Fondazione Eni Enrico Mattei

NOTA DI LAVORO

92.2009

Global Climate Policy Architecture and Political Feasibility: Specific Formulas and Emission Targets to Attain 460 ppm CO2 Concentrations

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SUSTAINABLE DEVELOPMENT Series
Editor: Carlo Carraro

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Summary

Three gaps in the Kyoto Protocol most badly need to be filled: the absence of emission targets extending far into the future, the absence of participation by the United States, China, and other developing countries, and the absence of reason to think that members will abide by commitments. To be politically acceptable, any new treaty that fills these gaps must, we believe, obey certain constraints regarding country-by-country economic costs. We offer a framework of formulas that assign quantitative allocations of emissions, across countries, one budget period at a time. The two-part plan: (i) China and other developing countries accept targets *at BAU* in the coming budget period, the same period in which the US first agrees to cuts *below* BAU; and (ii) all countries are asked in the future to make further cuts in accordance with a formula which sums up a Progressive Reductions Factor, a Latecomer Catch-up Factor, and a Gradual Equalization Factor. An earlier proposal for specific parameter values in the formulas – Frankel (2009), as analyzed by Bosetti, et al (2009) – achieved the environmental goal that concentrations of CO2 plateau at 500 ppm by 2100. It succeeded in obeying our political constraints, such as keeping the economic cost for every country below the thresholds of *Y*=1% of income in Present Discounted Value, and *X*=5% of income in the worst period. In pursuit of more aggressive environmental goals, we now advance the dates at which some countries are asked to begin cutting below BAU, within our framework. We also tinker with the values for the parameters in the formulas. The resulting target paths for emissions are run through the WITCH model to find their economic and environmental effects. We find that it is not possible to attain a 380 ppm CO2 goal (roughly in line with the 2°C target) without violating our political constraints. We were however, able to attain a concentration goal of 460 ppm CO2 with looser political constraints. The most important result is that we had to raise the threshold of costs above which a country drops out, to as high as *Y* =3.4% of income in PDV terms, or *X* =12 % in the worst budget period. Some may conclude from these results that the more aggressive environmental goals are not attainable in practice, and that our earlier proposal for how to attain 500 ppm CO2 is the better plan. We take no position on which environmental goal is best overall. Rather, we submit that, whatever the goal, our approach will give targets that are more practical economically and politically than approaches that have been proposed by others.

The authors would like to thank for support the Sustainability Science Program, funded by Italy's Ministry for Environment, Land and Sea, at the Center for International Development at Harvard University and the Climate Impacts and Policy Division of the EuroMediterranean Center on Climate Change (CMCC). The paper was written while Valentina Bosetti was visiting at the Princeton Environmental Institute (PEI) in the framework of cooperation between CMCC and PEI.

Keywords: International Climate Agreements

JEL Classification: Q, Q40, Q54

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FIRST DRAFT Sept. 21+Nov. 5, 2009

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Abstract

Three gaps in the Kyoto Protocol most badly need to be filled: the absence of emission targets extending far into the future, the absence of participation by the United States, China, and other developing countries, and the absence of reason to think that members will abide by commitments. To be politically acceptable, any new treaty that fills these gaps must, we believe, obey certain constraints regarding country-by-country economic costs. We offer a framework of formulas that assign quantitative allocations of emissions, across countries, one budget period at a time. The two-part plan: (i) China and other developing countries accept targets *at BAU* in the coming budget period, the same period in which the US first agrees to cuts *below* BAU; and (ii) all countries are asked in the future to make further cuts in accordance with a formula which sums up a Progressive Reductions Factor, a Latecomer Catch-up Factor, and a Gradual Equalization Factor. An earlier proposal for specific parameter values in the formulas – Frankel (2009), as analyzed by Bosetti, et al (2009) – achieved the environmental goal that concentrations of CO2 plateau at 500 ppm by 2100. It succeeded in obeying our political constraints, such as keeping the economic cost for every country below the thresholds of *Y*=1% of income in Present Discounted Value, and *X*=5% of income in the worst period.

In pursuit of more aggressive environmental goals, we now advance the dates at which some countries are asked to begin cutting below BAU, within our framework. We also tinker with the values for the parameters in the formulas. The resulting target paths for emissions are run through the WITCH model to find their economic and environmental effects.

We find that it is not possible to attain a 380 ppm CO2 goal (roughly in line with the 2°C target) without violating our political constraints. We were however, able to attain a concentration goal of 460 ppm CO2 with looser political constraints. The most important result is that we had to raise the threshold of costs above which a country drops out, to as high as *Y* =3.4% of income in PDV terms, or *X* =12 % in the worst budget period.

Some may conclude from these results that the more aggressive environmental goals are not attainable in practice, and that our earlier proposal for how to attain 500 ppm CO2 is the better plan. We take no position on which environmental goal is best overall. Rather, we submit that, whatever the goal, our approach will give targets that are more practical economically and politically than approaches that have been proposed by others.

Summary

This paper offers a framework of formulas that produce precise numerical targets for emissions of carbon dioxide (CO_2) in all regions of the world in all decades of this century. The formulas are based on pragmatic judgments about what is possible politically. The reason for this approach is the authors' belief that many of the usual science-based, ethics-based, and economics-based paths are not politically viable. It is not credible that successor governments will be able politically to abide by the commitments that today's leaders make, if those commitments would be costly.

Three political constraints seem inescapable if key countries are to join a new treaty and abide subsequently by their commitments: (1) Developing countries are not asked to bear any cost in the early years. (2) Thereafter, they are not asked to make any sacrifice that is different in kind or degree from what was made by those countries that went before them, with due allowance for differences in incomes. (3) No country is asked to accept an ex ante target that costs it more than *Y*% of income in present discounted value (PDV), *or more than X% of income in any single budget period*. The logic is that no country will agree to ex ante targets that have very high costs, nor abide by them ex post.

Further, one major country or region dropping out is fatal. The reason is that others will become discouraged and may also fail to meet their own targets; the entire framework may unravel. If such unraveling in a future decade is foreseeable at the time that long-run commitments are made, then those commitments will not be credible from the start. Firms, consumers, and researchers base their current decisions to invest in plant and equipment, consumer durables, or new technological possibilities on the expected future price of carbon: If government commitments are not credible from the start, then they will not raise the expected future carbon price.

The proposed targets for emissions are formulated assuming the following framework. Between now and 2050, the European Union follows the path laid out in the 2008 European Commission Directive; the United States follows the path in the version of the Waxman-Markey bill passed by the House in June 2009; and Japan, Australia and Korea follow statements that their own leaders have recently made. China, India and

other countries *agree immediately to quantitative emission targets*, which in the first decade*s merely copy their business-as-usual (BAU) paths*, thereby precluding leakage. These countries are not initially expected to cut emissions below their BAU trajectory.

When the time comes for developing countries to join mitigation efforts their emission targets are determined using a formula that incorporates three elements: a Progressive Reductions Factor, a Latecomer Catch-up Factor, and a Gradual Equalization Factor. These three factors are designed to persuade the joining countries that they are only being asked to do what is fair in light of actions already taken by others. In the second half of the century, the formula that determines the emissions path for industrialized countries is dominated by the Gradual Equalization Factor. But developing countries, which will still be in earlier stages of participation and thus will have departed from their BAU paths only relatively recently, will still follow in the footsteps of those who have gone before. This means that their emission targets will be set using the Progressive Reductions Factor and the Latecomer Catch-up Factor, in addition to the Gradual Equalization Factor. The glue that holds the agreement together is that every country has reason to feel that it is only doing its fair share.

We use the WITCH model to analyze the results of this approach in terms of projected paths for emissions targets, permit trading, the price of carbon, lost income, and environmental effects. Overall economic costs, discounted (at 5 percent), average 1.39 percent of Gross Product. The largest discounted economic loss suffered by any country from the agreement overall is 3.4 percent of income. The largest loss suffered by any country *in any one period* is 12.6 percent of income. Atmospheric CO_2 concentrations level off at 460 parts per million (ppm) in the latter part of the century. We were unable to attain CO2 concentrations of 380 ppm (the equivalent of 450 ppm for all greenhouse gases), without more serious violations of our political constraints. The latter concentrations would be required, approximately, to achieve the more aggressive collective goal set by the G-7 leaders meeting in Italy in July 2009: limiting the global temperature increase to 2°C.

Introduction

The political context of Copenhagen

The clock is running out on negotiations under the UN Framework Convention on Climate Change for a successor agreement to the Kyoto Protocol. But the road has been blocked by a seeming insurmountable obstacle. The United States, which until recently was the world's largest emitter of Greenhouse Gases (GHGs), is at loggerheads with China, the world's new largest emitter, and with India and other developing countries. Fortunately, there just might be a way to break through the roadblock.

On the one hand, the US Congress is clear: it will not impose quantitative limits on US GHG emissions if it fears that emissions from China, India, and other developing countries will continue to grow unabated. Indeed, that is why the Senate was unwilling to ratify the Kyoto Protocol ten years ago. Why, it asks, should US firms bear the economic cost of cutting emissions if energy-intensive activities such as aluminum smelters and steel mills would just migrate to countries that have no caps and therefore have cheaper energy -- the problem known as leakage -- and global emissions would continue their rapid rise?

On the other hand, the leaders of India and China are just as clear: they are unalterably opposed to cutting emissions until after the United States and other rich countries have gone first. After all, the industrialized countries created the problem of global climate change. And they got rich in the process. The poor countries should not be denied their turn at economic development. As the Indians point out, Americans emit more than ten times as much carbon dioxide per person as they do.

In June 2009, the US House of Representatives passed the American Conservation and Energy Security Act, known as the Waxman-Markey bill, which (among many other things) would set targets for American GHG emissions. But largely due to fears of leakage, the bill is unlikely to pass the Senate as long as major developing countries have not accepted quantitative targets of their own.

What is needed is a specific framework for setting the actual numbers that future signers of a Kyoto-successor treaty are realistically expected to adopt as their emission targets. There is one practical solution to the apparently irreconcilable differences between the US and the developing countries regarding binding quantitative targets. The United States would indeed agree to join Europe in adopting emission targets, something along the lines of the big cuts specified in the Waxman-Markey bill. *Simultaneously*, in the same agreement, China, India, and other developing countries would agree to a path that immediately imposes on them binding emission targets as well—but targets that in the first phase simply follow the so-called Business-as-Usual (BAU) path. BAU is defined as the path of increasing emissions that these countries would experience in the absence of an international agreement, as determined by experts' projections.

Of course an environmental solution also requires that China and the other developing countries subsequently make cuts below their Business as Usual path in future years, and eventually make cuts in absolute terms as well. This negotiation can become easier over time, as everyone gains confidence in the framework. But *the developing countries can and should be asked to make cuts that do not differ in nature from those made by Europe, the United States, and others who have gone before them, taking due account of differences in income*. Emission targets can be determined by formulas

(i) that give lower-income countries more time before they start to cut emissions, and
(ii) that lead to gradual convergence across countries of emissions per capita over the course of the century, while
(iii) taking care not to reward any country for joining the system late.

Speaking realistically, no country – rich or poor – will abide by targets in any given period that entail extremely large economic sacrifice, relative to the alternative of simply not participating in the system. It is time to stop making sweeping proposals that assume otherwise, and to pursue instead the narrow thread of the politically possible.

The problem to be solved

There are by now many proposals for a post-Kyoto climate change regime, even if one considers only proposals that accept the basic Kyoto approach of quantitative, national-level limits on GHG emissions accompanied by international trade in emissions permits. The Kyoto targets applied only to the budget period 2008–2012, which we are now in, and only to a minority of countries (in theory, the industrialized countries). The big task is to extend quantitative emissions targets through the remainder of the century and to other countries—especially the United States, China, and other developing countries.

Virtually all the existing proposals for a post-Kyoto agreement are based on scientific environmental objectives (e.g., stabilizing atmospheric CO_2 concentrations at 380 ppm in 2100), or ethical/philosophical considerations (e.g., the principle that every individual on earth has equal emission rights), or economic cost-benefit analyses (weighing the economic costs of abatement against the long-term environmental benefits).[1] This paper proposes a way to allocate emission targets for all countries and for the remainder of the century that is intended to be more practical in that it is also based on political considerations, rather than on science or ethics or economics alone.[2]

The industrialized countries did, in 1997, agree to quantitative emissions targets for the Kyoto Protocol's first budget period, so in some sense we know that it can be done. But the obstacles are enormous. For starters, most of the Kyoto signers will probably miss their 2008–2012 targets, and of course the United States never even ratified. At multilateral venues such as the United Nations Framework Convention on Climate Change (UNFCCC) meeting in Bali (2007) and the Group of Eight (G8) meeting in Hokkaido (July 2008), world leaders agreed on a broad long-term goal of cutting total global emissions in half by 2050. At a meeting in L'Aquila, Italy, in July 2009, the G8

[1] Important examples of the science-based approach, the cost-benefit-based approach, and the rights-based approach, respectively, are Wigley (2007), Nordhaus (1994, 2006), and Baer *et al.* (2008).

[2] Aldy, Barrett, and Stavins (2003) and Victor (2004) review a number of existing proposals. Numerous others have offered their own thoughts on post-Kyoto plans, at varying levels of detail, including Aldy, Orszag, and Stiglitz (2001); Barrett (2006); Nordhaus (2006); Olmstead and Stavins (2006); Karp and Zhao (2009) and Birdsall and Subramanian (2009).

leaders agreed to an environmental goal of limiting the temperature increase 2°C,[3] which corresponds roughly to a GHG concentration level of 450 ppm (or approximately 380 ppm CO2 only).

But these meetings did not come close to producing agreement on who will cut how much, nor agreement on multilateral targets within a near-enough time horizon that the same national leaders are likely to still be alive when the abatement commitment comes due. To quote Al Gore (1993, p.353), "politicians are often tempted to make a promise that is not binding and hope for some unexpectedly easy way to keep the promise." For this reason, the aggregate targets endorsed so far cannot be viewed as anything more than aspirational.

Moreover, nobody has ever come up with an enforcement mechanism that simultaneously has sufficient teeth and is acceptable to member countries. Given the importance countries place on national sovereignty it is unlikely that this will change. Hopes must instead rest on weak enforcement mechanisms such as the power of moral suasion and international opprobrium. It is safe to say that in the event of a clash between such weak enforcement mechanisms and the prospect of a large economic loss to a particular country, aversion to the latter would win out.

Necessary elements of a workable successor to Kyoto

Any proposed successor-agreement to the Kyoto Protocol should deliver five desirable attributes[4]:

- ***More comprehensive participation***—specifically, getting the United States, China, and other developing counties to join the system of quantitative emission targets.
- ***Efficiency***—incorporating market-flexibility mechanisms such as international permit trading and providing advance signals to allow the private sector to plan ahead, to the extent compatible with the credibility of the signals.

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[3] *Financial Times*, July 9, 2009, p. 5.

[4] Frankel (2007). (A sixth attribute, robustness under uncertainty is equally important to these five and also motivates out approach. But it is not explicitly addressed in this paper.) Similar lists are provided by Bowles and Sandalow (2001), Stewart and Weiner (2003), and others.

- ***Dynamic consistency—***addressing the problem that announcements about steep cuts in 2050 are not credible.
- ***Equity***—taking account of the point made by developing countries that industrialized countries created the problem of global climate change, while poor countries are responsible for only about 20 percent of the CO_2 that has accumulated in the atmosphere from industrial activity over the past 150 years. From an equity standpoint, developing countries argue they should not be asked to limit their economic development to pay for a climate-change solution; moreover, they do not have the capacity to pay for emissions abatement that richer countries do. Finally, many developing countries place greater priority on raising their people's current standard of living. These countries might reasonably demand quantitative targets that reflect an equal per capita allotment of emissions, on equity grounds.
- ***Compliance*** —recognizing that no country will join a treaty if it entails tremendous economic sacrifice and that therefore compliance cannot be reasonably expected if costs are too high. Similarly, no country, if it has already joined the treaty, will continue to stay in during any given period if staying in means huge economic sacrifice, relative to dropping out, in that period.

Unlike the Kyoto Protocol, our proposal seeks to bring all countries into an international policy regime on a realistic basis and to look far into the future. But we cannot pretend to see with as fine a degree of resolution at a century-long horizon as we can at a five- or ten-year horizon. Fixing precise numerical targets a century ahead is impractical. Rather, we need a century-long sequence of negotiations, fitting within a common institutional framework that builds confidence as it goes along. The framework must have enough continuity so that success in the early phases builds members' confidence in each other's compliance commitments and in the fairness, viability, and credibility of the process. Yet the framework must be flexible enough that it can accommodate the unpredictable fluctuations in economic growth, technology development, climate, and political sentiment that will inevitably occur. Only by striking the right balance between continuity and flexibility can we hope that a framework for addressing climate change would last a century or more.

Political constraints

We take as axiomatic five claims regarding political feasibility:

1. The United States will not commit to quantitative targets if China and other major developing countries do not commit to quantitative targets at the same time. (This leaves completely open the initial level and future path of the targets.) Any plan will be found unacceptable if it leaves the less developed countries free to exploit their lack of GHG regulation for "competitive" advantage at the expense of the participating countries' economies and leads to emissions leakage at the expense of the environmental goal.
2. China, India, and other developing countries will not make sacrifices they view as
    a. fully contemporaneous with rich countries,
    b. different in character from those made by richer countries who have gone before them,
    c. preventing them from industrializing,
    d. failing to recognize that richer countries should be prepared to make greater economic sacrifices than poor countries to address the problem (all the more so because rich countries' past emissions have created the problem), or
    e. failing to recognize that the rich countries have benefited from an "unfair advantage" in being allowed to achieve levels of per capita emissions that are far above those of the poor countries.
3. In the short run, emission targets for developing countries must be computed relative to current levels or BAU paths; otherwise the economic costs will be too great for the countries in question to accept. [5] But in the longer run, no country can be rewarded for having "ramped up" emissions far above 1990 levels, the reference year agreed to at Rio and Kyoto. Fairness considerations aside, if post-1990 increases are permanently "grandfathered," then countries that have not yet agreed to cuts will have a strong incentive to ramp up emissions in the interval before they join. Of course

[5] Cuts expressed relative to BAU have been called "Action Targets" (Baumert and Goldberg 2006).

there was nothing magic about 1990 but, for better or worse, it is the year on which Annex I countries have long based planning.[6]

4. No country will accept a path of targets that is expected to cost it more than *Y* percent of income throughout the 21st century (in present discounted value). Frankel (2009) set *Y* at 1 percent.
5. No country will accept targets in any period that are expected to cost more than *X* percent of income to achieve during that period; alternatively, even if targets were already in place, no country would in the future actually abide by them if it found the cost to doing so would exceed *X* percent of income. In this paper, income losses are defined relative to what would happen if the country in question had never joined. Frankel (2009) set *X* at 5 percent.

Squaring the circle

Of the above propositions, even the first and second alone seem to add up to a hopeless stalemate: Nothing much can happen without the United States, the United States will not proceed unless China and other developing countries start at the same time, and China will not start until after the rich countries have gone first.

There is only one possible solution, only one knife-edge position that satisfies the constraints. At the same time that the United States agrees to binding emission cuts in the manner of Kyoto, China and other developing countries agree to a path that immediately imposes on them binding emission targets—but these targets in their early years simply follow the BAU path. The idea of committing to only BAU targets in the early decades will provoke strong objections from environmentalists and business interests in advanced countries. But they might come to realize that this commitment is more important than it sounds: It precludes the carbon leakage which, absent such an agreement, would undermine the environmental goal and it moderates the competitiveness concerns of carbon-intensive industries in the rich countries. The developing countries can't exploit the opportunity to go above their BAU paths as they would in the absence of this commitment.

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6 If the international consenus base year shifts from 1990 to 2005, our proposal will do the same.

This approach recognizes that it would be irrational for China to agree to substantial actual cuts in the short term. Indeed China might well register strong objections to being asked to take on binding targets of any kind at the same time as the United States. But the Chinese may also come to realize that they would actually gain from such an agreement, by acquiring the ability to sell emission permits at the same world market price as developed countries. (China currently receives lower prices for lower-quality project credits under the Kyoto Protocol's Clean Development Mechanism.)

How do we know they would come out ahead? China is currently building roughly 100 power plants per year, to accommodate its rapidly growing demand. The cost of shutting down an already-functioning coal-fired power plant in the United States is far higher than the cost of building a new clean low-carbon plant in China in place of what otherwise might be a new dirty coal-fired plant. For this reason, when an American firm pays China to cut its emissions voluntarily, thereby obtaining a permit that the American firm can use to meet its emission obligations, both parties benefit, even in strictly economic terms. The environmental benefit is that China's emissions would (voluntarily) fall below its BAU commitment from the beginning. From a dynamic perspective, the incentive to shift towards a less carbon intensive capital stock will provide substantial additional benefits in ten or twenty years time, when China will face a constraining target, given the long-lived nature of these plants.

In later decades, the formulas we propose do ask substantially more of the developing countries. But these formulas also obey basic notions of fairness, by asking only for cuts that are analogous in magnitude to the cuts made by others who began abatement earlier and making due allowance for developing countries' low per capita income and emissions and for their baseline of rapid growth. These ideas were developed in earlier papers[7] which suggested that the formulas used to develop emissions targets incorporate four or five variables: 1990 emissions, emissions in the year of the negotiation, population, and income. One might also include a few other special

[7] Frankel (1999, 2005, 2007) and Aldy and Frankel (2004). Some other authors have made similar proposals.

variables such as whether the country in question has coal or hydroelectric power -- though the 1990 level of emissions conditional on per capita income can largely capture these special variables -- and perhaps a dummy variable for the transition economies.

We narrow down the broad family of formulas to a more manageable set, by the development of the three factors: a short-term Progressive Reductions Factor, a medium-term Latecomer Catch-up Factor, and a long-run Gradual Equalization Factor. We then put them into operation to produce specific numerical targets for all countries, for all remaining five-year budget periods of the 21st century (presented in Table 2). These are then fed into the WITCH model to see the economic and environmental consequences. International trading plays an important role. The framework is flexible enough that one can tinker with a parameter here or there—for example if the economic cost borne by a particular country is deemed too high or the environmental progress deemed too low—without having to abandon the entire formulas framework.

Emission targets for all countries: rules to guide the formulas

All developing countries that have any ability to measure emissions would be asked to agree immediately to emission targets that do not exceed their projected BAU baseline trajectory going forward. The objective of getting developing countries committed to these targets would be to forestall emissions leakage and to limit the extent to which their firms enjoy a competitive advantage over carbon-constrained competitors in the countries that have already agreed to targets below BAU under the Kyoto Protocol. We expect that the developing countries would, in most cases, receive payments for permits and thus emit less than their BAU baseline. Most countries in Africa would probably be exempted for some years from any kind of commitment, even to BAU targets, until they had better capacity to monitor emissions.

One must acknowledge that BAU paths are neither easily ascertained nor immutable. Countries may "high-ball" their BAU estimates in order to get more generous targets. Even assuming that estimates are unbiased, important unforeseen economic and technological developments could occur between 2010 and 2020 that will shift the BAU trajectory for the 2020s, for example. Any number of unpredictable events have already occurred in the years since 1990; they include German reunification, the 1997–1998 East Asia crisis, the boom in the BRIC countries (Brazil, Russia, India, and China), the sharp rise in world oil prices up to 2008, and the world financial crisis of 2007–2009.

A first measure to deal with the practical difficulty of setting the BAU path is to specify in the Kyoto-successor treaty that estimates must be generated by an independent international expert body, not by national authorities. A second measure, once the first has been assured, is to provide for updates of the BAU paths every decade. To omit such a provision—that is, to hold countries for the rest of the century to the paths that had been estimated in 2010—would in practice virtually guarantee that any country that achieves very high economic growth rates in the future will eventually drop out of the agreement, because staying in would mean incurring costs far in excess of X percent of income. Allowing for periodic adjustments to the BAU baseline does risk undermining the incentive for carbon-saving investments, on the logic that such investments would reduce future BAU paths and thus reduce future target allocations. This risk is the same as the risk of encouraging countries to ramp up their emissions, which we specified above to be axiomatically ruled out by any viable proposal. That is why the formula gives decreasing weight to BAU in later budget periods and why we introduce a Latecomer Catch-up Factor (explained below), which tethers countries to their 1990 emission levels in the medium run.

Countries are expected to agree to the second step, quantitative targets that entail specific cuts below BAU, at a time determined by their circumstances. In our initial simulations, the choice of year for introducing an obligation actually to cut emissions was generally guided by two thresholds: when a country's average per capita income exceeds $3000 per year and/or when its per capita annual emissions approach 1 ton or more. But we found that starting dates had to be further modified in order to satisfy our constraints regarding the distribution of economic losses.

As already noted, this approach assigns emission targets in a way that is more sensitive to political realities than is typical of other proposed target paths, which are constructed either on the basis of a cost-benefit optimization or to deliver a particular environmental and/or ethical goal. Specifically, numerical targets are based (a) on commitments that political leaders in various key countries have already proposed or adopted, as of early 2009, and (b) on formulas designed to assure latecomer countries that the emission cuts they are being asked to make represent no more than their fair share, in that they correspond to the sacrifices that other countries before them have already made.

Finally comes the other important concession to practical political realities: If the simulation in any period turns out to impose on any country an economic cost of more than *X*% of income, we assume that this country drops out. Dropping out could involve either explicit renunciation of the treaty or massive failure to meet the quantitative targets. For now, our assumption is that in any such scenario, other countries would follow by dropping out one by one, and the whole scheme would eventually unravel. This unraveling would occur much earlier if private actors rationally perceived that at some point in the future major players will face such high economic costs that compliance will break down. In this case, the future carbon prices that are built into most models' compliance trajectories will lack credibility, private actors today will not make investment decisions that reflect those projected future prices, and the effort will fail in the first period. Therefore, our approach to any scenario in which any major player suffers economic losses greater than *X*% has been to go back and adjust some of the starting dates or other parameters of the emission formulas, so that costs are lower and this is no longer the case.

We hope by these mechanisms to achieve political viability: non-negative economic gains in the early years for developing countries, average costs over the course of the century below *Y* percent of income per annum, and protection for every country against losses in any period as large, or larger than, *X* percent of income. Only if they achieve political viability are announcements of future cuts credible. And only credible announcements of future cuts will send firms the long-term price signals and incentives needed to guide investment decisions today.

Guidelines from policies and goals already announced by national leaders

Our model produces country-specific numeric emission targets for every fifth year: 2010, 2015, 2020, etc. For each five-year budget period, such as the Kyoto period 2008–2012, computations are based on the midpoint.

The European Union. The EU emissions target for 2008–2012 was agreed at Kyoto: 8 percent below 1990 levels. Regarding the second budget period, 2015–2020, Brussels announced in January 2008 and confirmed in December 2008[8] a target of 20 percent below 1990 levels. As with other targets publicly supported by politicians in Europe and elsewhere, skepticism is appropriate regarding EU member countries' willingness to make the sacrifices necessary to achieve this target.[9] However, conditional on other countries joining in, the European Union has said it would cut emissions 30 percent below 1990 levels if other countries joined in. For the year 2020, given assumptions on other countries commitment, we chose a target of 30% below 1990 levels.

For the third period (2020–2025), and thereafter up to the eighth period (2045–2050), the EU targets progress in equal increments to a 50 percent cut below 1990 levels: In other words, targets relative to 1990 emissions start at 35 percent below, and then progress to 50 percent below.

Japan, Canada, and New Zealand. These three Pacific countries are assigned the Kyoto goal of a 6 percent reduction below 1990 levels. Of all ratifiers, Canada is probably the farthest from achieving its Kyoto goal.[10] But Japan dominates this country

[8] *Financial Times*, Jan. 2, 2009, p.5.

[9] It is not entirely clear to Americans that even Europe will meet its Kyoto targets. Perhaps the European Union will need to cover its shortfall with purchases of emission permits from other countries. European emissions were reduced in the early 1990s by coincidental events: Britain moved away from coal under Margaret Thatcher and Germany with reunification in 1990 acquired dirty power plants that were easy to clean up. But Americans who claim on this basis that the European Union has not yet taken any serious steps go too far. Ellerman and Buchner (2007, 26-29) show that the difference between allocations and emissions in 2005 and 2006 was probably in part attributable to abatement measures implemented in response to the positive price of carbon.

[10] The current government's plan calls for reducing Canadian emissions in 2020 by 20 percent below 2006 levels (which translates to 2.7 percent below 1990 levels) and in 2050 by 60–70 percent below 2006 levels.

grouping in size. We assume that by 2010 the United States has taken genuine measures, which helps motivate these three countries to get more serious than they have been to date. In a small concession to realism, we assume that they do not hit the numerical target until 2012 (versus hitting it on average over the 2008–2012 budget period).[11]

Japan's then-Prime Minister, Yasuo Fukuda, on June 9, 2008, announced a decision to cut Japanese emissions 60–80 percent by mid-century and successor Taro Aso on June 10, 2009, announced a plan to cut 15 per cent by 2020.[12] On September 7, the incoming Prime Minister, Yukio Hatoyama, declared a goal of cutting emissions to 25 per cent below 1990 levels over the next 10 years, provided other countries were similarly ambitious.[13] We interpret Japan's targets as cuts of 10 percent every five years between 2010 and 2050, computed logarithmically. The cumulative cuts are 80 percent in logarithmic terms, or 51 percent in absolute terms (i.e., to 49 percent of the year–2010 emissions level).

The United States. The Lieberman–Warner bill of 2007[14] would have begun by reducing emissions in 2012 to below 2005 levels and would have tightened the emissions cap gradually each year thereafter, such that by the year 2050, total emissions would be held to 30 percent of 2012 levels.[15] A slightly revised "manager's" version of the Lieberman–Warner bill earned significant congressional support in June 2008,. though it did not garner a large enough majority to become law. During the 2008 US presidential election campaign, the Republican candidate, John McCain advocated a 2050 emissions

("FACTBOX – Greenhouse gas curbs from Australia to India," Sept.5, 2008, Reuters. www.alertnet.org/thenews/newsdesk/L5649578.htm.)

[11] In 2007, Japanese Prime Minister Shinzo Abe supported an initiative to half global emissions by 2050. *(Financial Times,* May 25). But ahead of the 2008 G8 Summit, Japan declined to match the EU's commitment to cut its emissions 20 per cent by 2020 (*FT*, April 24, 2008, p.3).

[12] "Japan Pledges Big Cut in Emissions," *FT,* June 10, 2008 p.6; and Associated Press, June 10, 2009, respectively.

[13] *The Japan Times*, September 8, 2009.

[14] S. 2191: America's Climate Security Act of 2007

[15] In other words, a 70 percent reduction from emissions levels at the start date of the policy. Section 1201, pages 30-32. (The percentage is measured non-logarithmically.)

target of 60 percent below 1990 levels[16] while Barack Obama endorsed a more aggressive target of reducing 2050 emissions 80 percent below 1990 levels.[17]

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The earlier paper (Frankel, 2009) assumed targets that cut the average annual emissions growth rate in half during the period 2008–2012, to 0.7 percent per year.[18] At that point, we assumed emissions plateau (growth is held to zero) for the period 2012–2017. Then we implemented the rest of the Lieberman–Warner formula, such that emissions in 2050 reach a level that is 67 percent below 1990 levels.[19] Spread over 38 years, this implies sustained reductions of 2.6 percent per year on average, or 13 percent every five years.

The Waxman-Markey bill that was passed by the House of Representatives in June 2009-- the American Clean-Energy and Security Act, or ACES Act -- was substantially less aggressive with respect to the near-term targets. The ACES Act specifies that US emission allowances continue to grow at 3 per cent per year from 2012 to 2017.[20] On the other hand, it is very aggressive with respect to the subsequent 33 years: Waxman-Markey or ACES assumes a US rate of reduction of about 5 per cent per year from 2017 to 2050 -- unless the price ceiling specified by an escape clause kicks in.

Australia. Canberra has been reluctant to take strong actions because the country is so dependent on coal. In July of 2008, however, Australian Prime Minister Kevin Rudd announced plans to cut emissions to 60 percent below 2000 levels by 2050.[21] In

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[16] Or 66 percent below 2005 levels. *Washington Post*, May 13, 2008, p. A14; and *FT*, May 13, 2008, p.4.

[17] *FT*, Oct. 17, 2008.

[18] Or 3.5 percent cumulatively, so that emissions in 2012 are 31.5 percent above 1990 levels. That is, 27 percent logarithmically. This is the preferred way of defining percentage changes. True, logarithms are too technical for non-specialist audiences. But measuring changes non-logarithmically has the undesirable property that a 50 percent increase [to 1.50] followed by a 50 percent reduction [to 0.75] does not get you back to your starting point [1.00].)

[19] Using our postponed base this is 98.5 percent below 2012 levels, logarithmically.

[20] Title VII, Part C, Section 721, sub-section *(e)* of HR 2454, also known as the Waxman-Markey bill. The preceding draft of the bill, proposed March 31, 2009, called for emissions targets that increased at about 2% per year from 2012 to 2017, peaked in 2021, and hit the same 2050 level as in the version passed by the House in June.

[21] A July 16, 2008, government "green paper," *Carbon Pollution Reduction Scheme*, reported details on implementation via a domestic cap-and-trade program. Rudd's initiative appears to have domestic political support (*The Economist*, July 26, 2008, p.52). The government went on to set a target of 15 percent above

the regional groupings of our model, Australia is classified together with South Korea and South Africa, which are also coal-dependent..

Korea and South Africa. Until recently it looked unlikely that any "non-Annex I" countries would consider taking on serious cuts below a BAU growth path within the next decade. But in March 2008, the new president of South Korea, Myung-bak Lee, "tabled a plan to cap emissions at current levels over the first Kyoto period."[22] This was an extraordinarily ambitious target in light of Korea's economic growth rate. He also "vowed his country would slash emissions in half by 2050,"[23] like the industrialized countries—of which Korea is now one. Emissions have risen 90 percent since 1990 and it is hard to imagine any country applying the brakes so sharply as to switch instantly from 5 percent annual growth in emissions to zero. We chose to interpret the Korean plan to flatten emissions as covering a period that stretches out over the next eleven years, so that in 2020 the level of emissions is the same as in 2005.[24]

Meanwhile, South Africa has evidently proposed that its emissions would peak by 2025 and begin declining by 2030. [25]

Mexico. President Felipe Calderon's environment minister, Juan Rafael Elvira, announced in mid-2009 that Mexico was committing itself to reduce its greenhouse gas emissions by 50 million metric tons a year between then and 2012, and by 50 percent below 2002 levels by 2050.[26]

1990 levels by 2020 (*FT*, Jan. 2, 2009, p.5) and then 5 per cent below 2000 levels by 2020 (*The Economist*, June 6, 2009, p. 39).

[22] "South Korea Plans to Cap Emissions," *International Herald Tribune*, March 21, 2008.

[23] "South Korea: Developing Countries Move Toward Targets," Lisa Friedman, *ClimateWire*, Oct. 3, 2008.

[24] One could note, first, that President Lee came to office setting a variety of ambitious goals beyond his power to bring about, especially for economic growth, and second that his popularity quickly plummeted. At the time of writing, his ability to persuade his countrymen to take serious measures was in question.

[25] *ClimateWire*, Oct.3, 2008, *op cit*. Statements from environmental or foreign ministries do not necessarily carry a lot of weight, if they have not been vetted by finance or economics ministries let alone issued by heads of government or approved by parliaments,. An example would be Argentina's announcement of a target in 1998.

[26] "Mexico: A Model for Developing Countries," Council on Hemispheric Affairs, August 12, 2009. http://www.coha.org/2009/08/mexico-a-model-for-developing-countries/.

China. Getting China to agree to binding commitments is the *sine qua non* of any successful post-Kyoto plan. In mid-August 2009, a Chinese top climate change policy-maker set a target for emissions to peak by 2050.[27] In the earlier paper we assumed that China starts cutting relative to BAU in 2030. But since we are now assuming more aggressive cuts by the industrialized countries during this period, and the year-2100 goal of CO2 concentrations at 460 ppm cannot be met without substantial effort by China as well, we now move up the date at which it begins to cut to 2025.

This still leaves three questions: (1) how to determine the magnitude of China's cuts in this first budget period—that is, for the first period in which it is asked to make cuts below BAU; (2) how to determine Korea's cuts in its second budget period; and (3) how to set targets for everyone else. The other regions are Latin America—which like Korea should logically act before China and India, in light of its stage of development—Russia, Middle East/North Africa, Southeast Asia, India/South Asia, and Africa. Table 1 shows the starting dates for each, which are placed earlier than in the preceding paper, in order to hit the more aggressive environmental goal.

Our general guiding principle for the emission targets, once they are to start cutting below BAU, is to ask countries only to do what is analogous to what has been done by others who have gone before them. This general principle is put into practice by means of the three factors.

Guidelines for formulas that ask developing countries to accept "fair" targets, analogous to those who have gone before

This section discusses the three factors for determining "fair" emissions targets for developing countries. The three factors are additive (logarithmically).

We call the first the **Progressive Reductions Factor**. It is based on the pattern of emission reductions (relative to BAU) assigned to countries under the Kyoto Protocol, as

[27] Su Wei, Director-General of the climate change department of China's planning body, as quoted in the *Financial Times*, August 15/16, 2009.

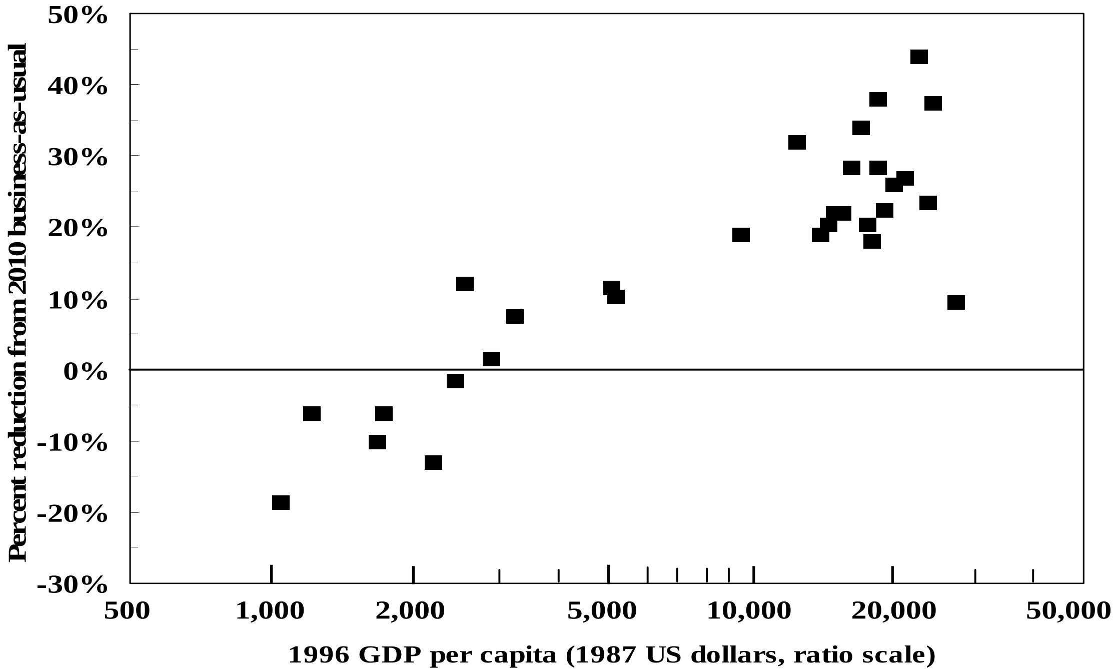
a function of income per capita. This pattern is illustrated in Figure 1, which comes from the data as they were reported at that time. Other things equal, richer countries are asked to make more severe cuts relative to BAU, the status quo from which they are departing in the first period. Specifically, each 1 percent difference in income per capita, measured relative to EU income in 1997, increases the abatement obligation by 0.14 percent, where the abatement obligation is measured in terms of reductions from BAU relative to the EU cuts agreed at Kyoto. Normally, at least in their early budget periods, most countries' incomes will be below what the Europeans had in 1997, so that this factor dictates milder cuts relative to BAU than Europe made at Kyoto. In fact the resulting targets are likely to reflect a "growth path"—that is, they will allow for actual emission increases relative to the preceding periods. The formula is:

PRF (expressed as country cuts vs. BAU)

*= EU's Kyoto commitment for 2008 relative to its BAU + .14 * (gap between the country's income per capita and the EU's 2007 income per capita).*

The parameter (0.14) was suggested by ordinary least squares (OLS) regression estimates using the data shown in Figure 1. Other parameters could be chosen instead, if the parties to a new agreement wanted to increase or decrease the degree of progressivity.

Figure 1: The Emissions Cuts Agreed at Kyoto Were Progressive with Respect to Income, when Expressed Relative to BAU



Sources: The World Bank, the U.S. Energy Information Administration, and national communications to the UNFCCC

The **Latecomer Catch-up Factor** is the second element in the formula. Latecomers are defined as those countries that have not ratified Kyoto or for which Kyoto did not set quantitative targets. (Perhaps it should also include those like Canada that ratified the treaty but are not expected to meet the goal.) These countries should not be rewarded by permanently readjusting their targets to a higher baseline. Aside from notions of fairness, such re-basing would give all latecomers an incentive to ramp up their emissions before signing on to binding targets, or at a minimum would undercut any socially-conscious incentives they might otherwise introduce to reduce emissions unilaterally in the time period before they join the system. Thus the Latecomer Catch-up factor is designed to close gradually the gap between the starting point of the latecomers and their 1990 emission levels. It is parameterized according to the numbers implicit in the Waxman-Markey bill to bring US emissions to 70 percent below 1990 levels by 2050 and the Lee proposal to flatten South Korea's emissions over a period beginning in 2008.

In other words, countries are asked to move gradually in the direction of 1990 emissions in the same way that the United States and Korea under current proposals will have done before them.

The formula for a country's Latecomer Catch-up Factor (LCF) is as follows. Further percentage cuts (relative to BAU plus a Progressive Reductions Factor) are proportional to how far emissions have been allowed to rise above 1990 levels by the time the country joins in. That is, it is given by:

$$LCF = \alpha + \lambda \text{ (percentage gap between country's lagged emissions and 1990).}$$

The parameter λ represents the firmness with which latecomers are pulled back toward their 1990 emission levels. The value of λ implicit for Europe at the time the Kyoto Protocol was negotiated was sufficient to pull the EU-average below its 1990 level. But to calibrate this formula, the most relevant countries are not European (since the Europeans are not latecomers), but rather the United States and Korea, since these are the only countries among those that did not commit themselves to Kyoto targets whose political leaders have said explicitly what targets they are willing to accept in the second budget period. The parameters α and λ were chosen as the unique solutions to two simultaneous equations representing the US target in the 2009 Waxman-Markey bill and the Korean target (a flattening of emissions being interpreted here as holding absolute emissions in 2020 equal to 2005 levels). The parameters then work out to $\alpha = 0.54$ and $\lambda = -0.773$

Thus:

$$LCF = 0.54 - 0.773 \log(\text{country's current emissions / country's 1990 emissions}).$$ [28]

In order to come close to our environmental target (460 ppmCO2 is as close as we get) without an unacceptable allocation of economic costs across countries, we had to sacrifice a little of the simplicity of the LCF equation, by adding a dummy variable for both TE and China. Transition Economies experienced emissions in 1990 that were

[28] If Korea were to back away from its president's commitment, but some other important middle-income country were to step up to the plate with explicit and specific numerical targets, then the calculation could be redone.

higher than the subsequent trend; whereas China would be experiencing extremely high costs due to the projected baseline. Hence, we introduced two dummy variables (ε_{China} = -0.13 and ε_{TE} = 0.38) so that the LCF becomes:

$$LCF = 0.54 + \varepsilon_{country} - 0.773 \ \log(\text{country's current emissions / country's 1990 emissions})$$[29]

The third element is the **Gradual Equalization Factor** (GEF). Even though developing countries under the proposal benefit from not being asked for abatement efforts until after the rich countries have begun to act, and face milder reduction requirements, they will still complain that it is the rich countries that originally created an environmental problem for which the poor will disproportionately bear the costs, rather than the other way around. Such complaints are not unreasonable. If we stopped with the first two factors, the richer countries would be left with the permanent right to emit more GHGs, every year in perpetuity. This seems unfair.

In the short run, pointing out the gap in per capita targets is simply not going to alter the outcome. India and other poor countries will have to live with it. Calls for the rich countries to cut per capita emissions rapidly, in the direction of poor-country levels, ignore the fact that the economic costs of such a requirement would be so astronomical that no rich country would ever agree to it. When one is talking about a lead time of 50 to 100 years, however, the situation changes. With time to adjust, the economic costs are not impossibly high, and it is reasonable to ask rich countries to bear their full share of the burden. Furthermore, over a time horizon this long some of the poor countries will in any case become rich (and possibly vice versa).

Accordingly, during each decade of the second half of the century, the formula includes an equity factor that moves per capita emissions in each country a small step in the direction of the global average. This means downward in the case of the rich countries and upward in the case of the poor countries. Asymptotically, the repeated application of this factor would eventually leave all countries with equal emissions per

[29] This is a departure from our preferred principle of applying the same formula for all countries, a simplicity that is appealing aesthetically and, more important, politically. (As in Frankel, 2009.) But it is one of the concessions we have to make to attain the more aggressive environmental goal.

capita, although corresponding national targets need not necessarily converge fully by 2100.[30]

The parameter (δ) for the speed of adjustment in the direction of the world average was initially chosen to match the rate at which the EU's already-announced goals for 2045–2050 converge to the world average. This number is δ=0.1 per decade, which is also very similar to the rate of convergence implicit in the goals set by the Lieberman bills for the United States during 2045–2050. Thus:

GEF
= -0.1 (percentage gap between country's lagged emissions per capita and the world's).

In order to attain lower stabilization levels one could adjust δ, but the effect would be that costs increase dramatically, especially for some countries like China and Transition Economies.

The formulas are summarized overall as follows:

$$\text{Log Target}(\text{country}_{i,t}) = \log(BAU_{i,t}) - (PCF_{i,t}) + (LCF_{i,t}) + (GEF_{i,t}) \;,$$

where the three factors (except in periods when set = 0 as indicated in Table 1) are given by:

$PCF_{i,t}$ = log (emission target EU $_{2008}$/ BAU EU $_{2008}$)
+ 0.14 log (country *i*'s income/cap $_{t-1}$ / EU income/cap $_{2007}$);

$LCF_{i,t}$ = 0.54 +$\varepsilon_{country}$- 0.773 log (country *i*'s emissions $_{t-1}$ / country *i*'s emissions $_{1990}$).

$GEF_{i,t}$ = - 0.1 log (country *i*'s emissions per cap$_{t-1}$ / global ave. emissions per cap $_{t-1}$).

The numerical emission target: paths that follow from the formulas

[30] Zhang (2008) and others, motivated by a rights-based approach, propose that countries "contract and converge" to targets that reflect equal emissions per capita. The Greenhouse Development Rights approach of Baer *et al*. (2008), as extended by Cao (2008), emphasizes, from a philosophical standpoint, the allocation of emission rights at the individual level, though these authors apparently recognize that, in practice, individual targets would have to be aggregated and implemented at the national level.

Table 2, at the end of the chapter, reports the emissions targets produced by the formulas for each of eleven geographical regions, for every period between now and the end of the century. We express the emission targets in several terms:

- in absolute tons (which is what ultimately matters for determining economic and environmental effects),
- in per capita terms (which is necessary for considering any issues of cross-country distribution of burden),
- relative to 1990 levels, which is the baseline used for Kyoto, and which remains relevant in our framework in the form of the Latecomer Catch-up term, and
- relative to the BAU path, which is important for evaluating the sacrifice asked of individual countries as they join the agreement in the early decades.

The eleven regions are:

EU = West Europe and Est Europe

US = United States	*KOSAU = Korea, South Africa, and Australia*
CAJAZ = Canada, Japan, and New Zealand	*TE = Russia and other Transition Economies*
MENA = Middle East and North Africa	*SSA = Sub-Saharan Africa*
SASIA= India and the rest of South Asia	*CHINA = PRC*
EASIA = Smaller countries of East Asia	*LAM = Latin America and the Caribbean*

Table 1 summarizes the dates at which all countries are asked to take on BAU targets and then reductions below BAU as governed by the different formula elements discussed previously (i.e., PRF, LCF, and then GEF).

The bar chart in Figure 2 shows actual emissions, expressed in per capita terms, for every region in every budget period. The United States, even more than other rich countries, is currently conspicuous by virtue of its high per capita emissions. But its target path begins to come down after 2010. Emissions in all the rich regions decline rapidly between 2020 and 2050. Emissions in developing countries continue to rise for a bit longer, and then come down more gradually. But their emissions per capita numbers of course start from a much lower base. China peaks at about 1 ½ ton C per capita in 2020. None of the other developing countries ever get above 1 ton C per capita. The industrialized countries, in contrast, emit between 2 and 5 ½ tons C per capita before they start to cut. In the second half of the century, everyone converges to levels below one ton per capita.

Figure 3 reports aggregate targets (caps) for member countries of the Organization for Economic Co-operation and Development (OECD). They decline from about 4 gigaton or Gt C in 2020 to 1 Gt C in 2060. The graph also shows the simulated value for actual emissions of the rich countries, which decline more gradually than the targets through 2070 because carbon permits are purchased on the world market, as is economically efficient. The total value of the permit purchases runs about ½ Gt C in the middle decades of the century. The quantity of permits purchased by the OECD countries is generally less than one fifth of their total reductions. The US is the larger buyer. This is a far smaller trading share than was the case in the earlier paper, a consequence of the tougher targets that are here imposed on the developing countries. The share falls off sharply in the second half of the century. (We assume no banking.)

Emissions peak in 2020 in the TE group (transition economies), MENA, China, and Latin America. Emissions in sub-Saharan Africa remain at very low levels throughout the century. Figure 4 shows that among non-OECD countries overall, both emissions targets and actual emissions peak in 2020. The simulated path of actual emissions lies a little above the target caps. The difference, again, is the value of permits sold by the poor countries to the rich countries. The total falls to 2 Gt C at the beginning of the 22nd century.

Figure 5 shows the global aggregate. Total world emissions peak in 2020 below 10 Gt C.

Figure 2: Actual Emission per capita throughout the century, for 11 regions

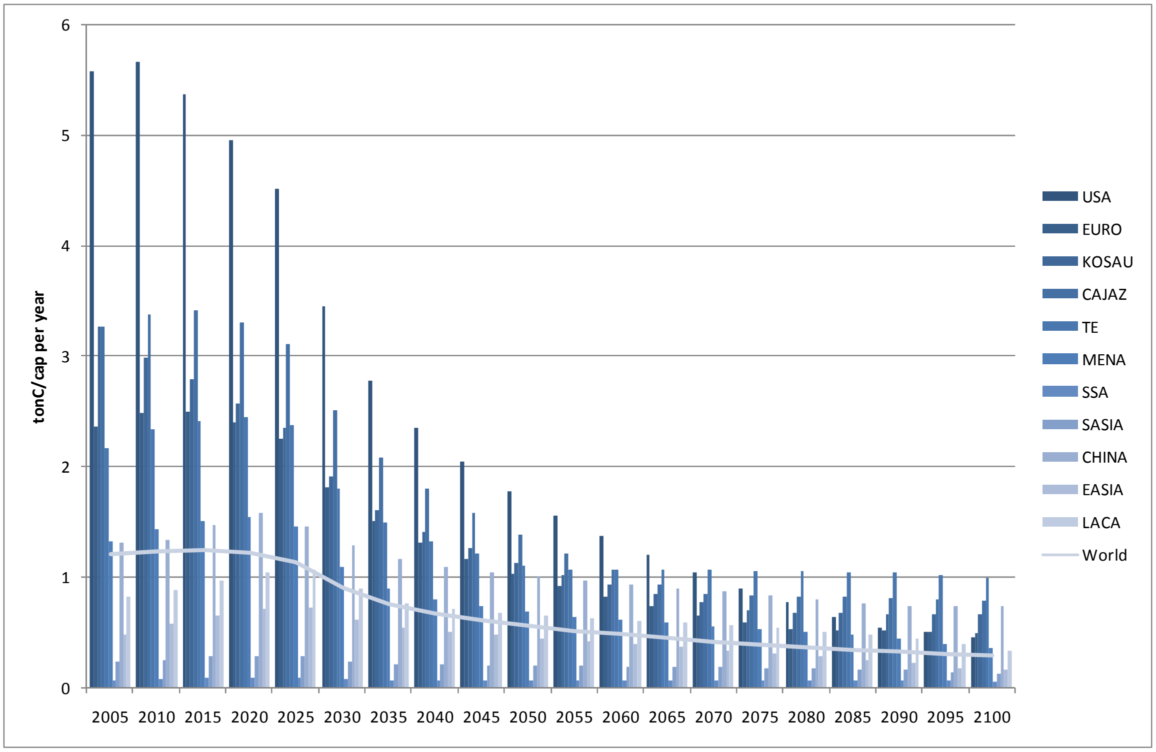

6
5
4
3
2
1
0
tonC/cap per year
2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100
USA
EURO
KOSAU
CAJAZ
TE
MENA
SSA
SASIA
CHINA
EASIA
LACA
World

Figure 3:

Assigned targets and actual emissions for industrialized countries in the aggregate

(Note: Predicted actual emissions exceed caps by amount of permit purchases)

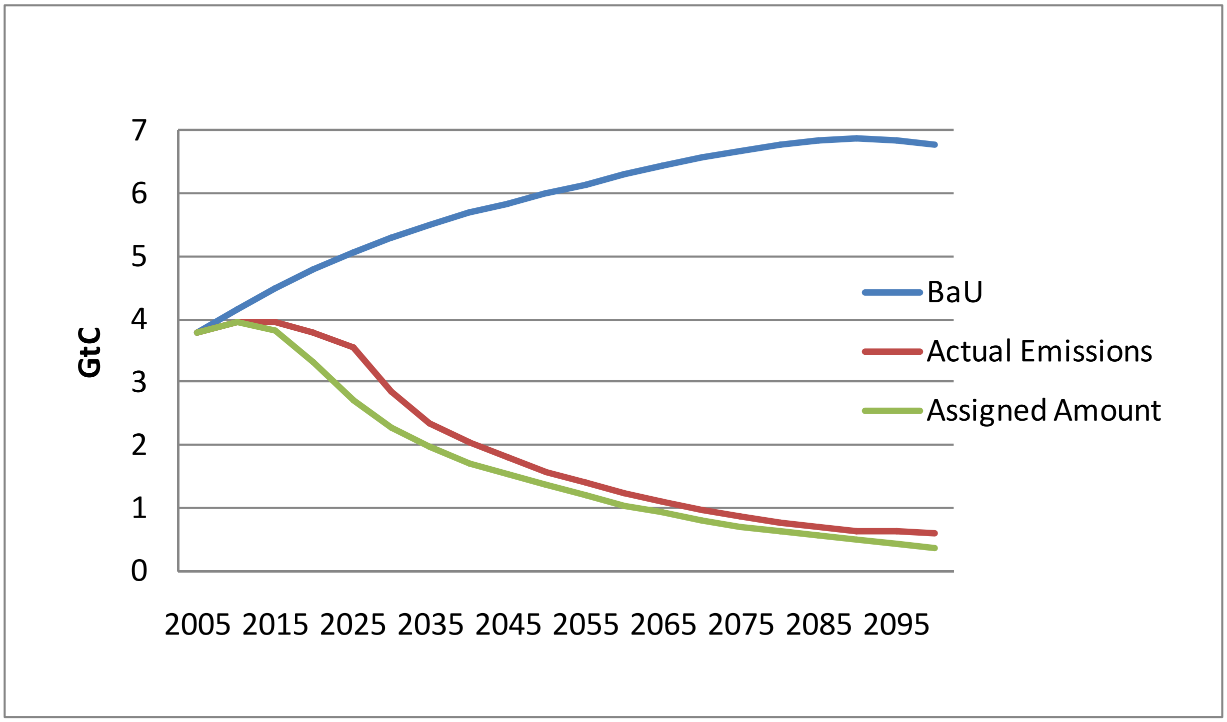


Figure 4: Assigned targets and actual emissions for poor countries in the aggregate

(Note: Predicted actual emissions fall below caps by amount of permit sales)

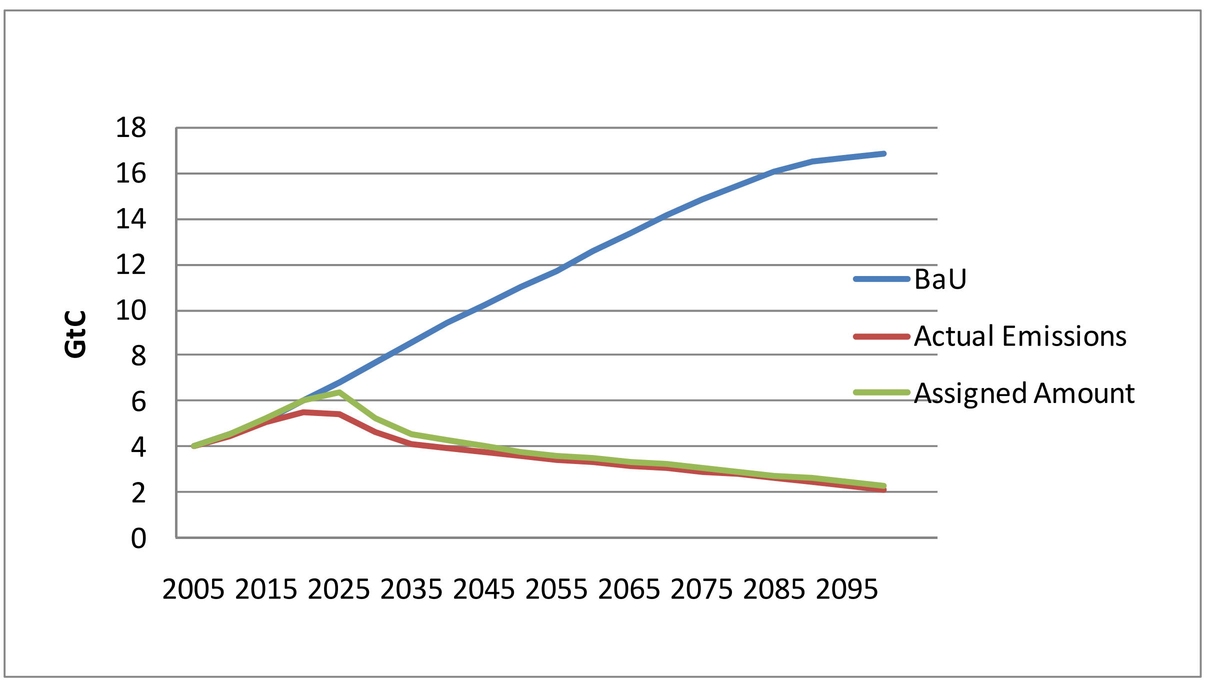
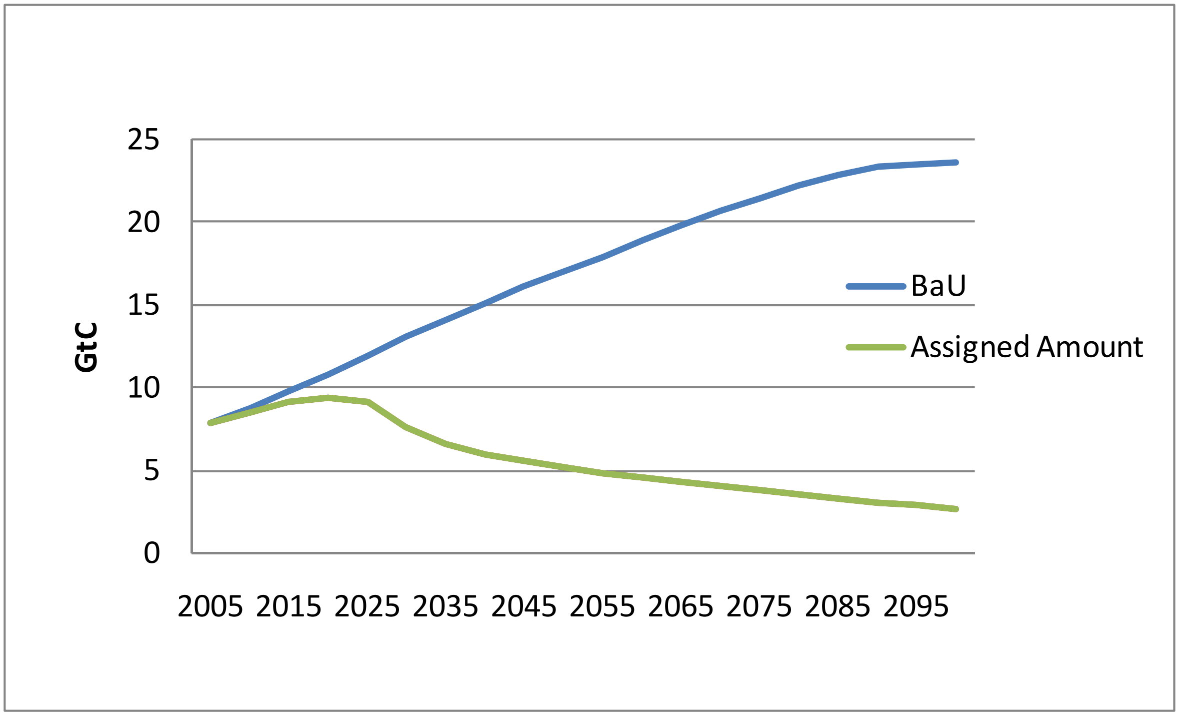


Figure 5: Emissions target path for the world, in the aggregate



Economic and environmental consequences of the proposed targets, according to the WITCH model

Estimating the economic and environmental implications of any set of targets is a complex task.[31] WITCH (www.feem-web.it/witch) is an energy-economy-climate model developed by the climate change modeling group at FEEM. The model has been used extensively in the past four years to analyze the economic impacts of climate change policies. WITCH is a hybrid top-down economic model with energy sector disaggregation. Those who might be skeptical of economists' models on the grounds that "technology is the answer" should rest assured that technology is central to this model. (Economists are optimists when it comes to what new technologies might be called forth by a higher price for carbon, but pessimists when it comes to how much technological response to international treaties will occur absent an increase in price.) The model features endogenous technological change via both experience and innovation processes. Countries are grouped in twelve regions, where Western Europe and Eastern Europe are counted separately, that cover the world and that strategically interact following a game theoretic set-up. The WITCH model and detailed structure are described in Bosetti *et al.* (2006) and Bosetti, Massetti, and Tavoni (2007).

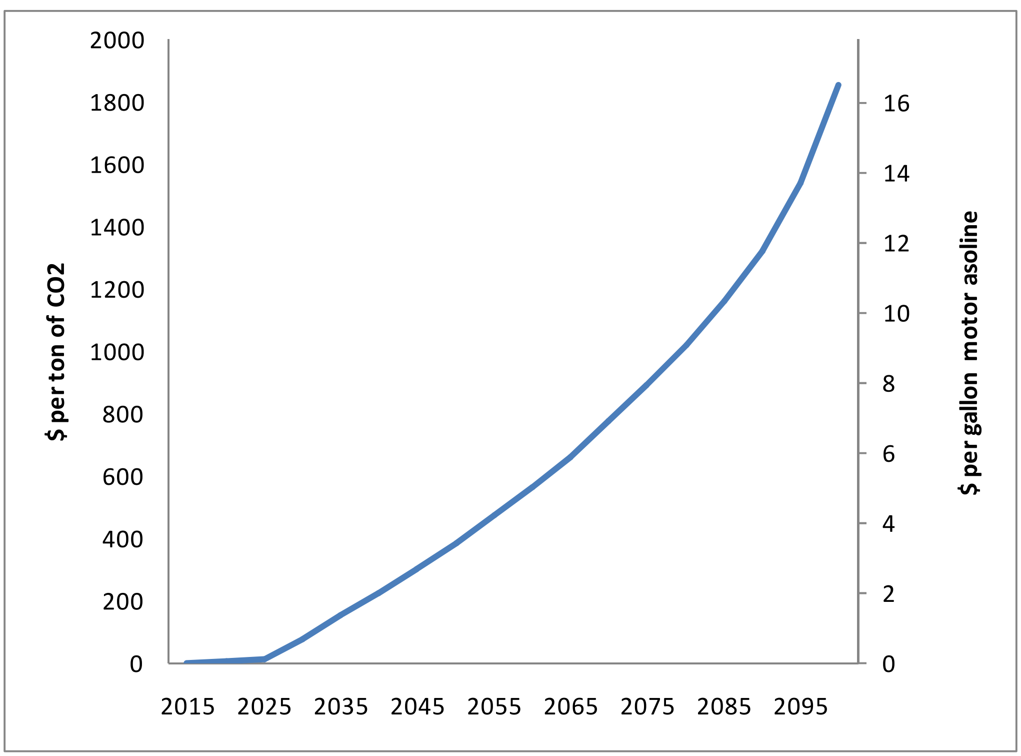
Original baselines in many models have been disrupted in recent years by such developments as stronger-than-expected growth in Chinese energy demand and the unexpected spike in world oil prices that culminated in 2008. WITCH has been updated with more recent data and revised projections for key drivers such as population, GDP, fuel prices, and energy technology characteristics. The base calibration year has been set at 2005, for which data on socio-economic, energy, and environmental variables are now available (Bosetti, Carraro, Sgobbi, and Tavoni, 2008).

[31] Researchers have applied a number of different models to estimate the economic and environmental effects of various specific proposed emission paths; see, for example, Edmonds, Pitcher, Barns, Baron, and Wise (1992); Edmonds, Kim, McCracken, Sands, and Wise (1997); Hammett (1999); Manne, Mendelsohn, and Richels (1995); Manne and Richels (1997); McKibbin and Wilcoxen (2006); and Nordhaus (1994, 2008). Weyant (2001) provides an explanation and comparison of different models.

Economic effects

Although economists trained in cost-benefit analysis tend to focus on economic costs expressed as a percentage of income, the politically attuned tend to focus at least as much on the predicted carbon price, which in turn has a direct impact on the prices of gasoline, home heating oil, and electric power. Figure 6 illustrates the price of carbon dioxide under these targets. It rises very substantially, reaching $1800 per ton in 2100, approximately twice what the CO2 price was with an environmental goal of 500 ppm. But at least the rise is smooth, which is a desirable property. (Kinks or discontinuities in the rate of price increase, such as a temporary flattening around 2020-2030 in the earlier paper, could distort behavior.) The right margin of the graph translates the cost from dollars per ton of carbon to terms that the American consumer can relate to: the increment to the cost of gasoline. It rises to European levels by 2040, and to $16 per gallon in 2100.

Figure 6: Price of Carbon Dioxide Rises Steadily Over the Century

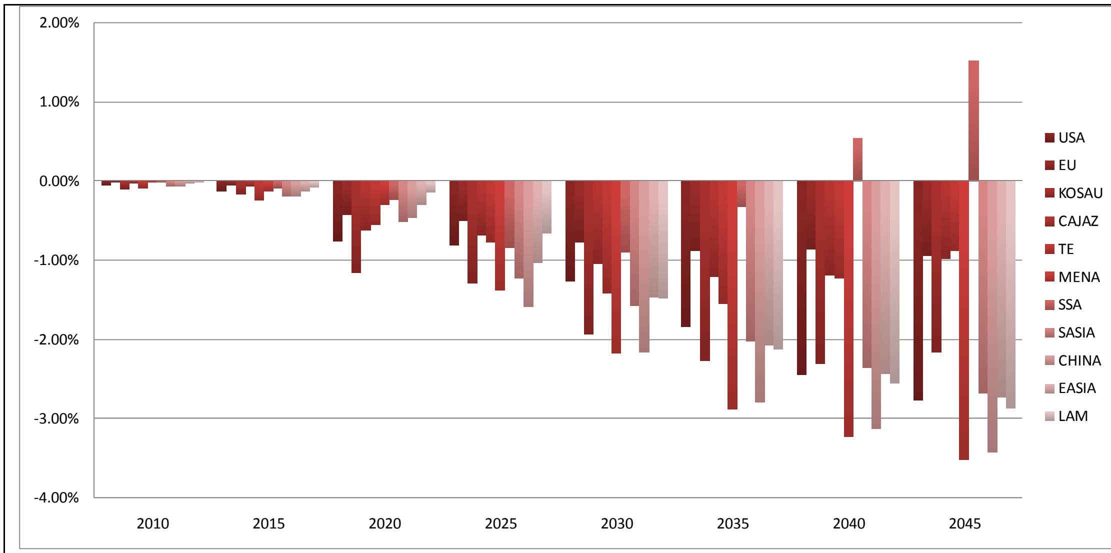


Economic losses measured in terms of national income are illustrated in Figure 7a and 7b, for the first and second halves of the century, respectively. They too rise gradually. Given a positive rate of time discount, this is a good outcome. As late as 2055, all regions sustain economic losses that are no greater than 3.5 per cent of income. (As of mid-century, the US is running the largest cost among OECD countries, relative to BAU, and MENA and China are running the largest costs among non-OECD countries.) Later in the century, the costs go much higher, above 11 percent of income in the case of TE and China. 32 The combination of parameters used produced imply costs that rise above our self-imposed threshold of 5 percent of national income, after 2065, a consequence of the more aggressive environmental goal. All economic effects are gross of environmental benefits—that is, no attempt is made to estimate environmental benefits or net them out.

Figure 7: Income Losses by Region and Period Over the Century

a) 2010-2045

[32] These costs of participation are overestimated in one sense, and increasingly so in the later decades, if the alternative to staying in the treaty one more decade is dropping out after seven or eight decades of participation. The reason is that countries will have already substantially altered their capital stock and economic structure in a carbon-friendly direction. The economic costs reported in the simulations and graphs treat the alternative to participation as never having joined the treaty in the first place. In another sense, however, the costs are underestimated: any country that drops out can in fact exploit leakage opportunities to the hilt. Its firms can buy fossil fuels at far lower prices than their competitors in countries that continue to participate.



b) 2050- 2100

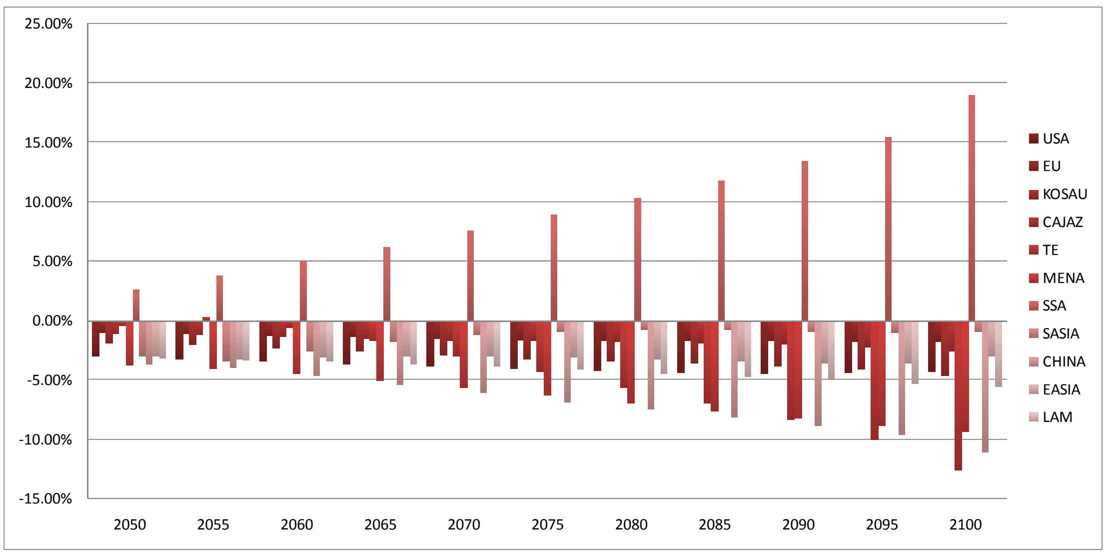


Figure 8 provides Gross World Product loss aggregated across regions worldwide, and discounted to present value using a discount rate of 5 percent. Total economic costs come to 1.39 percent of annual gross world product. Figure 9 provides the regional detail for these figures.

Figure 8:

Global Income Loss -- By Budget Period, 2010-2100, and PDV (discounted to 2005)

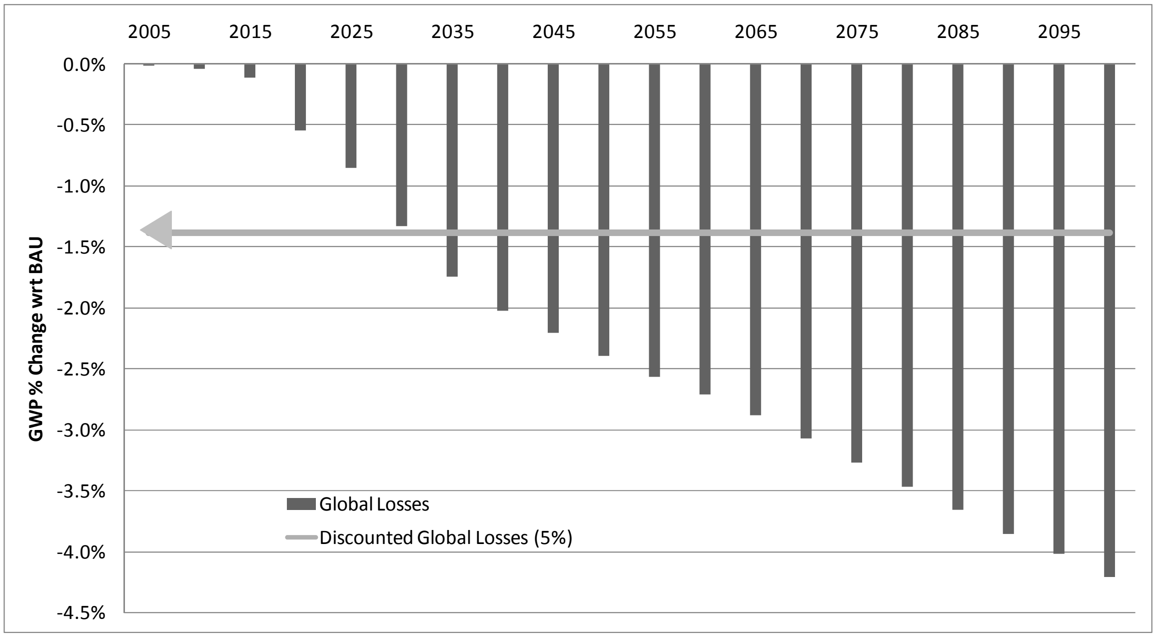
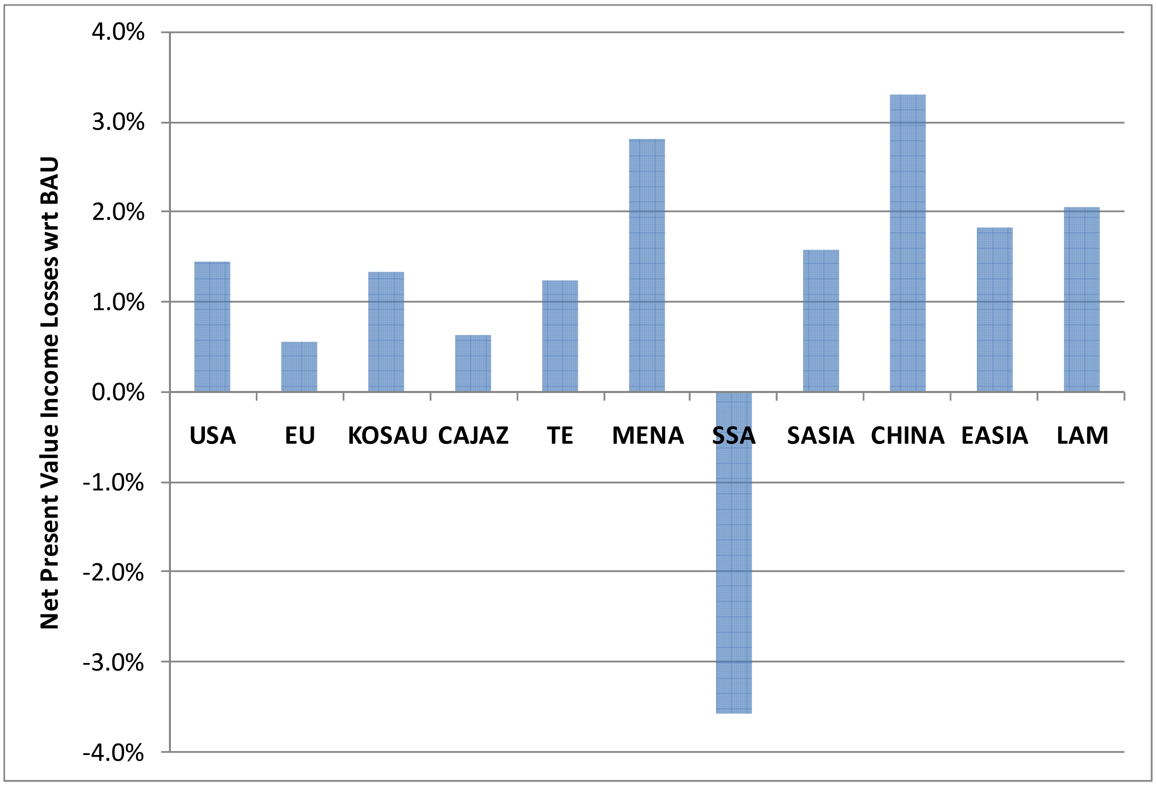


Figure 9:

Losses by Region -- PDV (discounted to 2005 at 5% discount rate), 2010-2100



Environmental effects

The outcome of this proposal in terms of cumulative emissions of GHGs is close to those of some models that build in environmental effects or science-based constraints, even though no such inputs were used here: The concentration of CO_2 in the atmosphere reaches 460 ppm in the latter half of the century.

Figure 10: CO_2 concentrations achieve year-2100 concentration goal of 460 ppm

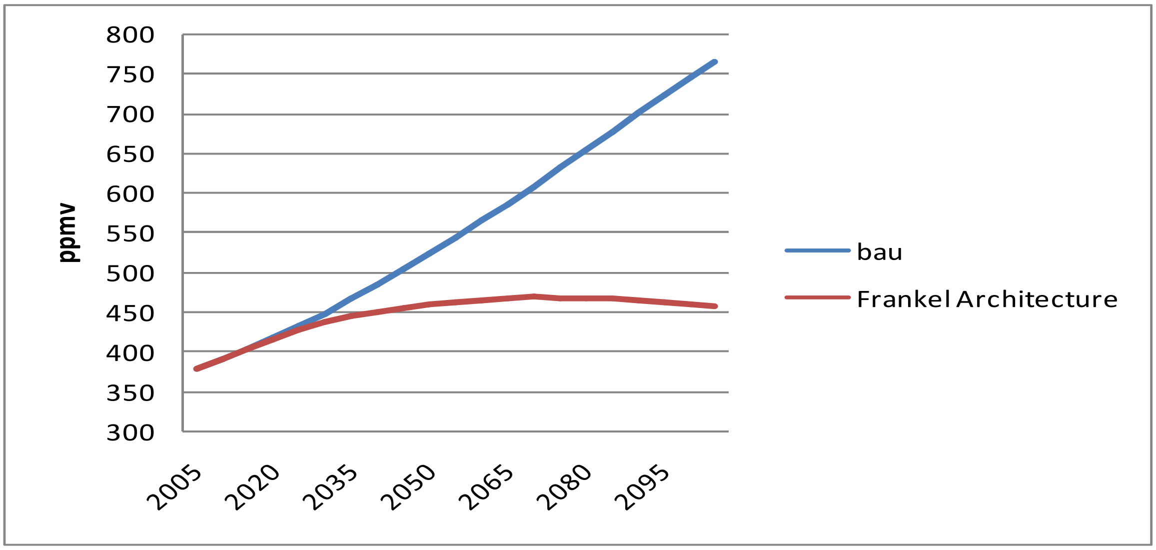
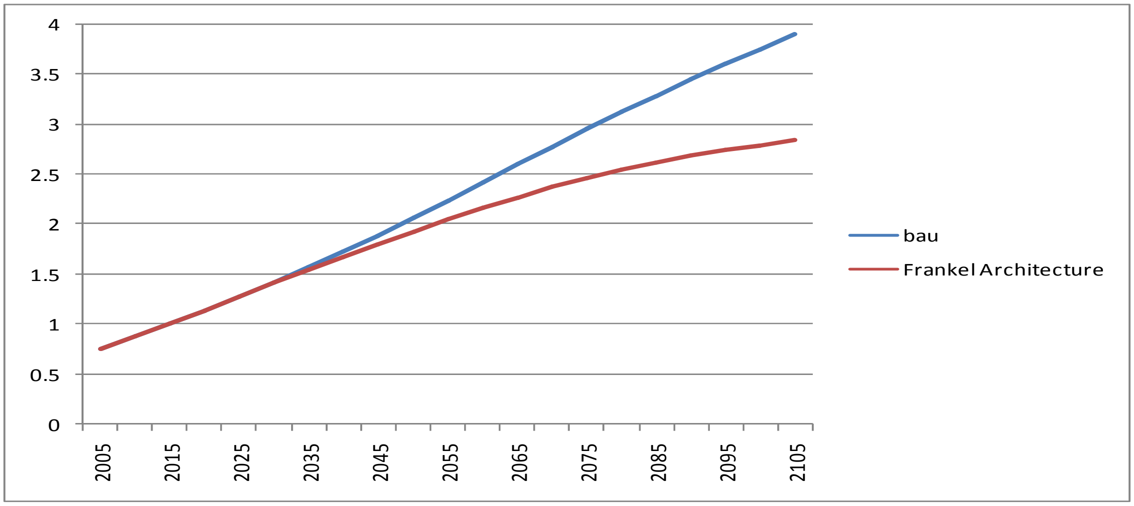


Figure 11 shows the path of temperature. Based on the modeled concentration trajectory, global average temperature is projected to stay below 2.8 degrees Celsius (°C) above pre-industrial levels at the end of the century[33], as opposed to almost 4°C under the BAU trajectory. Policies aiming at reducing emissions from land use and other greenhouse gasses could lead to a larger effect on concentrations and final temperature increase. Still, the result is less ambitious than the goal set by the G-8 leaders at their 2009 summit of stabilizing the temperature increase below 2°C.

Figure 11: Rise in temperature under proposed targets vs. BAU

[33] One might be surprised by the modest gain in temperature in which increasingly stringent climate policies result. The reason for this is that temperature is a logarithmic function of concentration.


4
3.5
3
2.5
2
1.5
1
0.5
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2005
2015
2025
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2045
2055
2065
2075
2085
2095
2105
bau
Frankel Architecture

Conclusion

Several particular extensions are possible for future research.

Directions for future research

First, we could compare our proposed set of emissions paths to other proposals under discussion in the climate change policy community or being analyzed using other integrated assessment models.[34] Our conjecture is that we could identify countries and periods in alternative pathways where an agreement would be unlikely to hold up because its targets were not designed to limit economic costs for each country.

Second, we could take into account GHGs other than CO_2.

Third, we could implement constraints on international trading, along the lines that the Europeans have sometimes discussed. Such constraints can arise either from a philosophical worldview that considers it unethical to pay others to take one's medicine, or from a more cynical worldview that assumes international transfers via permit sales will only line the pockets of corrupt leaders. Constraints on trading could take the form of quantity restrictions—for example, that a country cannot satisfy more than *Z* percent of its emissions obligation by international permit purchases. Or eligibility to sell permits could be restricted to countries with a score in international governance ratings over a particular threshold, or to countries that promise to use the funds for green projects, or to those that have a track record of demonstrably meeting their commitments under the treaty.

The fourth possible extension of this research represents the most important step intellectually: to introduce uncertainty, especially in the form of stochastic growth processes. The variance of the GDP forecasts at various horizons would be drawn from historical data. We would adduce the consequences of our rule that if any country makes an *ex post* determination in any period that by staying in the treaty it loses more than X percent of income, even though this had not been the expectation *ex ante*, that country

[34] For example, the CLEAR path proposed by Wagner *et al*. (2008, Table 2) proposes that by 2050 Russia has cut its emissions 30 percent below 1990 levels, China 46 percent below 2012 levels, India 8 percent above 2012 levels, and the other non-Annex I countries 23 percent below 2012. The Global Development Rights approach of Baer *et al.* (2008) apparently proposes a US emissions target for 2025 that is 99 percent below its BAU path.

will drop out. At a first pass, we could keep the assumption that if one country pulls out, the entire system falls apart. The goal would then be to design a version of the formulas framework that minimizes the probability of collapse.

The ultimate objective in making the model stochastic is to seek modifications of the policy framework that are robust, that protect against inadvertent stringency on the one hand—that is, a situation where the cost burden imposed on a particular country is much higher than expected—or inadvertent "hot air" on the other hand. "Hot air" refers to the possibility that targets are based on obsolete emission levels with the result that countries are credited for cutting tons that wouldn't have been emitted anyway. Three possible modifications to deal with uncertainty are promising. First, we could allow for some degree of re-adjustment to emission targets in the future, based solely on unexpected changes in the evolution in population and income. Second, when the target for each decade is set, it should be indexed to GDP within that budget period. Perhaps the constant of proportionality in the indexation formula would simply equal 1, in which case it becomes an efficiency target, expressed in carbon emissions per unit of GDP. This approach would be much less vulnerable to within-decade uncertainty.[35] A third possible feature that would make the policy more robust and that is strongly favored by many economists is an escape clause or safety valve that would limit costs in the event that mitigation proves more expensive than expected, perhaps with a symmetric floor on the price of carbon in addition to the usual ceiling.

A politically credible framework

Some may wish to conclude from the results in this paper that the environmental goals of 380 or 450 ppm in CO2 concentrations are not attainable in practice, and that our earlier proposal for how to attain 500 ppm is the better plan (Frankel, 2009). We take no position on which environmental goal is best overall, with economic and political realities factored in. Rather, we submit that, whatever the environmental goal, our approach will give targets that are more practical economically and politically than the various approaches that have been proposed by others.

[35] Lutter (2000).

Our framework specifies the allocation of emission targets across countries in such a way that every country is given reason to feel that it is only doing its fair share and in such a way as to build trust as the decades pass. Without such a framework, announcements of distant future goals are not credible and so will not have the desired effects. Furthermore, this framework—in providing for a decade-by-decade sequence of emission targets, each determined on the basis of a few principles and formulas—is flexible enough that it can accommodate, by small changes in the formula parameters, major changes in circumstances during the course of the century.

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EU = West Europe and East Europe
CAJAZ = Canada, Japan + New Zealand
MENA = Middle East + North Africa
SASIA= India and the rest of South Asia
EASIA = Smaller countries of East Asia
KOSAU = Korea, South Africa + Australia (all coal-users)
TE = Russia and other Transition Economies
SSA = Sub-Saharan Africa
CHINA = PRC
LAM = Latin America + the Caribbean

Table 1: Years when signers are to commit to targets at BAU and then below BAU

	year when they are assumed to commit to TARGET or BAU	year when they are assumed to commit to TARGET (PCF & LCF) never above BAU	year when GEF kicks in
USA	2010	2010	2050
EU	2010	2010	2050
KOSAU	2010	2020	2050
CAJAZ	2010	2015	2050
TE	2010	2025	2055
MENA	2010	2025	2055
SSA	2025	2050	2080
SASIA	2010	2025	2055
CHINA	2010	2025	2055
EASIA	2010	2025	2055
LAM	2010	2020	2050

Table 2: Emission Targets for each of 11 regions, according to the formulas

Table 2.a Fossil Fuel Emission Targets in Gton C

	USA	EU	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LAM
2010	1.88	1.11	0.40	0.58	0.84	0.51	0.06	0.41	1.83	0.40	0.50
2015	1.88	0.97	0.42	0.54	0.90	0.59	0.08	0.51	2.08	0.48	0.58
2020	1.88	0.84	0.25	0.36	0.96	0.66	0.09	0.64	2.41	0.58	0.68
2025	1.37	0.81	0.19	0.33	1.09	0.70	0.12	0.68	2.50	0.70	0.57
2030	1.00	0.77	0.17	0.32	0.84	0.59	0.14	0.56	2.05	0.58	0.49
2035	0.73	0.75	0.17	0.31	0.72	0.51	0.17	0.48	1.74	0.50	0.45
2040	0.54	0.70	0.16	0.30	0.66	0.47	0.20	0.45	1.59	0.46	0.42
2045	0.48	0.61	0.16	0.29	0.61	0.44	0.23	0.42	1.47	0.43	0.40
2050	0.43	0.53	0.15	0.24	0.57	0.42	0.26	0.39	1.36	0.40	0.38
2055	0.39	0.46	0.13	0.20	0.54	0.40	0.30	0.37	1.28	0.38	0.37
2060	0.35	0.41	0.12	0.17	0.45	0.37	0.34	0.50	1.12	0.38	0.36
2065	0.31	0.36	0.10	0.15	0.38	0.34	0.39	0.58	0.98	0.37	0.34
2070	0.28	0.31	0.09	0.12	0.32	0.31	0.44	0.63	0.86	0.35	0.32
2075	0.25	0.27	0.08	0.11	0.27	0.28	0.49	0.65	0.75	0.34	0.30
2080	0.23	0.24	0.07	0.09	0.23	0.26	0.54	0.65	0.66	0.31	0.27
2085	0.20	0.21	0.06	0.08	0.19	0.23	0.59	0.63	0.58	0.29	0.25
2090	0.18	0.19	0.05	0.07	0.17	0.21	0.63	0.60	0.51	0.27	0.23
2095	0.16	0.16	0.05	0.06	0.14	0.18	0.67	0.57	0.45	0.24	0.21
2100	0.14	0.14	0.04	0.05	0.12	0.16	0.70	0.52	0.40	0.22	0.19

Table 2.b Fossil Fuel Emission Targets in per capita terms

	USA	EU	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LAM
2010	6.0	2.2	3.4	3.5	2.4	1.4	0.1	0.2	1.3	0.6	0.9
2015	5.7	1.9	3.4	3.2	2.5	1.5	0.1	0.3	1.5	0.7	1.0
2020	5.5	1.6	2.0	2.2	2.7	1.6	0.1	0.3	1.7	0.8	1.1
2025	3.9	1.6	1.5	2.0	3.1	1.6	0.1	0.3	1.7	0.9	0.9
2030	2.7	1.5	1.3	2.0	2.4	1.3	0.1	0.3	1.4	0.7	0.7
2035	1.9	1.5	1.3	1.9	2.1	1.1	0.1	0.2	1.2	0.6	0.7
2040	1.4	1.4	1.3	1.9	1.9	0.9	0.1	0.2	1.1	0.5	0.6
2045	1.2	1.2	1.3	1.9	1.8	0.8	0.1	0.2	1.0	0.5	0.6
2050	1.1	1.1	1.2	1.6	1.7	0.8	0.1	0.2	1.0	0.4	0.5
2055	1.0	0.9	1.0	1.4	1.7	0.7	0.2	0.2	0.9	0.4	0.5
2060	0.8	0.8	1.0	1.2	1.4	0.7	0.2	0.2	0.8	0.4	0.5
2065	0.7	0.8	0.8	1.1	1.2	0.6	0.2	0.2	0.7	0.4	0.5
2070	0.7	0.7	0.7	0.9	1.0	0.5	0.2	0.3	0.6	0.4	0.4
2075	0.6	0.6	0.7	0.8	0.9	0.5	0.2	0.3	0.6	0.4	0.4
2080	0.5	0.5	0.6	0.7	0.8	0.5	0.2	0.3	0.5	0.3	0.4
2085	0.5	0.5	0.5	0.6	0.6	0.4	0.3	0.3	0.5	0.3	0.4
2090	0.4	0.4	0.4	0.5	0.6	0.4	0.3	0.2	0.4	0.3	0.3
2095	0.4	0.4	0.4	0.5	0.5	0.3	0.3	0.2	0.4	0.3	0.3
2100	0.3	0.3	0.4	0.4	0.4	0.3	0.3	0.2	0.3	0.3	0.3

Table 2.c Fossil Fuel Emission Targets relative to 1990 levels

	USA	EU	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LAM
2010	1.30	0.92	1.72	1.30	0.89	1.63	1.69	2.03	2.20	3.17	1.69
2015	1.30	0.80	1.81	1.21	0.95	1.89	2.25	2.52	2.50	3.81	1.96
2020	1.30	0.70	1.08	0.81	1.01	2.12	2.53	3.17	2.90	4.60	2.30
2025	0.95	0.67	0.82	0.74	1.15	2.24	3.38	3.37	3.01	5.56	1.93
2030	0.69	0.64	0.73	0.72	0.89	1.89	3.94	2.77	2.47	4.60	1.66
2035	0.51	0.62	0.73	0.70	0.76	1.63	4.79	2.38	2.09	3.97	1.52
2040	0.37	0.58	0.69	0.67	0.70	1.51	5.63	2.23	1.91	3.65	1.42
2045	0.33	0.51	0.69	0.65	0.64	1.41	6.48	2.08	1.77	3.41	1.35
2050	0.30	0.44	0.65	0.54	0.60	1.35	7.32	1.93	1.64	3.17	1.28
2055	0.27	0.38	0.56	0.45	0.57	1.28	8.45	1.83	1.54	3.02	1.25
2060	0.24	0.34	0.52	0.38	0.48	1.19	9.57	2.48	1.35	3.02	1.22
2065	0.21	0.30	0.43	0.34	0.40	1.09	10.98	2.87	1.18	2.94	1.15
2070	0.19	0.26	0.39	0.27	0.34	0.99	12.39	3.12	1.03	2.78	1.08
2075	0.17	0.22	0.34	0.25	0.29	0.90	13.80	3.22	0.90	2.70	1.01
2080	0.16	0.20	0.30	0.20	0.24	0.83	15.21	3.22	0.79	2.46	0.91
2085	0.14	0.17	0.26	0.18	0.20	0.74	16.61	3.12	0.70	2.30	0.84
2090	0.12	0.16	0.22	0.16	0.18	0.67	17.74	2.97	0.61	2.14	0.78
2095	0.11	0.13	0.22	0.13	0.15	0.58	18.87	2.82	0.54	1.90	0.71
2100	0.10	0.12	0.17	0.11	0.13	0.51	19.71	2.57	0.48	1.75	0.64

Table 2.d Fossil Fuel Emission Targets in relative to 2005 levels

	USA	EU	KOSAU	CAJAZ	TE	MENA	SSA	SASIA	CHINA	EASIA	LAM
2010	1.13	0.94	1.06	1.08	1.10	1.19	1.26	1.14	1.06	1.31	1.16
2015	1.13	0.82	1.11	1.01	1.18	1.38	1.69	1.42	1.21	1.57	1.35
2020	1.13	0.71	0.66	0.67	1.26	1.54	1.90	1.78	1.40	1.90	1.58
2025	0.82	0.68	0.50	0.62	1.43	1.64	2.53	1.89	1.45	2.29	1.32
2030	0.60	0.65	0.45	0.60	1.10	1.38	2.95	1.56	1.19	1.90	1.14
2035	0.44	0.63	0.45	0.58	0.94	1.19	3.58	1.33	1.01	1.64	1.04
2040	0.32	0.59	0.42	0.56	0.87	1.10	4.21	1.25	0.92	1.51	0.97
2045	0.29	0.51	0.42	0.54	0.80	1.03	4.85	1.17	0.85	1.41	0.93
2050	0.26	0.45	0.40	0.45	0.75	0.98	5.48	1.08	0.79	1.31	0.88
2055	0.23	0.39	0.34	0.37	0.71	0.94	6.32	1.03	0.74	1.25	0.86
2060	0.21	0.35	0.32	0.32	0.59	0.87	7.16	1.39	0.65	1.25	0.84
2065	0.19	0.30	0.26	0.28	0.50	0.80	8.22	1.61	0.57	1.21	0.79
2070	0.17	0.26	0.24	0.22	0.42	0.72	9.27	1.75	0.50	1.15	0.74
2075	0.15	0.23	0.21	0.21	0.35	0.65	10.32	1.81	0.43	1.11	0.70
2080	0.14	0.20	0.18	0.17	0.30	0.61	11.38	1.81	0.38	1.02	0.63
2085	0.12	0.18	0.16	0.15	0.25	0.54	12.43	1.75	0.34	0.95	0.58
2090	0.11	0.16	0.13	0.13	0.22	0.49	13.27	1.67	0.30	0.88	0.53
2095	0.10	0.13	0.13	0.11	0.18	0.42	14.12	1.58	0.26	0.79	0.49
2100	0.08	0.12	0.11	0.09	0.16	0.37	14.75	1.45	0.23	0.72	0.44

Table 3: Regions' GDP and Emissions Data before and after the target

	per cap GDP 2010 , K$ (2005 $)	per cap GDP year of 1st cut, K$ (2005 $)	per cap GDP 2100 (with policy), K$ (2005 $)	per cap GDP 2100 (with-out policy) K$ (2005 $)	per capita emissions 2010	per cap emissions, year of first target	per cap emissions 2100 (with policy)	per cap emissions 2100 (without policy)
USA	46.68	46.68	143.03	149.44	5.96	5.96	0.46	8.79
EU	22.95	22.95	67.76	69.00	2.54	2.54	0.48	4.22
KOSAU	17.10	21.29	69.01	72.34	3.33	3.62	0.66	5.02
CAJAZ	40.10	44.76	123.49	126.71	3.49	3.69	0.79	5.16
TE	4.83	8.79	34.62	39.64	2.36	2.86	1.00	4.32
MENA	4.49	7.06	35.36	39.02	1.45	2.38	0.35	3.04
SSA	0.64	2.13	8.86	7.45	0.07	0.15	0.05	0.32
SASIA	0.89	2.08	21.81	22.02	0.25	0.39	0.12	1.47
CHINA	2.49	6.36	48.27	54.29	1.35	1.91	0.74	5.30
EASIA	1.93	4.21	17.52	18.06	0.57	0.85	0.16	1.77
LAM	5.61	8.52	61.78	65.41	0.89	1.09	0.33	3.00

Table 4: Implied Economic Cost of Emission Targets for each of 11 regions

(PDV at discount rate = 5%, expressed as per cent of income loss)

USA	*EU*	*KOSAU*	*CAJAZ*	*TE*	*MENA*	*SSA*	*SASIA*	*CHINA*	*EASIA*	*LAM*
1.4%	0.6%	1.3%	0.6%	1.2%	2.8%	-3.6%	1.6%	3.3%	1.8%	2.0%

Appendix

We have performed a substantial number of alternative simulations -- changing starting dates for regional policies, and changing the parameters in the Latecomer Catch Up and Gradual Equalization factors -- in the quest for a set of targets abiding to our political rules and leading to increasingly stricter environmental targets.

We present below (Figures A1, A2 and A3) the results for a subset of policy agreements spanning the space of the long-term environmental target. Figure A1 reports global costs expressed as present value GWP losses. Figure A2 reports the maximum national income loss that is incurred in any period by any country. Finally, Figure A3 reports the maximum present value national income loss that is incurred by the major regional loser.

In figures A1, A2 and A3, agreements represented by blue diamonds differ only with respect to when developing regions get a target below BAU and in how fast they gradually converge to equal per capita emissions. All parameters are equal for all regions. Within this group the red square represent the agreement presented in the present paper. Agreements represented by green triangles were obtained by changing Latecomer Catch Up and Gradual Equalization factors for different regions, thus tailoring rules to regional cases with the aim of improving efficiency and lowering maximum regional costs.

First, it is immediately visible how the choice of target, mainly defined by the speed of long term equalization and the delaying of active reduction in developing countries, is the major driver of costs. Hence, although our general formulae could be improved in terms of maximum losses to any country (see green triangles in figure A1, A2 and A3), losing the simplicity and the political appeal of equal rules for all countries might not be justified in terms of global efficiency gains.

The second basic fact is that, given realistic assumptions on what will happen during the first half of the century, it will be increasingly costly to pursue policies aiming at 470 ppm CO2 and below. No matter how much we tailor the parameters to regional necessities and how we might change the ranking losers, maximum national income losses will be higher than 10% in the latest part of the century for any parameter specification.

Figure A1. Reports global costs expressed as present value GWP losses

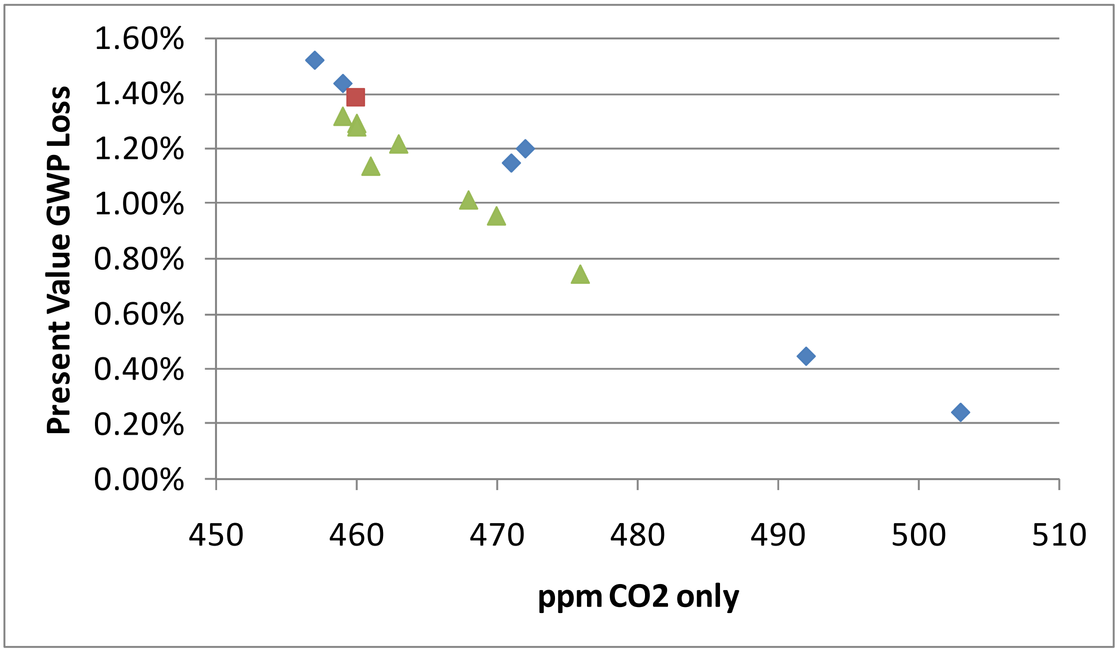


Figure A2. Maximum national income loss that is incurred in any period by any country

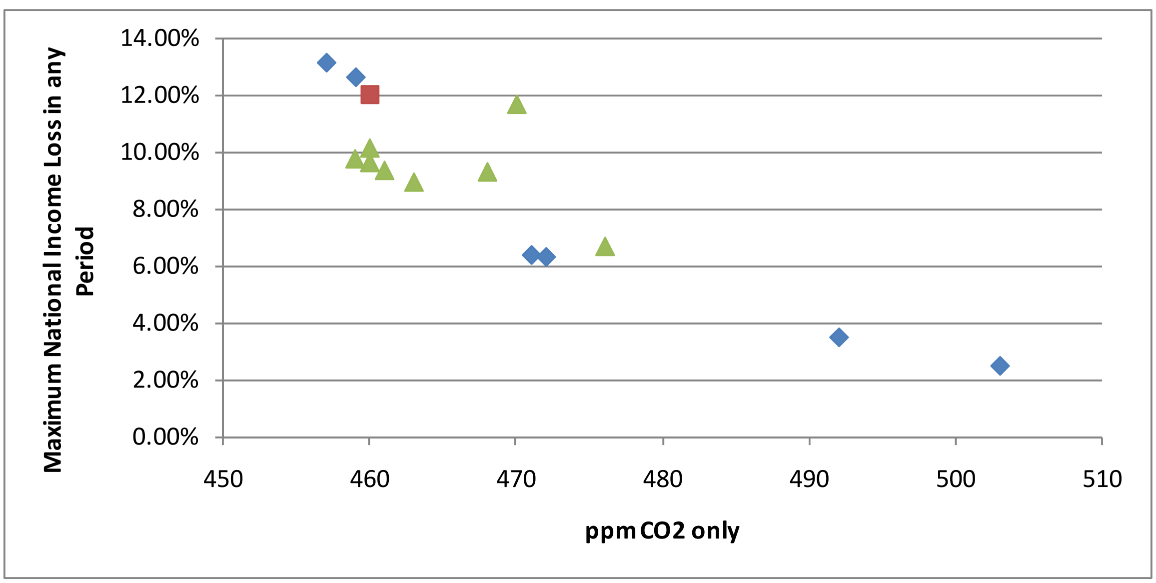
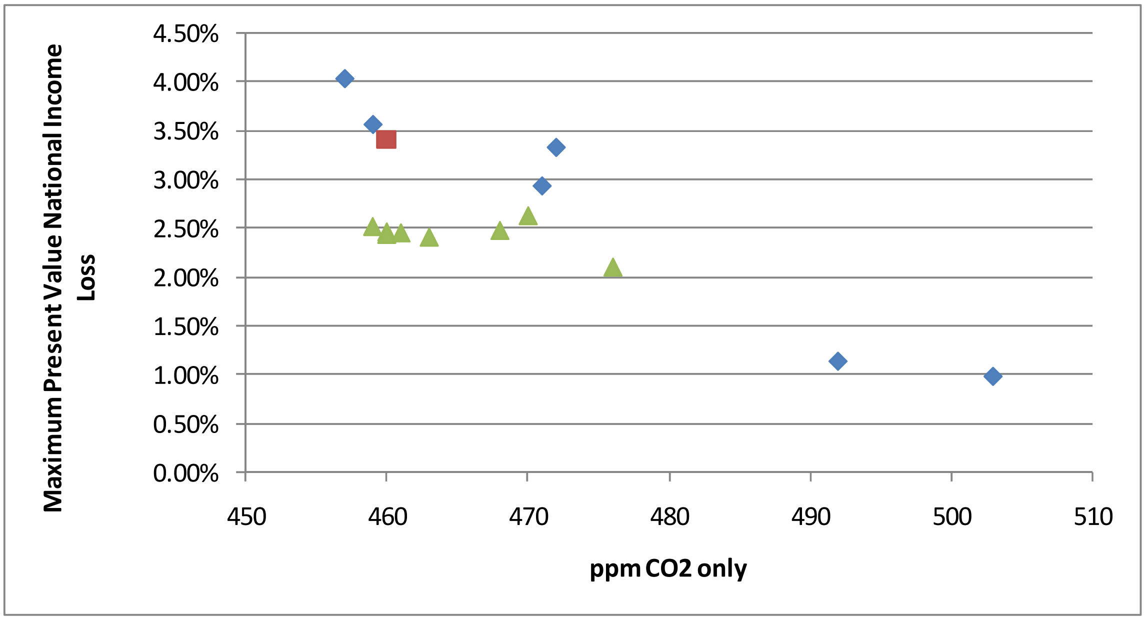


Figure A3. Maximum present value national income loss incurred by greatest loser



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(lxxxv) This paper has been presented at the 14th Coalition Theory Network Workshop held in Maastricht, The Netherlands, on 23-24 January 2009 and organised by the Maastricht University CTN group (Department of Economics, http://www.feem-web.it/ctn/12d_maa.php).