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THE POTENTIAL GLOBAL AND DEVELOPING COUNTRY IMPACTS OF ALTERNATIVE EMISSION CUTS AND ACCOMPANYING MECHANISMS FOR THE POST COPENHAGEN PROCESS

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ABSTRACT

We report numerical simulation results using a multiyear global multi country modeling framework which we use to assess the impacts of alternative emissions cuts which will likely come under consideration for the process to follow the December 2009 UNFCCC negotiation in Copenhagen. The Copenhagen Accord sets out prior country unilateral commitments, and provides a framework for further negotiation of mutually agreed cuts. We also consider possible financial transfers under the Adaptation Fund and possible trade linked border measures against non participants. Countries are linked not only through shared impacts of global temperature change but also through trade among country subscripted goods. We can thus evaluate the potential impacts of either explicit or implicit accompanying mechanisms including funds/transfers, border adjustments, and tariffs. We calibrate the model to alternative BAU damage scenarios largely as set out in the Stern report. The welfare impacts of both emission reductions and accompanying measures are computed in Hicksian money metric equivalent form over alternative potential commitment periods: 2012-2020, 2012-2030, and 2012-2050. We consider different depth, forms, and timeframes for reductions by China, India, Russia, Brazil, US, EU, Japan and a residual Row. Given the damage estimates we use all countries lose from joint reductions since their foregone consumption is more costly than saved damage from reduced climate change. With the use of larger damage estimates this reverses the depth of cut and allocation of cuts by country cause large differences in impacts by country, while differences in form of cut (intensity, embedment) matter less. Accompanying mechanisms also can make a large difference to participation decisions and especially for large population, low wage, rapidly growing non OECD countries, but are costly for the OECD countries. This all suggests that the bargaining set for the post Copenhagen process is very large, making an eventual jointly agreed outcome difficult to achieve.

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1 Introduction and policy context

Negotiations on climate change arrangements as part of the shaping of a post Kyoto/ post 2012 world concluded in Copenhagen in December 2009 in a 2 week end to a negotiation initiated in Bali in late 2007 but are now scheduled to continue in Mexico in late 2010. The result has been the Copenhagen Accord which only lists prior unilateral commitments and attempts to move to a joint verification process, but which also commits countries to further negotiation on deeper cuts. What is involved is effectively the second round of negotiations under the 1994 United Nations Framework Convention on Climate Change (UNFCCC) which in the first round produced the 1997 Kyoto Protocol.[2]

The post Copenhagen process will likely attempt to take this structure significantly further through deeper cuts (25% -40% by 2020, and 80%-95% by 2050 were indicated in the 2007 Bali meeting which launched the negotiation); a broadened coverage to also include adaptation, mitigation, and finance; and all in an effort to produce a fully inclusive outcome incorporating the large population, rapidly growing economies of China, India, and Brazil who now, unlike in Kyoto, would also take on commitments. These economies are large and with rapidly growing emissions (and China poised to become the world's largest emitter) are seen as key to global mitigation. In the group of BASIC countries (Brazil, South Africa, India, China) they played a key role in negotiating the Accord jointly with the US prior to its adoption more widely.

These countries have consistently argued both that as rapid growers and relatively new to industrialization they should be treated differently from more mature OECD countries, and that this was committed to under the Principle of Common But Differentiated Responsibilities in the United Nations Framework Convention on Climate Change (UNFCCC) and also underlies the Annex 1 / non Annex 1 categorization in Kyoto. As a result, a range of proposals have emerged as to what form any special developing country treatment should take as far as emissions reductions are concerned. One is that any emissions reductions targets by countries should be based on a single global target allocated to countries on a cumulative basis rather than the current Kyoto annual emissions basis. Their argument is that emissions in the upper atmosphere have mostly originated from OECD countries over many years, and that emissions targets by country should reflect this. Another argument is that emissions reduction targets should focus on reducing emissions intensities (emissions/dollar of GDP) rather than emissions levels so as to allow more

[2] The Kyoto Protocol is relatively simple in structure. Countries are divided into two groups A and B; signatory countries in Annex 1 agreed to reduce emissions by 2012 relative to 1990 base date emissions; Non Annex 1 countries (developing) took on no commitments. There were then accompanying emissions trading arrangements (Joint Implementation and the Clean Development Mechanism (CDM)) involving both groups.

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. Under this approach, exports (which embed carbon) would be deducted from GDP and imports added to give the basis for country allocations of emissions reductions. Where countries run large trade imbalances, such as the US and China, this could yield a potentially significant difference. Finally, some developing countries argue that Common But Differentiated Responsibilities implies preferential and lower emissions reduction targets for them relative to OECD countries.

But other features of potential joint emissions reductions also enter which can also impact differentially on individual countries. A key one is the choice of base date for calculating reductions with 1990 (the Kyoto data) being strongly preferred by Russia (and the EU) due to negative (slow) growth between 1990 and today, and 2012 being strongly resisted by China for the opposite reason. And details within issues such as with the use of intensity target, how GDP is calculated (using market exchange rates or PPP for conversion into US$) matters.

Finally, there is the use of accompanying financial arrangements through the Adaptation and Innovation Funds, as well as possible trade measures against non participants which can affect outcomes. Developing countries, as represented by the GTT, consistently argued in Copenhagen for a large Fund to help them adapt to climate change, at the top end of $300 billion per year by 2013. The Accord as agreed talks of "working towards" a climate change Fund for developing countries of $100 billion per year by 2020. On the trade front, both the US (through the Waxman-Markey Bill) and the EU have in place legislation proposals for the use of carbon emission based tariffs and export rebates affecting trade with non participant countries.

There is little or no quantitative model based evaluation work on the potential welfare and other impacts of both these different proposals for mitigation. Here, we report results on the impacts of these proposals on both the large population rapidly growing economies of China, India, Russia and Brazil and the major OECD economies of the US, the EU, and Japan using an N country N good modeling framework used earlier by Cai, Riezman, and Whalley (2009). Their original use of the framework was only used to explore whether international trade makes participation in climate change negotiations more likely. Here we extend it to capture both different mitigation targets and potential accompanying financial and trade related mechanisms.

In this framework, countries can set aside part of their potential consumption available under a no mitigation business as usual (BAU) scenario and lower global temperatures giving a utility gain, but at a utility cost in terms of foregone consumption. We 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. This structure goes beyond the one good structure of the PAGE model referenced in the Stern (2006) report which simply imputes an isoelastic intertemporal utility function to forecast GDP damage. Unlike PAGE, the modeling framework we use here enables us both to evaluate the effects of different mitigation negotiation proposals using the model in counterfactual mode, and also evaluate the potential impacts of accompanying inducements or penalties which involve trade. We thus also include another side of special treatment for developing countries in the post Copenhagen process, since the negotiation contains both explicit elements and implicit indications as to how countries may be treated if they do not fully participate in proposed emissions reductions.

We use calibrations to alternative business as usual (BAU) scenarios, for periods out to 2020 and 2030. We first use annual data for 2006 which we project to synthetic (nonobserved) 2012 base data 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 and adopt abatement cost estimates.

Our results on these emissions reduction proposals suggest that given the damage estimates from climate change the countries we consider will both individually and collectively all lose from the climate reduction initiatives under discussion in Copenhagen and so the issue for them is which form of mitigation minimizes country losses. If we calibrate to larger damage cost estimates the pattern changes to joint gains, but the relative picture across countries is much the same. Our results emphasize the wider range of potential outcomes depending on the formulae used to allocate cuts to countries, and hence a large bargaining set for the post Copenhagen process which may make it difficult to conclude. The differences between country allocations of emissions reductions based on cumulative and annual emissions are especially large and this would seemingly continue to be a major issue in negotiation. Other issues such as consumption or production as a basis for cuts on the use of intensity targets have smaller but still pronounced impacts. The same is true of a 1990 versus a 2012 base date for certain countries (Russia (1990), China (2012), EU (1990)). Finally comes the issue of the relative depth of emissions reduction between developed and developing countries. Here our results indicate that each percentage point differentiation in cuts between developing and developed countries significantly benefits developing countries.

Our results on accompanying mechanisms suggest that the current indications of size of accompanying funds are critical for developing countries. An Adaptation Fund of $100 billion a year seems insufficient to induce participation, while $200 billion/year does seem sufficient. The costs to the developed countries, however, are also large. Money, therefore, will be a key element in a joint arrangement, and the ranges again are 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.

The bottom line from these calculations would seem to be that while we use a simple modeling structure and parameters are uncertain the potential ranges of impacts of adopting alternative formula cuts, or using accompanying Funds or trade mechanisms are very large. This points to a negotiation which may be difficult to conclude, although the large political momentum behind the drive globally to respond to climate change may be enough to reach conclusions despite this.

2. The Copenhagen Accord and the Post Copenhagen Negotiation to Come

The current UNFCCC negotiations on climate change are the latest continuation of a climate change negotiating process which has its origins in the UNFCCC, and which evolved from the Earth Summit in 1992. The UNFCCC has only a vague mandate for negotiation which only focuses on achieving the participation of individual countries in joint discussions on climate change. These are thus few or no constraints through agreed rules on the form that any mitigation takes. One concrete element is the principle of 'common yet differentiated responsibility' for developing countries, although the precise interpretation of this has remained vague, which has also created later problems in the ongoing negotiation process (Tian & Whalley, 2008).

Kyoto represented the first negotiating round within the overarching constitutional mandate provided by the UNFCCC, much as the trade negotiating rounds under the GATT from 1947 onwards built upon the constitutional structure which the GATT provided. But unlike the GATT, there are no detailed articles providing firm, clear rules for climate arrangements such as MFN and national treatment. The vagueness of the negotiating mandate is something which has been pointed to by many as an impediment to further agreed modification of emissions by participating countries. It is also not clear within the UNFCCC structure how the UNFCCC secretariat can move to a final determination of compliance with Kyoto provisions. There are notifications of emissions by countries and discussions with the UNFCCC, and the process can simply continue on with no mechanism for a firm determination of emissions levels.

Out of the initial Kyoto process, however, has emerged a follow on negotiating process now focused on a post-2012 regime, sometimes referred to as the post Bali-roadmap negotiations because of the meeting which took place in Bali which launched these negotiations in December 2007. This occurred in COP13, with an intermediate meeting of a COP14 in Poznan in the fall of 2008, and with the COPI5 negotiation held in December 2009 which produced the Copenhagen Accord. This process aim to generate arrangements for a global environmental regime after 2012 for a extended period of time, possibly to 2020 or 2020 or even 2050. The December 2009 Copenhagen Accord has three central elements; a listing of unilateral commitments by countries (to be completed within 2 years), a process of joint verification (yet to be defined), and a commitment to work towards a climate change Fund by 2020 to provide around $100 billion per year to developing countries. Some see the agreement as lacking in firm commitment, but it also specifies an ongoing negotiating process to achieve firmer commitments for a post 2012 world.

As agreed in Bali, there are four elements to the continuing negotiation.

One is emissions reduction and mitigation, determining both the form and depth of emissions reduction commitments. Another is adaptation mechanisms expanding greatly on the existing Adaption Fund to facilitate the adaptation of the economies of UN members to climate change. Third is innovation, expanding on a further fund to promote the development of emissions reduction technologies either through renewables or through more carbon-efficient energy generation processes. Fourth is trade and finance. This is, in principle, built around various estimates of the amount of funding needed to achieve emissions reductions of the type foreseen, with a central estimate of $45 trillion in financing required to cut emissions by 50% over the implementation period out to 2050 produced by the International Energy Agency (IEA) (IEA, 2008) for the 2001 Bali meeting. There are no formal negotiating elements involved in trade and finance, although the border tax adjustment issues which are discussed later fit within this broad rubric. The negotiation involves a COP negotiating structure similar to the previous rounds of negotiation within the UNFCCC, and was to be concluded in the two weeks of negotiation in Copenhagen which generated the Accord, but now continues on to Mexico.

This negotiation has faced and continues to face difficulties not only because of the ongoing vagueness of the mandate and the imprecision of issues, but also the sharp differences between developed and large developing countries in terms of potential growth performance, their differences in historical rather than annual emissions, and their developmental aspirations. A central issue in mitigation is the depth of emissions cuts involved. There were efforts made by the EU in Bali to build into the negotiating mandate precise figures, but these were left on a recommended basis as a footnote suggesting possible ranges of 25-40% cuts by 2020 and 80-95% by 2050 to keep global temperature rises below 2°C as advised by IPCC. But developing countries claim rights to growth and development and argue that emissions reductions should not overly constrain their growth, and that any emissions reductions should be asymmetric between the developed and the developing countries.

China, India, Brazil, Indonesia and South Africa, as the larger of the emerging economies and the more rapidly growing ones, were out of the negotiation in Kyoto from which the Annex 1, Non Annex 1 structure emerged. The pressure has been on these countries to be part of the post Bali process because they are the most rapidly growing emitters and China is poised to become the world's largest emitter of carbon. This, in turn, has led to discussion of the basis for cuts as well as the depth of cuts, in addition to cumulative vs annual emissions and the historical basis for cutting developed countries want to continue to use annual emissions much as in the Kyoto structure.

There have been debates on the issue of intensity vs level calculations of emissions. Intensity targets refer to calculations of emissions intensity relative to GDP, the argument being that the use of emissions intensity as targets would allow room for developing countries to grow, whereas level targets for rapidly growing economies are inappropriate. China's unilateral commitments are for a 40-45% reduction in intensity of emissions by 2020.

A further issue involves the use of consumption rather than production as a basis for emissions reductions, reflecting the Chinese focus on so-called embedment. The Chinese claim that perhaps 35% of emissions are already embodied in exports and should be treated as emissions of importing countries rather than China.

Behind these debates are differences in the interpretation of 'common yet differentiated responsibilities' for emissions reduction, with sharply differing interpretations circulating. Some of the developing countries argue that they should be entitled to rights to growth and development, and if they undertake climate commitments they should be compensated through financial transfers. Another interpretation is that there should be differing forms of commitment for different types of countries, perhaps with the developed countries taking on level commitments and the developing countries taking on intensity based commitments.

There are also issues circulating relating to contingent rather than firm commitments. Chancellor Merkel, for instance, has suggested that there be targets established for maximum temperature change, and whatever emissions reductions are necessary to live within the targets for temperature change be implemented. She has suggested that temperature change be restricted to no more than 2 degrees C by 2050 from the base year of 1990.

Another set of negotiating issues involve enforcement and concerns raised by the developing countries about the credibility of a second round of negotiation when perhaps as many as 15 developed countries will be in violation of their first round Kyoto commitments. This raises two issues: one is the determination of compliance or non-compliance, on which the present mandate is vague, and the second is how any overhang of unfulfilled commitments from Kyoto will be dealt with post 2012. The use of enforcement mechanisms including possibly a large fund has been suggested which would be held in escrow, with contributions from countries only to be returned to them once determinations have been made as to compliance, raising issues of who makes such determinations and what data will be used. Other proposals involve the entering of commitments into domestic law granting rights allowing private parties to sue on the basis of violations of commitments.

Trade and border tax adjustment issues enter these negotiations through implicit linkage, with claims for their use coming from countries which see themselves as going faster and further than other countries on climate change action, particularly the EU and ,increasingly, the US. One argument is that some form of compensation mechanism should be available for domestic producers because of the cost disadvantages they face. The recent Waxman-Markey bill in the US congress would require exporters to the US to buy emission allowances if imports enter from countries not matching US commitments. There are also issues of so-called leakage, other countries increasing emissions with the room created by countries taking on more stringent commitments. The mechanisms under current discussion involve trade barriers on imports from low commitment countries and subsidies on exports to these countries to offset the cost differentials involved for domestic producers. Some discussion has, however, gone beyond border adjustments with export rebates to focus solely on tariffs based on carbon content. These are then defended as consistent with the WTO exception (Article 20) for trade measures which defend human life.

Because of all the elements involved and the depth of country differences on them and the sizes of potential impacts involved, the negotiation in Copenhagen was difficult, and the resulting Copenhagen Accord facilitates the continuation of negotiation. For the large developing economies, and particularly China and India, the issue is which elements of these proposals they should concentrate on. Is it the country allocation of reductions, the depth of reduction, the degree of asymmetry in any commitments, or the form commitments take that is the most important? And how severe are costs they face of potential penalties from their non participation relative to the costs of compliance? And what size of financial compensation through Adaption Funds might induce their participation?

3. A Modeling Framework for the Evaluation of Post Copenhagen Emissions Reduction Options

To analyze the potential impacts of the various negotiating possibilities we set out in the preceding section, we have adapted a modeling framework used earlier by Cai, Riezman, and Whalley (2009) and Tian and Whalley(2010) to analyze linkages between trade, trade policy and climate change arrangements. Here we take this framework further and use it to evaluate the 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, and focus the analysis on the large population rapidly growing developing economies of China, India, Russia and Brazil. We also explore whether border taxes, tariffs, and/or transfers and at what level make participation in these climate change negotiations more likely.

3.1 Temperature change and top level country utility functions

We analyze a single period of a number of years during which each national economy is assumed to grow at a compounding constant rate[3]. Each country is assumed in the period to be able to consume or export have one country heterogeneous good whose potential consumption (or use) grows at this rate 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 temperature. 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 have an upper bound on the use of their own good reflecting a Business as Usual (BAU) scenario. 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 will later work with the impacts of agreements to reduce carbon emissions over a given period of time, we take the single period to cover alternative horizons from 2012 out to 2020, 2030 or 2050. These reflect possible commitment periods for a UNFCCC Agreement on a post 2012 world. 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.

[3] 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. 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.

The utility of each country over the period is reflected in a utility change function relative to utility under zero growth with arguments given by its own country change in composite consumption as well as the temperature change of the world. The utility function is thus defined over multi year changes in consumption and temperature change. Potential use of each country good thus reflects changes in 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, and with no global or single country emissions limitation initiatives in place.

We initially assume the utility change function for each country has the form

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

In this specification, ΔRC_i represents the change in consumption for each country *i* over the period. This is 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. This provides the crucial link between trade, tariffs and sanctions and emission reduction incentives used to explore the possible impacts of accompanying measures for a UNFCCC post 2012 package.

In this form, *H* can be thought of the global temperature change at which all economic activity ceases (say 20°C). As ΔT approaches *H*, utility goes to zero and ΔT goes to zero there is no welfare impact of temperature change. Utility change over any model period increases as temperature change falls.

The share parameter β 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 reported by Stern (2006) and Mendelsohn (2007), and this procedure determines β. For simplicity, we assume β is the same value across countries.

Global temperature change, in turn, is determined by the change in carbon emissions over the period across all countries in the model. We adopt a simple temperature change function 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. Defining the emissions intensity of country *i* as e_i, we use a power function (2) for 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*.[4] In the central case formulation of the model, e_i is

[4] Ideally, this power function should have the property that there is increasing marginal impact on temperature change for progessive increases in consumption, i.e., $b > 1$. We however 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 $b < 1$.

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. The typical scenario we consider is where countries in the model can commit to emission reductions which are a given percentage of their $\overline{\Delta RS_i}$. We thus also conduct sensitivity analyses in which the e_i change over time to reflect increased efficiency of energy use over time. When we also consider accompanying trade and finance mechanisms, 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).

3.2 Composite consumption goods by country

In this structure, a carbon reduction commitment by a single country implies a reduction in composite consumption, and this has both negative and positive effects on utility change 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.

The composite consumption good RC_i is 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.

The RC_i are determined by solving the country optimization problems.

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

$$s.t. \quad p_i^w D_i + p_i^m M_i \le I_i = p_i^w RS_i \tag{4}$$

where D_i and M_i represent, in turn, 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, and σ as the substitution elasticity[5].

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

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

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

The composition of 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)). I_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 the climate change agreement.

3.3 Composites of Imported Goods

The CES import composites M_i are 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

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[5] We use the same central case settings of elasticities as Cai, Riezman and Whalley (2009) of $\sigma = 0.5$ and $\sigma_m = 0.9$. Cai et al provide literature based discussion of these values, which we later vary in sensitivity analysis.

is the outcome of a sub-utility maximization problem

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

$$s.t. \quad \sum_{j \neq i} p_j^{d_i} R_j^i \leq I_i^m = p_i^m M_i \tag{8}$$

where R_j^i is the country good *j* imported by country *i* p_i^m is the composite import price for country *i*, κ_j^i is the consumption share and σ_m is the second level substitution elasticity. I_i^m is the income devoted to expenditures on imports (from (6)). These CES sub-utility maximizations give:

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

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

3.4 Trade Equilibrium

Given values of ΔRS_i, a trade equilibrium is given by prices $p_1^w, ..., p_N^w$ for which global markets clear, i.e.

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

The ΔRS_i take on the values $\overline{\Delta RS_i}$ in the base case and one of two values in counterfactual analyses. ΔRS_i can be the implied reduction in $\overline{\Delta RS_i}$ for countries meeting emissions reduction commitments. Alternatively, ΔRS_i is equal to $\overline{\Delta RS_i}$ for non OECD countries if they do not participate.

In this structure, when countries participate in a global climate agreement, if they reduce emissions by reducing GDP there will be general equilibrium implications for all prices and quantities. Importantly, if there are accompanying mechanisms, tariffs against countries will cause the price of their own good *i* to fall giving a terms of trade loss for the country not making the emission reduction. 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.

3.5 Costs of Mitigation

A further key element in the model is the cost of mitigating damage from climate change through emission reduction, or abatement costs. We capture these in a simple mitigation cost function where country mitigation costs are a linear constant marginal cost function of use of own good (consumption plus export). Stern (2006) places these costs for a 50% reduction in emissions by 2050 at 1% of GDP±3%. We use a central case estimate of 2.5% and then use sensitivity ranges for this key parameter. The mitigation (abatement) cost function can be written as;

$$MC_i = \varphi \frac{(\overline{\Delta E_i} - \Delta E_i)}{\overline{\Delta E_i}} RS_i \qquad (11)$$

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

3.6 Model Extensions

We use the model to analyze different counterfactuals relative to the BAU scenario. For emissions reductions of various forms we compute counterfactuals over the chosen period.

There are, however, some experiments we conduct with the simulation structure which require extensions to the basic model form. One arises where we evaluate the impacts of using intensity targets in a simple uncertainty extension of the model, since in the certainty case the two instruments are typically equivalent in impact. We also incorporate trade policies and transfers to evaluate the possible impacts of accompanying trade and/or finance mechanisms and modify the model appropriately.

Uncertainty

The model captures uncertainty in a simple way by considering three alternative growth scenarios: high growth, low growth and BAU growth and computing a different base case (no emission reduction) scenario for each. For each scenario we first compute utility 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 emission reduction under the emission 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.

Trade Related Penalties and Financial Incentives for Countries to Participate in Negotiations

The model can also be 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.

4. Data and Model Calibration

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 agreement. In this, we use varying estimates of associated damage over the ranges reported by Stern (2006) and Mendelsohn (2007) 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 construct a BAU growth profile using forward projections of 2006 data, and model calibration to this profile determines key model parameters.

4.1 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 the basis of 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 data for each growth scenario: projected base case data in 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.

China, India, Russia, Brazil, USA, EU, Japan and the Rest of the World (Row) are assumed to 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 of 2000 to 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 (2007). 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.

Preferences towards goods and temperature change are determined for each country using alternative damage estimates from the same sources.

Table 1 Total Output, Emission, and Intensity data and Growth Rates assumed out 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 emission 1900-2012, bmt	165.06	45.67	117.89	14.41	385.11	354.93	54.88	321.50
Projected emission from 2006 to 2012, bmt	62.61	16.75	22.72	3.91	51.30	23.43	8.67	111.00
Projected emission from 2012 to 2020, bmt	176.94	41.49	56.35	8.66	108.44	47.90	17.57	243.83
Projected emission from 2012 to 2030, bmt	731.944	152.110	206.782	28.380	341.927	147.587	54.113	798.795
Projected emission 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 average of country growth rates above/below BAU growth for 2000-2006.

4.2 Calibration of Model Parameters

We use data on consumption and trade for OECD and BRIC economies and along with country growth profiles analyze various damage and temperature change assumptions as business as usual (BAU) scenarios. 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.

We first discuss the calibration of preference parameters. According to the Stern Review (2005), Mendelssohn (2006) and other literature, the damage cost from emissions on BAU paths range 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 and use it to calibrate the preference parameters in the model.

Without temperature change, the utility function is:

$$U_i^* = RC_i \qquad (12)$$

And with damage we have :

$$U_i^* / U_i = \left(\frac{H - \Delta T}{H}\right)^{\beta} \qquad (13)$$

With temperature change, there will thus be a utilities loss from damage. We can thus calibrate β using equation (13) above for given different values of H. For illustration 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 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:

$$\Delta T = a(\sum_i \Delta E_i)^b \qquad (14)$$

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 degree by around 2050. For simplicity, we assume that zero growth in the global economy will lead to no temperature change.

With the data on growth rates and emission intensities for each country under the BAU growth scenarios, we can then calibrate the parameters *a* and *b*. We have data for 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*.[6]

We are able to relax this assumption to allow for autonomous (exogenous) improvements in energy efficiency (intensity) overtime.

4.3 Emissions Reductions

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

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		
	20%	0.322	$\Delta T^{2030} = 3$	$\Delta T^{2030} = 1.5$
	50%	1.000	$\Delta T^{2050} = 5$	$\Delta T^{2050} = 3$
20	10%	0.366		
	20%	0.776	*a*= 0.044	*a*= 0.005
	25%	1.000	*b*=0.287	*b*=0.389
30	10%	0.578		
	16.7%	1.000		

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

Table 3 Emission Reductions over period 2012-2020 implied by different country allocations of a global 30% emissions reduction

		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%

5. Model Results on Impacts of Emission Reductions

We evaluate the impacts of alternative emissions reductions. We first consider cases involving all countries under the different apportionment of global reductions set out in Table 3. We then later consider accompanying mechanisms being used in which we assume participation of the OECD countries and with participation of non OECD countries linked to trade sanctions, border tax adjustment or financial transfers. This enables us to assess how large these have to be to induce participation.

We first use 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% equip report and 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. For 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 4 Welfare impact by Country of equiproportional reductions in emissions for each country using central case model assumptions

($ bill, Money Metric Hicksian measures)

	China	India	Russia	Brazil	US	EU	Japan	Row
30% reduction by 2020	-159.544	-46.242	-58.165	-92.185	-427.538	-314.755	-134.951	-531.404
50% reduction by 2030	-272.330	-51.391	-107.040	-46.734	-32.769	-145.795	-120.405	-648.884

Table 5 Welfare impact by Country of global 30% proportional cuts in emissions for each country by 2030 using 2012 base data under varying model assumptions

		China	India	Russia	Brazil	US	EU	Japan	Row
A. Central case model specification in Table 4		-159.549	-46.242	-58.165	-42.185	-427.538	-314.755	-134.951	-537.404
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

Table 5 then reports welfare impacts by country for similar global 30% proportional cuts in emissions by 2020 but withy 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 estimates to 20% of GDP, gains accrue to all countries as the benefits of slowed global warming increases. 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 shrinks. Using PPP measures for GDP increases losses in China and India as their economies are proportionally larger.

Table 6 Welfare by Country of alternative globally equivalent emissions cuts 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		-159.549	-46.242	-58.165	-42.185	-427.538	-314.755	-134.951	-537.404
Change base data to 1990		-276.45	-95.63	-50.016	-22.851	-219.295	-172.099	-79.867	-277.864
30% globally 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		-154.26	-44.40	-56.56	-40.77	-410.21	-302.49	-130.14	-519.59
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

In Table 6 we report the impacts of alternative country allocation procedures for emissions reductions which keep the same global total of a 30% global emissions reduction by 2020. The results indicate sharp changes by country in impacts as different allocations are used. Changes to 1990 have nearly doubled 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 dramatic 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 as to 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. Varying the temperature change upper bound has little impact.

Table 7 Sensitivity of Welfare results for 30% proportional out 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
	$\sigma = 0.5$ $\sigma_m = 0.9$	-159.549	-46.242	-58.165	-42.185	-427.538	-314.755	-134.951	-537.404
	$\sigma = 1.2$ $\sigma_m = 0.9$	-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%	-159.549	-46.242	-58.165	-42.185	-427.538	-314.755	-134.951	-537.404
	20%	8.692	12.252	-6.906	2.955	123.307	75.084	17.940	29.330
Varying temperature change upper bound (H)	10	-159.549	-46.242	-58.165	-42.185	-427.538	-314.755	-134.951	-537.404
	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

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 reflect the cost consumption due to emissions reductions. Under a 30% equi-proportional cut the percent reductions in consumption are similar. Changes in country imports mirror these falls since in this model countries only trade a single good and so relative price effects of carbon pricing on energy intensive non intensive goods are excluded.

Table 8 impacts on country GDP and trade of 30% and 50% equiproportional cuts by 2020 and 2030 using 2012 projections

($bill, Money Metric Hicksian measures)

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 reports results for the welfare impacts over the period 2012 to 2020 of alternative accompanying funds of varying sizes which 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 period losses of India disappear and for China, Russia and Brazil losses become negligible. Losses to the US, EU and Japan who finance the transfer double. Even larger redistributions occur when transfers at a rate 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.

Table 9 Welfare impacts over period 2012 to 2020 of Alternative Accompanying Funds to accompany equal country proportional emission reduction 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 presents results which report welfare impacts by country of 30% equiproportional emissions reductions being accompanied by alternative trade related mechanisms involving tariffs and export rebates in the OECD. The first row reports welfare impacts from 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, all 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 10 welfare Impacts of Alternative Accompanying Trade Related Mechanisms to accompany equal country 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 30% reduction by 2020	77.774	29.827	19.980	21.093	-624.785	-449.682	-184.689	-710.842
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

6. Concluding Remarks

This paper presents numerical simulation results for a multi-country model which allows the analysis of country welfare impacts of global carbon emission reduction situations which may follow in the post Copenhagen process of negotiating a post Kyoto/post 2012 world. In the model goods consumption and temperature change both enter utility 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 and 2030. Counterfactual exercises are then conducted around these various BAU scenarios. Results stress the large changes which occur in country impacts as alternative formulae are utilized. This indicates a large bargaining set for the post Copenhagen negotiation. Further results highlight the role to be potentially played by financial transfers and trade based sanctions.

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