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ABSTRACT

Large population / rapidly growing economies such as China and India have argued that in the upcoming UNFCCC negotiations in Copenhagen, any emission reduction targets they take on should be based on their intensity of emissions (emissions/$GDP) on a target date not the level of emissions. They argue that this will allow room for their continued high growth, and level commitments in the presence of sharply differential growth between OECD and non-OECD economies represent asymmetric and unacceptable arrangements. Much of the policy literature agrees with this position, also arguing that while there is equivalence between commitments if growth rates are certain, where growth rates are uncertain equivalence breaks down. However, no explicit models or experimental design are used to support this claim. Here we use a modeling framework in which countries face a business as usual (BAU) growth profile under no mitigation, and can mitigate (reduce consumption) and lower temperature change but with a utility loss. International trade enters through trade in country differentiated goods, and the impact of mitigation on country welfare depends critically on the assumed severity of climate related damage. We then consider cases where country growth rates are uncertain, and compare the impacts of levels versus intensity commitments, with the latter made equivalent in the sense that expected emissions are the same. There are different senses of this equivalence; global equivalence with differing country impacts, or strict country by country equivalence. Under intensity commitments there is more variation in both consumption and emissions than is the case with level commitments, and we show cases where level commitments are preferred to intensity commitments by all countries. Whether this is the case also depends upon how growth rate uncertainty is specified. We are also able to consider packages of mixed level and intensity commitments by country which might be the outcome of UNFCCC negotiations. Outcomes can thus be opposite to prevailing opinion, but it depends on how the equivalent targets are specified.

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1. Introduction

A central difference in the form of commitment which has been debated for upcoming global negotiations on climate change in Copenhagen in December 2007 is between absolute commitments to reduced annual levels of emissions (on a flow basis such as per year) as measured on an agreed commitment date, and relative commitments to reduced levels of emissions per unit of GDP, again as measured on an agreed commitment date. Developing countries argue that such forms of commitment are necessary for them given their high growth, and also commitments of this form will encourage them to become more energy and emission efficient more quickly.

In this paper, we take up the issue of level versus intensity commitments in a formal analytical structure. It is widely agreed that in the certainty case there is an equivalence between the two commitment forms. For any level target an intensity target exists whose impacts will be identical. The critical differences arise with uncertainty over growth rates, autonomous reductions in energy conversion efficiency, technical progress, and other considerations.

While much of the policy based literature (see Pizer (2005)) argues in favor of intensity commitments on the grounds it leaves more emission room for high growth countries, little of it explicitly compares the two commitment forms in well specified experiments. In the presence of uncertainty as to growth performance, intensity commitments will typically generate more variance in both output and emissions for equivalent level commitments with the same expected emissions reduction across the two commitment forms, but at the same time there are differing senses of equivalence. For instance, equivalence may hold only globally so that expected global emissions are the same, while country emissions on an expectations basis vary, or equivalence may hold more strictly on a country by country basis.

We use a general equilibrium model applied to a multi decade business as usual (BAU) scenario in which global output determines emission levels, and countries trade country specific goods with both goods and temperature change entering preferences. Countries can forgo use of their own good to meet targets, reducing emissions with a welfare gain from temperature change and welfare loss from reduced consumption. We use an eight region structure (China, India, Russia, Brazil, US, EU, Japan, Rest of the World) which we calibrate to a Business as Usual (BAU) scenario over 50 years. We are able to compare intensity to level targets being used by all countries, being used by a subset of countries (China, India, Russia, Brazil) while others use level targets, or only by individual countries (China, for instance). The higher variance of output and emissions can make intensity commitments unattractive for countries compared to levels commitments when strict country equivalence holds, although individual country impacts also reflect terms of trade effects. Significant differences across countries apply when looser global equivalence is used. What stands out is the difference in perspective relative to the policy based discussion in that details of equivalence assumed in the experiment and how growth rate uncertainty is specified matter for country impacts. Numerical results are also sensitive to the assumed damage from climate change and model parameters used.

2. Level versus intensity commitments

In December 1997, more than 150 countries concluded negotiations on the Kyoto Protocol, a landmark agreement on global climate change. Signed by 84 countries, including the United States, the treaty committed industrialized countries to legally binding limits on their emissions of greenhouse gases that are linked to global climate change. These limits were expressed as reductions (or, in a few cases, increases) in absolute emissions levels relative to a 1990 baseline.

Developing countries took on no commitments under Kyoto and countries were divided into two groups; Annex A with commitments and Annex B with no commitments. This was seen at the time as an interpretation of the principle of "Common but Differentiated Responsibilities" applying to developing countries and adopted as part of the earlier 1994 UN Framework Convention on Climate Change.

Kyoto commitments terminate in 2012 and with the end of the Kyoto implementation period, the focus has now shifted to arrangements for a post Kyoto world and further negotiations under UNFCCC which are to conclude in Copenhagen in December 2009. In these negotiations the participation of large population rapidly growing developing countries (China, India, Brazil, Russia) is seen as key as their emissions will progressively come to dominate global emissions if their (pre crisis) high growth rates continue. These countries, in turn, cite not only common but differentiated responsibilities, but also their need for growth and development as the basis for them taking on different forms of commitment compared to developed countries.

Level (or absolute) emissions targets typically specify a percentage reduction in the amount of carbon dioxide and other greenhouse gases (Kg of carbon Dioxide equivalent) to be released on a flow basis on a specified date. Intensity (or relative) emissions target reductions involve a percentage reduction in the amount of emissions relative to some measure of output (such as GDP) usually stated in dollar or local currency terms, on a specified date. The commitment in both cases is to percentage reduction by some specified date relative to an earlier base date.

Level commitments were the mechanism used in the 1997 Kyoto Protocol and are also widely used in other treaty arrangements (such as the Montreal Protocol on CFC's). Intensity commitments have attracted growing attention in global negotiations on greenhouse gas (GHG) emissions due to arguments from rapidly growing large population economies (China, India, Russia, Brazil) that they need room to accommodate high growth and that this points to emissions intensity targets. Intensity-based limits which restrict emissions to some pre-specified ratio relative to input or output are much more widely used in domestic environmental regulation.

Intensity targets can be interpreted as performance standards. For a company, the standard maybe relative to company total sales or relative to units of a good produced. For a country, the standard is typically specified as tons of carbon dioxide equivalent relative to country GDP. If emissions intensities are used the choice of exchange rate in calculating US$ dominated GDP becomes a critical issue. This is especially important for China and India due to large differences in the dollar measure of GDP depending upon whether or not purchasing power parity or market exchange rates are used.

Both the form of commitment and the target date for any commitments in the second round of global emissions reduction negotiations to conclude in Copenhagen in December 2009 are at this point unresolved. The Bali 2007 UNFCCC documents contained language suggesting indicative targets of a 25-40% reduction by 2030. Developing countries have raised the issue of the form of commitment not only in terms of levels versus intensity but also as it relates to other issues such as the treatment of emissions embedded in exports. In the G8, there has been discussion of 50% cuts by 2050. Chancellor Merkel has also been associated with proposals for targets for maximum temperature change (2℃) by 2050. 2050 targets might also be accompanied by intermediate targets, say a 30% cut by 2030, and a 20% cut by 2020.

Available literature on the intensity / level issue stresses that in the presence of certainty the two commitment forms are equivalent, in the sense that for any level commitment, an equivalent intensity commitment can be found with the same impacts. It is where growth and any autonomous reductions in energy conversion efficiency are uncertain that differences rise.

Pizer (2005) argues that absolute emissions targets are too constraining in face of unexpectedly high growth and too lax in face of unexpectedly low growth, and that intensity targets better accommodate unexpected growth and favor developing countries. His arguments reflect four key claims: that greenhouse gas emissions will continue to rise over the near term, that absolute targets emphasize zero or declining emissions growth while intensity targets do not, that developing countries' economic development is integrally tied to emissions growth for the foreseeable future, and that intensity targets are not any more complicated to administer than levels targets.

Ellerman and Wing (2003) also discuss the differences between these two forms of emission targets, arguing like others that the two forms have identical effects in a world where future emissions and economic output (i.e. GDP) are known with certainty. They show that outcomes for emissions and welfare only diverge when the variance of GDP diverges from its forecast expectation. They then argue that intensity targets reduce the importance of what is the most important unknown for any country considering the cost of meeting emission targets; future economic performance. Their conclusion is that if uncertainty about the effects of absolute targets impedes agreement or causes existing agreements to unravel, then some form of indexation of targets to economic growth seems both desirable and necessary to enable agreements to be made.

Jacoby et al. (1998) also argue that intensity targets are more compatible with the overall architecture of environmental agreements. They argue that an absolute cap is only a limiting form of emission targets in which the degree of indexation to GDP growth is a choice variable. They suggest that the widespread use of intensity targets in environmental regulation, including some use as an instrument to reach Kyoto targets by parties adhering to the Protocol, suggests that more attention should be paid to this than in the past.

Our point of departure relative to this literature is to argue that in any comparison of the economy wide performance of level versus intensity targets, a basis for the comparison is needed in clearer analytical terms. Precedents for such comparisons lie in the tax literature where the efficiency and distributional impacts of alternative tax structures are compared on an equal yield basis. Here, the natural experiment would seem to be to consider uncertainty in, say, the growth rate of countries comparing a business as usual scenario (with uncertainty in emissions levels) to outcomes under emissions targets in level (absolute) and equivalent intensity form, calibrated such that expected emissions levels are the same across the two forms of limitation. We also argue that there are differing forms of equivalence. One might be where the expected global emissions intensity reduction is the same but with the same absolute reduction in intensity country differences apply in proportional reductions, and another might be where equivalence of expected proportional emissions intensity applies on a country by country basis.

While emission intensity targets may be argued as inconsistent with arrangements under the Kyoto Protocol, there is no reason why the form that targets take cannot change from one environmental negotiation to another.[2] For more than a decade, international climate negotiations have focused on absolute emissions targets and timetables. The result has been a system that is biased toward halting and reversing emissions growth, even as evidence suggests that emissions will continue to grow for decades in industrialized countries and much longer in the developing world. This bias arises because progress viewed in terms of emissions inevitably means emissions reductions—not slowing growth of emissions. Shifting the focus of the negotiation towards intensity targets can thus be defended as opening the door to more inclusive negotiations where a range of approaches—including slowing, stopping, or even reversing emissions growth—can be discussed. Intensity targets can then be interpreted as performance standards for the whole economy.

The question remains whether intensity-based emissions targets offer a preferable alternative to level emissions targets both globally and for individual countries. Do intensity targets better accommodate growth and make targets for developing countries more likely to be acceptable than absolute emissions limits? Or do intensity targets instead increase the expected variance of both emissions and output and increase

[2] Some would even abandon entirely the targets-and timetables architecture of the Kyoto Protocol and replace it with agreements on R&D expenditures and technology transfer (Barrett, 2001) or with a global carbon tax (Cooper, 1998).

uncertainty relative to level targets? What is needed is experimental analysis to investigate, with the same expected reduction in emissions whether the expected utility under intensity limits will be higher or lower than that in the certainty case.

3. Model Structure and Experiment Specification

We use an extended version of a multi country modeling framework recently developed by Tian, Whalley & Cai (2009) in which the effects of alternative climate change policies relative to a BAU scenario can be assessed over many years considered as a single period. Into this, we introduce uncertainty of country growth rates and compare the expected welfare differences involved using comparable level and intensity targets as counterfactual model experiments. We specify the intensity equivalent experiments in different ways, with varying forms of uncertainty of country growth rates as well as expected global equivalence in terms of expected emission. In one case there are equal absolute reductions in intensity with country differences in expected proportional reductions, and in the other equal proportional intensity reductions and country by country equivalence in proportional expected reductions. We are also able to compute the distributional implications of using one form of intensity target over another.

The model considers multiple regions (China, India, Brazil, Russia, US, EU, Japan, Rest of the World). Each region is endowed with a single good and goods are heterogeneous across countries (the Armington (1969) assumption). Countries export their own good, and import the other country goods. Country utility is defined over consumption of goods and temperature change. In the model countries can reduce global emissions by forgoing consumption since emissions are linked to the total value of consumption world wide. In this way, countries can induce lowered world temperature change which benefits all, but at a cost to themselves in terms of foregone consumption.

We use data on consumption and trade for the eight economies, along with country growth rate data for 2000-2006. We forward project BAU scenarios alternatively to 2036 and 2056, using various damage and temperature change assumptions as our BAU case. This base data is thus for a single 30 or 50 year period 2006-2056 with assumed yearly growth rates over the period. We calibrate the model to a temperature change function for prospective changes in temperature under the three growth scenarios out to 2056. In these we use varying estimates of associated damage reported by Stern (2006) and Mendelsohn (2006).

In the model, we introduce uncertainty in the form of three different growth scenarios: BAU growth and a higher and lower growth scenario for each region. Our BAU growth rates reflect average annual country growth rates over the period

2000-2006 projected forward. We consider one case where high and low growth rates reflect the same percentage deviation in country growth rates across all countries. We consider an alternative case where growth rates for high and low growth scenarios reflect averages of above and below mean growth rates for the period 2000-2006.

For simplicity, we assume that the high and low growth scenarios occur in each case with equal probabilities. We then use these to assess the impacts of different emission reduction targets: comparing the BAU outcome without any emissions reduction to a 20% level target reduction in country emissions; and to alternative intensity targets that are equivalent to the absolute target in terms of expected impacts on emission levels specified both globally and by country. We compute the welfare level under the BAU scenario and under the high and low growth scenarios in each case for both absolute and intensity targets. This allows us to assess whether the expected welfare of the two weighted average cases in the level target case is higher or lower than in the intensity target case.

3.1 Temperature change and top level country utility functions

We analyze a single period of a number of years during which each of the economies we analyze grows at a compounding constant rate. Each country is assumed to have one heterogeneous good whose availability also grows at this rate in the base case (BAU). We assume that consumption of the good by the country directly generates emissions of carbon which, in turn, raises global temperature. Countries generate positive utility from consumption of goods, but negative utility from temperature change. Countries have an upper bound on their own use of their good (consumption plus export) reflecting the BAU scenario. If they use less than the upper bound they experience less temperature change, as do all other countries. If they are small, their own actions have little or no effect on temperature change.

We analyze the impacts of emissions reductions over a given period of time which we consider as a single period which covers either 30 or 50 years. There are no explicit dynamics. For this period, we focus on changes in consumption (of both own and foreign goods via international trade) and utility, and measure changes in these variables relative to the outcome of zero growth over the period. The utility function is thus defined over 30 or 50 year changes in consumption and temperature change. The potential use of the own good by an economy can thus be thought to reflect changes in potential output from the economy over 30 or 50 years. We first analyze a business as usual (BAU) scenario which reflects current observed growth rates remaining unchanged over 30 or 50 years, and with no global or single country emissions limitation initiatives in place, and then consider alternative high and low growth cases. We then compute model solutions under alternative emissions reductions for each scenario.

The utility of each country in all cases is reflected in a utility change function with arguments given by the country's own change in composite consumption as well as the temperature change of the world. We assume the utility change function for each country has a Cobb-Douglas form given by (1).

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

In this specification, ΔRC_i represents the change in consumption for each country i *(i=1,…,N)*. ΔRC_i is, in turn, a composite of their own good and other country's goods which they acquire by exporting their own good and importing other country's goods. This structure can thus be used to also analyze links between trade penalties (tariffs) and financial transfers and participation in emission reduction initiatives.

H can be thought of the global temperature change at which all economic activity ceases (say 20℃). As ΔT approaches C utility goes to zero, and as ΔT goes to zero there is no welfare impact from temperature change. Utility change over the model period (2006-2036 or 2005-2036) increases as temperature change falls. The share parameter β reflects the severity of damage (in utility terms) from any given temperature change. We calibrate the model to various damage estimates from business as usual global temperature change reported by Stern (2006) and Mendelsohn (2006), and this procedure determines β.

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 region i as e_i, we use a simple power function (2) for global temperature change due to changes in emissions by all countries over the model period.

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

where ΔRS_i represents the change in the use (consumption plus export) of the own good for each country *i*. We treat the e_i as exogenous and constant over the period, but the structure can be extended to also incorporate an exogenous improvement in emissions intensity overtime reflecting increased efficiency of energy conversion. Consumption across all regions of each country own good is less than ΔRS_i because of international trade. ΔRS_i in turn is less than or equal to the upper bound $\overline{\Delta RS_i}$ associated with the base case scenario as countries lower use of their own good to meet emissions targets.

3.2 Composite consumption goods by country

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

The composite consumption good RC_i is a CES function of domestic and imported consumption goods, similar to the nested CES Armington functions in trade models (see Whalley (1985)). The model effectively becomes an Armington N good N country pure trade economy in which the endowment of each region is variable and temperature change enters utility.

The demands for consumption goods reflect the outcome of sub utility maximization.

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

$$s.t.\quad p_i^w D_i + p_i^m M_i \le I_i = p_i^w RS_i \qquad (i=1\ldots N) \qquad (4)$$

where D_i and M_i 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, and σ as the substitution elasticity. 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.

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

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

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

3.3 Composites of Imported Goods and Trade Equilibrium

The CES imported composite commodities are in turn 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 defines an import composite. This is also the outcome of a sub-utility maximization exercise

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

$$s.t. \quad \sum_{j \neq i} p_i^w R_j^i < I_i^m = p_i^m M_i \qquad (8)$$

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

$$p_i^m = \left[\sum_{j \neq i} \kappa_j^i (p_j^w)^{1-\sigma_m}\right]^{\frac{1}{1-\sigma_m}} \quad (i=1\ldots N) \qquad (9)$$

$$R_j^i = \frac{\kappa_j^i p_i^m M_i}{(p_j^w)^{\sigma_m} \sum_{j \neq i} \kappa_j^i (p_j^w)^{1-\sigma_m}} = \kappa_j^i \left(\frac{p_i^m}{p_j^w}\right)^{\sigma_m} M_i \quad (i=1\ldots N) \qquad (10)$$

A trade equilibrium in the model is given by world prices p_i^{w*} for each of the country goods for which make clear globally, i.e

$$D_i + \sum_j R_j^i = RS_i, \quad (i = 1, \ldots N) \qquad (11)$$

Climate change polices that affect RS_i change equilibrium prices, as do trade measures (tariffs) or transfers between countries used as mechanisms to generate participation in such agreements.

3.4 High, Low and BAU growth scenarios and Model Experiments

The model captures uncertainty in a simple way by analyzing three alternative growth scenarios: high growth, low growth and BAU growth. For each scenario we compute utility and consumption of goods by region. We consider two different specifications of high and low growth rates. In one there is equal percentage variation in growth rates across high and low growth states by country. In the other, we consider high growth rates as average growth rates above mean growth rates for 2000-2006, and low growth as average growth rates below the mean. For the high and low growth scenarios we consider each will occur with probability one half, and we compute expected utility and expected emissions.

We then introduce different emission targets for the various growth scenarios by using alternative forms of level and intensity target equivalence. In one case we use equivalence in expected emissions by country, in the other the target is loser in the form of equal expected emissions globally. In the first case, the global target implies an equi proportional reduction in intensities by country. In the second case, the emission level target as a common reduction in emissions intensity subject to a lower bound on emissions intensity. We then compute the impacts of equivalent emission intensity reductions which give the same expected emission reduction to be achieved as under emission level targets given the BAU output of the region. We thus compute the model utility change under high, low and BAU growth scenarios respectively for each of the emissions targets, and then compare expected utility for high and low growth scenarios across the two targets. We measure the impacts of use of one target relative to another using a Hicksian money metric equivalent variation of the utility difference expressed in $ trillion. These amounts can then be compared to the value of GDP (discounted where discounting earlier) over the model period (30 or 50 years).

4 Model Calibrations

We calibrate our model to a base case business as usual (BAU) scenarios for two different model periods 2006-2036 and 2006-2056. 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 Description

We use GDP growth as the measure of potential change in consumption by each country over the period. We use averaged data between 2006 and 2000 to calculated growth rates. We first assume that under the different (BAU, high, low) growth scenarios, country growth rates in the period 2000-2056 remain unchanged over the whole period of 50 years between 2006 and 2056. All the data for each time period are forward projected based on the data for 2006. We have three components in our data for each growth scenarios: base case data in 2006, cumulative data for 2056 given high, BAU and low growth, and cumulative data over the period relative to the base year for the same three growth scenarios.

Base year output, emissions and growth rates are reported in Table 1. 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 of 2000 to 2006 (data from World Bank website). We use two different specifications of high and low growth rate scenarios since these serve to illustrate how the specification of growth scenario affects the comparison between level and intensity targets. For the first specification, high growth scenarios use averages of country growth rates for years between 2000 and 2006 with above mean growth, while low growth scenarios use averages of growth rates for years between 2000 and 2006 with below mean growth. This yields high growth rates for China, India, Russia, Brazil, USA, EU, Japan and Row of: 0.105, 0.089, 0.080, 0.042, 0.033, 0.030, 0.025, 0.037 respectively and low growth rates of 0.086, 0.043, 0.054, 0.017, 0.016, 0.013, 0.006 and 0.020 respectively. In the second specification, we use high and low growth rate data in which we assume that high growth rates are a 50% higher than in the relevant BAU rate in all countries, and low growth rates a 50% lower than in the relevant BAU rate in all countries. This gives high growth rates for China, India, Russia, Brazil, USA, EU, Japan and Row of 0.135, 0.105, 0.105, 0.048, 0.039, 0.030, 0.025 and 0.045, and low growth rates of 0.05, 0.04, 0.04, 0.02, 0.013, 0.01, 0.008 and 0.015 respectively. The larger the variance of BAU growth rates, then typically the larger the difference between high and low growth rates for eight countries. In the second specification of high and low growth rates, China, India, Russia and Brazil have more variation in growth rates than the developed countries.

We use BAU growth rates to calibrate the temperature change function using BAU temperature change over the two periods 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. Preferences towards goods and temperature change are determined for each country using alternative damage estimates from the same sources.

Table 1 Output, Emission Intensity data in 2006 and Growth Rates out to 2036 and 2056

	China	India	Russia	Brazil	U.S	E.U.	Japan	ROW
Output in 2006, trill$	1.067	0.987	0.912	2.645	13.164	10.636	4.368	14.682
Emission in 2006, ktonC	0.53	2.54	1.83	5.88	6.81	3.13	1.19	14.37
Emission intensity 2006	0.500	2.577	2.012	2.222	0.517	0.294	0.273	0.979
BAU growth rate	0.09	0.070	0.069	0.032	0.026	0.020	0.017	0.030
High growth rate (1)	0.105	0.089	0.080	0.042	0.033	0.030	0.025	0.037
Low growth rate (1)	0.086	0.043	0.054	0.017	0.016	0.013	0.010	0.020
High growth rate (2)	0.135	0.105	0.105	0.048	0.039	0.03	0.0255	0.045
Low growth rate (2)	0.045	0.035	0.035	0.016	0.013	0.010	0.009	0.015

Note: (1) is the growth specification 1 where all rates are average of country growth rates above/below BAU growth for 2000-2006. (2) is the growth specification 2 where growth rates are a 50% higher / lower in all BAU country growth rates for 2000-2006.

4.2 Calibration of preference parameters

We first turn to the calibration of preference parameters. According to the Stern Review (2006), Mendelsohn (2006) and other literature, the damage cost of emissions with 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 and use it to calibrate the preference parameters in the model. Without temperature change, the utility function is:

$$U_i^* = RC_i \tag{12}$$

And with damage we have :

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

With temperature change, there will be a loss from damage. We can thus calibrate β using equation (13) above for given different values of H. A time period of 50 years as the base case yields the β values reported in Table 2. In our simulation analysis, we use H=10 as the base case, and perform sensitivity analysis with H=20 and H=30.

We next turn to the temperature change function. The temperature change function is written as a function of emission changes. We treat it as a power function of total emission (not output) change for the world:

$$\Delta T = a\left(\sum_i \Delta E_i\right)^b \tag{14}$$

Based on the results from Stern Review (2006), the BAU path of emissions will lead to about 3 degree temperature increases around the year 2035, and near 5 degree C 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 calibrate the parameters *a* and *b*. We have data for year 2006 and projections emission and output data for 2036 and 2056. For simplicity, we choose 2006 as the base year, and assume that 30 years later, that is by 2036, the global average temperature will increase by 3 degrees, and 5 degrees by 2056. 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. We are able to relax this assumption to allow for autonomous (exogenous) improvements in energy efficiency (intensity) overtime. Table 2 also reports the calibrated values of a and b.

Table 2 Calibration Model Parameters for 50 Year Time Horizon

H	$\hat{\beta}$ in preferences		*a*, *b* in temperature change function assuming $\Delta T^{2036} - 3$ $\Delta T^{2056} - 5$
	BAU Damage cost assumed	β	
10	10%	0.152	*a*=0.304 *b*=0.296
	20%	0.322	
	50%	1.000	
20	10%	0.366	
	20%	0.776	
	25%	1.000	
30	10%	0.578	
	16.7%	1.000	

5. Results of Model Experiments

Using the 2 alternative specifications of high and low country growth rates, and the two different specifications of equivalence between level and intensity targets, we can make 4 calculations of country welfare under alternative emission reduction targets. We can then compute expected utility under level and intensity targets for each country for each of 4 specifications (with differences in the sense of equivalence of the intensity target, and the setting of high and low growth rates). We can also compare the distributional implications across countries in the sense of intensity equivalence (absolute or proportional). We can also compare how other model features, such as timeframe, commitment level, and assumed BAU damage from climate change impact the choice of emission target both by country and globally.

Table 3 reports the reductions in emission intensity over the model period implied by alternative level equivalent experiments. This intensity reduction is an equi proportional reduction of 20% in emissions intensity implemented over the whole of the model period of either 30 or 50 years, equivalent in expectations form to a 20% level reduction. The second reduction is an equal absolute reduction in emissions intensity calculated to give the same expected global reduction as both the level commitment and the other intensity commitment. We use a lower bound of an 80% absolute emission intensity reduction to preclude country cases (EU & Japan) where emission intensity reductions would otherwise be negative.

Table 3 Percentage Changes in Base Year (2006) Intensity by Country Under Alternative 20% Level Equivalent Reduction[3]

Country	BAU Emission intensity In 2006	Reduction 1 Emission intensity over model period after proportional reduction equivalent to 20% level reduction in emission	Reduction 2 Emission intensity over model period after absolute reduction (subject to 80% lower bound) in equivalent intensity target to 20% level reduction in emission
China	2.22	20%	15%
India	2.01	20%	16%
Russia	2.58	20%	13%
Brazil	0.50	20%	65%
US	0.52	20%	62%

[3] The reductions in intensity by country in each case are calculated so as to generate equal expected reductions in emissions.

EU	0.29	20%	80%
Japan	0.27	20%	80%
Row	0.98	20%	33%

In Table 4 we report welfare impacts by country of emission reductions in the certainty case for two alternative reductions of 20% and 30% as this provides a basis for comparison of the alternative intensity commitments in the growth uncertainty cases. It has been acknowledged in literature for some time that only with large BAU damage costs from climate change countries individually benefit in narrow self interest terms from climate change reduction. Here we assume a 10% damage estimate in calibrating the model and in both 20% and 30% reduction cases all countries lose. Proportional to size China loses the most reflecting both its size and high emission intensity. The issue with levels versus intensity targets in this case is thus under which instrument are expected losses larger or smaller, and for which country.

Table 4 Incremental Utility from Goods Consumption and Climate Change with and Without Emission Reductions Targets in the Certainty Case (2006-2056)[4]

	BAU scenario No target	20% level reduction for all countries	30% level reduction for all countries
China	1900.403	1877.75	1857.49
India	280.44	277.684	274.987
Russia	231.972	228.708	225.983
Brazil	56.903	56.149	55.504
US	484.571	480.962	476.871
EU	240.304	238.746	236.836
Japan	92.656	91.64	90.697
Row	607.638	598.289	590.751

In Table 5, we report welfare comparisons in money metric terms for the use of level and the two intensity equivalent commitments for the period 2006-2056 as well as the differences between the two intensity equivalent commitment forms. Welfare

[4] Assuming 10% damage from climate change in the BAU case.

measures are in Hicksian money metric form over the whole model period of 50 years. We use the two different specifications of equivalence (equal proportional, equal absolute) discussed earlier. We also use the two different growth rates scenarios set out above.

These results indicate how both for individual countries and globally these comparisons can produce either level or intensity preference. Globally, under high/low growth specification (1) proportional intensity targets are preferred to level targets but this result is reversed under high/low growth specification (2). Under growth specification (2) all countries gain from the use of a level target relative to an equivalent intensity target, reflecting the added uncertainty created by intensity targets. All countries except China gain from intensity targets with the alternative specification of high and low growth rates.

Results for the comparison of proportional and absolute intensity commitment by country show significant distributional variation by country. Countries with high BAU intensities (China, India) are considerably worse off with proportional intensity targets and the US and the EU are much better off.

Table 6 reports results for the same comparison as in Table 5, but where the timeframe is varied to run from 2006-2036 instead of 2006-2056. These welfare comparisons report lower numbers in $ trillion for the shorter timeframe since the economy is smaller in size, but under growth rate specification (2) the gains from using proportional intensity targets while still all positive, are proportional to GDP lower. For growth rate specification (1), these are 4 results of change in sign in the comparison, and 4 cases where loses increase in size. Under absolute equivalence a similar picture of change emerges, emphasizing the sensitivity of these comparisons to specification.

In Table 7 we report results for variations in the depth of commitment in comparisons between level and level equivalent intensity targets for the same 2 growth rate specifications and the two cases of absolute and proportional equivalence. In these cases, for growth rate specification (2), the welfare gain accruing to countries in level equivalent intensity target specification from using proportional intensity equivalence increases sharply for all countries with deeper commitments, except the US. For growth rate specification (1) for 7 of 8 losses become gains; China is the exception. Similar changes occur for absolute rather than proportional senses of equivalence, and for the US relative loses from absolute equivalent targets increase.

In Table 8, we report results where we instead compare the welfare impacts of mixed packages of level and intensity commitments to the outcome under common 20% level reduction commitments. As this is a potential outcome from the Copenhagen negotiations, these results are of special interest.

For proportional equivalence under both growth scenarios (1) & (2) we show loses to the BRIC countries (Brazil, Russia, India, China) and gains to the large OECD (EU, US, Japan). Under growth scenario (2) these effects are large. Under absolute equivalence, the losses to BRIC are smaller and under growth scenario (1) for absolute equivalence gains occur.

If intensity targets are restricted in their use to China, under growth scenario (1) gains accrue to China and losses to all others for both absolute and proportional equivalence. Results reverse for growth scenario (2).

In Table 9 we report results from cases in which the BAU damage cost assumption used to calibrate preferences in the model is varied prior to comparisons of level and level equivalent intensity commitments. These cases are computed once again for the two different growth scenarios and under differing senses of equivalence. For growth scenario (1), increasing the damage cost increases gains and reduces losses for all countries for proportional equivalence. For growth scenario (2) results go uniformly in the opposite direction for proportional equivalence. Different results are obtained for absolute equivalence.

Finally in Table 10, we report results where we vary elasticity parameters in the model. For space reasons, we limit this to results for growth specification (1) and for proportional equivalence. These results indicate limited sensitivity of findings in this dimension.

6. Concluding Remarks

This paper reports numerical simulation results comparing the use of level and level equivalent intensity commitments to carbon emissions reduction by large countries in potential global treaty arrangements convening potential commitment periods of 30 or 50 years. The current Copenhagen 2009 negotiation on a post Kyoto world have seen low wage rapidly growing economies, such as China and India argue that they should take on intensity targets rather than level targets as this will allow them room to grow given their prospective high GDP growth rates. There has been considerable policy discussion of this issue, but (to our knowledge) no work in an analytical framework.

Here we use a multi country trade model augmented by temperature change intensity in preferences in which countries set aside part of their endowment to meet emissions reductions and lower utility and reduce global temperature change and raised utility (of all countries). This model is calibrated to two alternative BAU growth profiles for 2006-2036 and 2006-2056.

The main feature of our results is that country impacts can be either positive or negative, and significant or insignificant depending on a range of factors. These include the way in which uncertainty is specified in the model via differing country high and low growth scenarios, the way in which level equivalence for intensity targets is specified, the timeframe used, the depth of commitments, and (to a smaller degree) elasticity values. Cases occur in which level targets significantly dominate intensity target for all countries, opposite to current policy opinion. Also, mixed level and intensity targets seem to favor rapidly growing low wage economies including China and India. Proportional equivalence is preferable for OECD over non OECD economies and vice versa for absolute equivalence. The conclusion offered is that in this framework unambiguous claims for level or intensity seem unsupportable, but insights on potential impacts can be obtained via numerical modeling once specific proposals and circumstances.

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