Developing Countries and the UNFCCC Process: Some Simulations — From an Armington Extended Climate Model

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ABSTRACT

We report simulation results for alternative multilateral emissions cuts and accompanying policies which could come under renewed reconsideration for the process to follow the Durban UNFCCC negotiations. The model is an Armington type trade model extended to capture climate change. We calibrate the model to alternative BAU damage scenarios following the Stern report and the literature that has followed. We consider different depth, forms, and timeframes for emissions reductions by China, India, Russia, Brazil, US, EU, Japan and a residual Row both jointly and block wise. We assume regionally uniform percentage both climate change and damages by region, which are relax later in sensitivity analysis. The welfare impacts of both emission reductions and accompanying measures are computed in Hicksian money metric equivalent form over 3 alternative potential commitment periods: 2012-2020, 2012-2030, and 2012-2050. Our multiyear multicounty global modeling framework captures the benefit of emissions mitigation through preferences incorporating temperature change. Countries are linked not only through shared welfare impacts of global temperature change but also through trade among country subscripted goods. These trade impacts influence net country benefits from alternative emissions reduction agreements. We also evaluate the potential impacts of potential accompanying mechanisms including funds/transfers, border adjustments, and tariffs.

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I. Global Policy Context and Introduction

Negotiations on climate change arrangements under the United Nations Framework Convention on Climate Change (UNFCCC) as part of the shaping of a post Kyoto/ post 2012 regime have moved from a negotiation initiated in Bali in late 2007 through Copenhagen meetings in December 2009 to an inconclusive Durban meeting in late 2011. Discussions are to continue through until 2015, and the role of large developing countries (China, India, and Brazil) is the key as they are more rapidly growing. Here, we use a numerical general equilibrium climate model incorporating Armington type features. It captures the benefit side of emissions reductions in preferences in cooperating temperature change and is used to evaluate the impacts of possible joint actions on emissions, transfers, and other actions by developed and developing countries post Durban. We adopt an assumption of uniform percentage both climate change and damages by region which we relax in later sensitivity analysis.

In the negotiation process thus far, there has been little by way of clear agreement. The notification and verification of the unilateral reductions tabled in Copenhagen as part of the Copenhagen Accords is the main content of what has been achieved even though the post 2012 process has attempted to achieve much broadened issue coverage to also include adaptation, mitigation, and finance. It has also aimed to fully include the large population, rapidly growing economies of China, India, and Brazil in the global process, who unlike in Kyoto have been asked to take on commitments. These countries, in turn, have consistently argued both that as rapid growers and countries relatively new to industrialization they should be treated differently from more mature OECD countries. Furthermore, they argue that this was committed to under the principle of Common but Differentiated Responsibilities (CBDR) in the United Nations Framework Convention on Climate Change (UNFCCC).

A range of contentious issues have emerged in the negotiations as to what form any special developing country treatment should take as far as emissions reductions are concerned. One is whether emissions reductions targets by countries should be based on a single global target (and target date) with country targets allocated to countries on a cumulative basis rather than the Kyoto annual emissions basis. The developing country argument has been that emissions in the upper atmosphere have mostly originated from OECD countries over many years, and that emissions targets allocated by country should reflect this historical responsibility. Another is whether emissions reduction targets should focus on reducing emissions intensities (emissions/dollar of GDP) rather than emissions levels, so as to allow more room for growth by rapidly growing developing countries. Yet another is that emissions targets should be based on the carbon content of consumption of goods in countries, rather than geographical location of production. Finally, some developing countries have argued that the principle of CBDR implies preferential and lower emissions reduction targets for them relative to OECD countries.

But other issues have also arisen. One is the choice of base date for calculating reductions with, for example, 1990 (the Kyoto data) being strongly preferred by Russia (and the EU) due to negative (slow) growth between 1990 and today, and 1990 being strongly resisted by China for the opposite reason. And details within broad issues, such as with the use of intensity targets, how GDP is calculated and used in setting intensity targets (using market exchange rates or PPP for conversion into US$) also enter.

Finally, there has been discussion of the use of accompanying financial arrangements through the Adaptation and Innovation Funds, as well as possible trade measures against non-participants since these affect country outcomes. Developing countries, represented by the G77, argued in both Bali and Copenhagen for a large fund to help them adapt to climate change, initially proposed at the top end of $300 billion per year by 2013. The Copenhagen Accords adopted language of “working towards” a climate change fund for developing countries of $100 billion per year by 2020. And on the trade front, both the US and the EU have made proposals for the use of carbon emission based tariffs and export rebates affecting trade with non-participant countries.

There is neither little nor no quantitative model based evaluation work either on the potential welfare and other impacts of either different concrete proposal for global mitigation and/or the accompanying financial or trade mechanisms. Earlier work (such as Goulder (2000),Veenendaal (2008)), has rather focused on impacts of across the board percentage cuts without relating these to the global negotiating process.

Here we use an extended version of the *N* country *N* good Armington type climate modeling framework developed by Cai, Riezman, and Whalley (CRW) (2012) and building on Uzawa (2004). The original use of the CRW framework was to explore whether international trade makes participation in climate change negotiations more likely. In this framework, temperature change directly enters preferences and countries can set aside part of their potential consumption available under a no mitigation business as usual (BAU) scenario to meet climate policy commitments and lower global temperatures. This gives them a utility gain, but at a utility cost in terms of foregone consumption. CRW then specify a temperature change function linking global temperature change to emissions, and an abatement cost function which captures the marginal cost of mitigation which, in turn, implies country resource or abatement costs of emission reduction. Here we also extend it to capture different mitigation targets and potential accompanying financial and trade related mechanisms.

Our formulation treats commitment periods of several decades as a single period and compares a BAU scenario to model outcomes under alternative emissions reductions and use of accompanying mechanisms. We do not explicitly model any multi period dynamics. Explicit intertemporal allocation issues such as savings and investment impacts are not at the centre of climate policy debate and in our view are secondary.

We use calibrations to alternative business as usual (BAU) scenarios for 3 different potential commitment periods out to 2020, 2030 and 2050. We first use annual data for 2006 which we project to a 2012 base data set using 2000-2006 country growth rates. We then calibrate a temperature change function to Stern like BAU damage estimates of both damage and temperature change out to 2050. These damage estimates exceed those of the bounds of the IPCC-AR4 and AR5 confidence ranges, and we perform sensitivity analysis.

Our results produce a wide range of potential outcomes depending on the formulae used to allocate cuts to countries, and hence a large bargaining set for the post 2012 process, which in turn suggests it may be difficult to conclude. Our results suggest that given the central case damage estimates from climate change we use in model calibrations, the countries we consider will both individually and collectively lose from climate reduction initiatives proposed both in post 2012 process if there are no accompanying mechanisms. The issue for them becomes the form of mitigation which minimizes country losses. But if we calibrate to larger damage cost estimates the pattern changes to joint gains, while the relative picture across countries is much the same.

The differences between country emissions reductions based on cumulative and annual emissions are especially large. Other issues such as consumption or production as a basis for cuts or the use of intensity targets have smaller but still pronounced cross country impacts. The same is true of a 1990 versus a 2012 base date for certain countries (Russia (1990), China (2012), EU (1990)). Our results also indicate that each percentage point differentiation in cuts between developing and developed countries significantly benefits developing countries.

Results on accompanying mechanisms suggest that the size of accompanying funds is critical for developing countries. In the model, an Adaptation Fund of $100 billion a year is insufficient to induce developing country participation, while $200 billion/year is sufficient. The costs to the developed countries are, however, large. Border tax adjustments emerge as quantitatively relatively less significant in impact. Here, effects depend on the size of border adjustment and who undertakes them. Finally, trade sanctions (tariffs) can also have significant effects but typically need to be large to convert loses from participation into country gains from avoiding the sanction.

II. An Armington Type Extended Climate Modeling Framework for the Evaluation of Possible UNFCCC Emissions Reduction Arrangements

1. Model Summary

To analyze the potential impacts on large developing countries of the various possibilities for UNFCCC agreements we set out in the preceding section, we have used a modeling framework due to Cai, Riezman, and Whalley (2012) and Tian and Whalley (2010) (and building on that set out in Uzawa (2004)) to analyze links between trade, trade policy and climate change policy arrangements which various proposed emission reductions and financial arrangements imply. We evaluate the welfare impacts of alternative emissions reduction mechanisms such as using a cumulative or annual emission basis, emission intensity or emission level targets, carbon content of consumption or geographical location of production. We also explore whether border taxes, tariffs, and/or transfers and at what level make participation in specific climate change arrangements more likely. The emphasis is on net country welfare benefits from participation in jointly agreed packages of emissions reductions and accompanying measures (transfers, border taxes). We focus the analysis on the large population rapidly growing developing economies of China, India, Russia and Brazil.

We use a single period model covering a number of years during which each national economy is assumed to grow at a compounding constant rate[3]. As such it is a static model with a multiyear single period of analysis. Explicit dynamic effects on capital accumulation are excluded to avoid excessive model complexity as they are not central to the global climate policy debate, although they also arise with issues of the speed of emissions slowing as noted by Nordhaus (1990). Because the model uses a single period, discounting does not formally enter the analytic structure. Discounting does, however, arise with the use of a discount rate in calculating the discounted present value of GDP over the model period. We consider cases in sensitivity analysis with a common discount rate of 1% across all countries, since the growth rates of key OECD countries (EU, Japan) are low. We adopt an assumption of uniform percentage both climate change and damages by region in our central case results, which we relax in later sensitivity analysis

In the model, each country is able to consume or export one country specific heterogeneous good in the period whose potential consumption (or use) grows at the rate set in the base case. We assume that consumption of the good either by the country directly, or by others through trade, generates emissions of carbon which, in turn, raise global temperatures. Countries receive positive utility from consumption, but negative utility from temperature change. Countries export their own good and import other country goods. If countries are small, their own actions have little or no effect on temperature change. Countries effectively face an upper bound on the use of their own good reflecting a Business as Usual (BAU) scenario since a BAU represents zero emissions reduction, and if they use (consume or export) less than the upper bound they experience less temperature change, as do all other countries. The amount of resources needed to be put aside to achieve given reductions reflects abatement cost estimates.

As we later work with the impacts of agreements to reduce carbon emissions over different periods of time, we take the single period to cover alternative horizons from 2012 out to 2020, 2030 or 2050. These reflect different commitment periods for possible UNFCCC agreements on a post 2012 regime. In this multi year period, we focus on changes in consumption (use of own and foreign goods) and utility, and measure changes in these variables relative to the outcome of zero growth over the period. We report changes in utility in money metric (Hicksian) form in US$ amounts.

The model differs from recent Integrated Assessment Models (IAM) of climate change in being a single internally consistent Arrow-Debreu type model in which welfare analysis can be

[3] See also the discussion of discounting and climate change policy in Weitzman (2007) and Dasgupta (2008), and the key role discounting plays in the conclusions of the Stern (2006) report.

conducted. IAMs involve modeling structures with less well defined welfare metrics.[4]

2. Preferences

The preferences of each country over the period are reflected in a utility function with arguments given by its own composite consumption as well as temperature change. The utility function is thus effectively defined over multiyear both consumption and temperature change. The potential use of each country good reflects potential output from the economy over the same period. We first analyze a business as usual (BAU) scenario which reflects current observed growth rates remaining unchanged over the model period, temperature change as projected with no global or single country emissions limitation initiatives in place.

We assume the utility function for each country has the form

$$U^i = U(RC_i, \Delta T) = RC_i * \left((\frac{H - \Delta T}{H}) \right)^{\beta_i} \qquad (1)$$

In this specification,[5] RC_i represents the change in consumption of a composite of their own good and other country's goods which they acquire by importing other country's goods and exporting their own good for each country i over the period. This structure provides the link between trade, tariffs and sanctions and emission reduction incentives used to explore the possible impacts of accompanying measures in possible UNFCCC post 2012 packages and is that used in Armington type trade models.

ΔT is temperature change in period and H is an assumed upper bound global temperature change at which all economic activity ceases (say 20°C). As ΔT approaches H, utility goes to zero. If ΔT goes to zero, there is no welfare impact of temperature change. Utility over any model period thus increases as temperature change falls.

The share parameter β_i determines the severity of damage (in utility terms) from any given temperature change. We later calibrate the model to various damage estimates from business as usual global temperature change estimates reported by Stern (2006) and Mendelsohn (2006), and this procedure determines β_i. For simplicity, we assume β is the same value across countries. This is a strong assumption since available evidence indicates heterogeneity in climate change damage across countries, and we later relax this assumption in sensitivity analysis.

3. Temperature Change Function

Global temperature change is determined in the model by the change in carbon emissions over the period across all countries. We first adopt a simple single global temperature change

[4] See, for example the World Integrated Assessment General Equilibrium Model (WIAGEM; Kemfert, 2002), the World Induced Technical Change Hybrid (WITC H) model (Bosetti et al., 2006), the Dynamic Integrated model of Climate and the Economy (DICE; Nordhaus and Boyer, 2000), the Integrated Assessment Model for Global Climate Change (MERGE; Manne and Richels, 2004), the Global C hange Assessment Model (GCAM; Kim et al., 2006), and the Integrated Model to Assess the Global Environment (IMAGE; Bouwman, 2006).

[5] Weitzman (2007) suggested that writing down preferences to adequately capture temperature change impacts on welfare was an unsolved problem. The formulation (1), first used by CRW, seems a reasonable specification for this purpose.

function which applies to all regions and assume that emissions by each country equal the change in consumption times country emissions intensity (emissions/GDP) so as to allow for differing emissions intensities by country. In later sensitivity analysis we relax this strong assumption. Defining the emissions intensity of country i as e_i, we use the power function (2) to represent global temperature change due to changes in emissions by all countries over the model period.

$$\Delta T = g(\sum_i e_i \Delta RS_i) = a(\sum_i e_i \Delta RS_i)^b + c \quad (2)$$

where ΔRS_i represents the change in the use (consumption plus exports) of the own good for each country i.[6] ΔRS_i and RC_i thus differ.

In the central case formulation of the model, e_i is exogenous and fixed at its 2006 base case levels. Consumption of each country good by all countries is less than or equal to ΔRS_i; and ΔRS_i is less than or equal to the upper bound $\overline{\Delta RS_i}$ associated with the base case scenario since countries can choose to participate in emission reductions initiatives and reduce the use of their own good. The typical scenario we consider is where countries in the model can commit to emission reductions which are a given percentage of their own $\overline{\Delta RS_i}$. We also conduct sensitivity analyses in which the e_i change over time to reflect increased efficiency of energy use over time. When we consider accompanying trade and finance mechanisms along with emissions reductions, developing countries then have the option of joining with the same or differentially negotiated percentage reduction (and also possibly receiving transfers) or not joining (and possibly facing border adjustments and/or tariffs).

4. Composite Consumption by Country

We model the composite consumption good RC as a CES function of domestic and imported consumption goods, similar to that used in nested CES Armington trade models (see Whalley (1985)). The model is thus effectively an Armington N good N country pure trade economy in which the endowment is variable and temperature change enters preferences.

In this structure, a carbon reduction commitment by a single country implies a reduction in composites of consumption in all countries. This has both negative and positive effects on utility for all countries over the model period. On the one hand, a reduction in consumption lowers utility for the consuming country, but on the other hand, country consumption reductions lower global emissions and hence world temperature change, and increase the utility both of the country reducing emissions and all other countries.

For each country, the RC_i are determined by solving the country optimization problems.

[6] Ideally, this power function should have the property that there is increasing marginal impact on temperature change for progressive increases in consumption, i.e., $b > 1$. However, we calibrate this function to estimates of temperature change of 3°C by 2030 and 5°C by 2050 given in the Stern (2006) report, which jointly implies $b < 1$.

$$\text{Max}\quad RC_i = RC_i(D_i, M_i) = ((\lambda_1^i)^{\frac{1}{\sigma}} D_i^{\frac{\sigma-1}{\sigma}} + (\lambda_2^i)^{\frac{1}{\sigma}} M_i^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}} \qquad (3)$$

$$s.t.\quad p_i^w D_i + p_i^m M_i \leq I = p_i^w RS_i \qquad (4)$$

where D_i and M_i, in turn, represent consumption of the domestic and a composite imported good respectively, with p_i^w and p_i^m as their prices, λ_1^i and λ_2^i as the consumption shares, I as income, and σ as the substitution elasticity[7].

Demands for domestic consumption goods and imported composite consumption goods are:

$$M_i = \frac{\lambda_2^i I}{(p_i^m)^\sigma(\lambda_1^i(p_i^w)^{(1-\sigma)} + \lambda_2^i(p_i^m)^{(1-\sigma)})} \quad (i = 1 \ldots N) \qquad (5)$$

$$D_i = \frac{\lambda_1^i I}{(p_i^w)^\sigma(\lambda_1^i(p_i^w)^{(1-\sigma)} + \lambda_2^i(p_i^m)^{(1-\sigma)})} \quad (i = 1 \ldots N) \qquad (6)$$

Where I is country income and is given by sales of own good RS_i at the world price p_i^w. Unlike in a conventional Armington trade model, RS_i is endogenous and also the outcome of a discrete choice optimization problem involving participation or non participation in any proposed UNFCCC climate change arrangement. The composition of the M_i is determined by a third level of nesting in the model, and p_i^m is a price index of seller's prices p_i^w (see equation (9)).

5. Composites of Imported Goods

The CES import composites M_i are modeled as composites of imported goods from each supplying country. Given that each country has one good it can sell, but N-1 goods it imports, the CES composite of other goods define the import composite, and are the outcome of a sub-utility maximization problem

$$\text{Max}\quad M_i = H(R_1^i, R_2^i, \ldots, R_{i-1}^i, R_{i+1}^i, \ldots, R_N^i) = (\sum_{j \neq i} (\kappa_j^i)^{\frac{1}{\sigma_m}} (R_j^i)^{\frac{\sigma_m - 1}{\sigma_m}})^{\frac{\sigma_m}{\sigma_m - 1}} \qquad (7)$$

$$s.t.\quad \sum_{j \neq i} p_j^{d_i} R_j^i \leq I^m = p_i^m M_i \qquad (8)$$

where R_j^i is the country good j imported by country i, p_i^m is the composite import price for

[7] We use the same central case settings of elasticities as Cai, Riezman and Whalley (2012) $\sigma = 0.5$ and $\sigma_m = 0.9$. Cai et al provide literature based discussion of these values, which we later vary in sensitivity analysis.

country i, κ_j^i is the consumption share and σ_m is the second level substitution elasticity. I^m is the income devoted to expenditures on imports (from (6)).

These CES sub-utility maximizations give:

$$p_i^m = [\sum_{j \neq i} \kappa_j^i (p_j^{d_i})^{1-\sigma_m}]^{\frac{1}{1-\sigma_m}} \tag{9}$$

$$R_j^i = \frac{\kappa_j^i p_i^m M_i}{(p_j^{d_i})^{\sigma_m} \sum_{j \neq i} \kappa_j^i (p_j^{d_i})^{1-\sigma_m}} = \frac{\kappa_j^i (p_i^m)^{\sigma_m} M_i}{(p_j^{d_i})^{\sigma_m}} \tag{10}$$

6. Costs of Mitigation

The final element in the model is the cost of mitigating damage from climate change through emissions reduction, or abatement costs. We use a simple mitigation cost function where country mitigation costs are a constant marginal cost function of use of own good (ΔRS_i or consumption plus export). Stern (2006) places these costs for a 50% reduction in emissions by 2050 at 1% of GDP with a variation of ±3%. We use a central case estimate of 2.5% and then use sensitivity ranges around this value. Later estimates summarized in Clarke et al (2009) report differences in abatement cost schedules across countries due to differences in energy sources and production patterns. These are not captured here but could be modelled in sensitivity analysis. The mitigation (abatement) cost function we use is:

$$MC_i = \varphi \frac{(\overline{\Delta E_i} - \Delta E_i)}{\overline{\Delta E_i}} RS_i \tag{12}$$

where MC_i are the mitigation costs of country i for a change in emissions given by ($\overline{\Delta E_i}$ (base case) - ΔE_i (new emissions)). $\overline{\Delta E_i}$ are the emissions along the BAU path and ΔE_i are the emissions implied by the emissions reduction. $\frac{(\overline{\Delta E_i} - \Delta E_i)}{\overline{\Delta E_i}}$ is the proportional change in emissions. φ is the emission reduction cost factor linking the proportional change in emissions to own resources RSi. We set φ equal to 0.025 in the base case, and conduct the sensitivity analyses with values of 0.01 and 0.04.

7. Equilibrium in the Model

Given values of ΔRS_i (which imply emission reductions), an equilibrium for the model is given by prices $p_1^w, \ldots, p_N^w$ for which global markets in all N country goods clear, i.e.

$$\sum_{j \neq i} R_i^j + D_i = RS_i \qquad (i = 1....N) \tag{11}$$

In this structure, when countries participate in a global climate agreement, if they reduce emissions there will be general equilibrium implications for all prices and quantities. Importantly, if there are accompanying mechanisms, tariffs used against exporting countries will cause the price of their own good *i* to fall giving a terms of trade loss for the country not making the emissions reduction. As emphasized by CRW, this will, in turn, increase the willingness of countries to participate in global emission reductions negotiations. Transfers do not exert this direct term of trade effect through a relative price intervention, but as countries receiving transfers spend most of their income on their own good, in the calibrated Armington structure a terms of trade effect will come into play through income effects.

The RS_i are the values $\overline{RS_i}$ in the base case. They then take on one of two values in counterfactual analyses. RS_i captures the implied reduction in emissions for countries participating in UNFCCC emissions reduction arrangements. Alternatively, RS_i is equal to $\overline{RS_i}$ for non OECD countries if they do not participate.

8. Model Extensions

We can use the model to analyze different counterfactuals relative to the BAU scenario and for emissions reductions of various forms we can compute counterfactual equilibria for the chosen period. There are some experiments which we conduct with the simulation structure which require extensions to the basic model form. One is where we evaluate the impacts of using intensity targets. For this we use a simple uncertainty extension of the model, since in the certainty case the two instruments are typically equivalent in impact.

The model captures uncertainty in a simple way by considering three alternative growth scenarios: high growth, low growth and BAU growth and we compute a different base case (no emission reduction) scenario for each. For each scenario we first compute utility change and consumption of goods by region. We then introduce different level and intensity emission targets for the various growth scenarios. We first treat an emission level target case as a given percentage reduction in use of own good in the country making the emission reduction, and then compute an equivalent country emission intensity reduction which gives the same expected emissions reduction under the emissions level target, given the BAU output of each country. We can then compute the model utility change under high, low and BAU growth scenarios respectively for each of the emissions targets, and compare expected utility for high and low growth scenarios across the two targets to assess the impact of using intensity targets. This extension allows us to analyze the relative country attractiveness of intensity versus level targets for emissions reduction, given that in the certainty case they are equivalent.

We also incorporate trade policies and transfers to evaluate the possible impacts of accompanying trade and/or finance mechanisms and modify the model appropriately. For this purpose, the model is extended to capture border tax adjustments, tariffs, and financial transfers as penalties or inducements to participate in negotiations. The size of transfers, either as a percentage of recipient country GDP or of donating country GDP, or as an amount in $ transferred from developed countries is treated as exogenous, but can be varied in counterfactual analyses. Tariffs and border adjustments apply to the prices of goods crossing national borders and generate revenues. Trade imbalances (including transfers) are exogenous in the model.

III. Data and Model Calibration

We construct a BAU growth profile using forward projections of 2006 data, and model calibration to this profile determines key model parameters. In this, we use varying estimates of associated damage over the ranges reported by Stern (2006) and Mendelsohn (2006) and abatement cost estimates as in Stern (2006). We use an 8 country grouping, of Brazil, Russia, India, China, US, EU, Japan, and the Rest of the World (ROW). We use calibration to a temperature change function for prospective changes in temperature under business as usual scenarios, out to 2020, 2030 and 2050. These correspond to possible commitment periods in a UNFCCC post 2012 arrangement.

1. Data Sources

We use GDP growth as the measure of potential change in consumption by country over the period of analysis. Because of our analysis of intensity as well as level targets we use three growth scenarios: high, BAU and low growth rates. We first assume that under the different (BAU, high, low) growth scenarios, country growth rates in the period 2006-2050 remain unchanged over the whole period. Data for 2012 are forward projected based on data for 2006 and provide the reference base case. We use averaged data between 2000 and 2006 as country growth rates. We have three components in our BAU data for each growth scenario: projected base case data for 2012, cumulative data for 2020, 2030, 2050 given high, BAU and low growth rates, and cumulative data over the period relative to the base year for the same three growth scenarios.

We assume China, India, Russia, Brazil, USA, EU, Japan and the Rest of the World (Row) have BAU growth rates of 0.09, 0.07, 0.07, 0.032 0.026, 0.020, 0.17, and 0.30 respectively, given by average growth rates between 2000 and 2006 (data from World Bank website). We then use the BAU growth path data to calibrate the temperature change function using estimated BAU temperature change over the period drawing on key literature sources, including Stern (2006) and Mendelsohn (2006). This implies that in high growth scenarios emissions are larger and also temperature change is higher. Table 1 reports the 2006 output and emissions data used in our projections, and the growth rates used.

2. Calibration of Model Parameters

We use data on consumption and trade for both OECD and larger developing (BRIC) economies and along with country growth profiles to yield business as usual (BAU) scenarios under various damage and temperature change assumptions. Preferences towards goods and temperature change are determined for each country using alternative damage estimates from the same sources. We undertake numerical investigation with our analytical structure using calibration to determine model parameters values followed by counterfactual analyses of various forms. The base data are for 3 different periods 2012-2020, 2012-2030 and 2012-2050 with assumed yearly growth rates over the period.

Table 1: BAU Total Output, Emissions, and Emissions Intensity and Growth Rates Projected to 2020, 2030 and 2050

	China	India	Russia	Brazil	U. S	E.U.	Japan	ROW
Output in 2006, trill$	2.65	0.91	0.99	1.07	13.16	10.64	4.37	14.68
Emission intensity 2006	2.22	2.01	2.58	0.50	0.52	0.29	0.27	0.98
Emission in 2006, bmt	5.88	1.83	2.54	0.53	6.81	3.13	1.19	14.37
Cumulative emissions 1900-2012, bmt	165.06	45.67	117.89	14.41	385.11	354.93	54.88	321.50
Projected emissions from 2006 to 2012, bmt	62.61	16.75	22.72	3.91	51.30	23.43	8.67	111.00
Projected emissions from 2012 to 2020, bmt	176.94	41.49	56.35	8.66	108.44	47.90	17.57	243.83
Projected emissions from 2012 to 2030, bmt	731.944	152.110	206.782	28.380	341.927	147.587	54.113	798.795
Projected emissions from 2012 to 2050, bmt	6111.658	946.295	1289.959	132.775	1454.634	606.404	230.369	3848.604

Note: The high/low growth specification is where all rates are averages of country growth rates above/below average BAU growth rates for 2000-2006.

We first discuss the calibration of preference parameters. According to the Stern Review (2006), Mendelssohn (2006) and other literature, damage costs from emissions on BAU paths ranges from 1 to 20% of GDP out to 2050. We treat damage from climate change in the model as a utility change of the same proportion over the same time period and use it to calibrate the preference parameters in the model.

Without temperature change, the utility function is:

$$U_i^* = RC_i \tag{13}$$

And with damage we have:

$$U_i^* / U_i = (\frac{H - \Delta T}{H})^\beta \tag{14}$$

With temperature change, there will thus be a utility loss from damage. We can thus calibrate β using equation (14) above for given different values of H. For illustrative purposes, in Table 2 we report calibrated β values for a time period of 50 years as the base case. In our simulation analysis, we use H=10 as the base case, and perform sensitivity analysis with H=20 and H=30.

The temperature change function (2) is written as a function of emission changes over the same period, and we treat it as a power function of total emission (not output) change for the world.

Based on the findings from Stern (2006), we assume the BAU path of emissions will lead to about 3-degree temperature increases around the year 2030, and near 5 degrees by around 2050, although as we note earlier these exceed IPCC ranges. For simplicity, we assume that zero growth in the global economy will lead to no temperature change, i.e., $c = 0$.

With growth rates and emission intensities for each country for the BAU growth scenarios, we can then calibrate the parameters a and b. We have data for the year 2006 and projections of emissions and output data for 2030 and 2050. We choose 2006 as the base year, and assume that 25 years later that is by 2030 the global average temperature will increase by 3 degrees and 5 degrees by 2050. We assume that the BAU path implies output growth for each country comparable to that of 2000-2006, while emission intensities are unchanged from 2006. Table 2 reports the calibrated values of a and b.[8] We are also able to incorporate into the model calibration procedures autonomous (exogenous) improvements in energy efficiency (intensity).

Table 2: Calibrated Model Parameters

H	β in preferences		*a, b* in temperature change function assuming 50-year time horizon	
	BAU Damage cost assumed	β		
10	10%	0.152	$\Delta T^{2030} = 3$ $\Delta T^{2050} = 5$ $a = 0.044$ $b = 0.287$	$\Delta T^{2030} = 1.5$ $\Delta T^{2050} = 3$ $a = 0.005$ $b = 0.389$
	20%	0.322		
	50%	1.000		
20	10%	0.366		
	20%	0.776		
	25%	1.000		
30	10%	0.578		
	16.7%	1.000		

3. Emissions Reductions

Table 3 reports the percentage emissions reductions over the commitment period 2012-2020 implied by different allocation formulas, as well as projected 2020 emissions. Given China's high growth, China accounts for over 50% of global emissions by 2020, and so how different emissions reductions affect China is critical. Large differences occur using cumulative rather than annual emissions, with only small differences with a consumption base for emissions. The choice of base data of 1990 over 2012 also makes a large difference. In the case of cumulative emissions based reductions, we use an upper bound on emission reductions of 80%.

Table 3: Percentage Emission Reductions over Period 2012-2020 Implied by Different Country Allocations of a Global 30% Emissions Reduction

[8] Given the Stern estimates, $b < 1$ which implies diminishing not increasing marginal impacts of growing consumption on temperature change.

		China	India	Russia	Brazil	US	EU	Japan	Row
30% proportional reduction in emissions for each country by 2020; Using base data of projected 2012 emissions		30%	30%	30%	30%	30%	30%	30%	30%
30% proportional reduction in emissions for each country by 2020; Using base data of 1990 emissions		45.6%	40.3%	25.5%	19.7%	14.9%	12.7%	10.2%	17.4%
30% proportional reduction in emissions globally allocated using cumulative emissions 1900-2012 (80% upper bound)		15%	17%	33%	26%	55%	80%	49%	21%
30% proportional reduction in emissions for each country by 2020 using projected 2012 base data and using consumption rather than production		28%	32%	26%	29%	32%	31%	30%	28%
30% reduction globally by 2020 using projected 2012 base data but with developing country targets 1%, 3%, 5% lower for non OECD	1%	29%	29%	29%	29%	33.0%	33.0%	33.0%	29%
	3%	27%	27%	27%	27%	39.1%	39.1%	39.1%	27%
	5%	25%	25%	25%	25%	45.2%	45.2%	45.2%	25%

IV. Model Results

We use the calibrated model to evaluate the impacts of alternative joint emissions reductions and possible accompanying activity on border adjustment and transfers. We first consider cases involving all countries under the different allocations of global reductions set out in Table 3. We then later consider accompanying mechanisms, including border tax adjustments and/or financial transfers being used in which we assume there is participation of the OECD countries but with participation of developing countries linked to possible trade sanctions. This enables us to assess how large these have to be to induce participation.

We first report results from using the modeling framework set out above to make calculations of the welfare impacts of emissions reductions in Hicksian money metric form (in $billion over the commitment period) by country. These are reported in Table 4 for a 30% equi-proportional reduction by all countries by 2020 and a 30% reduction by 2030. In these results, given the damage cost estimate of 5% by 2050 used (from Stern (2006)) all countries lose from participation in climate arrangements for all three periods out to 2020, 2030 and 2050. This indicates infeasibility in concluding a negotiation on this basis, even with side payments. For the reductions out to 2020 the largest losses occur for the US and ROW, followed by the EU and Japan. For 50% reductions by 2030, losses increase for China due to their higher growth rate, but fall for the US and the EU due to restrained growing emissions in China and India.

Table 5 then reports welfare impacts by country for similar global 30% proportional reductions in emissions by 2020, but with changed model assumptions. We first change the assumed BAU damage cost estimates used in model calibration. If we lower damage cost estimates to 5% of GDP from 10% of GDP, country losses increase as consumption losses remain, but benefits of slowed global warming fall. If we increase climate change damage estimates used in calibration to 20% of GDP, gains accrue to all countries as the benefits of slowed global warming increase. In this case, an international negotiation can seemingly conclude. If we lower assumed temperature change, the benefits of slowed global warming fall. If we discount GDP growth at 1% and 0.5% for non OECD and OECD respectively, losses fall as the size of economies over the commitment period shrinks. Using PPP measures for GDP increases losses in China and India as their economies are proportionally larger.

Table 4: Welfare Impacts by Country of Equiproportional Reductions in Emissions for each Country Using Central Case Model Specification

($ bill, Money Metric Hicksian measures)

	China	India	Russia	Brazil	US	EU	Japan	Row
30% reduction by 2020	-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
50% reduction by 2030	-272.330	-51.391	-107.040	-46.734	-32.769	-145.795	-120.405	-648.884

Table 5: Welfare Impacts by Country of 30% Global Proportional Cuts in Emissions for Each Country by 2030 Using 2012 Base Data Under Varying Model Specifications

($bill; Money Metric Hicksian Measures)

		China	**India**	**Russia**	**Brazil**	**US**	**EU**	**Japan**	**Row**
A. Central case model specification in Table 4		-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
B. Variation model specification									
Change assumed BAU damage cost estimated in model calibration of temperature change function out to 2050	5%	-231.212	-71.160	-79.997	-61.413	-662.196	-480.823	-200.078	-778.808
	20%	8.692	12.252	-6.906	2.955	123.307	75.084	17.940	29.330
Change assumed temperature change to $\Delta T^{2030}=1.5$, $\Delta T^{2050}=3$		-226.263	-69.405	-78.525	-60.083	-645.634	-469.148	-195.543	-762.137
With discounting of GDP at 1% for Non OECD and 0.5% for OECD		-141.913	-41.051	-50.599	-37.424	-398.992	-293.014	-125.524	-500.368

With use of PPP measures of GDP in 2006	-260.614	-89.514	-71.489	-46.078	-323.776	-205.939	-100.658	-569.233

In Table 6 we report the impacts of alternative country allocations of emissions reductions which keep the same global total of a 30% global emissions reduction by 2020. These results indicate sharp changes by country in impacts as different allocations are used. Changes in the base date to 1990 nearly double the losses of both China and India as the high growth economies, while losses of slower growing US and EU fall sharply. Using historical emissions over the period 1900-2012 makes a large difference to both India and China whose losses nearly disappear. Losses to the US and the EU both nearly double. Changing to a consumption basis from production makes relatively little difference to country impacts. The use of differential cuts for OECD and non OECD is progressively more advantageous to China, India, Brazil and Russia and disadvantageous to the US and the EU.

In Table 7 we report the sensitivity of model results on welfare impacts by country for a 30% proportional cut in emissions. We vary alternative sets of key model parameter values. Varying trade elasticities for all countries together has little impact on model results. Varying damage costs, as above, has larger impacts and with a 20% damage cost estimate losses become gains. If damage costs are higher in non OECD countries, they benefit more from emission reductions. Varying the temperature change upper bound has little impact, as does varying temperature change differentially between China and India, and other countries in the model.

Table 6: Welfare Impacts by Country of Alternative Globally Equivalent Emissions Reductions by 2020 Relative to a 30% Proportional Cut by Country Using 2012 Projections as Base Data ($ bill, Money Metric Hicksian Measures)

		China	India	Russia	Brazil	US	EU	Japan	Row
Central case model specification		-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
Change base date to 1990		-276.45	-95.63	-50.016	-22.851	-219.295	-172.099	-79.867	-277.864
30% global cut allocated using 1900-2012 emissions by country		-7.15	-1.68	-66.45	-30.20	-354.02	-278.52	-190.56	-315.50
Change to consumption basis from production embedment		-146.397	-46.733	-50.413	-39.190	-441.1	-312.773	-128.134	-493.710
Use of differential cuts OECD/ non OECD (non OECD preference)	1%	-143.58	-40.64	-53.24	-37.86	-497.30	-364.78	-155.17	-483.06
	2%	-124.89	-34.04	-47.43	-32.75	-680.21	-495.52	-207.63	-418.97
	3%	-106.20	-27.44	-41.62	-27.64	-863.13	-626.27	-260.10	-354.90

Table 7: Sensitivity of Country Welfare Impacts for 30% Proportional Reduction by 2020 to Key Parameter Values

($ bill, Money metric Hicksian measures)

		China	India	Russia	Brazil	US	EU	Japan	Row
Changing trade elasticities σ, σ_m	$\sigma = 0.5$ $\sigma_m = 0.5$	-155.210	-44.786	-58.444	-40.836	-422.570	-301.116	-129.300	-518.138
	$\sigma = 0.5$ $\sigma_m = 0.9$ (BAU)	-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
	$\sigma = 1.2$ $\sigma_m = 0.9$	-102.342	-30.075	-36.292	-27.841	-270.675	-189.613	-86.023	-318.845
Varying damage cost	5%	-231.212	-71.160	-79.997	-61.413	-662.196	-480.823	-200.078	-778.808
	10% (BAU)	-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
	5% for OECD country, and 10% for Non-OECD country	-73.457	-16.307	-31.937	-19.086	-405.843	-299.403	-128.932	-247.395
	20%	8.692	12.252	-6.906	2.955	123.307	75.084	17.940	29.330
Varying temperature change upper bound (H)	10 (BAU)	-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
	20	-142.040	-40.173	-52.811	-37.489	-370.405	-274.297	-119.060	-478.425
	30	-139.488	-39.293	-52.027	-36.804	-362.119	-268.424	-116.748	-469.827
Varying Temperature change across country (ΔT_i)	If China and India $\Delta T + 0.5$	-141.780	-40.131	-57.194	-41.306	-416.584	-307.038	-131.954	-526.391
	If China and India $\Delta T + 1$	-129.493	-35.931	-58.229	-42.196	-427.232	-314.600	-134.948	-537.580

Table 8 reports the impacts of 30% proportional cuts by 2020 and 50% proportional cuts by 2030 on country GDP and country imports. The impacts on country GDP also reflect the cost of emissions reductions. Under a 30% equi-proportional cut the percent reductions in consumption are similar. Changes in country imports mirror these falls since in the model countries only trade a single good, and so relative price effects of carbon pricing on energy intensive and non intensive goods are excluded.

Table 9 reports results for the welfare impacts over the period 2012 to 2020 if alternative accompanying funds of varying sizes accompany the emissions reductions. These funds are assumed to be transferred over the period 2012 to 2020. With transfers of approximately $150 billion per year (totaling $1.2 trillion over the eight-year commitment period) losses for India disappear and for China, Russia and Brazil losses become negligible. Losses to the US, EU and Japan who finance the transfers double. Even larger redistributions occur when transfers of $200 billion per year occur over the same period. These results thus highlight the critical role that can be played by transfers of resources in facilitating developing country participation in the post Kyoto process (Springmann, 2012).

Table 10 reports country welfare impacts for 30% equi-proportional emissions reductions in the OECD being accompanied by alternative trade related mechanisms involving tariffs and export rebates by the OECD and non OECD countries. The first row reports welfare impacts for a case where emissions reductions are limited to the US, EU, Japan and the ROW. In these cases China, India, Russia and Brazil all benefit from slowed climate change. These gains then fall as various measures of increasing severity are applied against them. 20% and 30% tariffs induce China to participate by inflicting net losses; 10% and 30% tariffs play the same role for Brazil. Impacts of border adjustments are less pronounced due to the export subsidy rebates involved.

Table 8: Impacts on Country GDP and Trade of 30% and 50% Equiproportional Cuts by 2020 and 2030

A: 30% proportional cut by 2020								
	China	India	Russia	Brazil	US	EU	Japan	Row
% change in country GDP	-0.79%	-0.72%	-0.88%	-0.79%	-0.71%	-0.73%	-0.76%	-0.79%
% change in country imports	-0.82%	-0.59%	-1.06%	-0.90%	-0.49%	-0.67%	-0.80%	-0.84%
B: 50% proportional cut by 2030								
	China	India	Russia	Brazil	US	EU	Japan	Row
% change in country GDP	-1.31%	-1.13%	-1.46%	-1.36%	-1.05%	-1.18%	-1.28%	-1.32%
% change in country imports	-1.32%	-1.18%	-1.41%	-1.30%	-1.14%	-1.19%	-1.27%	-1.32%

Table 9: Welfare Impacts Over the Period 2012 to 2020 of Alternative Accompanying

Transfers of Funds to Accompany Equal Country Proportional Emissions Reductions of 30% by all Countries

($bill, Money Metric Hicksian measures)

Welfare impact in $ bill of various accompanying mechanisms to 30% proportional emissions reduction by 2020 by country	China	India	Russia	Brazil	US	EU	Japan	Row
1.Central case with no accompanying mechanisms	-152.928	-43.938	-56.150	-40.408	-405.843	-299.403	-128.932	-515.100
2.Distributing $ 1.2 trillions of accompanying funds to Non OECD proportional to GDP paid for by OECD proportional to GDP	-3.381	6.720	-8.755	-0.103	-962.618	-700.992	-444.474	-393.960
3.Distributing $ 1.6 trillions of accompanying funds to Non OECD proportional to GDP paid for by OECD	71.690	32.154	15.012	20.100	-1239.748	-901.038	-601.163	-333.343

Table 10: Welfare Impacts of Alternative Trade Related Mechanisms to Accompany Proportional Emissions Reduction of 30% by 2020 Only by OECD With Non Participation by Non OECD

($ bill, Money Metric Hicksian measures)

Welfare impact in $ tril	China	India	Russia	Brazil	US	EU	Japan	Row
1.Central case model specification with participation only by US, EU, Japan, Row in	77.774	29.827	19.980	21.093	-624.785	-449.682	-184.689	-710.842

30% reduction by 2020								
2.Non participation by non OECD plus 10% border adjustment in OECD	29.335	32.543	-18.567	13.598	-816.014	-511.382	-187.734	-599.481
3.Non participation by non OECD plus 20% border adjustment in OECD	-32.026	32.615	-60.501	4.247	-1020.428	-601.217	-200.955	-539.014
4.Non participation by non OECD plus 50% border adjustment in OECD	-172.57	25.638	-118.109	-23.926	-1855.346	-1040.474	-305.078	-144.382
5. Non participation by non OECD plus 10% tariff in OECD	31.962	38.378	-25.296	10.927	-853.046	-530.503	-181.341	-604.664
6. Non participation by non OECD plus 20% tariff in OECD	-11.869	46.483	-68.908	1.168	-1086.031	-635.944	-189.945	-549.113
7. Non participation by non OECD plus 210 % tariff in OECD	-164.73	64.502	-142.869	-30.323	-3134.875	-2296.720	-658.162	-142.076

V. Concluding Remarks

This paper presents numerical simulation results for a multi-country Armington climate extended general equilibrium model which captures the benefit side of climate change in preferences and allows for the analysis of country welfare impacts of global carbon emission reduction arrangements. The model embodies an assumption of uniform percentage climate change and damages by region, which we relax in later sensitivity analysis. These results are taken as possibilities for the post Kyoto/post 2012 period after the Bali roadmap UNFCCC negotiation process which concluded in Durban in 2011. The main focus is impacts on large rapidly growing developing countries (India, China, Brazil, etc.) In the model goods consumption and temperature change both enter utility change functions and countries jointly benefit from the emissions reductions of others. Trade effects enter through the heterogeneity of country goods, and consumption reducing emissions reductions have terms of trade effects.

The model is calibrated to alternative Business as Usual (BAU) scenarios out to 2020, 2030 and also 2050. Counterfactual exercises are then conducted around these various BAU scenarios. Results show all countries as losing if the damage estimates used in calibration from climate change are less than 10%. This suggests a possible inability to conclude a jointly agreed negotiation, unless sanctions of some form are used or damage costs are considerably higher. Large changes in country impacts as alternative reduction arrangements are considered.

Developing countries are more affected by the form that reduction takes than they are by the depth of reductions.

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