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How large are the incentives to join sub-global carbon reduction initiatives?

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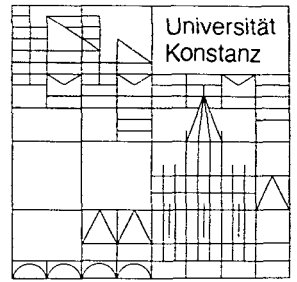
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**Sonderforschungsbereich 178
„Internationalisierung der Wirtschaft“**

Diskussionsbeiträge

Juristische
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Fakultät für Wirtschafts-
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**How Large Are the Incentives
to Join Sub-Global
Carbon Reduction Initiatives?**

**HOW LARGE ARE THE INCENTIVES TO JOIN
SUB-GLOBAL CARBON REDUCTION INITIATIVES?***

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Serie II - Nr. 154

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ABSTRACT

This paper attempts to shed some light on what the incentives are for international participation in 'sub-global' carbon reduction initiatives.

We use a six-region global general equilibrium trade and carbon emission model recently used by Whalley and Wigle to analyze the international incidence effects of various global carbon tax schemes. Here we modify this model so as to also capture the benefit side of reduced global warming by including emission reduction in the specification of preferences in each region. This change in model structure allows us to examine the strength of the incentives for sub-global arrangements to form with the aim of achieving reduced carbon emissions. Because there are no reliable estimates of the benefits from slowed global warming, we have adopted a procedure of evaluating incentives for any sub-global arrangements to be used relative to a reference point: 50 percent global emission reduction target, as in the 1988 Toronto call, is assumed to represent a full-participation global optimum, in which the sum of marginal country benefits from further global abatement exactly balance marginal country costs from further reductions in use of carbon-based energy.

A number of interesting points emerge from our calculations. Incentives for the larger regions to engage in unilateral emission reductions (including the U.S. which accounts for nearly 25 percent of global emissions) are surprisingly strong (more than half the assumed optimal 50% global reduction). The optimal reduction increases further when pairs of regions who each provide emission reduction benefits to the other are considered (more than 35 percent for North America and Europe). Also, terms-of-trade effects from such cuts help energy importers and amplify (in some cases substantially) the benefits to them of reduced emissions from slowed global warming. But both production and consumption-based cuts create spillover effects stimulating production or consumption in other regions, suggesting that sub-global arrangements to reduce emissions are more likely to be successful if accompanied by constraints on non-participants. The overall picture that emerges is that even with limited country participation in such schemes, significant emission reductions (given the assumed 50% full participation optimal cut) are still beneficial to participating countries.

1. INTRODUCTION

Whether to implement global policies to reduce atmospheric emissions of carbon, and if so, by how much and by whom, remain issues of controversy in environmental debate. But despite calls for global carbon emission reduction targets emanating from the scientific community (such as the call from the 1988 Toronto Atmosphere Conference), and the commitments made by various OECD governments (Canada, Australia, U.K., Italy, and others) admittedly conditional upon other governments acting similarly to achieve target reductions, the economic case for these initiatives remains unclear. Both Nordhaus (1991) and Schelling (1991) have recently argued that the benefits of slowing global warming are hard to quantify, but are likely to be small for industrialized OECD economies (where most economic activity takes place in buildings, and is largely unaffected by climate change). They also argue that warming will occur slowly over a long period of time, and adaptation and adjustment to climate change will be relatively easy. Hence, if abatement through reduced consumption of carbon-based energy is socially costly, a major global emission reduction effort seems unjustified.

In contrast, Cline (1991) has emphasized the sharply escalating costs of a more pronounced acceleration in emissions beyond those implied by the frequently used $2xCO_2$ (doubling of atmospheric carbon content) scenario (say to six times current CO_2 atmospheric concentration by the end of the next century). European economists also emphasize what they see as the small social cost of modest (15 to 20 percent) emission reductions in arguing their case for a carbon limitation initiative. Hence, not only is the scientific evidence in favour of global warming clouded, the economic debate on the costs and benefits of abatement seems similarly confused.

Global discussions on a framework to guide any future substantive negotiation on carbon emission reduction targets are now underway despite all the uncertainties listed above, even though

it has long been emphasized by economists (see Hoel [1989], Grubb [1990]) that these negotiations are fraught with a number of difficulties. Countries have an incentive to free-ride and not comply, unless other penalty devices (such as trade sanctions) are invoked. International monitoring and enforcement of targets is problematic. Developing countries worry about the impact of emission reductions on their development. And the allocation of targets and choice of instrument has many pitfalls (should prior emissions enter target calculations, are taxes or permits to be used and how are they to be administered, should existing domestic policies be credited in some way [credits to Europe for high energy taxes, for instance]).

This paper attempts to shed some light on what the incentives are for international participation in such negotiations, focusing on what we term 'sub-global' carbon reduction initiatives. We examine the incentives (or lack of them) for sub-groups of countries to band together and agree on joint carbon emission reductions, despite the fact that some of the benefits accrue to countries other than those participating in the agreement. These groups might be North America and Europe, all OECD countries, just the North American economies, or other coalitions.

Our procedure is to use a six-region global general equilibrium trade and carbon emission model recently used by Whalley and Wigle (1991) to analyze the international incidence effects of various global carbon tax schemes. Here we modify this model so as to also capture the benefit side of reduced global warming by including temperature change (emission reduction) in the specification of preferences in each region. This change in model structure allows us to examine the strength of the incentives for sub-global arrangements to form with the aim of achieving reduced carbon emissions. Because there are no reliable estimates of the benefits from slowed global warming, we have adopted a procedure of evaluating incentives for any sub-global arrangements to be used relative to a reference point. We have chosen as our standard that a 50 percent global

emission reduction target, as in the 1988 Toronto call, represents a full-participation global optimum, in which the sum of marginal country benefits from further global abatement exactly balance marginal country costs from further reductions in use of carbon-based energy. We emphasize that the assumption of a 50% cut being optimal in this way is strong and in no way do we mean to assert that it is necessarily realistic. However, using a reference point such as this enables us to evaluate the strength of incentives for sub-global arrangements of various kinds involving less than full international participation, and this reference point can then be varied in subsequent sensitivity analysis.

A number of interesting points emerge from our model calculations. Incentives for the larger regions to engage in unilateral emission reductions (including the U.S. which accounts for nearly 25 percent of global emissions) are surprisingly strong (more than half the assumed optimal 50% global reduction). The optimal reduction increases further when pairs of regions who each provide emission reduction benefits to the other are considered (more than 35 percent for North America and Europe). Also, terms-of-trade effects from such cuts help energy importers and amplify (in some cases substantially) the benefits to them of reduced emissions from slowed global warming. But both production and consumption-based cuts create spillover effects stimulating production or consumption in other regions. The overall picture that emerges is that even with limited country participation in such schemes, significant emission reductions given the assumed 50% full participation optimal cut) are still beneficial to participating countries.

2. A NUMERICAL GENERAL EQUILIBRIUM MODEL FOR ASSESSING SUB-GLOBAL CARBON REDUCTION INITIATIVES

To assess the incentives for groups of countries to pursue various sub-global carbon reduction initiatives, we have extended the global general equilibrium model earlier used by Whalley and Wigle (1991) to analyze the international incidence effects of carbon taxes. We modify this earlier model by explicitly incorporating the benefits from slowed global warming from reduced carbon emissions through a specification of preferences which captures climate change. This enables us to make a number of counterfactual calculations for alternative reduction initiatives in which the benefits from slowed global warming and the costs of reduced use of carbon based energy both appear. Because countries fully bear the costs of reduced carbon energy use, but only receive a portion of the global benefits from slowed global warming, go it alone reduction initiatives will typically involve smaller reductions than global reductions with full participation.

The model incorporates trade, production, and consumption of both energy and non-energy products for a number of countries (or groups of countries) over a single forty-year projection period of 1990-2030¹ ². The forty-year time span is treated as a single period, and the model incorporates no explicit dynamics. The model also does not incorporate existing taxes on energy products, although in practice these vary by region, and would affect results. To further keep the

¹ This has been chosen somewhat arbitrarily to capture the initial period and subsequent intermediate term during which a carbon tax would have its largest effects, since with discounting the significance in present value terms of later-year effects recedes. It is relatively easy to run the model for a longer projection period (say, 80 or 100 years), and were this done, we believe that the main themes of our results would remain.

² A weakness of this 40-year projection period approach is that in the base year data used for these projections, most carbon energy trade takes place in oil rather than in other carbon-based fuels. If, as some expect, trade in oil is slowly replaced by trade in coal into the next century, the data used here may be misleading since the countries who are potential future coal exporters (U.S., U.S.S.R., Australia, China) are quite different from current oil exporters (POEC countries, Mexico).

model manageable, the model does not identify fuel types within the broader category of carbon-based energy products, even though in practice various elements within this category (oil, coal, natural gas) have different carbon content.

In the model, the world is divided into six regions, indicated in Table 1. These are the European Community, North America, Japan, other OECD, oil exporters (including all OPEC countries, and major non-OPEC energy exporters) and a residual rest of the world, representing most developing countries (those who are not oil exporters) along with the centrally planned economies. Data difficulties have precluded a separation between the two groups (i.e., between centrally planned and other developing countries) for now.

Table 1
Regions in the Global Equilibrium Model Used
to Evaluate Sub Global Carbon Reduction Initiatives

1. **EUROPEAN COMMUNITY (of the 12) [EC]***
2. **NORTH AMERICA (U.S., Canada) [NAM]**
3. **JAPAN [JPN]**
4. **OTHER OECD [O/OECD]**

Austria, Switzerland, Finland, Iceland, Norway, Sweden, Australia, New Zealand.
5. **OIL EXPORTERS (OPEC countries, plus major non-OPEC exporters) [OEXP]**

Algeria, Libya, Nigeria, Tunisia, Mexico, Venezuela, Indonesia, Iran, Iraq, Kuwait, Saudi Arabia, United Arab Emirates.
6. **REST OF THE WORLD (Developing Countries and Centrally Planned Economies) [ROW]**

This is a residual category containing all other countries; including USSR, Eastern Europe, China, Brazil, India, and other developing countries not in category 5.

* Abbreviations in square brackets are used to identify regions in the results tables which follow.

Nested CES functions are used to represent production and demand in each region; with the nesting structure set out in Table 2. Each region is endowed with four non-traded primary factors: (i) primary factors, exclusive of energy resources, (ii) carbon-based energy resources (deposits of oil, gas and coal), (iii) other energy resources (hydro-electric and nuclear capacity), and (iv) sector-specific skills and equipment in the energy-intensive manufacturing sector. Both energy resources are treated as able to be converted into the relevant energy products through a refining/extraction process which uses other resources (primary factors). There are three internationally traded commodities: carbon-based energy products, energy-intensive manufactures, and other goods (all other GNP). Energy-intensive manufactures, other goods, and the composite energy product (carbon-based and non-carbon-based energy) enter final demands.

For each of five produced goods in each region (listed in Table 1), production is represented by nested CES functions. Carbon-based and non-carbon-based energy products use the respective energy resources and primary factors. Non-carbon-based energy products are non-traded, since hydro-electric, solar and nuclear power are not traded in significant quantities between the regions as defined. A domestic energy composite is produced by a third (energy conversion) industry, using inputs of the two energy products. The two final-goods (energy-intensive manufactures, and other goods) use primary factors and the composite domestic energy product as inputs. Perfect competition is assumed throughout in all regions and for all sectors.

Table 2

**Production and Demand Structures in the
Global General Equilibrium Model Used to Evaluate
Sub Global Carbon Reduction Initiatives**

A. Factors and Goods in Each Region

Endowments

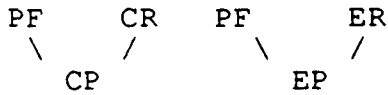
Carbon-Based Energy
Resources (CR)
Non-Carbon-Based Energy
Resources (ER)
Sector-Specific Factors
in Energy-Intensive
Manufacturing (SF)
Other Primary Factors (PF)

Produced Goods

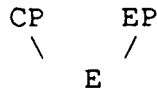
Carbon-Based Energy
Products (CP)
Non-Carbon-Based Energy
Products (EP)
Composite Energy (E)
Energy-intensive Goods (EI)
Other Goods (OG)

B. Structure of Production in Each Region (CES³ Functions used at each stage)

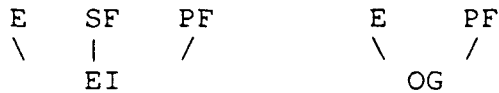
Stage 1: Production of Energy Products



Stage 2: Production of Composite Energy



Stage 3: Production of Energy-Intensive and Other Goods



C. Arguments in Final Demands⁴

EI, OG, E, ΔT

D. Commodities in Which International Trade Takes Place

EI, OG, CP

3 from original (5)

4 ΔT denotes temperature change

Equilibrium involves full global market clearing in the single 40-year period in all three traded goods (carbon-based energy products, energy-intensive manufactures, and other goods). For the two non-traded goods (non-carbon energy products, and composite energy) there is separate domestic market clearing within each economy. Since prices in this system are treated as completely flexible, they will adjust to the levels required to clear the relevant international and domestic markets. Counterfactual analyses with the model for any hypothesized policy change involve the computation of a new equilibrium model solution. Policy evaluation with the model is based on a comparison between counterfactual model solutions and the base data to which the model has been calibrated.

The base case equilibrium solution for the model represents an assumed future evolution of the global economy over a forty-year period between 1990-2030. This is based on an assumption of continuing OECD growth at rates prevailing in the late 1980s, unchanged energy use, and consumption and production of other goods. Hicksian neutral growth is assumed to occur in each of the regions in the model at average growth rates reported in the 1989 World Development Report. These are assumed to apply over the entire period under consideration. The Oil Exporting region is assumed to grow at 2.5 percent, the Rest of the World at 2.7 percent, and the remaining regions at 2.3 percent. Each region's endowment of non-produced factors during this period thus reflects the present value of their resources (at constant prices) over the entire period. We assume that a 5 percent real discount rate applies for all years in the period. The model is solved to yield a forty-year base line solution representing the world economy in the absence of any response to global warming over the period 1990-2030 (in discounted present value terms at 1990 prices, and in \$U.S. billion). Policy experiments are then evaluated against this base line, with a comparison of the base and counterfactual equilibria.

The structure of the regional economies in the base data used in the model largely corresponds to data available for 1982. Data for regional population and GNP in 1982 are obtained from the 1987 World Tables. Value-added, production and trade in energy-intensive manufactures (primary metals, glass, ceramics and other basic manufactured products) are obtained from Nguyen, Perroni and Wigle [1990]. These are identified as those industries having the highest energy input requirements. Input ratios from Ross (1989) are used to infer energy input requirements for energy-intensive and other industries.

Production, consumption and trade in carbon-based energy products and non-carbon-based energy (for 1982) come from U.N. Energy Statistics. Raw data are in (metric) kilotons of coal equivalent. To determine the carbon content of production and consumption for the regions in the model these are converted using conversion coefficients from the CDIAC CO₂ Glossary (1990). To convert production data into value terms, we use price information from World Resources 1990-1991.

To incorporate the benefit side of slowed global warming, we have extended the preference functions for each of the regions identified in the earlier Whalley-Wigle model to include not only goods directly consumed, but also the disutility associated with temperature change, which in turn is linked by a simple linear relation to carbon emissions. This, in effect, involves an additional level of nest within the utility function U_i to capture this component. For each region, goods consumed (G_i) are region specific, but global carbon emissions are common to all regions. G_i in turn is a composite of the goods identified in Table 2 in preferences (EL_i , OG_i , CP_i). The link between global carbon emissions and temperature change thus directly reflects the global externality associated with global warming.

Important values in the parameterization of preferences toward climate change are the elasticity

of substitution between temperature change and produced goods, and the marginal valuation of reduced global warming. Cobb Douglas preferences over temperature change and produced goods are assumed. The marginal valuation of reduced global warming is calculated assuming the elasticity of the marginal valuation of temperature change with respect to income is 1.5. Per capita income and the population in each region combine to determine the values of parameters used in each case.

While this change in the model is conceptually straightforward, and parallels the analysis of public goods in the public finance literature (see Atkinson and Stiglitz (1989)) there are major problems with numerical specification of these preference functions in a model such as this. As is by now well-known, there are no widely agreed estimates as to how large or small the benefits of a slowing of global warming are. On the other hand, there are suggestions such as those in Nordhaus (1990) and Schelling (1990), that the benefits of slowing global warming are likely quite small. Nordhaus puts these at no more than three-quarters of one percent of GDP for the United States over a seventy-five year period, whereas Schelling suggests that these are so imperceptibly small and likely to take place over a long period of time (say seventy-five years) that they would be little noticed by most individuals. On the other hand, economists such as Cline (1991) have argued that with a possible septupling in levels of carbon dioxide in the atmosphere by the end of the next century, the potential costs associated with this are so large that emission reductions should be undertaken immediately. He emphasizes how most debate on the global warming has focused on the consequences of a doubling of atmospheric CO₂ by the middle of the next century, for which temperature rise could be modest, rather than on the larger increases in CO₂ content which would occur in the century to follow and for which the consequences are more alarming.

While our analysis of incentives to participate in sub-global carbon reduction initiatives would

obviously be more convincing if there were a firmer fix on the size of the possible benefits involved, given the profile of the policy debate we think it is nonetheless instructive to make calculations based on various assumptions on the benefit side. What we have done, therefore, is to assume that calls for emission reductions voiced at various international conferences would be consistent with a global optimal allocation if they were implemented on a full participatory basis. We then evaluate incentives for various sub-global arrangements relative to that reference point. The call for emission reductions emerging from the 1988 Toronto conference (A 20 percent emission reduction by the year 2005, with a 50 percent emission reduction to follow to stabilize CO₂ content) provides the basis for the strongest of our assumptions: that a 50 percent carbon emission reduction by all regions corresponds to a global full participation externality correcting intervention. We are then able to analyze incentives for various sub-global initiatives to be pursued by including sub-groups of two or three countries or regions.

The parameterization of the extended version of the Whalley-Wigle model, therefore, allows for calibration of preferences, with both the preference and production side parameters being correspondingly generated. Counterfactual analysis then allows us to compute the implications of various carbon reduction relative to the base case scenario for the model, given assumptions on the form of full participation carbon emission reduction, and the decision criterion for the size of the cut. If a 50% reduction is assumed to be a full participation optimum, the question we pose is how large is the go it alone cut for the U.S., the E.C., the U.S. plus the E.C., the OECD countries, and so on.

3. RESULTS

If global negotiations on carbon reduction initiatives are taken further in the next decade, the incentives to free-ride, particularly for the smaller countries may well be such that less than full global participation is the outcome. Despite such an outcome, however, individual countries or regions may nonetheless have an incentive to participate in reduction initiatives by sub-groups of countries, such as the OECD countries, the EC and the U.S., or pursue go-it-alone incentives. The intuition is that the smaller the group of countries involved, the smaller the incentive to make large cuts in carbon emissions because of the spillover of benefits to other countries³.

We have used the model described earlier including the specification of regional preferences towards global warming to investigate how large these incentives are. We use a series of model runs in which we compute what we call the 'maximum consensus emission reduction' for various groups of countries or regions in the model, given the assumed optimality of a full participation equilibrium at various levels. These maximum consensus reductions are the minimum of the joint participation emission reductions that each member of a group of countries or regions would be willing to undertake on a sub-group basis, using the criterion that no country is made worse off by participating. It should be noted that in the single country case, this is not the optimal single country cut, but that cut equivalent in welfare terms to no cut. Such cuts are therefore typically larger than optimal cuts in the single country case.

Table 3 reports results for twelve combinations of countries and regions cutting consumption of carbon based energy. We initially report the six individual region go-it-alone cases, calculating the cuts implied by the parameterization and model specification described earlier, and then report

³ See Brainard (1967) and Mansur and Whalley (1982) for further analysis of spills and spillouts.

results for various combinations of regions. The maximum go-it-alone emission reduction is 30 percent for the EC and 29 percent for North America, with 22 percent for the Soviet Union, China and other developing countries reflecting the large population concentration in these countries and hence the strength of the externality effects associated with reductions in carbon emissions.

Table 3

**Sub-Global Maximum Consensus Carbon Emission Reductions⁴ under
Calibration to a 50% reduction full participation global optimum**

**Cuts in Carbon Emissions
over 40 years**

Regional Grouping						Maximum Consensus Regional Cut %	Implied Global Cut in New Equilibrium %
E.C.	NAM	JPN	ODV	OIL	ROW		
X						30	1.1
	X					29	2.8
		x				17	0.2
			X			7	0.1
				X		22	4.2
X	X					42	6.0
	X	X				34	3.4
X			X			34	1.6
X	X	X				45	7.5
X	X	X	X			47	9.0
X				X	X	24	7.7

⁴ These are all cases of reductions in consumption by participating regions.

These results suggest that for the U.S. (NAM) and the E.C. that if 50 percent is the optimal full participation equilibrium reduction, the maximum non-losing go-it-alone cut for these regions is more than one-half of this. Even for Japan the go-it-alone cut is 17 percent. Hence, the incentives for carbon emission reductions remain high, even without a full participation global treaty.

The reason for these striking results is that, in this model, with smoothly substitutable preferences and technology there is diminishing marginal utility to slowed global warming, while (from Harberger's rule and ignoring the global externality effects) there are increasing marginal welfare costs of emission reduction through carbon-based energy taxes or quotas. Hence small reductions are at higher marginal benefits and lower marginal cost than is true with larger reductions. Hence, with the U.S. and E.C. each accounting for around one-quarter of gross world product, their go-it-alone emission reduction is still one-half the assumed global full participation reduction. For Europe and North America taken together, the maximum consensus emission reduction jumps to 36 percent, which in turn jumps to 42 percent if Japan is added into the coalition. For the group of all OECD countries, the maximum consensus emission reduction remains at 47 percent, in contrast to the assumed 50 percent optimal full participation cuts. Thus the OECD countries, in combination, would on these criteria be prepared to undertake a cut of approximately nine tenths of the optimal global cut, despite the fact that China and the Soviet Union between them constitute around 30 percent of global emissions of carbon. The same feature of the shape of marginal cost and marginal benefit schedules in the model accounts for this result.

Table 4 reports results showing the differences involved with sub-global incentives for emission reduction, depending upon whether these are production or consumption-based cuts. For global reduction schemes, this should make little difference outside of any revenue disbursement effects involved, but sub-globally it makes a big difference since consumption reductions are localized to

the country involved on the consumption side, while production reductions more directly affect global markets.

Table 4

**Differences Between Production versus Consumption-Based Carbon
Emission Reduction Initiatives**

	% Maximum Consensus Cut in Carbon Emissions			
1. OECD Regions Separately	E.C.	NAM	JPN	ODV
Production Measure	36	55	12	7
Consumption Measure	30	29	17	7
2. Region Groups	E.C.+NAM		OECD	
Production measure	72		77	
Consumption measure	42		47	

Maximum consensus production reductions, even on a go-it-alone basis, are typically larger than comparable consumption reductions. This is an important result indicating differences from a national point of view between consumption and production emission reductions, even though these may not be present at a global level. It is a direct reflection of the relative elasticities on production and consumption.

These results, therefore, highlight a feature of emission reduction initiatives not thus far widely appreciated in the literature; namely, the difference between regional incentives to make production or consumption reductions. Reducing production in one country induces other countries to increase production through the associated effect on prices, rather than localize the effect to the region in which the emission reduction takes place.

Table 5 highlights a further important difference between different types of sub-global emission reduction initiatives, illustrating how different sub-global carbon reduction initiatives can come into play under different arrangements. We consider cases of production and consumption reduction initiatives with and without constraints which maintain production and/or consumption at the same levels in the non-participating countries as in the base case in the model. In practice, this might involve a scenario in which larger countries (the E.C., the U.S.) use trade or other sanctions to prevent non-participant countries increasing consumption of carbon-energy-based products following a consumption reduction in the U.S. and lowered world energy prices.

Table 5

The Importance of Quantity Constraints on Non-Participant Activity in Evaluating Sub-Global Carbon Emission Reduction Incentives

	% Maximum Consensus Cut in Carbon Emissions	% Reduction in Global Carbon Emissions
1. E.C.		
Production measure, no constraint	36	1.9
Production measure, with constraint	57	4.2
Consumption measure, no constraint	30	1.1
Consumption measure, with constraint	60	8.7
2. E.C. and NAM		
Production measure, no constraint	72	18.6
Production measure, with constraint	88	27.3
Consumption measure, no constraint	42	6.0
Consumption measure, with constraint	69	28.0
3. E.C., NAM, JPN, ODV		
Production measure, no constraint	77	18.6
Production measure, with constraint	91	30.4
Consumption measure, no constraint	47	9.0
Consumption measure, with constraint	69	28.8

The differences between these results are striking. With such a constraint the go-it-alone emissions reductions are larger than the full participation optimal cut, in part due to associated terms of trade effects.

Table 6 reports changes in consumption of carbon-based energy and of carbon-based energy production in a number of cases, indicating the spillover effects between alternative cases. For instance, a 30% consumption cut in the EC generates a 3-5% energy production increase in the other regions, and only a 1.2% reduction globally. Terms-of-trade effects are also significant, strongly emphasizing their role in the results discussed above.

Finally in Table 7, we report some model sensitivity analyses for maximum consensus emission reductions under different elasticity assumptions, calibration specifications, and other model assumptions. What emerges is a reasonable robustness of results for the EC+NAM coalition. In each case, the value of the maximum consensus cut moves in the expected direction, increasing for higher carbon energy supply elasticities, and decreasing for calibration to an optimal 25% cut. Higher elasticities between carbon and non-carbon energy make little difference. The difference between production and consumption based cuts is less when the size of the optimal cut to which we calibrate the model in the base case is reduced.

Table 6

**Impact of Sub-Global Arrangements on Consumption, Production, and
Terms-of-Trade**

	Maximum Consensus Cut in E.C. Consumption	Maximum Consensus Cut in E.C. + NAM Consumption	Maximum Consensus Cut in OECD Consumption
% Change in Carbon- Based Energy Production in: (base=100)			
E.C.	99.4	94.8	93.0
NAM	98.8	95.4	93.6
JPN	98.9	94.0	92.6
ODV	98.9	93.9	92.8
OIL	98.8	93.6	91.5
ROW	98.7	93.3	91.1
% Change in Carbon-Based Energy Consumption in: (base=100)			
E.C.	70.0	58.0	53.0
NAM	103.3	58.0	53.0
JPN	104.3	122.9	53.0
ODV	103.6	119.6	53.0
OIL	103.4	118.9	126.6
ROW	103.3	118.4	125.4
Total Carbon Energy	98.8	94.0	91.9
% Change in Terms-of-Trade of: (base=100)			
E.C.	103.4	118.7	125.8
NAM	103.3	118.3	125.0
JPN	103.4	118.9	125.2
ODV	101.3	105.4	108.2
OIL	96.9	84.5	80.0
ROW	100.6	103.6	103.8

Table 7

Sensitivity of Maximum Consensus Emission Reductions to Model

Specification

E.C. + NAM Sub-Group	% Maximum Consensus Cut in Carbon Emissions
1. Base Case: consumption production	42 72
2. Increase energy supply elasticity to 1.0: consumption production	54 82
3. Calibrate to a 25 percent full participation cut rather than a 50% cut: consumption production	22 22
4. Increase carbon/non-carbon energy substitution elasticity in model to 3.0: consumption production	42 72

4. CONCLUDING REMARKS

In this paper, we use an earlier model due to Whalley and Wigle to analyze the incentives for countries to undertake sub-global carbon reduction initiatives under various assumptions. We extend the consumption side of the earlier Whalley-Wigle model to include a representation of preferences with benefits of slowed global warming. We emphasize the problems in calibrating models of global warming as far as the benefits which may follow any reduction in global warming are concerned, and are only able to calibrate the model under strong assumptions. We use as our reference point that one of the current proposals for carbon reduction initiatives is consistent with a full participation global optimal allocation. This then enables us to analyze incentives for sub-global carbon reduction emissions relative to the reference point.

Some important themes emerge from our results. The go-it-alone cut for the EC and the U.S. (North America) is (in percentage terms) about two thirds of the calibrated global cut. For the OECD countries in combination, over nine tenths of the globally optimal cuts would remain as a sub-global participation initiative for these countries. These large go-it-alone cuts reflect the model generated marginal benefit and marginal cost schedules of reduced global warming. Marginal cost schedules are accelerating in the depth of cut, reflecting Harberger's triangle rule, while marginal benefit schedules are decelerating reflecting diminishing marginal utility of slowed global warming. As a result, even with the large spillover effects on the benefit side, the U.S. and the E.C. each have an incentive for a go-it-alone reduction equal to one-half of full participation global reductions.

Important differences in sub-global reduction initiatives also emerge from our results, particularly differing country incentives to undertake production or consumption reductions. Production reduction initiatives have the effect of increasing global producer prices and, therefore, increasing production in other regions. Consumption reduction initiatives are more localized to the country

undertaking such a measure, reducing world prices and increasing consumption in other regions. Terms-of-trade effects also emerge from model results as important, and tend to compound with crossover effects from slowed emission reduction, and reduced energy consumption or production.

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APPENDIX A

Elasticities in the Model

In the model, the implied demand and supply elasticities for carbon-based energy products are important parameters as far as the effects of carbon emission reduction initiatives are concerned. The values of these elasticities are not directly specified in the model formulation, but instead reflect preferences and intermediate production technology on the demand side, and the relative importance of fixed and variable factors in carbon-based energy production (oil in the ground versus extraction costs) and the marginal productivity of variable factors in this production process on the supply side.

We are able to solve the model under varying carbon energy product supply elasticity assumptions relatively easily, since in the special case where the production function for carbon-based energy products is Cobb-Douglas, the supply elasticity is given simply as $1-\theta/\theta$ where θ is the share parameter on the carbon resource input in the carbon-based energy product production function.

Surprisingly, there are relatively few estimates of energy supply elasticities in the literature; most estimation is concerned with income and own-price elasticities on the demand side, or interfuel substitution elasticities (see Kouris [1981] and Pindyck [1979]). The supply elasticities that have been estimated are mainly for OPEC countries, and focus on strategic supply response over relatively short periods of time; not the longer run elasticities at issue here which reflect exploration and extraction cost functions.

The ease with which the composite energy output can be produced from varying mixes of energy inputs (carbon and non-carbon-based energy), and the ease of substitution between composite

energy and the two non-energy products in consumption are the model features which affect the elasticity of demand for energy. In the absence of any literature estimates of the elasticity of input substitution in composite energy production, we set this equal to 1.0. This reflects two competing factors. First, for many industrial and home purposes (such as heating), it is relatively easy to substitute between fossil fuels and electricity. At the same time, substitution between fossil and non-fossil fuels is not as easy in transportation. Literature on elasticity estimation for industrial electricity demand (see Nainar [1989]) provides some support for a range around the value we use.

In the final demand function involving composite energy and the two non-energy final products, the CES function used has an elasticity of substitution set equal to 0.5. A demand elasticity for energy in this range is consistent with that suggested by several studies of the long-run demand for energy (see Pindyck [1975], Kouris [1981], Nguyen [1986], Hunt and Manning [1989], Considine [1989], and Estrada and Fugleberg [1989]).

Since all of the traded goods produced in each of the three regions are perfect substitutes, the model does not employ the Armington structure of product heterogeneity by region for traded goods common in other applied general equilibrium models. Trade elasticities therefore play no direct role in calibration.

WORKSHOP ON
ISSUES IN INTERNATIONAL ECONOMICS: QUESTIONS TO AND ANSWERS FROM
COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

JULY 8-9, 1991
UNIVERSITY OF KONSTANZ

MONDAY, JULY 8, 1991

10.00 Opening Address

Wolfgang Franz (Dean, University of Konstanz)

Bernd Genser (University of Konstanz)

"General Equilibrium Economics: Computation and Application"

John Whalley (University of Western Ontario)

11.00 Session 1: International Taxation

"Value-Added Tax Harmonization in the EC"

Wolfgang Wiegard/Hans Fehr/Christoph Rosenberg (University of Regensburg)

"Commodity Tax Reform under the Restricted Origin Principle"

Andreas Haufler (University of Konstanz)

14.30 Session 2: Factor Supply

"Simulation Models of Labour Supply"

Alan Duncan (Institute for Fiscal Studies, London)

"An Intertemporal General Equilibrium Model for Austria with Application to Foreign Trade"

Christian Keuschnigg (University of Bonn)/Wilhelm Kohler (University of Innsbruck)

17.00 Session 3: Environment

"CGE Modelling of International Public Goods: Air Quality and Global Warming"

John Piggott (University of New South Wales)

TUESDAY, JULY 9, 1991

09.00 Session 4: Imperfect Competition and Growth

"AGE Models in International Economics with Special Reference to Imperfect Competition and Increasing Returns to Scale"

Albert Schweinberger (University of Konstanz)

Growth and International Capital Movement: A Simulation Study

Karl-Josef Koch (University of Konstanz)

(presentation cancelled due to accident)

10.45 Round Table: "The Payoff of Investment in CGE - Modelling"

Chair: Bernd Genser

Introductory Statements:

John Chipman (University of Minnesota)

Friedrich Schneider (University of Linz)

Closing Address: Bernd Genser