of variables.

A.1 Production

Within each region (indexed by the subscript *r*), each producing sector (indexed interchangeable by *i* and *j*) is represented by a single-output producing firm which chooses input and output quantities in order to maximize profits. Firm behavior can be construed as a two-stage procedure in which the firm selects the optimal quantities of primary factors *k* (indexed by *f*) and intermediate inputs *x* from other sectors in order to minimize production costs given input prices and some production level $Y = \varphi(k,x)$.

The second stage, given an exogenous output price, is the selection of the output level *Y* to maximize profits. The firm's problem is then:

$$\underset{y_{jir},x_{jir},k_{fir}}{Max} \; \Pi_{ir} = p_{ir} \cdot Y_{ir} - C_{ir}\left(p_{jr}, w_{fr}, Y_{ir}\right) \;\; s.t. \;\; Y_{ir} = \varphi_{ir}\left(x_{jir}, k_{fir}\right) \qquad [1]$$

where Π denotes the profit functions, C the cost functions which relate the minimum possible total costs of producing Y to the positive input prices, technology parameters, and the output quantity Y, and p and w are the prices for goods and factors, respectively.

Production of each good takes place according to constant elasticity of substitution (CES) production functions, which exhibit constant returns to scale. Therefore, the output price equals the per-unit cost in each sector, and firms make zero profits in equilibrium (Euler's Theorem). Profit maximization under constant returns to scale implies the equilibrium condition:

$$\pi_{ir} = p_{ir} - c_{ir}(p_{jr}, w_{fr}) = 0 \quad \text{(zero profit condition)} \qquad [2]$$

where c and π are the unit cost and profit functions, respectively.

Demand functions for goods and factors can be derived by Shepard's Lemma. It suggests that the first-order differentiation of the cost function with respect to an input price yields the cost-minimizing demand function for the corresponding input. Hence, the intermediate demand for good j in sector i is:

$$x_{jir} = \frac{\partial C_{ir}}{\partial p_{jr}} = Y_{ir} \cdot \frac{\partial c_{ir}}{\partial p_{jr}} \qquad [3]$$

and the demand for factor f in sector i is:

$$k_{fir} = \frac{\partial C_{ir}}{\partial w_{fr}} = Y_{ir} \cdot \frac{\partial c_{ir}}{\partial w_{fr}} \qquad [4]$$

The profit functions possess a corresponding derivative property (Hotelling's Lemma):

$$x_{jir} = \frac{\partial \Pi_{ir}}{\partial p_{jr}} = Y_{ir} \cdot \frac{\partial \pi_{ir}}{\partial p_{jr}} \quad \text{and} \quad k_{fir} = \frac{\partial \Pi_{ir}}{\partial w_{fr}} = Y_{ir} \cdot \frac{\partial \pi_{ir}}{\partial w_{fr}} \qquad [5]$$

The variable, price dependent input coefficients, which appear subsequently in the market clearance conditions, are thus:

$$a_{jir}^{x} = \frac{\partial c_{ir}}{\partial p_{jr}} = \frac{\partial \pi_{ir}}{\partial p_{jr}} \quad \text{and} \quad a_{fir}^{k} = \frac{\partial c_{ir}}{\partial w_{fr}} = \frac{\partial \pi_{ir}}{\partial w_{fr}} \qquad [6]$$

The model captures the production of commodities by aggregate, hierarchical (or nested) constant elasticity of substitution (CES) production functions that characterize the technology through substitution possibilities between capital, labor, energy and material (non-energy) intermediate inputs (KLEM). Two types of production functions are employed: those for fossil fuels (in our case v = COL, CRU, GAS – see Table B.1) and those for non-fossil fuels (in our case n = EIS, ELE, OIL, ROI – see Table B.1).

Figure A.1 illustrates the nesting structure in non-fossil fuel production. In the production of non-fossil fuels *nr,* non-energy intermediate inputs M (used in fixed coefficients among themselves) are employed in (Leontief) fixed proportions with an aggregate of capital, labor and energy at the top level. At the second level, a CES function describes the substitution possibilities between the aggregate energy input E and the value-added aggregate KL (for the sake of simplicity, the symbols α, β, ϕ and θ are used throughout the model description to denote the technology coefficients):

$$Y_{nr} = \min\left\{ (1-\theta_{nr}) M_{nr}, \theta_{nr}\phi_{nr} \left[\alpha_{nr} E_{nr}^{\rho^{KLE}} + \beta_{nr} KL_{nr}^{\rho^{KLE}} \right]^{1/\rho^{KLE}} \right\} \qquad [7]$$

where $\sigma^{KLE} = 1/(1\text{-}\rho^{KLE})$ denotes the elasticity of substitution between energy and the primary factor aggregate and θ the input (Leontief) coefficient. Finally, at the third level, capital and labor factor inputs trade-off with a constant elasticity of substitution σ^{KL}:

$$KL_{nr} = \phi_{nr} \left[\alpha_{nr} K_{nr}^{\rho^{KL}} + \beta_{nr} L_{nr}^{\rho^{KL}} \right]^{1/\rho^{KL}} \qquad [8]$$

As to the formation of the energy aggregate E, we employ several levels of nesting to represent differences in substitution possibilities between primary fossil fuel types as well as substitution between the primary fossil fuel composite and secondary energy, i.e. electricity. The energy aggregate is a CES composite of electricity and primary energy inputs FF with elasticity $\sigma^{E} = 1/(1\text{-}\rho^{E})$ at the top nest:

$$E_{nr} = \phi_{nr} \left[\alpha_{nr} ELE_{nr}^{\rho^{E}} + \beta_{nr} FF_{nr}^{\rho^{E}} \right]^{1/\rho^{E}} \qquad [9]$$

The primary energy composite is defined as a CES function of coal and the composite of refined oil and natural gas with elasticity $\sigma^{COA} = 1/(1-\rho^{COA})$. The oil-gas composite is assumed to have a simple Cobb-Douglas functional form with value shares given by θ:

$$FF_{nr} = \phi_{nr}\left[\alpha_{nr} COA_{nr}^{\rho^{COA}} + \beta_{nr}\left(OIL^{\theta_{nr}} \cdot GAS^{1-\theta_{nr}}\right)^{\rho^{COA}}\right]^{1/\rho^{COA}} \qquad [10]$$

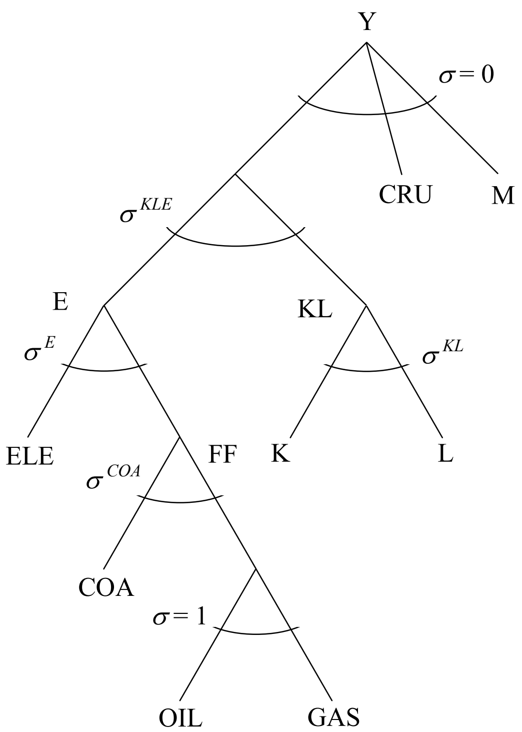

Figure A.1: Nesting structure of non-fossil fuel production

Fossil fuel resources v are modeled as graded resources. The structure of production of fossil fuels is given in Figure A.2. It is characterized by the presence of a fossil fuel resource in fixed supply. All inputs, except for the sector-specific resource R, are aggregated in fixed proportions at the lower nest. Mine managers minimize production costs subject to the technology constraint:

$$Y_{vr} = \phi_{vr}\left[\alpha_{vr} R_{vr}^{\rho_v^f} + \beta_{vr}\left[\min\left(\theta_{vr}^K K_{vr}, \theta_{vr}^L L_{vr}, \theta_{vr}^E E_{vr}, \theta_{vr}^M M_{jvr}\right)\right]^{\rho_v^f}\right]^{1/\rho_v^f} \qquad [11]$$

The resource grade structure is reflected by the elasticity of substitution between the fossil fuel resource and the capital-labor-energy-material aggregate in production. The substitution elasticity between the specific factor and the Leontief composite at the top level is

σ_{vr}^{f} = 1/(1-ρ_{vr}^{f}). This substitution elasticity is calibrated in consistency with an exogenously given supply elasticity of fossil fuel ε_{vr} according to

$$\varepsilon_{vr} = \frac{1-\gamma_{vr}}{\gamma_{vr}} \sigma_{vr}^{f} \qquad [12]$$

where γ_{vr} is the resource value share.

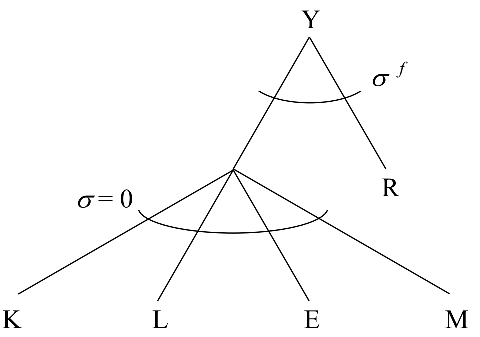

Figure A.2: Nesting structure for fossil fuel production

We now turn to the derivation of the factor demand functions for the nested CES production functions, taking into account the duality between the production function and the cost function. The total cost function that reflects the same production technology as the CES production function for e.g. value added *KL* in non-fossil fuel production given by [8] is:

$$C_{nr}^{KL} = \frac{1}{\phi_{nr}} \left[\alpha_{nr}^{\sigma^{KL}} PK_{nr}^{1-\sigma^{KL}} + \beta_{nr}^{\sigma^{KL}} PL_{nr}^{1-\sigma^{KL}} \right]^{1/\left(1-\sigma^{KL}\right)} \cdot KL_{nr} \qquad [13]$$

where PK and PL are the per-unit factor costs for the industry including factor taxes if applicable. The price function for the value-added aggregate at the third level is:

$$PKL_{nr} = \frac{1}{\phi_{nr}} \left[\alpha_{nr}^{\sigma^{KL}} PK_{nr}^{1-\sigma^{KL}} + \beta_{nr}^{\sigma^{KL}} PL_{nr}^{1-\sigma^{KL}} \right]^{1/\left(1-\sigma^{KL}\right)} = c_{nr}^{KL} \qquad [14]$$

Shepard’s Lemma gives the price-dependent composition of the value-added aggregate as:

$$\frac{K_{nr}}{KL_{nr}} = \phi_{nr}^{\sigma^{KL}-1}\left(\alpha_{nr}\cdot\frac{PKL_{nr}}{PK_{nr}}\right)^{\sigma^{KL}}, \quad \frac{L_{nr}}{KL_{nr}} = \phi_{nr}^{\sigma^{KL}-1}\left(\beta_{nr}\cdot\frac{PKL_{nr}}{PL_{nr}}\right)^{\sigma^{KL}} \qquad [15]$$

In order to determine the variable input coefficient for capital and labor $a_{nr}{}^{K} = K_{nr} / Y_{nr}$ and $a_{nr}{}^{L} = L_{nr} / Y_{nr}$, one has to multiply [15] with the per unit demand for the value added aggregate KL_{nr} / Y_{nr}, which can be derived in an analogous manner. The cost function associated with the production function [7] is:

$$PY_{nr} = (1-\theta_{nr})PM_{nr} + \frac{\theta_{nr}}{\hat{\phi}_{nr}}\left[\hat{\alpha}_{nr}^{\sigma^{KLE}} PE_{nr}^{1-\sigma^{KLE}} + \hat{\beta}_{nr}^{\sigma^{KLE}} PKL_{nr}^{1-\sigma^{KLE}}\right]^{\frac{1}{1-\sigma^{KLE}}} \qquad [16]$$

and

$$\frac{KL_{nr}}{Y_{nr}} = \theta_{nr}\,\hat{\phi}_{nr}^{\sigma^{KLE}-1}\left(\hat{\beta}_{nr}\cdot\frac{PY_{nr}}{PKL_{nr}}\right)^{\sigma^{KLE}} \qquad [17]$$

with θ_{nr} the *KLE* value share in total production. The variable input coefficient for e.g. labor is then:

$$a_{nr}^{L} = \theta_{nr}\,\phi_{nr}^{\sigma^{KL}-1}\,\hat{\phi}_{nr}^{\sigma^{KLE}-1}\left(\beta_{nr}\cdot\frac{PKL_{nr}}{PL_{nr}}\right)^{\sigma^{KL}}\left(\hat{\beta}_{nr}\cdot\frac{PY_{nr}}{PKL_{nr}}\right)^{\sigma^{KLE}} \qquad [18]$$

A.2 Households

In each region, private demand for goods and services is derived from utility maximization of a representative household subject to a budget constraint given by the income level *INC*. The agent is endowed with the supplies of the primary factors of production (natural resources used for fossil fuel production, labor and capital) and tax revenues. In our comparative-static framework, overall investment demand is fixed at the reference level. The household's problem is then:

$$\underset{d_{ir}}{Max}\ W_r(d_{ir}) \ \ s.t.\ \ INC_r = \sum_f w_{fr}\bar{k}_{fr} + TR_r = \sum_i p_{ir} d_{ir} \qquad [19]$$

where W is the welfare of the representative household in region r, d denotes the final demand for commodities, $\bar{k}$ is the aggregate factor endowment of the representative agent, and TR are total tax revenues. Household preferences are characterized by a CES utility function. As in production, the maximization problem in [1] can thus be expressed in form of an unit expenditure function e or welfare price index pw, given by:

$$pw_r = e_r\left(p_{ir}\right) \qquad [20]$$

Compensated final demand functions are derived from Roy's Identity as:

$$d_{ir} = \overline{INC}_r \frac{\partial e_r}{\partial p_{ir}} \qquad [21]$$

where $\overline{INC}$ denotes the initial level of expenditures.

In the model, welfare of the representative agent is represented as a CES composite of a fossil fuel aggregate and a non-fossil fuel consumption bundle. Substitution patterns within the latter are reflected via a Cobb-Douglas function. The fossil fuel aggregate in final demand consists of the various fossil fuels (*fe* = COL, OIL, GAS) trading off at a constant elasticity of substitution. The CES utility function is:

$$U_r = \left[\alpha_r\left(\sum_{fe}\beta_{fe,r}C_{fe,r}^{\rho^F}\right)^{\rho^C/\rho^F} + \phi_r\left(\prod_{j\notin fe}C_{jr}^{\theta_j}\right)^{\rho^C}\right]^{1/\rho^C} \qquad [22]$$

where the elasticity of substitution between energy and non-energy composites is given by $\sigma_C = 1/(1-\rho_C)$, the elasticity of substitution within the fossil fuel aggregate by $\sigma_{FE} = 1/(1-\rho_{FE})$, and θ_j are the value shares in non-fossil fuel consumption. The structure of final demand is presented in Figure A.3.

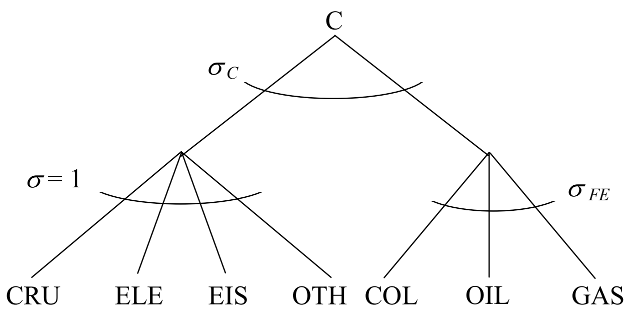

Figure A.3: Structure of household demand

Total income of the representative agent consists of factor income, revenues from taxes levied on output, intermediate inputs, exports and imports, final demand as well as tax revenues from CO_2 taxes (TR) and a baseline exogenous capital flow representing the balance of payment deficits *B* less expenses for exogenous total investment demand *PI·I*. The government activity is financed through lump-sum levies. It does not enter the utility function and is hence exogenous in the model. The budget constraint is then given by:

$$PC_r \cdot C_r = PL_r \cdot \overline{L}_r + PK_r \cdot \overline{K}_r + \sum_v PR_{vr} \cdot \overline{R}_{vr} + TR_r + \overline{B}_r - PI_r \cdot I_r \qquad [23]$$

where *C* denotes the aggregate household consumption in region *r* and *PC* represnts its associated price.

A.3 Foreign Trade

All commodities are traded on world markets and characterized by product differentiation. There is imperfect transformability (between exports and domestic sales of domestic output) and imperfect substitutability (between imports and domestically sold domestic output). Bilateral trade flows are subject to export taxes, tariffs and transportation costs and calibrated to the base year 1995. There is an imposed balance of payment constraint to ensure trade balance, which is warranted through flexible exchange rates, incorporating the benchmark trade deficit or surplus for each region.

On the output side, two types of differentiated goods are produced as joint products for sale in the domestic markets and the export markets, respectively. The allocation of output between domestic sales *D* and international sales *X* is characterized by a constant elasticity of transformation (CET) function. Hence, firms maximize profits subject to the constraint:

$$Y_{ir} = \phi_{ir} \left[\alpha_{ir} D_{ir}^{\eta} + \beta_{ir} X_{ir}^{\eta} \right]^{1/\eta} \qquad [24]$$

where $\sigma^{tr} = 1/(1 + \eta)$ denotes the transformation elasticity.

Regarding imports, the standard Armington convention is adopted in the sense that imported and domestically produced goods of the same kind are treated as incomplete substitutes (i. e. wine from France is different from Italian wine). The aggregate amount of each (Armington) good *A* is divided among imports and domestic production:

$$A_{ir} = \phi_{ir} \left[\alpha_{ir} D_{ir}^{\rho^D} + \beta_{ir} M_{ir}^{\rho^D} \right]^{1/\rho^D} \qquad [25]$$

In this expression $\sigma^D = 1/(1-\rho^D)$ is the Armington elasticity between domestic and imported varieties. Imports M are allocated among import regions s according to a CES function:

$$M_{ir} = \phi_{ir} \left[\sum_s \alpha_{ir} X_{isr}^{\rho^M} \right]^{1/\rho^M} \qquad [26]$$

with X the amount of exports from region s to region r and $\sigma^M = 1/(1-\rho^M)$ the Armington elasticity among imported varieties. Intermediate as well as final demands are, hence, (nested CES) Armington composites of domestic and imported varieties.

The assumption of product differentiation permits the model to match bilateral trade with cross-hauling of trade and avoids unrealistically strong specialization effects in response to exogenous changes in trade (tax) policy.

A.4 Carbon emissions

Carbon emissions are associated with fossil fuel consumption in production, investment, government and private demand. Each unit of a fuel emits a known amount of carbon where different fuels have different carbon intensities. The applied carbon coefficients are 25 MT carbon per EJ for coal, 14 MT carbon per EJ for gas and 20 MT carbon per EJ for refined oil.

Carbon policies are introduced via an additional constraint that holds carbon emissions to a specified limit. The solution of the model gives a shadow value on carbon associated with this carbon constraint. This dual variable or shadow price can be interpreted as the price of carbon permits in a carbon permit system or as the CO_2 tax that would induce the carbon constraint in the model. The shadow value of the carbon constraint equals the marginal cost of reduction. It indicates the incremental cost of reducing carbon at the carbon constraint. The total costs represent the resource cost or dead-weight loss to the economy of imposing carbon constraints. Carbon emission constraints induce substitution of fossil fuels with less expensive energy sources (fuel switching) or employment of less energy-intensive manufacturing and production techniques (energy savings). The only means of abatement are hence inter-fuel and fuel/non-fuel substitution or the reduction of intermediate and final consumption.

Given an emission constraint producers as well as consumers must pay this price on the emissions resulting from the production and consumption processes. Revenues coming from the imposition of the carbon constraint are given to the representative agent. The total cost of Armington inputs in production and consumption that reflects the CES production technology in [25] but takes CO2 emission restrictions into account is:

$$C_{ir}^{A} = \left[\left(\alpha_{ir}^{\sigma^D} PD_{ir}^{1-\sigma^D} + \beta_{ir}^{\sigma^A} PM_{ir}^{1-\sigma^D} \right)^{1/\left(1-\sigma^D\right)} + \tau_r \cdot a_i \right] \cdot A_{ir} \qquad [27]$$

where a_i denote the carbon emissions coefficient for fossil fuel i and τ represents the shadow price of CO_2 in region r associated with the carbon emission restriction:

$$\overline{CO2}_r = \sum_i A_{ir} \cdot a_i \qquad [28]$$

where $\overline{CO2}_r$ is the endowment of carbon emission rights in region r.

A.5 Zero Profit and Market Clearance Conditions

The equilibrium conditions in the model are zero profit and market clearance conditions. Zero profit conditions as derived in [2] require that no producer earns an "excess" profit in equilibrium. The value of inputs per unit activity must be equal to the value of outputs. The zero profit conditions for production, using the variable input coefficient derived above, is:

$$PK \cdot a_{ir}^{K} \cdot Y_{ir} + PL \cdot a_{ir}^{L} \cdot Y_{ir} + \sum_j PA_j \cdot a_{jir}^{M} \cdot Y_{ir} = PY_{ir} \cdot Y_{ir} . \qquad [29]$$

The market clearance conditions state that market demand equals market supply for all inputs and outputs. Market clearance conditions have to hold in equilibrium. Domestic markets clear, equating aggregate domestic output plus imports, i.e. total Armington good supply, to aggregate demand, which consists of intermediate demand, final demand, investment and government demand:

$$A_{ir} = \sum_j Y_{jr} \frac{\partial \pi_{jr}^{Y}}{\partial PA_{ir}} + C_r \frac{\partial e_r}{\partial PA_{ir}} \qquad [30]$$

where PA denotes the price of the Armington composite. π_{ir}^{Z} is the per unit zero profit function with Z the name assigned to the associated production activity. The derivation of π_{ir}^{Z} with respect to input and output prices yields the compensated demand and supply coefficients, e.g. $\partial \pi_{jr}^{Y} / \partial PA_{ir} = a_{ijr}^{A}$ denoting the intermediate demand for Armington good i in sector j of region r per unit of output Y. Output for the domestic market equals total domestic demand:

$$Y_{ir} \frac{\partial \pi_{ir}^{Y}}{\partial PD_{ir}} = \sum_{j} A_{jr} \frac{\partial \pi_{jr}^{A}}{\partial PD_{ir}} \qquad [31]$$

where PD is the domestic commodity price. Export supply equals import demand across all trading partners:

$$Y_{ir} \frac{\partial \pi_{ir}^{Y}}{\partial PX_{ir}} = \sum_{s} M_{is} \frac{\partial \pi_{is}^{M}}{\partial PX_{ir}} \qquad [32]$$

where PX is the export price. Aggregate import supply equals total import demand:

$$M_{ir} = A_{ir} \frac{\partial \pi_{ir}^{A}}{\partial PM_{ir}} \qquad [33]$$

where PM is the import price.

Primary factor endowment equals primary factor demand:

$$\overline{L}_{r} = \sum_{i} Y_{ir} \frac{\partial \pi_{ir}^{Y}}{\partial PL_{r}}, \qquad [34]$$

$$\overline{K}_{r} = \sum_{i} Y_{ir} \frac{\partial \pi_{ir}^{Y}}{\partial PK_{r}}, \qquad [35]$$

$$\overline{R}_{vr} = Y_{vr} \frac{\partial \pi_{vr}^{Y}}{\partial PR_{vr}}. \qquad [36]$$

An equilibrium is characterized by a set of prices in the different goods and factor markets such that the zero profit and market clearance conditions stated above hold.

A.6 International Permit Trade and Monopolistic Permit Supply

Under competitive permit trading, all countries can import or export CO_2 permits considering the international permit price as exogenous. The zero-profit condition for export activities of country r is given as weak inequality:

$$\Pi_{r}^{CEXP} = P - \tau_{r} \leq 0. \qquad [37]$$

where P is the international permit price, τ_r reflects the domestic carbon price (see [28]) and $CEXP_r$ is the associated dual variable, which indicates the activity level of CO_2 exports from region r . Likewise, the zero-profit condition for import activities of country r is given by:

$$\Pi_r^{CIMP} = \tau_r - P \leq 0 . \qquad [38]$$

where $CIMP_r$ is the associated dual variable, which indicates the activity level of CO_2 imports in region r.

The market clearance condition for tradable permits is:

$$\sum_r CEXP_r = \sum_r CIMP_r \ . \qquad [39]$$

where P - the international permit price - is the associated dual variable.

Monopolistic permit supply is characterized as a situation where one country - in our case FSU - has supply power in the permit market while all other countries behave as price takers. The monopolist sets the permit price as a markup on its marginal abatement costs to maximize profits (with the usual inverse relationship between the markup rate and the price elasticity of permit demand). Given the complexity of functional forms in our computable general equilibrium framework, it is not possible to derive an algebraic formula for the markup rate. We therefore represent the markup in the model as an export tariff which drives a wedge between the international permit price and the marginal abatement costs in FSU:

$$\Pi_{FSU}^{EXP} = P - \tau_{FSU} (1 + t_{FSU}^{EXP}) \leq 0 \ . \qquad [40]$$

The markup is equivalent to a quota on the sales of permits where the quota rents accrue to FSU. In order to determine the optimal tariff or quota numerically, we raise the tariff of FSU in sufficiently small steps and then identify that rate which maximizes its welfare in terms of real consumption C.

A.7 Overview of Elasticities

Table A.1 provides a summary of elasticity values adopted for the core simulations.

Table A.1: Default values of key substitution and supply elasticities

	Description	Value
	Substitution elasticities in non-fossil fuel production	
σ^{KLE}	Energy vs. value added	0.5
σ^{KL}	Capital vs. labor	1.0
σ^{E}	Electricity vs. primary energy inputs	0.3
σ^{COL}	Coal vs. gas-oil	0.5
	Substitution elasticities in final demand	
σ_{C}	Fossil fuels vs. non-fossil fuels	0.8
σ_{FE}	Fossil fuels vs. fossil fuels	0.3
	Elasticities in international trade (Armington)	
σ^{D}	Substitution elasticity between the import composite vs. domestic inputs	2.0
σ^{M}	Substitution elasticity between imports from different regions forming the import composite	4.0
σ^{tr}	Transformation elasticity domestic vs. export	4.0
	Exogenous supply elasticities of fossil fuels ε	
Crude oil		1.0
Coal		1.0
Natural gas		1.0

For the sensitivity analysis reported in section 5, the lower and upper values of the uniform probability distributions for six key elasticities are as follows: $1 < \sigma^D < 4$; $2 < \sigma^M < 8$; $0.25 < \sigma^{KLE} < 0.75$; $0.6 < \sigma^C < 1$; $0.25 < \varepsilon_{CRU} < 1$; $0.25 < \varepsilon_{COL} < 1$.

Appendix B: Benchmark Data - Regional and Sectoral Aggregation

The model is built on a comprehensive energy-economy dataset that accommodates a consistent representation of energy markets in physical units as well as detailed accounts of regional production and bilateral trade flow. The underlying data base is GTAP-EG (ver.5) which reconciles the most recent GTAP economic production and trade dataset for the year 1997 with OECD/IEA energy statistics for 50 regions and 23 sectors (Rutherford and Paltsev 2000). Benchmark data determine parameters of the functional forms from a given set of benchmark quantities, prices, and elasticities. Sectors and regions of the original GTAP-EG data set are aggregated according to Tables B.1 and B.2 to yield the model's sectors and regions.

Table B.1: Sectoral aggregation

Sectors in GTAP-EG			
AGR	Agricultural products	NFM	Non-ferrous metals
CNS	Construction	NMM	Non-metallic minerals
COL	Coal	OIL	Refined oil products
CRP	Chemical industry	OME	Other machinery
CRU	Crude oil	OMF	Other manufacturing
DWE	Dwellings	OMN	Mining
ELE	Electricity and heat	PPP	Paper-pulp-print
FPR	Food products	SER	Commercial and public services
GAS	Natural gas works	T_T	Trade margins
I_S	Iron and steel industry	TRN	Transport equipment
LUM	Wood and wood-products	TWL	Textiles-wearing apparel-leather

Mapping from GTAP-EG sectors to model sectors as of Table 1

Aggregate model sectors as of Table 1		Sectors in GTAP-EG
	Energy	
COL	Coal	COL
CRU	Crude oil	CRU
GAS	Natural gas	GAS
OIL	Refined oil products	OIL
ELE	Electricity	ELE
	Non-Energy	
EIS	Energy-intensive sectors	CRP, I_S, NFM, NMM, PPP, TRN
ROI	Rest of industry	AGR, CNS, DWE, FPR, LUM, OME, OMF, OMN, SER, T_T, TWL

Table B.2: Regional aggregation

Regions in GTAP-EG			
ARG	Argentina	MYS	Malaysia
AUS	Australia	NZL	New Zealand
BRA	Brazil	PHL	Philippines
CAM	Central America and Caribbean	RAP	Rest of Andean Pact
CAN	Canada	RAS	Rest of South Asia
CEA	Central European Associates	REU	Rest of EU
CHL	Chile	RME	Rest of Middle East
CHN	China	RNF	Rest of North Africa
COL	Columbia	ROW	Rest of World
DEU	Germany	RSA	Rest of South Africa
DNK	Denmark	RSM	Rest of South America
EFT	European Free Trade Area	RSS	Rest of South-Saharan Africa
FIN	Finland	SAF	South Africa
FSU	Former Soviet Union	SGP	Singapore
GBR	United Kingdom	SWE	Sweden
HKG	Hong Kong	THA	Thailand
IDN	Indonesia	TUR	Turkey
IND	India	TWN	Taiwan
JPN	Japan	URY	Uruguay
KOR	Republic of Korea	USA	United States of America
LKA	Sri Lanka	VEN	Venezuela
MAR	Morocco	VNM	Vietnam
MEX	Mexico		

Mapping from GTAP-EG regions to model regions as of Table 1

Aggregate model regions as of Table 1		Regions in GTAP-EG
	Annex B	
USA	United States	USA
EUR	OECD Europe (incl. EFTA)	DEU, DNK, EFT, FIN, GBR, REU, SWE
JPN	Japan	JPN
CAN	Canada	CAN
AUN	Australia, New Zealand	AUS, NZL
CEA	Central and Eastern Europe	CEA
FSU	Former Soviet Union	FSU
	Non-Annex B	
ROW	Rest of the World	KOR, LKA, MYS, PHL, RAS, SGP, THA, TWN, VNM, IDN, MEX, RME, RNF, VEN, MAR, ROW, RSA, RSS, SAF, TUR

Appendix C: Baseline Projections - Forward Calibration

The magnitude and distribution of abatement costs associated with the implementation of the Kyoto emission constraints crucially depend on the business-as-usual (*BaU*) projections for gross domestic product, fuel prices, energy efficiency improvements, etc. In our comparative-static framework, we infer the *BaU* economic structure of the model's regions for the year 2010 using most recent projections by the International Energy Outlook for growth in gross domestic product, fossil fuel production, and future energy prices. We incorporate autonomous energy efficiency improvement factors which scale energy demand functions to match the exogenous emission forecasts of the International Energy Outlook. The concrete forward calibration of the model entails three steps.

First, we fix the time profile of fossil fuel supplies from the model's regions to the exogenous baseline projections by making supplies inelastic and scaling sector-specific resources with the exogenous growth rates in fossil fuel production. This allows us to partially control the emission profile from the supply side. Within the *BaU* calculation, we endogenously adjust the resource endowments of fossil fuels to calibrate the model to given exogenous target prices for fossil fuels. At the same time we incorporate exogenous, region-specific growth rates for gross domestic product to scale the labor and capital stock of our static model.

Second, we incorporate exogenous autonomous energy efficiency improvements (AEEI) to match the exogenous carbon emission profiles as provided by the International Energy Outlook. The AEEI reflects the rate of change in energy intensity, i.e. the ratio of energy consumption over gross domestic product, holding energy prices constant. It is a measure of all non-price induced changes in gross energy intensity including technical developments that increase energy efficiency as well as structural changes.

Third, we recalibrate fossil fuel supply functions locally to exogenous estimates of supply elasticities. The last step assures empirical reaction of fossil fuel production to policy induced changes in world energy prices of fuels.

To account for the importance of exogenous baseline projections, the model can be calibrated to alternative data sources in an automated way. In the current setup, one can perform sensitivity analysis with respect to the three different core scenarios of the International Energy Outlook: low economic growth, reference case, and high economic growth.

Appendix D: Emission Reduction Targets for Annex B Countries

	Label[a]	Original Kyoto Targets (*OLD*)[b] (% of 1990 base year emissions)	Revised Targets (*NEW*)[c] (% of 1990 base year emissions)
Australia	AUN	108	110.7
Austria	EUR	87	92.9
Belgium	EUR	92.5	93.8
Bulgaria	CEA	92	95.2
Canada	CAN	94	107.9
Croatia	CEA	95	95
Czech Republic	CEA	92	94.1
Denmark	EUR	79	81.1
Estonia	FSU	92	94.7
Finland	EUR	100	107.8
France	EUR	100	103.9
Germany	EUR	79	80.7
Greece	EUR	125	133.1
Hungary	CEA	94	97.8
Iceland	EUR	110	118
Ireland	EUR	113	116.2
Italy	EUR	93.5	95.3
Japan	JPN	94	99.2
Latvia	FSU	92	98
Liechtenstein	EUR	92	107.9
Lithuania	EUR	92	96.5
Luxemburg	EUR	72	79.6
Monaco	EUR	92	93
Netherlands	EUR	94	95.2
New Zealand	AUN	100	107
Norway	EUR	101	105.3
Poland	CEA	94	96.5
Portugal	EUR	127	130.7
Romania	CEA	92	96.2
Russian Federation	FSU	100	105.7
Slovakia	CEA	92	96.3
Slovenia	CEA	92	100.4
Spain	EUR	115	118.9
Sweden	EUR	104	109.5
Switzerland	EUR	92	96.6
Ukraine	FSU	100	102.4
United Kingdom	EUR	87.5	88.8
United States	USA	93	96.8

[a] Label of aggregate model region which includes the respective Annex B country
[b] UNFCCC (1997)
[c] Estimates by the European Commission accounting for sink credits as agreed in Bonn and Marrakech (Nemry 2001)