MIT Joint Program on the Science and Policy of Global Change

Sharing the Burden of GHG Reductions

Henry D. Jacoby, Mustafa H. Babiker, Sergey Paltsev, and John M. Reilly

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This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

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Henry D. Jacoby[†], Mustafa H. Babiker, Sergey Paltsev, and John M. Reilly

Abstract

The G8 countries propose a goal of a 50% reduction in global emissions by 2050, in an effort that needs to take account of other agreements specifying that developing countries are to be provided with incentives to action and protected from the impact of measures taken by others. To help inform international negotiations of measures to achieve these goals we develop a technique for endogenously estimating the allowance allocations and associated financial transfers necessary to achieve predetermined distributional outcomes and apply it in the MIT Emissions Prediction and Policy Analysis (EPPA) model. Possible burden sharing agreements are represented by different allowance allocations (and resulting financial flows) in a global cap-and-trade system. Cases studied include agreements that allocate the burden based on simple allocation rules found in current national proposals and alternatives that specify national equity goals for both developing and developed countries.

The analysis shows the ambitious nature of this reduction goal: universal participation will be necessary and the welfare costs can be both substantial and wildly different across regions depending on the allocation method chosen. The choice of allocation rule is shown to affect the magnitude of the task and required emissions price because of income effects. If developing countries are fully compensated for the costs of mitigation then the welfare costs to developed countries, if shared equally, are around 2% in 2020, rising to some 10% in 2050, and the implied financial transfers are large—over $400 billion per year in 2020 and rising to around $3 trillion in 2050. For success in dealing with the climate threat any negotiation of long-term goals and paths to achievement need to be grounded in a full understanding of the substantial amounts at stake.

Contents

1. INTRODUCTION

In response to the ever-clearer threat posed by climate change the G8 countries have adopted a goal of a 50% reduction in global emissions by 2050. Together with existing developed-country commitments and proposals, and equity principles written into various climate

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agreements, this target provides a starting point for consideration of a post-2012 climate agreement. Success in upcoming negotiations should be aided by a clear-eyed view of the implications of this confluence of emissions targets and equity goals, and the analysis that follows is intended as a contribution to this important international process.

While the 50% target resides in statements of the major industrialized countries it is clear that meeting it will require participation of countries beyond that small group, [1] and the Climate Convention and subsidiary agreements lay out broad terms of reference for sharing the task. For example, the Convention and the Kyoto Protocol divide the world into a set of developed countries (Annex I) and developing countries (Non-Annex I) with "common but differential responsibilities". The Bali Action Plan, setting the terms for long term cooperative action for the post-2012 period, reflects this equity principle and emphasizes the need for "positive incentives for developing country Parties for the enhanced implementation of national mitigation strategies and adaptation action." Among the responsibilities of the developed countries is to provide financial and other resources to "meet the specific needs and concerns of developing country Parties arising from adverse effects of climate change and/or *the impact of the implementation of response measures*" (Climate Convention, Article 4.8, italics added). Note that the language stipulates that developed countries should cover not only the direct costs of mitigation measures within the developing countries, creating incentives to take on commitments, but provide compensation for the indirect effects of emissions mitigation undertaken elsewhere.

We analyze this set of objectives in the context of a global emissions trading scheme. One attraction of emissions trading is that the allowance allocation mechanism provides a means for altering the distributional effects of an emissions target while equating marginal costs of reduction among those participating in trade. Thus in principle an international trading regime can be designed so that allowance allocations take care of developing country concerns about costs while ensuring the adoption of least-cost abatement opportunities. Note, however, that the insights drawn from this analysis are not limited to agreements based on universal cap and trade. For example, reductions could be achieved instead with a harmonized carbon tax, augmented by side payments equal to the level of the financial flows we show as necessary to meet burden-sharing objectives. While strictly speaking the analysis is based on implementation of a highly

[1] A 50% global reduction is closest to the tightest target considered in the US CCSP (2007) study, which achieves CO_2 stabilization at 450 ppmv.

efficient policy mechanism such as cap and trade or a CO_2 tax, the results might still be used to inform negotiations on levels of international compensation while allowing countries to implement reductions using policy mechanisms of their choice. In that case, the welfare costs and CO_2 prices would obviously differ from the results shown here, which, in any case, depend on the specific assumptions about future economic growth and technology and resource availability.

While actual international agreement may fall short of ideal solutions ,the analysis of such policies can help inform judgments about the nature of the challenge ahead. To explore possible burden sharing in this context we develop a technique for endogenously estimating the allowance allocations necessary to achieve predetermined distributional outcomes, implemented within the MIT Emissions Prediction and Policy Analysis (EPPA) model, and apply this facility to abatement scenarios that would bring the world to 50% below year 2000 emissions by 2050. We consider a variety of possible policy architectures and explore the allowance allocations, and the associated financial flows under a trading regime, that are consistent with particular distributional goals.

Note that our focus is on mitigation costs only. Under the Climate Convention developed countries are also responsible for helping developing countries adapt to climate change. If achieved, the mitigation goal proposed by the G8 would avoid some of the projected change and lessen the economic cost of adaptation assistance. Our estimate of financial flows to compensate developing countries does not include consideration of amounts that might be needed to meet this obligation, or the effects of residual climate change itself. Also, our analysis does not take account of the potential for welfare-enhancing reductions in energy subsidies, which are particularly prominent among the energy exporters.

Our presentation of the analysis begins, in Section 2, with a description of the EPPA model and the endogenous instruments used to simulate mitigation policy while achieving distributional goals. In Section 3 we present the reference scenario of greenhouse gas emissions that will underlie the analysis and summarize the policy scenarios to be considered. Section 4 then presents a comparison of costs and financial flows under allowance allocations motivated by current policy proposals, and these are contrasted with cases where allowances are allocated endogenously to either fully or partially compensate developing-country parties for their burdens associated with the global effort, including both direct costs (mitigation expenses) and indirect costs (e.g., terms-of-trade effects).[2] We also explore different assumptions about the distribution of mitigation and compensation burdens among developed regions, comparing proportional reduction to an allocation that imposes the same welfare loss on all. In Section 5 we summarize our findings and speculate about their implications for post-2012 negotiations.

2. THE EPPA MODEL AND ENDOGENOUS ALLOCATION

2.1 The EPPA Model

The Emissions Prediction and Policy Analysis (EPPA) model is a general equilibrium model of the world economy resolved for sixteen individual countries and regional groups that has been developed in the MIT Joint Program on the Science and Policy of Global Change (Paltsev et al., 2005). It is designed to provide scenarios of anthropogenic greenhouse gas emissions and to estimate the economic impact of climate change policies either as a stand-alone model or as part of a larger Integrated Global Simulation Model (IGSM) of the climate system (Sokolov et al., 2005). For economic data the EPPA model relies on the GTAP dataset (Dimaranan and McDougall, 2002), which accommodates a consistent representation of regional macroeconomic consumption, production and bilateral trade flows. Energy data in physical units are based on energy balances from International Energy Agency. Additional data for greenhouse gases (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) are from inventories maintained by the United States Environmental Protection Agency. For data on other air pollutants (sulphur dioxide, SO_2; nitrogen oxides, NO_x; black carbon, BC; organic carbon, OC; ammonia, NH_3; carbon monoxide, CO; and non-methane volatile organic compounds, VOC) we rely on the global EDGAR data (Olivier and Berdowski, 2001).

Regions, sectors, and primary factors are shown in **Table 1**. For the most part, regional groupings attempt to include contiguous areas. The sectors and primary factors are disaggregated to focus on energy demand, supply, resource use and depletion, and key technology alternatives to fossil fuel use. The model can be solved recursively or dynamically at five-year time steps. Solving the model as a fully dynamic problem requires some sacrifice of detail and so here we solve it recursively. The EPPA model production and consumption sectors

[2] The terms of trade is defined as the prices of a country's exports in relation to the prices of its imports. In this analysis a main concern is the effect on energy exporters of a reduction in oil, gas and coal prices, leading to deterioration in their terms of trade.

are represented by nested Constant Elasticity of Substitution (CES) production functions (or the Cobb-Douglas and Leontief special cases of the CES). The model is written in the GAMS software system and solved using the MPSGE modeling language (Rutherford, 1995). The model has been used in a wide variety of policy applications (e.g., Babiker et al., 2004; US CCSP, 2007; Paltsev et al., 2007; Paltsev et al., 2008).

Table 1. Regions, Sectors, and Primary Factors in the EPPA Model.

Country or Region†	Sectors	Factors
Developed	***Non-Energy***	Capital
United States (USA)	Agriculture (AGRI)	Labor
Canada (CAN)	Services (SERV)	Crude Oil
Japan (JPN)	Energy-Intensive Products (EINT)	Natural Gas
European Union+ (EUR)	Other Industries Products (OTHR)	Coal
Australia & New Zealand (ANZ)	Transportation (TRAN)	Shale Oil
Former Soviet Union (FSU)	Household Transportation (HTRN)	Nuclear
Eastern Europe (EET)	Other HH Consumption	Hydro
Developing	***Fuels***	Wind/Solar
India (IND)	Coal (COAL)	Land
China (CHN)	Crude Oil (OIL)	
Indonesia (IDZ)	Refined Oil (ROIL)	
Higher Income East Asia (ASI)	Natural Gas (GAS)	
Mexico (MEX)	Oil from Shale (SYNO)	
Central & South America (LAM)	Synthetic Gas (SYNG)	
Middle East (MES)	Liquids from Biomass (B-OIL)	
Africa (AFR)	***Electricity Generation***	
Rest of World (ROW)	Fossil (ELEC)	
	Hydro (HYDR)	
	Nuclear (NUCL)	
	Solar and Wind (SOLW)	
	Biomass (BIOM)	
	Coal with CCS	
	Adv. gas without CCS	
	Gas with CCS	

† Specific detail on regional groupings is provided in Paltsev *et al.* (2005).

2.2 Endogenous Instruments for Policy Targets and Distributional Goals

The GAMS-MPSGE algorithms applied in the EPPA model conveniently allow constrained solutions. Thus the shadow value of a CO_2 emissions constraint can be interpreted as the price that would result if the CO_2 target were implemented by a cap-and-trade system. The EPPA model is set up so that caps can be specified separately for each country, each sector within a country, and for each major greenhouse gas. The option then exists to create markets that allow trading of allowances among any of these separately capped regions, sectors, or gases where trading equilibrates the marginal cost of abatement as observed by the trading entity.[3] Trading among gases occurs at Global Warming Potential (GWP) exchange rates which can be set to other values if desired or as GWPs change. For this analysis, we enforce the cap on total greenhouse gas emissions with trade among all sources, sectors, and regions except where we exclude some regions from the policy. Land use emissions and/or sinks are not explicitly capped and no incentives are provided to enhance sinks.

In this analysis it is assumed that any allowance revenue is returned to the representative consumer in each region in a lump-sum manner. This assumption is consistent with a cap-and-trade system under competitive conditions where allowances are distributed free or are auctioned with the revenue distributed as a lump sum. Under these conditions how the allowances are distributed within a country does not affect production (or abatement) decisions.[4] For example, lump-sum free distribution to firms will be a windfall gain to them, whose value will increase the equity value of the firms or otherwise be distributed to shareholders of the firm and therefore increase the value of stocks held by households (our representative consumer). But that distribution will not affect decisions by the firm. It will abate based on the GHG price observed in the allowance market recognizing the opportunity cost/value of any free allowances it was awarded. If instead allowances are auctioned the firm would see the same price and abate the same amount. This approach does not consider other uses of funds such as using revenue from an allowance auction to replace existing distortionary taxes, support energy R&D, eliminate possible market failures in energy efficiency, or alter within-country distributional outcomes of the policy.

Emissions targets and distributional objectives are jointly implemented in the EPPA model through the use of an endogenous procedure developed for this study. These instruments allocate emissions allowances among parties in such a way that the targeted mitigation and distributional goals are achieved simultaneously. Two forms of endogenous instruments are used

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[3] GAMS-MPSGE solves the model as a mixed complementarity problem—that is, it finds equilibrium in factors and goods markets. Under idealized conditions—perfect competition, small open economy or a closed economy, no market distortions—this is consistent with a welfare maximization. In the presence of distortions, taxes, terms of trade effects and the like the solution represents a market solution; consumers and producers are optimizing on the basis of distorted prices and without considering the economy-wide impact of their actions on terms-of-trade. Thus, in the presence of distortions it is possible that there is a solution that is better in welfare terms than an unfettered emissions trading system.

[4] As noted below, different allocations among countries lead to differences in global price and cost because of income effects.

to simulate the policy cases. One such internal procedure is needed to simulate the allocations (and resulting financial transfers from emissions trading) required to compensate the mitigation-associated costs of developing countries. Another must be employed to simulate the requirement that the same percentage welfare burden be imposed across developed regions. While these two approaches differ from a technical standpoint they both use mechanisms that (re)allocate allowances to achieve specific welfare cost targets in different regions.

Though a full description of this technique is beyond the scope of this discussion, it may be briefly described. The first endogenous instrument starts from a given global allocation of allowances among countries and determines a reallocation of them such that the welfare cost of mitigation in developing countries is capped at a given level while meeting the global emissions reduction target. Technically, the implementation of this scheme involves two components: one determines the allowances needed by each participating developing countries to achieve the distributional objective, and a second to scale back developed countries emissions allowances so that the overall global emissions reduction target remains fixed. We apply this procedure by scaling back emissions allowances proportionally in each developed country and so the economic consequences depend on the original distribution of allowances.

Another potential outcome simulated for this paper involves equating the welfare-cost of mitigation in percentage terms across developed countries while again limiting costs in developing countries. To achieve this result a second, global allowance-allocation instrument, starts from a global emissions reduction target and simply allocates it across countries to meet the developed and developing country objective. The technical implementation of this scheme in EPPA makes use of one endogenous instrument to allocate emission allowances among parties, and a second to ensure that the overall reduction target is exactly met.

3. REFERENCE PROJECTION AND 2050 POLICY GOALS

3.1 A Reference Projection

The reference projections for this study, for developed (Annex I) and developing (Non-Annex I) parties, are shown in **Figure 1**. Estimates of abatement costs to meet a specific fixed policy target depend strongly on this baseline or "reference" case level of emission. A decade or so ago a reference projection with no climate policy was reasonably considered a "business-as-usual" scenario. We are moving into an era where some mitigation measures are already in place, so differences emerge between a reference case with no policy and a business-as-usual scenario that includes policies and measures already on the books. Where existing climate policies are explicit and underway such as the European Emissions Trading Scheme (ETS) or national Kyoto commitments it is fairly clear that they should be considered for inclusion under a business-as-usual projection. However, if the focus is on the full cost of greenhouse gas mitigation, and calculation of what carbon prices may be in the future, there is a need to start from a counterfactual or reference case absent the ETS and other policies already in place. For purposes of this analysis of various scenarios of policy development the appropriate reference, for comparison with various scenarios of policy development is a case without existing mitigation measures. As a result of this assumption the reference emissions projection will not include the effect of the ETS and other commitments made within or outside the Kyoto Protocol.[5] Also, measures of welfare cost will include the influence of these policies already undertaken.

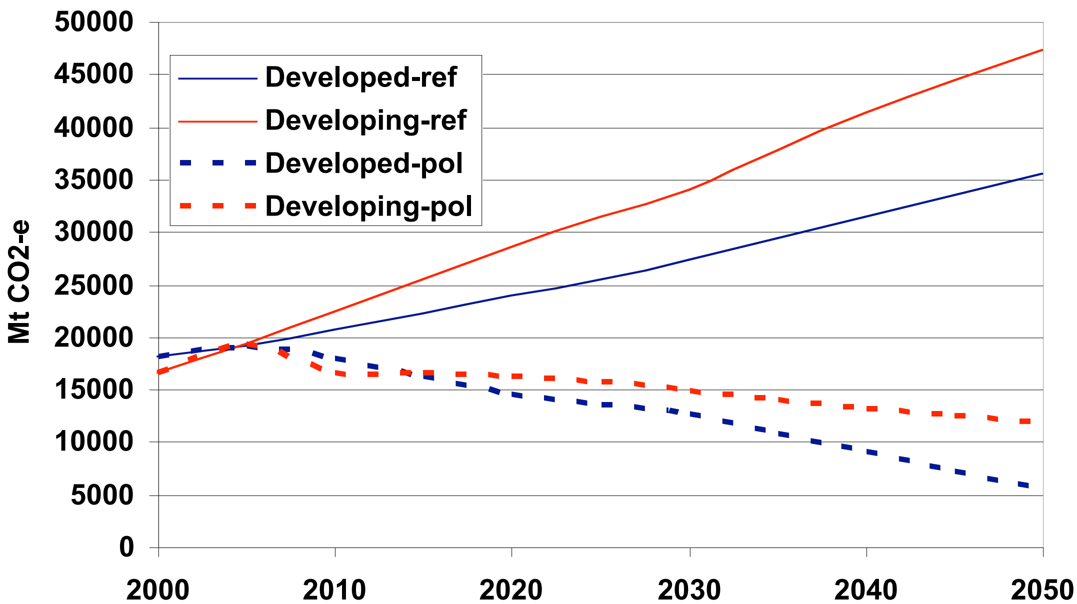

Figure 1. Developing and Developed Country Emissions.

This reference projection is similar to that underlying the EPPA-derived results in a multi-model study conducted for the US Climate Change Science Program (US CCSP, 2007). It has emissions growing relatively rapidly through 2050, not unlike central forecasts of the International Energy Agency and the Energy Information Administration. For the US, economic

[5] The total of reference emissions in 2050 in Figure 1 is 83 $MtCO_2$-e. If existing commitments under the Kyoto protocol were taken into account, and maintained for 2008-2050, the 2050 projection would be reduced to 73 $MtCO_2$-e.

and emissions growth are closer to the EIA projections in 2007. In 2008 the median EIA projection of US economic growth was revised downward, leading to lower energy and emissions growth. Hence emissions growth in the developed-country aggregate is somewhat more robust than other projections that either include emissions mitigation actions already on the books or have been subject to recent revision. On the other hand, early decade projections for China appear to be below the growth actually experienced in the past few years. [6] All these projections are well within the range of uncertainty about future growth in emissions, to 2020 and even more clearly for 2050 (Webster et al., 2008).

Finally, all fuel and energy price in EPPA are determined endogenously and so they reflect underlying long-term factors. The rapid increases in oil prices that appear to have peaked in 2008 are not simulated or reflected in the model results. Since the model solves on a five-year time step, 2008 is not even a solution year, and thus it cannot represent project volatility over days, months, or even inter-annually. That said, the EPPA model projection for oil prices, in the absence of climate policy, has them nearly tripling from 2005 levels by 2050 thus reaching about $145 per barrel in 2005 dollars, though they rise gradually and do not exceed $100 until 2025.

3.2 Scenarios of Allocation and Compensation

The analysis is based on a set of seven scenarios, shown in **Table 2**, of international agreement that either implicitly or explicitly allocates the economic cost of abatement. All assume universal participation. The first three consider simple rules like fixed percentage reductions for Annex I vs. Non-Annex I parties (Case 1) and allocation based on population or ability to pay (Cases 2 and 3). These first three are discussed in Section 4.1. Cases 4 and 5, covered in Section 4.2, explore the implications of agreement by the developed countries to compensate the developing ones for all costs associated with emissions mitigation, and consider different ways to distribute the burden of this responsibility. The final two scenarios are designed to reveal the effects of only partial compensation of developing countries—one case allowing up to a 3% loss for all and another compensating energy exporting countries for the direct costs of mitigation but not their indirect costs (e.g., through terms-of-trade effects).

[6] Recent analysis by Blanford et al. (2008) suggests that many modeling exercise – e.g., those in the US CCSP (2007) study – underestimate the near term rate of increase in China's emissions. In this regard it is worth noting that the EPPA model shows the highest emissions of the three in the CCSP study.

Table 2. Scenarios of Allocation and Compensation.

Allocation Rule	
1. 30-70	2050 allocation with developed at 30% and developing at 70% of 2000 emissions
2. Pop based	Allocations based on share of 2000 population
3. GDP based	Allocations based on inverse share of year 2000 GDP per capita
Full Compensation of Developing Countries	
4. Full comp-equal alloc	Full compensation of all costs in developing countries with developed countries given equal allowances as a percentage of their year 2000 emissions
5. Full comp-equal cost	Full compensation of all costs in developing countries with developed bearing equal percentage costs
Partial Participation of Developing Countries	
6. 3% cost cap	Compensation so that no developing country region's welfare costs exceeds 3%, with developed countries given equal allowances as a percentage of their year 2000 emissions
7. Direct only	Compensation to developing countries for the cost of their participation but not for the indirect costs of developed country mitigation through terms of trade effects

Note: All scenarios achieve the global goal of 50% reduction of emissions from 2000 levels by 2050, linearly falling from 2015.

Several assumptions apply to all of these scenarios: Emissions caps are formulated to cover all GHG emission and are relative to 2000 emissions, and it is further assumed that an efficient cap-and-trade system within each country includes all sectors and all greenhouse gases. In addition, all cases involve international emissions trading. The one activity that is not included is land use—either emissions or possible enhancements of sinks. In principle, creating incentives for enhancing sinks could reduce policy costs, but an important contributor to abatement in our analysis is the availability of cellulosic ethanol which we credit as a zero carbon fuel. Thus, including land use emissions would raise the cost of that abatement option even as it might lead to additional abatement opportunities through sink enhancement or avoided deforestation. Exactly how sinks and land use emissions might be included in an international agreement is a critical topic identified under the Bali Action Plan but is beyond the scope of this analysis.

Not shown here are results of an investigation of the implications if full participation is not achievable. It has been suggested that negotiations would be easier if fewer countries were involved so talks could focus on the larger developed economies and major developing-country emitters like China and India. In this case, the 50% goal becomes infeasible: the participating regions are not able to meet the 2050 goal and also provide the full compensation for costs in participating developing nations without a contribution in emissions reduction from the excluded regions. Indeed, in these projections the 50% goal becomes unachievable if only a small number of parties is excluded. One case (not shown here) examined what happens if only two energy exporters regions, the Middle East and Africa, are left out of an agreement, perhaps as a result of disagreement about compensation for energy market effects. Pushing reductions in participating regions to the limit of the model's solution capability results in global emissions that reach just 38% below 2000 when only these two energy exporting regions are excluded, in part due to carbon leakage to these non-participating regions.[7]

4. RESULTS

4.1 Simple Allocation Rules

The first three cases in Table 2 involve simple allocation rules derived from existing proposals of ways that responsibility for emissions reductions might be shared among parties to a universal agreement. All three are intended to require greater effort by the developed countries of Annex I and thereby allocate more of the allowances (relative to 2000 emissions levels) to the developing countries of Non-Annex I. The *30-70* scenario gradually reduces the allowances allocated to developed countries to 30% of year-2000 emissions by 2050, a disproportionately larger reduction than the global 50% reduction goal, and it can be seen as an offer implicitly put on the table by developed countries.[8]

Given the global goal and a 30% figure for developed countries, the requirement for developing countries is a reduction to 70% of their 2000 level emissions by 2050. These calculations are independent of any projection but simply reflect the year 2000 emissions and an assumed linear reduction from 2015 to get to the 2050 target. These time paths of allocation also are shown in Figure 1. With a trading system there will emerge a common global CO_2-equivalent price, which is shown in **Figure 2** for this case. Actual emissions will not necessarily follow the 30% and 70% paths, which only form the basis for allocation; instead they will depend on where abatement actually occurs, which will be dictated by the market for allowances as it seeks out the

[7] Carbon leakage (an increase in GHG emissions in non-participating regions compared to their reference emissions) in 2050 in this case is 34% for Africa and 63% for the Middle East.

[8] Proposals in the U.S. Congress, like the Lieberman-Warner bill, and targets suggested in a number of state initiatives, would cut emissions by 70 or 80%. Similar proposals are put forward in Europe, such as the "Factor 4" objective, a fourfold reduction by 2050 supported by ministries of the French government..

lowest cost abatement options. Associated with this adjustment from initial allocation to realized emissions will be a flow of net financial payments among countries.

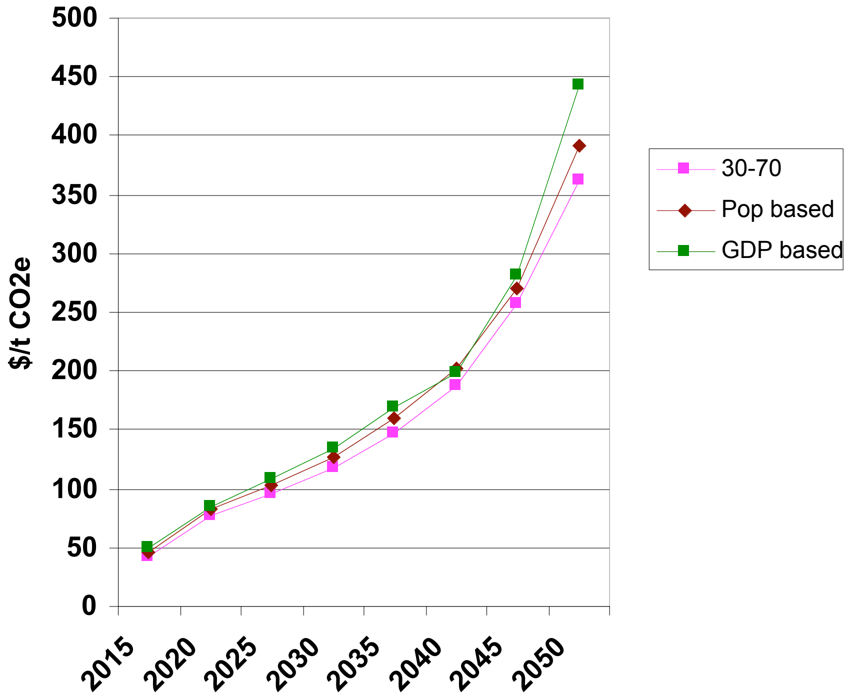

Figure 2. CO_2-e. Prices under Alternative Allocations Rules.

Generous though the *30-70* offer may appear, many developing countries would see a larger percentage welfare cost (approximately, the reduction in national consumption) than developed ones, as shown in the first column of **Table 3**. Among the Non-Annex I all but China experience welfare losses greater than does the US, and most carry a larger burden than the rest of the Annex I parties. The larger welfare costs among developing countries are largely a result of their more rapidly-growing emissions. The use of a historical-year benchmark will over time impose tighter constraints on countries with more-rapidly growing emissions. This phenomenon is familiar from the Kyoto experience where countries like Canada and Australia have rapidly growing emissions while Europe's are growing slowly, and relative to the benchmark year of 1990 Russia's emissions had actually fallen. The US and China see relatively small costs under a *30-70* rule because both use a lot of coal in power generation and large cuts are possible through the application of CO_2 capture and storage. The US also tends to gain through improvements in the terms of trade.

Table 3. Welfare effects in 2020 & 2050, universal participation (% change from reference).

	Allocation Rule			Full Compensation	
	30-70	*Pop based*	*GDP based*	*Full comp-equal alloc*	*Full comp-equal cost*
2020					
Annex I					
USA	-0.1	-2.8	-3.7	-1.3	-1.9
CAN	-2.7	-6.0	-5.9	-4.2	-1.9
JPN	-0.2	-0.8	-1.5	-0.7	-1.9
ANZ	-1.4	-4.9	-4.1	-3.0	-1.9
EUR	-1.2	-2.3	-3.5	-2.1	-1.9
EET	0.0	-5.0	5.4	-4.5	-1.9
FSU	-2.0	-8.4	-6.7	-7.7	-1.9
Non-Annex I					
MEX	-2.4	-2.9	1.2	**0.0**	**0.0**
ASI	-0.4	-3.4	-5.0	**0.0**	**0.0**
CHN	-0.1	5.3	-2.7	**0.0**	**0.0**
IND	-4.9	20.9	39.0	**0.0**	**0.0**
IDZ	-4.8	7.0	56.1	**0.0**	**0.0**
AFR	-9.1	7.6	14.3	**0.0**	**0.0**
MES	-18.2	-21.6	-18.8	**0.0**	**0.0**
LAM	-2.7	-1.7	-5.6	**0.0**	**0.0**
ROW	-1.9	10.2	12.2	**0.0**	**0.0**
2050					
Annex I					
USA	-2.6	-5.5	-7.2	-7.4	-9.4
CAN	-11.8	-15.6	-16.0	-18.1	-9.4
JPN	-2.6	-3.0	-4.3	-4.5	-9.4
ANZ	-6.3	-10.0	-9.1	-12.5	-9.4
EUR	-5.2	-6.3	-8.6	-8.9	-9.4
EET	-8.5	-11.6	3.4	-25.0	-9.4
FSU	-21.6	-24.5	-22.5	-41.0	-9.4
Non-Annex I					
MEX	-7.4	-11.2	-3.7	**0.0**	**0.0**
ASI	-4.3	-11.0	-14.0	**0.0**	**0.0**
CHN	-0.4	2.2	-7.7	**0.0**	**0.0**
IND	-11.4	21.0	48.9	**0.0**	**0.0**
IDZ	-15.8	-3.7	63.2	**0.0**	**0.0**
AFR	-28.5	-7.5	4.7	**0.0**	**0.0**
MES	-51.7	-61.0	-56.8	**0.0**	**0.0**
LAM	-12.2	-13.2	-20.0	**0.0**	**0.0**
ROW	-9.8	5.1	10.2	**0.0**	**0.0**

Note: Entries in **bold** indicate pre-specified welfare outcomes.

Notably, the large energy exporters—the Middle East (MES), Africa, Canada, Central and South America (LAM) and Russia (FSU) suffer larger losses, because of terms-of-trade changes in the other direction. The MES losses are dramatic—over 18% in 2020 rising to over 50% in 2050. This result is not surprising as much of the economy of this region revolves around oil production, and a stringent target extracts much of the rent associated with oil resources.

Table 4 shows the net financial transfers, as nations adjust through emissions trading from the initial allocation to the allowances needed under an efficient distribution of actual reductions. The 30-70 case is provided in the first column. The last line for 2020 and 2050, noted "AnxI net" is the total financial flow to developing countries. One might expect a *30-70* allocation to always lead to net purchases of allowances by developed countries, creating a financial flow to developing countries to provide some of the financial assistance agreed in international treaties. In fact, this "deal" actually results in some developing countries purchasing allowances. Several Non-Annex I parties are purchasing in 2020, and Indonesia (IDZ) and Central and South America are still purchasing in 2050. Because of its ability to abate emissions from coal relatively inexpensively in this scenario, China is the largest seller of allowances, and those sales substantially offset abatement costs. Interestingly, the Middle East (MES) is selling allowances in 2050, but the revenue is not enough to overcome the direct costs and terms-of-trade effects leading to their large losses (shown in Table 3).

For comparison with this *30-70* case two commonly-discussed alternatives are of interest. Some proposals are based on the notion that all global citizens have an equal right to the absorptive capacity of the atmosphere, and the *Pop based* scenario represents this equity goal by allocating allowances proportionally to year 2000 population. Other proposals hold that a fair allocation of burden would be based on ability to pay. To investigate the latter idea a *GDP based* scenario allocates according to the inverse of year 2000 GDP per capita, which gives the most allowances to the poorest countries.[9] **Table 5** (second and third columns) shows the allowance allocations under these rules. All but a few developing countries receive greater allocations than under a *30-70* rule (first column), and as a general pattern these allocations lead to large sales of allowances from Non-Annex I to Annex I parties (shown in Table 4) as these allocations will short the developed countries to a much greater extent than does the *30-70* allocation.

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[9] The share based on the inverse of per-capita GDP (pcgdp) for region r is calculated by the formula: share(r) = (1/pcgdp(r))/sum(r, 1/pcgdp(r)). The underlying GTAP data base on which the EPPA model relies converts all economic data for all regions to US dollars using market exchange rates prevailing in the base year.

Table 4. Net financial transfers, 2000 US$ billions, resulting from allowance trade in 2020 & 2050, universal participation (+ is sale, - is purchase).

	Allocation Rule			Full Compensation	
	30-70	*Pop based*	*GDP based*	*Full comp-equal alloc*	*Full comp-equal cost*
2020					
Annex I					
USA	-30.3	-368.7	-483.5	-196.7	-264.5
CAN	-2.7	-36.2	-36.4	-20.0	4.5
JPN	-13.1	-47.4	-92.6	-44.8	-118.9
ANZ	-5.2	-32.3	-29.2	-18.5	-8.8
EUR	-12.3	-127.7	-270.1	-116.9	-86.3
EET	8.6	-9.3	36.9	-9.9	3.2
FSU	41.0	-27.1	-9.1	-26.7	44.6
Non-Annex I					
MEX	0.1	-3.8	22.9	16.4	14.6
ASI	-23.7	-87.9	-122.8	-13.8	-14.9
CHN	69.4	222.5	26.7	73.9	74.4
IND	10.1	232.7	439.7	51.8	52.3
IDZ	-10.1	33.1	238.6	8.0	8.2
AFR	-10.8	154.9	220.0	81.2	79.3
MES	-32.3	-59.5	-40.2	119.4	116.5
LAM	-0.8	23.6	-57.1	62.7	61.3
ROW	12.2	133.1	156.0	33.9	34.4
AnxI net	14.0	648.7	883.9	433.5	426.2
2050					
Annex I					
USA	-179.6	-668.8	-1024.0	-1239.4	-1715.5
CAN	-35.7	-87.2	-93.6	-148.8	2.1
JPN	-172.8	-187.3	-288.6	-358.6	-942.1
ANZ	-30.1	-72.7	-70.3	-120.5	-78.6
EUR	-195.9	-299.9	-715.6	-866.1	-985.3
EET	-9.1	-15.5	119.4	-146.9	7.1
FSU	-44.2	-58.8	0.8	-434.3	299.9
Non-Annex I					
MEX	31.5	-9.2	66.7	108.4	110.1
ASI	130.5	-131.2	-241.3	355.8	363.8
CHN	484.0	577.1	80.8	589.0	578.3
IND	14.7	513.9	1056.3	176.4	189.5
IDZ	-40.9	32.9	574.1	85.0	91.2
AFR	43.4	373.1	609.7	543.0	558.7
MES	77.4	-15.4	51.1	761.1	797.3
LAM	-81.9	-158.6	-428.3	536.8	556.7
ROW	8.6	207.6	302.9	159.1	167.0
AnxI net	667.3	1390.3	2071.9	3314.6	3412.5

Table 5. Allowance allocations in 2020 & 2050 (% change relative to 2000 emissions).

	Allocation Rule			Full Compensation	
	30-70	*Pop based*	*GDP based*	*Full comp- equal alloc*	*Full comp- equal cost*
2020					
Annex I					
USA	80	20.5	1.7	49.3	37.3
CAN	80	21.2	21.7	49.3	92.0
JPN	80	48.4	8.1	49.3	-20.8
ANZ	80	20.9	29.6	49.3	71.7
EUR	80	44.2	3.6	49.3	57.7
EET	80	49.1	110.1	49.3	67.7
FSU	80	49.0	56.5	49.3	80.5
Non-Annex I					
MEX	98	88.3	144.7	134.2	129.8
ASI	98	56.5	33.3	104.4	103.6
CHN	98	130.8	78.9	98.1	97.6
IND	98	265.4	405.2	127.6	127.5
IDZ	98	200.0	668.1	142.3	142.3
AFR	98	219.2	266.9	168.1	165.8
MES	98	71.0	92.3	263.8	259.6
LAM	98	108.5	49.0	139.4	137.9
ROW	98	193.1	211.0	114.4	114.1
Global	89	89	89	89	89
2050					
Annex I					
USA	30	11.4	0.9	-8.3	-22.5
CAN	30	11.8	12.0	-8.3	44.4
JPN	30	26.8	4.5	-8.3	-113.4
ANZ	30	11.6	16.4	-8.3	12.3
EUR	30	24.5	2.0	-8.3	-12.3
EET	30	27.2	61.0	-8.3	32.7
FSU	30	27.1	31.3	-8.3	58.7
Non-Annex I					
MEX	70	48.9	80.2	101.9	99.7
ASI	70	31.3	18.4	96.8	94.9
CHN	70	72.5	43.7	71.2	68.7
IND	70	147.1	224.6	93.3	93.5
IDZ	70	110.9	370.3	133.8	133.6
AFR	70	121.5	147.9	143.3	141.3
MES	70	39.4	51.1	238.6	234.8
LAM	70	60.1	27.2	152.2	150.7
ROW	70	107	117.0	95.1	94.6
Global	50	50	50	50	50

These population or GDP per capita rules do impose greater welfare costs on developed countries, as seen in Table 3. However, these formulae have widely varying effects among developing-country regions. Welfare is improved in some regions, India and Indonesia most notably. There the scheme goes well beyond compensating for mitigation costs and turns the GHG mitigation policy into an instrument for global income redistribution. On the other hand they raise the costs further in the Middle East exporters (MES) and to a lesser extent in higher income Asian countries (ASI) and Latin America (LAM). With such wildly different economic outcomes, these two proposals are hard to justify on equity or responsibility grounds for they penalize some developing countries while redistributing sums to others that go well beyond the principles of compensation for mitigation costs. Also, which of the two formulae is used makes a big difference for some regions. Indonesia realizes a large increase in welfare under the *GDP based* allocation, but suffers a loss of near 4% if the allocation is *Pop based*.

Other aspects of these scenarios based on simple allocation rules merit attention, and one is the effect of the allocation rule on emissions price. Given the assumption of global emissions trading we would expect the CO_2 prices to be unaffected by the allocation rule as long as the global constraint remained the same. And, in general, the prices in these three cases are similar, as shown in Figure 2. However, while the general similarity is as expected, the differences among them are surprisingly large in some cases. In 2020 the *GDP based* scenario has a price over \$8/tCO_2 (10%) higher than the *30-70* case. By 2050 the largest difference is still between these two cases and it has risen to \$82 per ton, a 23% difference. This variation is due to a differential income effect in developing vs. developed countries. The GDP-based case leads, especially in later years, to large income transfers to developing countries which spur their consumption of fuels to a degree that exceeds the reduction in fuel use that the income loss yields in developed countries. Thus, an interesting indirect effect of this particular equity-driven proposal is that it actually raises the marginal abatement cost and thereby makes the overall global solution more expensive than a partial equilibrium analysis might suggest.

The large economic impacts, particularly among developing countries (and developed energy exporters) are perhaps surprising because the global cost estimates in the literature are often much lower—on the order of 1 to 2% (e.g., IPCC, 2007; Stern, 2006). We estimate the costs in terms of welfare (lost consumption) rather than GDP as do many of these other studies, and there are some important technical differences between these measures. At the level of this discussion, however, they are broadly comparable, and several other aspects of the estimates can explain the difference. First, many of these other studies are based on a review of literature that generally does not include targets as tight as those proposed by the G8. Most have looked at most at something like 450 ppm CO_2 rather than CO_2-eq. As a result, some of the tightest recent mitigation scenarios in the literature achieve a one-third reduction from 2000 by 2050. Also, within the literature are older scenarios that significantly underestimate the growth in emissions experienced over the years since the analysis was done; and further, our analysis cannot take account of the benefit of these intervening years and start a mitigation program in 2000 or 2005. And, of course, much of the work reports global average cost (or individual country studies) and thus fails to deal with the complex issue of dividing up the burden.

Also contributing to costs in developing countries is the fact that energy is a larger share of their GDP than in developed regions, and many also have large emissions of non-CO_2 GHGs from agriculture that are difficult to control, and so as a share of the economy mitigation costs are larger. The abatement costs are not necessarily larger in absolute terms in these countries—as our model is designed they have access to the same technology as developed countries—it is simply that because they are poorer these costs are a much larger share of income. Also, the developing economies are growing relatively rapidly in the EPPA reference and are in a structural transition that for many involves energy-intensive infrastructure development, growth of energy-using consumption (more automobiles, air conditioning, appliances), and the replacement of traditional fuels (firewood, etc.) with commercial fuels.

Finally, allocation schemes designed without attention to the likely CO_2 prices and the size of the financial flows involved can result in sums that are massive compared with the size of a developing country economy. One might dub this the "Ireland effect." Ireland went from one of the poorest countries in Europe to one of the richest in just a decade or so, in substantial measure because of favorable treatment within the EU. Ireland was a relatively small economy and a small diversion of business activity that otherwise might have located across the EU had a massive effect on Ireland's economy. In the same way, an ad hoc allocation may favor some developing countries, but not all. Realization of this feature of simple Annex I vs. Non-Annex I allocation schemes suggests a search for systems that deal more directly with the economic conditions in various individual countries.

4.2 Full Compensation of Developing Countries

Scenarios 4-5, summarized in Table 2, are designed to achieve the same 50% global emissions reductions target, still with universal participation, but include provisions to implement the Climate Convention mandate to protect developing countries from "the impact of the implementation of response measures." Here the "impact" to be avoided is defined in terms of the welfare cost in Table 3 (loss in national consumption). The two cases allocate allowances so that developing-country parties are fully compensated (denoted *Full comp*)—that is, each developing country experiences no economic cost at all. The two differ according to allocation of burdens among the developed nations: equal allocations relative to year 2000 emissions (*equal alloc*) or allocations set to impose the same welfare burden (*equal cost*). The price paths for these two cases lie between the *Pop based* and *GDP based* scenarios in Figure 2.

The analysis is based on the assumption that the instrument used to achieve the equity goal is the allowance allocation. We determine with the model just that allocation that would in each year leave the Non-Annex I parties with zero welfare cost.[10] In the *equal alloc* case the Annex I parties take an equal proportional reduction from year 2000 emissions. The resulting allocations for 2020 and 2050 are shown in the fourth column of Table 5. While the notion of differential responsibilities between developed and developing countries is a key component of international negotiations, individual national circumstances also figured into the negotiation of levels of Kyoto reduction, applying only to developed regions. If each bears responsibility for providing compensation proportional to its reference emissions (the *equal alloc* case) there are strong differences among them, particularly in later decades of the period studied. Developed countries would need to set a target for themselves more on the order of a 49% reduction in 2020, as shown in Table 5. In 2050 each would start not with a positive allocation but with a *deficit* of 8.3% of its 2000 level (shown here as an allocation of –8.3%). Acceptance of a negative allocation may seem odd, but in a trading system the idea is not that the developed countries would achieve negative emissions. Rather, they would be required to purchase allowances for *all* of their emissions *plus* an additional 8.3% of their 2000 levels.

[10] Such a calculation can be done within a model setting. Just how this would be accomplished in real negotiations is problematic because it would need to rely on a projection of reference emissions and costs, and that would obviously be a highly contentious issue even if the principle of compensation were fully accepted by some group of developed countries.

Under an agreement on these terms the energy exporting countries of Annex I would bear the heavy welfare costs, as can be seen in Table 3. Besides the cost of allowance purchase and direct abatement costs they also lose from terms-of-trade effects (the price of their energy-heavy export bundle falling in relation to the prices of their imports). Thus the economic burden falls disproportionately on Canada, Russia (FSU), and Australia/New Zealand (ANZ). The poorer of the developed regions—FSU and EET—also face a high cost as a percent of GDP compared with the richer countries such as the US and Japan. Even the US has a relatively efficient economy in terms of GHG emissions per dollar of GDP because of the large role the relatively energy efficient service sector plays in the economy. The costs in Japan, because it is so energy- and GHG-efficient per dollar of GDP, remain a very low percent of GDP in any allocation scheme based on present emissions.

In the *Full comp-equal cost* case allowances are allocated so that an equal welfare burden is imposed on the Annex I parties. As can be seen in the far right column of Table 5, this leads to similar allocations among the Non-Annex I parties but very different ones among the Annex I. And, as shown in Table 3, this assumption gives a bottom-line average cost for the developed countries of 1.9% in 2020, rising to 9.4% by 2050.

Seen strikingly in the *Full comp-equal cost* scenario is the large negative balance Japan would need to accept: 113% in 2050 (Table 5). Again, this reflects the relatively small level of GHG emissions relative to the size of the Japanese economy. In a sense, if a fair rule is thought to be based on income levels, then GDP or GDP/capita is the direct measure we should use for dividing up responsibility. Benchmarking the allocation to historical emissions means we are using emissions as a proxy for GDP. But if economies have very different GHG intensities then emissions are a very poor proxy for GDP and the "differentiation" of allocation relative to historical emissions must be very large. Thus for Japan to bear an equal share of the cost burden of compensating developing countries for their mitigation costs the allowance allocation in 2050 must be nearly 200% below their year 2000 emissions.[11]

If the initial allocation is as assumed in these last two cases, with compensation by financial transfers, then the net transfers from and to each EPPA region as a result of the net purchase and

[11] This rule of dividing up compensation costs is mostly about sharing the burden of mitigation costs in the poorer countries and so the size of the economy is a fairly relevant measure. For adaptation or damage costs, a case may be made that Japan should not bear as large a share of those costs because their low emissions mean they are not responsible for as much of the damage.

sale of allowances are as shown in the two right-most columns of Table 4. With full compensation the total net flow from the developed to developing countries is over $400 billion in 2020 and reaches over $3 trillion (annually) in 2050. The largest recipient region is the MES, accounting for nearly one-quarter of the total.

We can put these flows into perspective. If these financial flows are viewed as aid to developing countries then one comparison is Official Development Assistance (ODA). In recent years that transfer has run at about $80 billion per year. So from that perspective these transfers imply an assistance level that is a five-fold increase from today by 2020 and nearly 40-fold increase by 2050. This transfer might also be compared to market flows—purchases of allowances will become part of developed countries import bill. To maintain trade balance an increase in imports of permits would need to be balanced by a reduction of other imports or an increase in exports. For the US exports were about $120 to $155 billion per month in 2007-08. Assuming US exports maintained the same relation to (projected) GNP, they would rise to $175 to $225 billion per month in 2020, and $385 to $500 billion in 2050. The US purchase of allowances in those years (taking *Full comp-equal cost* as an example) would require a 10% to 13% increase in exports in 2020 to maintain trade balance, and 29% to 37% in 2050 in 2050.

4.3 Partial Compensation of Developing Countries

Full coverage of all developing country costs likely is an extreme version of potential international agreement based on "common but differentiated responsibilities" and therefore it is useful to look at a couple of scenarios where some costs go uncompensated. One case explores the implications of an agreement under which developing countries accept some level of welfare cost: 3% in the experiment shown here. In the other case we consider the implications if developing countries are compensated for their direct costs of emissions mitigation but not for losses, mainly though terms-of-trade effects, caused by mitigation actions by the developed countries. The CO_2 prices for these cases are not substantially different from the *Full comp equal alloc* case in Figure 2.

The welfare effects in the case where developing country cost is held to 3% is shown in **Table 6**, and denoted *3% Cost cap*. In 2020 the compensation cap is not yet binding on all the developing countries, but by 2050 it constrains the welfare loss on all but China. The saving to Annex I regions can be seen in comparison with the *Full comp equal alloc* case in Table 3. The result is a large reduction in welfare cost in 2020: for example, the US cost drops from 1.3% to

0.7% in 2020. The reduction in 2050 is reduced from 7.4% to 6.5%, which is a smaller change in percentage terms but larger in absolute value given the larger economy projected by mid-century. Similar reductions are achieved by other Annex I regions. The reduction in financial transfers to Non-Annex I parties is about $200 billion in 2020, rising to over $500 billion in 2050.[12]

Table 6. Welfare effects in 2020 and 2050, partial compensation (% from reference).

	2020		**2050**	
	3% Cost cap	*Direct only*	*3% Cost cap*	*Direct only*
Annex I				
USA	-0.7	-1.1 (-0.3)	-6.5	-7.1 (-3.0)
CAN	-3.5	-3.9 (-1.8)	-16.8	-17.6 (-10.3)
JPN	-0.5	-0.6 (-0.4)	-4.1	-4.3 (-4.5)
ANZ	-2.3	-2.7 (-1.3)	-11.3	-12.0 (-7.9)
EUR	-1.7	-1.9 (-1.2)	-8.1	-8.6 (-7.4)
EET	-2.3	-3.6 (-0.8)	-21.7	-23.9 (-9.5)
FSU	-4.9	-6.5 (-1.1)	-37.0	-39.7 (-15.2
Non-Annex I				
MEX	-2.3	**-0.5** (-0.5)	**-3.0**	**0.0** (1.0)
ASI	-0.5	**0.0** (0.5)	**-3.0**	**0.0** (1.2)
CHN	-0.1	**0.0** (0.1)	0.1	**0.0** (0.8)
IND	**-3.0**	**0.0** (0.8)	**-3.0**	**0.0** (5.5)
IDZ	**-3.0**	**-0.6** (-0.6)	**-3.0**	**0.0** (0.9)
AFR	**-3.0**	**-2.1** (-2.1)	**-3.0**	**-0.6** (-0.6)
MES	**-3.0**	**-5.4** (-5.4)	**-3.0**	**-9.0** (-9.0)
LAM	-2.6	**-0.4** (-0.4)	**-3.0**	**-0.1** (-0.1)
ROW	-1.9	**0.0** (0.6)	**-3.0**	**0.0** (7.7)

Note: Entries in **bold** indicate pre-specified welfare outcomes.

Figures in parentheses are the welfare effects of when Annex I countries only pursue the cut, showing gains in some Non-Annex I regions. The pre-specified losses are those welfare losses from the Annex I only policy that are not compensated.

The other potential outcome we explore would exclude compensation for the indirect costs of developed country actions, an issue which has generally been debated separately from incentives for participation. The welfare results for this assumption are shown for 2020 and 2050 as the *Direct only* case in Table 6. To estimate this effect we first simulate a case where only the Annex I regions undertake reductions, meeting the allocation of the *30-70* case. (There will be some

[12] A scenario was also explored where the Non-Annex I parties accept as high as a 5% welfare loss. The case seems implausible because by 2050 the percentage welfare loss in the developing countries is not substantially below that in the United States, Europe and Japan.

indirect costs as well resulting from actions of developing regions, but this more limited calculation is a good way to get a feel for the magnitude of this component of compensation.) The welfare consequences of this Annex I-only policy scenario are shown in parentheses in the table. Previous studies of this issue (e.g., Babiker and Jacoby, 1999) have shown that, by far, the main indirect effect is on the oil exporting regions. Therefore we focus on those regions in the EPPA aggregation that capture a good deal of this effect: the Middle East (MES), Africa (AFR), Indonesia (IDZ), Mexico (MEX), and Latin America (LAM). Note they have welfare losses of 5.4%, 2.1%, 0.6%, 0.5% and 0.4% respectively, attributable to the indirect effects of the Annex I actions. Therefore for this scenario we do not compensate them for these losses, only covering any costs over and above this level in a simulation when all parties are involved (the numbers shown in bold).

Compensation of direct costs only would lower the welfare cost of the Annex I parties somewhat, as can be seen in a comparison of the results in Table 6 with the figure for *Full comp equal alloc* in Table 3. For example, the US welfare loss would be reduced from 1.3% to 1.1% in 2020 and from 7.4% to 6.5% in 2050. Interestingly, the uncompensated *indirect* welfare loss the Middle East is greater than the cost to all but the FSU in 2020 and still greater than the United States, Europe and Japan in 2050. Compared to the case where all the developing countries are fully compensated for all costs, the annual financial transfers to these three regions, if indirect effects are not compensated, are lower by $77 billion 2020 and $108 billion in 2050.

5. CONCLUSIONS

The G8 proposes to reduce global emissions by 50% by 2050, though the proposal does not provide detail on how this would be accomplished, or even specify the base year to which the percentage applies. We have represented it as a reduction from year 2000 emissions levels, which is between the Kyoto benchmark of 1990 and the 2008 to 2010 benchmarks in proposed US legislation. There is a general sense that developed countries would take a disproportionate share of the reduction burden, and goals of 70% to 80% reductions by 2050 have been expressed in US federal and state legislation and in proposals from a number of other countries. Extended to include developing countries this goal implies an allocation of abatement that would require them to be at 70% of their 2000 emissions in 2050. While this implicit *30-70* proposal may appear to be a generous offer from the developed countries, it turns out that it would result in net purchases of allowances by some developing countries from the developed countries, in effect partially compensating the richer ones for their mitigation. It is the reverse of what is called for in international agreements and the Bali Action Plan. Other allocation proposals advanced by developing country groups, including allowances distributed on a per capita basis or inversely related to GDP per capita, may shift costs toward the richer countries but they also raise other difficulties. For some developing countries they produce large net benefits beyond costs related to mitigating climate change but are even more costly than the 30% reduction for others, and also result in divergent impacts on the Annex I countries.

One perhaps-not-surprising conclusion from this analysis, therefore, is that simple rules of this sort are incapable of dealing with the highly varying circumstances of different countries. Sometimes the results are peculiarly perverse, with richer countries faring very well while poorer ones bear particularly large costs. Moreover they can lead to differences in burden among developed countries that likely are unacceptable as well. Further discussion of these simple rules seems a waste of time, for they likely will generate little support, even as an opening gambit between the G8 and the G77, from which negotiators might seek some middle ground.

A second point highlighted by these simulations is that the proposed goal of a 50% global reduction below the 2000 level is very ambitious. The origin of the specific 50% number is not clear, although if it could be attained and sustained beyond 2050 there would be a good chance of keeping atmospheric CO_2 concentrations below 450 ppmv. Combined with mitigation of other greenhouse gases the long-term radiative forcing would be limited to around 3.4 W/m^2 (US CCSP 2007) yielding something like 50-50 odds of keeping the global temperature rise in the 2°C range, a policy target of several European governments and environmental groups. Absent near universal participation, however, such a 50% emissions goal is not achievable given our projection of economic growth of the various regions and the associated emissions in part because leakage of emissions to unrestricted regions can be quite large. The emissions of only a few excluded nations, bolstered by projected carbon leakage, more than fill the available emissions window. Even with all nations taking commitments there are substantial costs to be shared, and therefore our analysis leads to the view that meeting targets at this level of stringency would require not only universal participation but also a complex web of transfers to share the burden.

Two interacting equity concerns would have to be dealt with to have any hope of meeting the 50% goal. First, incentives and compensation for developing country participation will be required. No one really expects them to bear the full burden of their own reductions. Second, meeting a big part of the costs then imposed on developed countries will substantially increase their costs, so an acceptable sharing of the burden among them will also be essential. Our policy scenario designed to explore this possibility is the *Full comp equal cost* case, which holds the welfare costs imposed on Non-Annex I parties to zero while imposing an equal welfare cost on all the Annex I parties. This case is perfect in its compensation and burden-sharing features, so it exceeds likely human abilities to solve these equity problems while simultaneously minimizing costs. Still, it does give an impression of the challenge implied.

Even under this ideal agreement the welfare costs to developed countries are substantial: around 2% in 2020 rising to a bit less than 10% in 2050.[13] Associated with this agreement would be large international financial transfers, modeled as flows from emissions trading in this analysis. The net transfer to developing countries ranges from near $500 billion per year in 2020 to over $3 trillion in 2050. Just from the US the implied transfer is over a trillion dollars in 2050, though in 2020 it is only around $200 billion.

Of course, it is an extreme assumption that developing countries will demand complete compensation, and if, as is more likely, they are willing to bear some costs, then the welfare burden on the developing countries, and the implied financial transfers, are reduced. Also, the burden is lowered somewhat if compensation only covers direct mitigation costs and not other losses associated with the policy, as might come through terms-of-trade effects. Even with less than full compensation the welfare burden on the developing countries remains substantial, and the international financial transfers of unprecedented scale.

Naturally, all these projections are subject to uncertainty. The task could turn out to be easier than our analysis suggests. Global growth could be lower than projected. Oil prices higher than our projection could take some pressure off the required CO_2 price and mitigation effort, as would a breakthrough agreement on forest destruction and degradation. Technical change could be more rapid than represented in the EPPA model, lowering mitigation costs. On the other hand, there are many features of these simulations that could turn out to be optimistic regarding the ease of emissions control. Growth, oil prices and technical change could be less favorable than we assume. Very important, the solution assumes that CO_2 capture and storage technology will

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[13] To put these costs in context, under this policy US welfare increases by 62% between 2005 and 2020 (222% between 2005 and 2050) rather than 65% and 255% under the reference case.

be demonstrated, with the needed regulatory structure in place, so it can begin to take market share in 2020. Based on recent history this assumption is questionable. Also, a model like EPPA implements mitigation in cost-minimizing way, equating reduction across all sources. In practice, domestic policies and international agreements are messier than the calculation implies, leading to higher costs. On balance, then, the results shown here are in our view a sound basis for forming judgments about the challenge of meeting targets like the one the G8 has proposed.

Negotiations on a post-2012 agreement will be difficult. New evidence as portrayed in the IPCC and elsewhere suggest that the risks of climate change are more serious than previously thought, and robust economic growth, especially in developing countries, has spurred energy use and emissions growth over the past decade at rates faster then was previously projected. Economic growth is a good thing for them but the evidence on growth, energy use, and emissions suggests that beliefs that emissions growth would naturally or easily be decoupled from economic growth were highly optimistic. Recent MIT analysis also confirms that, absent a strong policy response, the climate change risk is great (Sokolov et al., 2008).

The G8 countries, spurred by the science reports of the greater risks of climate change, have called for an aggressive global emissions goal. Under the Bali Action Plan and previous climate change agreements there is a framework for discussing developing country participation, and it involves incentives for mitigation provided by developed countries and perhaps compensation for other costs of a global effort. These transfers could come in different guises but it would seem the magnitude of the incentives offered must be on an order of that of the mitigation costs that would be borne by developing countries in achieving their own reductions. Putting all these things together suggests an increased willingness on all sides to reach an agreement, but also that the selection of targets is not well conditioned by an understanding of the complexities involved in finding a mutually acceptable way to share the economic burden.

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