Containing Global Warming after Copenhagen: One-Shot and Learning-by Doing Approaches

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Abstract

The perceived success of post Kyoto Protocol mitigation policy largely revolves around the ability of parties to agree to binding targets in 2020 that provide a reasonable likelihood of avoiding 2°C warming. However, neither theory nor practice supports the assumption that a one-shot agreement can deliver such success, nor that it is preferable to a learning-by-doing approach. By contrast, changing information about current and future emissions growth and about evolving climate risks can be used to guide multi-stage processes of adjustment to achieve a given target. To demonstrate this, we examine the effect of changing climate policy on projected emissions over the years 2006–2010. Four cases of projected emissions to 2030 are examined under a consistent set of assumptions: Policy settings in 2006 and 2008, the impact of the Global Financial Crisis (GFC) and commitments given under the Copenhagen Accord. Under 2006 assumptions, median projected warming in 2100 reaches 3.9°C. By late 2009, policy changes are estimated to have reduced the projected atmospheric concentration of Kyoto gases and mean global warming in 2100 by about 15–18%. The impact of the GFC was only about one-quarter of that. Incorporating Copenhagen Accord commitments and a minimum emissions path from 2020 results in projected warming in 2100 of 2.6°C, 30% less than for the 2006 policy settings. Further learning in the short-term, though it may not be easily achieved, may bring the <2°C target within reach. The results provide a strong case for the global community to accept that the learning-by-doing approach is both feasible and potentially effective. The development of policy mechanisms, institutional frameworks and assessment systems that can apply learning in all of these risk domains remains the best hope of achieving the ultimate goals of climate policy.

Keywords

Climate change, climate policy, mitigation strategies, learning-by-doing

Introduction

One important outcome of the 15th meeting of the Council of Parties (COP15) of the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen was agreement that global warming should be limited to no more than 2°C relative to pre-industrial levels. This paper contrasts two ways of seeking to achieve this or similar objectives. One, which we call *the one-shot approach*, sets out to achieve a universal, legally binding agreement on emissions paths that will stabilise the atmospheric concentration of greenhouse gases (GHGs) at a level consistent with this temperature objective (Bosetti et al., 2008; Stern, 2008). Such an approach has been widely pursued since the signing in 1992 of the United Nations Framework Convention on Climate Change, with its central objective of stabilising "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (United Nations, 1992). It has been commonly described as an equilibrium approach (IPCC, 2001), and in terms of the reductions necessary by various parties to stabilise the atmospheric concentration of GHGs or climate forcing at a target level (e.g., 450 ppm CO_2e or 3.5 W/m^2; IPCC, 2007b).

The other, which we call *the learning-by-doing approach*, involves the major GHG-producing nations entering into a cooperative and evolving process to contain warming to the target level, by adopting serious but in some cases non-binding emissions reduction targets. These targets would be reviewed and revised over time incorporating new knowledge, changing circumstances, progress towards meeting the temperature target and perhaps even an emerging need to change the temperature target. This is one interpretation of the central outcome of the COP15 meeting – the Copenhagen Accord – in the context of which a large number of countries offered non-binding and conditional commitments to reduce national total emissions or emissions intensity.

The uncertainty that surrounds the 'best' mitigation policy also concerns the question of the 'best' target, both interim and final. A limit of 2°C warming through to stabilization (WBGU, 2003) was adopted by the European Union (den Elzen and Meinshausen, 2006), before being adopted by the Copenhagen Accord, but this target could potentially be altered with new information about key vulnerabilities (e.g., Schneider et al., 2007). Physical uncertainties also affect concentration targets measuring atmospheric concentrations of GHG's as CO_2 only or CO_2 equivalents. Cumulative emissions targets, for example tonnes CO_2 emitted by 2050, provide more robust measures of temperature exceedance (Allen et al., 2009; Meinshausen et al., 2009). The high rate of emissions growth and time elapsed means that emissions pathways involving overshoot, or peak and decline, are preferred to stabilization scenarios as being consistent with acceptable temperature outcomes such as in the Representative Concentration Pathway, RCP2.6, in the IPCC new scenarios process (Moss et al., 2010).

This issue is not about whether the UNFCCC process should seek to put in place a legally binding agreement covering a wide range of issues. Rather it is whether, within such an agreement, there should be scope for some countries, and especially developing countries, to adopt a learning-by-doing approach by providing strong targets that they will pursue on a 'best endeavours' basis, retaining the right to revise them over time, especially as we may learn a great deal about pathways and targets in terms of managing risk (Keeney and McDaniels, 2001).

Our argument has three elements. First, we review the types of risks and uncertainty involved in seeking to establish a way ahead. Given the complexity of the risks and the likelihood of different levels of risk across countries, as well as different perceptions of and attitudes to risk, we show that there are no clear grounds for thinking that a one-shot agreement is achievable at a level consistent with the temperature target nor that it is to be preferred to a learning-by-doing approach to the same goal. For some countries a non-binding commitment in a learning and review context may allow them to target, and then to achieve, a greater reduction in emissions than that to which they would be willing to commit on a one-shot basis.

Secondly, in the context of ongoing international negotiations the world has made progress in reducing projected emissions over the past five years or so using a learning-by-doing, bottom-up approach. As the reality of global warming has become apparent many countries have developed and implemented new policies to limit energy use and emissions. A wide range of companies and research groups have invested heavily in developing and implementing new clean technologies. These activities culminated in the wide range of commitments offered under the Copenhagen Accord.

Using a series of emissions projections to 2030 and a common method for extending them to 2100, we show that projected atmospheric concentrations of greenhouse gases and warming in 2100 have been reduced by about 25% over the period 2006–10, assuming that the commitments under the Copenhagen Accord are met. The reduction in emissions intensity attributed to changes in policy and technology results in a net 15–18% reduction. While projected emissions remain too high for policy objectives to be met, further progress of similar dimensions over the next five years or so could bring within reach the target of stabilising global mean temperatures at less than 2°C.

Thirdly, adoption by the global community of the 2°C target has important learning implications that should be taken into account in designing international policy. Given current realities, achieving this target inevitably involves an overshooting path in terms of the atmospheric concentration of GHGs, with the point of transition from peak to decline in terms of concentration occurring well before 2100 (Anderson and Bows, 2008; Sheehan et al., 2008). The 2°C target therefore implies a commitment to reducing global emissions in major countries to close to zero well before 2100. Such a trajectory will provide both increased incentives and growing opportunities for countries to reduce emissions, with substantial learning implications. The adverse impacts of further warming will continue to be felt over the next few decades, while technological change will continue to accelerate and to shape the competitiveness of nations.

These propositions – that there are no grounds for believing that an adequate one-shot international agreement is achievable or that it would be the most effective approach, that good progress is being made by the current learning-by-doing approach and that the 2°C target implies strong future learning dynamics – need to be seen in the context of the current impasse in the international climate negotiations. That impasse centres on the attempt to achieve a binding, one-shot universal agreement to emissions reductions by 2020 widely considered to be necessary to achieving the 2°C temperature target. At COP15 the two main issues were whether the whole global community, including large developing country emitters, would agree to binding commitments and whether the level of those commitments would be sufficient to achieve the agreed temperature target. Given the current impasse, there is a strong case for the global community to accept that the learning-by-doing approach is both feasible and potentially effective. This would mean shifting attention from pursuing a single, binding agreement about emissions reductions covering all countries to setting up formal processes to manage the learning-by-doing approach over time. Even in a one-shot agreement was to be forged and ratified we consider this type of process to be necessary in any case to ensure emissions targets can be met. We comment briefly at the end of this paper on what these processes might involve.

International agreements with risk, uncertainty and learning

Setting up the problem

Three areas of risk need to be considered in trying to develop a global approach to climate change: climate risk, climate policy risk and political risk. *Climate risks* constitute human-induced climate change and its impacts, summarised by the Intergovernmental Panel on Climate Change (IPCC)'s Fourth Assessment Report (IPCC, 2007b) and recently updated in time for COP15 (The Copenhagen Diagnosis, 2009). As widely discussed in the literature, there is considerable uncertainty about the nature, timing and incidence of these risks. *Climate policy risks* relate to the potential costs and benefits arising from the implementation of climate policy. Substantial uncertainties accompany the actual impact of any particular policy and what constitutes the most appropriate set of climate policies (Blyth et al., 2007). For example, while the effect of introducing a carbon tax has been widely modelled, its actual effect in areas such as economic growth, technological change and energy use remains unclear. *Political risk* covers the risks, for governments and political leaders, from taking action to reduce emissions (e.g., by introducing a carbon tax) or indeed from failing to take such action. In a number of developed economies (such as the USA and Australia) political resistance to increases in taxation is strong, but there are also substantial political risks in failing to address climate change.

There are a number of pertinent characteristics of these risks. First, the actual extent of each of these risks is likely to differ across countries. The likely damage from a given level of global warming will be unequally distributed across countries, both in physical terms and in terms of economic costs, especially having regard to national capacity to respond (IPCC, 2007a). Different countries are likely to be affected in different ways by policies to reduce emissions, depending on many factors, such as the nature of their energy systems and their level of development and of technological competitiveness (IPCC, 2007c). While some countries see heavy economic costs in substantially reducing emissions, an increasing number (such as Japan, Korea, some countries in the EU and China) are beginning to see this as a potential source of a new round of competitiveness and growth. Political risks also vary markedly across countries, depending on political systems, public attitudes and other factors.

Secondly, not only do these risks vary across countries in an 'objective' sense, but perceived risk will be critical in determining action and in many cases there will be a wide range of different perceptions of a given risk, both within and across countries. It may well be the case that divergent perceptions of risk amplify the underlying variations in the incidence of risk across countries. Thirdly, our knowledge of each of these types of risk will be shaped over time by a continuous process of learning (Keeney and McDaniels, 2001; Lorenzoni et al., 2005). Perceived risk is also known to be much higher when strategies for risk mitigation are unfamiliar and seen to be risky in themselves (Slovic et al., 2004). As the world warms, the likely impact of that warming in any given region will become better defined, as will the likely level of warming associated with a given emissions path. As policies are implemented and new technologies are developed, the shape and distribution of climate policy risks will become clearer, and the political risks surrounding climate policy implementation are likely to be better defined.

These characteristics help to define the challenge involved in reaching a one-shot, binding agreement to contain global warming. The problem involves strategic interaction between many countries, pursuing both their individual national and global interests, with differing incidence of each of the three types of risk across countries and with different perceptions of risk, in the context of substantial future learning. In both analytical and practical terms this is a deeply complex challenge. In the sections below we provide some general considerations relevant to this problem and then review briefly what can be said about it from the literature in economics and related social science disciplines.

General considerations

It has been widely assumed that a one-shot, binding agreement is the preferred approach, for a number of reasons: because a binding agreement covering at least all major emitters is necessary to avoid free-riding; because such an agreement will encourage individual parties to commit, as they will have confidence that the commitments of other parties will be met; and that the binding nature of the agreement will maximise the chances of the reductions being achieved and global warming actually being curtailed (Stern, 2008).

On the other hand, the risk in seeking a one-shot, binding agreement is that it may not be achievable at the level required to achieve the temperature target, because some countries do not feel able to commit to large binding reductions, because of the uncertainty about either the climate risks or the climate policy risks involved (e.g., China and India) or because they are not able to manage the political risks involved in such reductions (e.g., USA and Australia; Alessi et al., 2010). Related to this point, some countries may be willing to commit to more aggressive targets on a non-binding, learning-by-doing basis than on a binding basis. This may be the case, for example, if they wish to reduce energy use per unit of GDP and emissions sharply but remain concerned about the impact of any particular target on future development.

It is by no means clear that the balance of these considerations favour the one-shot approach. COP15 demonstrated the severe difficulties of achieving a binding agreement in the face of strong opposition from many countries, and also showed that major commitments could be offered on a ‘best endeavours’ basis. It is also possible that, with effective management, the putative benefits of the one-shot, binding approach – avoidance of free-riding, encouragement of country commitments and certainty of outcomes – might be equally well achieved under a learning-by-doing approach. For example, a periodic process in which major countries report on their achievement against commitments, in the context of ongoing review of global progress, of the likely warming implications and of technology developments, could generate as much moral force and shared learning to avoid free-riding and achieve desired outcomes as any legally binding agreement.

Perspectives from economics and other disciplines

In analytical terms we are dealing with a case in which many countries interact strategically in the context of uncertainty and learning, with heterogenous risks across countries. There is an extensive theoretical literature in economics on uncertainty and learning in the context of climate change, but most of it applies to a single global decision maker with uniform uncertainty related to climate risk only (e.g., Heal and Kriström, 2002; O'Neill, 2008; Kolstad, 2010). While work has investigated multiple agents (e.g., Na and Hyun, 1998; Kolstad and Ulph, 2008a), Kolstad and Ulph (2008b) point out that the literature describing heterogenous agents acting in the context of uncertainty and learning is very thin. The modelling of strategic interaction needs to be undertaken using game theoretic approaches, and there are severe limitations on such models with heterogonous agents, multiple risks, uncertainty and learning[1].

Kolstad and Ulph (2008b) develop a model with multiple agents whose expected damage from warming (the only uncertainty) is the same *ex ante* but different *ex post*. They model a two stage game. Agents first play the membership game, in which they decide whether or not to enter an agreement to act in the common interest. They subsequently play the emissions game, in which they choose whether to emit or to abate. If an agent chooses to join the agreement, she acts in the common interest of the agreement parties in the emissions game. If she chooses to stand aside from the agreement, she acts in her own self interest in the emissions game. For this set-up the authors study three learning cases: complete learning, in which the distribution of damages is known before the membership game; partial learning, in which it is known after the membership game but before emissions are decided; and no learning. It is partial learning that is relevant to the actual case of a climate agreement (that is, there is learning about diverse damage outcomes after the membership decision is taken but before all emissions decisions are finalised).

Kolstrad and Ulph (2008b) show that, in this case, expected welfare from an agreement is lower with partial learning than with either complete or no learning and that the expected membership with partial learning is lower. In such cases, agreements do not necessarily bring significant welfare gains over the non-cooperative equilibrium. More generally, the current economic literature views a one-shot agreement on climate change negatively on two grounds: there is certainly no model which shows that in the actual situation described above, the one-shot approach is either achievable or to be preferred, and the existing models suggest that partial learning and multiple risks with heterogenous agents will tend to make an agreement both less likely and less welfare generating.

An extensive literature in other social science disciplines - such as sociology, public administration and cultural theory - is also relevant, but only a few themes can be noted here. The climate negotiations have become an intractable policy problem in the sense of Schon and Rein (1994) where different framings of risk mean that the central issue of avoiding dangerous climate change has become immune to appeal via particular sets of facts. The dominant policy framework for managing climate change risks through mitigation policy (the one-shot approach) can be characterised as rational-comprehensive (after Lindblom, 1959). Various strands of this literature

[1] Some empirical modelling of these cases can be undertaken without strategic interaction, but this appears to miss some of the key elements of the decision making challenge for an international agreement. For example, Dellink et al. (2008) use an empirical model with a richer set of options (uncertainties about both damage and abatement costs, and a continuum of abatement options) but do not consider the case of partial learning.

argue are that, for such complex intractable problems, 'clumsy' approaches based on organisational and policy-oriented learning and/or reflexive approaches are necessary, rather than the single rational solution implicit in the one-shot approach.

Schon and Rein (1994) pioneered the exploration of methods for resolving such intractable problems, which are seen as arising from the different structures of belief, perception and appreciation which different agents bring to a common set of facts. They recommend an approach which emphasises organisational learning and reflective practice, with an emphasis on maintaining the trust of the parties through the process. Another important body of literature deals with the issue of reflexivity, in the sense of an action turning back on itself and affecting the individual or entity taking the action, and hence giving rise to reflexive feedback (e.g., Giddens, 1984; Wynne, 2002). Climate policy is clearly a reflexive problem, in that the initial actions of the parties will impact on them and others in many ways, and hence shape the context in which they take action in the future. It is argued that it is a mistake either to ignore these reflexive feedbacks or to assume that they can be known in the initial period. Given the difficulties in identifying the 'best' policy option in complex policy environments (Lindblom, 1959), another stream of literature has addressed the need for policy-oriented learning (Sabatier and Jenkins-Smith, 1993) and for clumsy solutions (those in which all voices are heard and which evolve over time through vigorous debate; Verweij et al., 2006) to address problems in such environments. Each of these themes is inconsistent with the one-shot approach.

Conclusion

The attempt to reach a one-shot, binding agreement to contain global warming needs to be seen as a response to a problem involving strategic interaction between many countries, pursuing both their individual national and global interests, with differing incidence of each of three different types of risk across countries and with different perceptions of risk, in the context of substantial future learning. Our understanding of such a complex problem is limited. But there is no assurance in either theory or practice that a one-shot agreement can be achieved at a level consistent with the warming target, or that this approach is to be preferred to the learning-by-doing approach. The putative benefits of the one-shot, binding approach – avoidance of free-riding, encouragement of country commitments and certainty of outcomes – might be equally well achieved under a learning-by-doing approach, and there are grounds for the view that a reflexive, learning-by-doing approach might be more effective in dealing with such complex strategic interaction.

Climate policy and economic change since 2005 – methods

The empirical analysis in this paper is driven by three relevant phenomena: the surge in global growth evident after 2000 as the world shifted to a new global growth path; the impact of the global financial crisis in 2008 and 2009, together with the uneven but generally rapid recovery from it; and the widespread policy and commercial response to a growing awareness of the threat of climate change.

Between 2000 and 2007, the globalisation of the knowledge economy fuelled more rapid economic growth than projected in the storylines of the IPCC Special Report for Emission Scenarios (SRES; Nakicenovic and Swart, 2000), especially in Asia (Garnaut et al., 2008; Sheehan, 2008). This accelerated growth has contributed to GHG emissions and atmospheric concentrations of those gases rising at the upper level of IPCC projections (Raupach et al., 2007). In particular, the five year period from 2002 to 2007 was one of high growth in world GDP by historical standards (4.7% per annum), with growth in global emissions of 3.8% per annum. An analysis of this high growth pathway led us to conclude that warming of >1.5°C by 2030 from a pre-industrial baseline was possible if it was left unchecked (Sheehan et al., 2008).

Towards the end of 2007, the signs of a looming financial crisis were becoming evident (Shin, 2009; Claessens et al., 2010). The global financial crisis (GFC) led to sharp falls in industrial production and GDP in many advanced countries in late 2008 and 2009, but only briefly stalled the rapid growth taking place in countries such as China and India. As shown in Table 1, the real annual average change in GDP in the advanced countries fell from 2.7% over 2002–07 to -1.4% over 2007–09, while for developing countries the fall was from 7.3% to 4.3%, giving global growth of only 1.2% per annum over the two crisis years. Table 1 also shows the April/June 2010 IMF projections for GDP growth to 2015. They imply that a rapid recovery from the crisis period is underway in the world as a whole, although not in all countries, and is led by major developing countries such as China and India. The pace of this recovery is such that the IMF anticipates that growth rates close to those achieved over 2002–07 will occur over 2009–15, with global growth of 4.5% per annum and developing countries growing at 6.7% per annum. Our unchanged policy projections, discussed below, envisage a return to rapid emissions growth over this period (Table 1) but at rates below that of 2002–07.

Table 1: Growth in GDP and CO_2 emissions (excluding land use), by major country, 2002–15

	2002–07	2007–09	2009–15*
GDP	(Annual growth rates - % pa)		
Advanced countries	2.7	-1.4	2.4
Developing countries	7.3	4.3	6.7
World	4.7	1.2	4.5
CO_2 emissions			
Advanced countries	0.7	-4.6	0.0
Developing countries	7.6	5.1	5.0
World	3.8	0.3	2.6

*Period is 2010–15 for emissions.

Sources: GDP data are from the IMF World Economic Outlook, April 2010; GDP projected growth rates for 2010 and 2011 are from the IMF July 2010 update, while that for 2011-15 is from the April report. Data on CO_2 emissions for 2001-09 are from (Olivier and Peters, 2010) while the 2010-15 projections are those of the authors, for the base case described below.

The lower emissions intensity of growth in the projection period reflects the evolution of climate policy in recent years. With growing awareness of the threat of global warming, after 2005 many countries began to implement policies to contain energy use and emissions[2], and to encourage R&D and investment in clean energy technologies. At the same time, negotiations for a post-Kyoto Protocol regime in climate policy were underway (Ott et al., 2008). Preparatory meetings developed text and a range of countries committed to undertaking significant policy measures (Clemencon, 2008). While, as noted above, COP15 made little progress towards a binding agreement covering all countries, through the Copenhagen Accord it did lead to 55 countries accounting for 78% of emissions to provide new commitments, albeit often on a conditional basis, to limit their emissions by 2020.

Here we study the impact of this process of bottom-up policy change, in the context of the ongoing new global growth path and the financial crisis, on the basis of

[2] For details of these policy changes see successive issues of the International Energy Agency's annual *World Energy Outlook* and its series of reviews of the energy policies of member countries (www.iea.org).

four projections of emissions to 2030, based on different unchanged policy assumptions:

- One (2006), based on the policies in force in 2006;
- One (2008), based on the policies in force in 2008 and pre-GFC economic projections;
- One (GFC), based on the policies in force in 2008 and post-GFC economic projections; and
- One (COP15), based on the implementation of the COP15 commitments in the context of post-GFC economic projections.

Each of these projections to 2030 is extended to 2100 on a common basis: the minimum emissions path (MEP) method of Sheehan et al. (2008) and their climate implications are explored by using the MAGICC simple climate model (MAGICC V5.3). This method provides a way of estimating the impact of policy changes over 2006–10 and of the economic crisis on long run global warming. A fifth projection implements the COP15 commitments to 2020 then applies the MEP to 2100, bringing it forward be a decade from 2030.

Projected greenhouse gas emissions

The historical data and the projections of CO_2 emissions from energy use to 2030 start from those of IEA (IEA 2006, 2008), adjusted by the authors to take account of additional economic and emissions data and other factors for selected developing countries, notably India and China (see Sheehan et al. (2008) for a detailed description of the method used and of the 2006 projection). Projections were calculated for all six greenhouse gases included in the Kyoto Protocol, the so-called Kyoto gases. CO_2 was estimated separately for coal, gas, oil, cement and land-use and land cover change (LU-LCC). Projections for methane and nitrous oxide covered fossil fuel combustion, industrial and agricultural emissions, and some LU-LCC emissions. Projections for fluorocarbons, hydrofluorocarbons and sulphur hexafluoride were estimated from industrial uses. Total LU-LCC emissions in 2006 were taken from the latest stabilisation scenarios from Wigley (2008). For 2008 onwards they were sourced from the Global Carbon Project (Le Quere et al., 2009).

There is a considerable economic literature on the extent to which a major shock to GDP (such as in the GFC) affects the long run level and rate of growth of GDP (e.g., Cerra and Saxena, 2005, 2008; Becker and Mauro, 2006; Cerra et al., 2009)). The issue is often framed in terms of three options: 1) the economy in question eventually returns to the pre-shock trend *level* of GDP through a period of above trend growth; 2) the economy returns to the pre-shock trend *rate of growth* but does not recover the lost GDP in the crisis; or 3) the economy fails for some time even to recover to the pre-shock trend rate of growth. In a recent empirical review of past shocks Cerra and Saxena (2008) find evidence of a range of outcomes, with a few cases in which there is full return to trends levels, many in which only a return to pre-shock rates of growth are achieved and a range of intermediate positions. Having regard to the specific characteristics of the GFC and of the rapid recovery in some countries, we assume full recovery to trend levels (or better[3]) in China and India, recovery only to trend growth rates in OECD countries (with significant loss of output) and partial recovery to trend in other developing countries. The crisis pattern

[3] Given the massive nature of the stimulus package in China, and the return to traditional patterns of investment led growth, our projections of medium term post GFC growth for China is higher than the pre GFC rate, so that the long term trend level of GDP is actually exceeded post GFC.

of GDP to 2011 across the eight global country groupings (OECD, Transition, China, India, Other Asia, Latin America, Africa and the Middle East) follows IMF forecasts (IMF, 2009), again adjusted for other available information by the authors.

Copenhagen Accord commitments

We applied commitments made by 55 countries to the Copenhagen Accord – most in formal submissions made by the parties by the February deadline, but several made before COP15 were also included (e.g., Belarus). In most cases where there were a range of commitments provided we used those at the low to mid range. For Annex 1 countries, these conditional commitments imply reductions of about 12% below total 1990 emissions by 2020. Full commitments would equal about 17% but we have not modelled these. The estimates are extended to 2030, where a 2030 commitment is given or implied, and for other commitment countries the rate of change over 2010–20 is extended to 2030. In all cases, except those specified below where no commitments have been given, the pre-Copenhagen base-case projection is used.

Commitments specified in terms of reductions in emissions per unit of GDP (e.g., South Africa, South Korea and China) were applied on the basis of growth rates in the post GFC projections. Transition countries in Annex I that made no commitment were given equivalent reductions to Russia in percentage terms. In most cases, this constitutes a decrease from 1990 emissions but an increase from 2005 emissions. All countries within the larger EU, the so-called EU-27, were given targets of 20% below 1990. Land-use commitments were applied specifically for Indonesia and Brazil, reducing the LU-LCC component of emissions in the input data to the simple climate model.

Comparing the climate implications of medium term emissions paths

The desire to assess and compare the climate implications of various medium term emissions paths to 2030 (such as an unchanged policy projection or a set of outcomes under the Copenhagen Accord) raises important methodological issues, particularly in relation to the commitment to future climate change. Several methods are used in the literature. One common approach (e.g., den Elzen and Höhne, 2008; den Elzen et al., 2010) relies on a widely documented result from a range of models that "an emission level of 44 to 46 Gt CO_2e seems to be consistent with an emission trajectory that has a reasonable chance of meeting the 2°C target" (den Elzen et al 2010). But this is a rule of thumb only because it is the area under the curve that really matters, or total emissions to a given date. Cumulative emissions from 2000–2050 of 275 Gt C are estimated to offer a 75% chance of avoiding 2°C and a 50% chance at 380 Gt C (Meinshausen et al., 2009). Therefore, with emissions of 74.9 Gt C 2000–2009 (Gullison et al., 2007), the post-2020 trajectory of emissions will have a major impact on overall warming. An alternative approach is to calibrate the emissions path in terms of one or more of the SRES marker scenarios (Swart et al., 2002). But both the emergence of the new global growth path and the adoption of the 2°C target by the international community limit the relevance of the SRES scenarios for this purpose.

Projections from 2030 to 2100 follow the concept of the minimum emissions path introduced in Sheehan et al. (2008). The MEP from a given point on an unchanged policy projection specifies the lowest emissions path that might reasonably be achieved if effective global policies to reduce emissions were implemented from that date, given likely economic and technological conditions. MEPs apply the following specifications:

- if an MEP is established from year n, emissions are stabilised, via a progressive reduction in annual emission growth rates to zero, over a stabilisation period from year n which may vary across different countries and regions;
- when stabilised, emissions are reduced to a given proportion of the stabilised level (e.g., 10%) over a given time period (e.g., 100 years). Reductions can be in equal annual amounts implying a linear rate of decline, implying an accelerating rate of decline, in equal annual percentage reductions or according to some other formula.
- An MEP from year *n* is not a projection or forecast, but a lower bound path based on an assessment of the maximum realistic potential of new technologies and committed global policies. Even as a lower bound, the emissions path is indicative only and other specifications could be provided.

For the first four projections we use a common MEP based on 2030: after 2030 emissions are stabilised over periods ranging from 5 years for OECD countries, 10 years for transition economies, 15 years for China and 20 years for Latin America, the Middle East, India, other developing Asia and Africa. After stabilisation emissions are reduced in all countries in equal annual amounts to be 10% of the stabilised level after 100 years. Using this common approach in all four cases implicitly assumes that technology and policy capabilities in 2030 will enable such a reduction profile to be achieved, whatever the 2030 level of emissions. In a fifth case, to be discussed below, an MEP from 2020 is used, with equivalent percentage reductions after stabilisation.

The starting point for the analysis is an unchanged policy projection to 2030 based on energy and emissions policies in force in mid 2006 (MEP2030-2006). This projection is then revised to incorporate the policies in force in mid 2008 made prior to the full impact of the GFC (MEP2030-2008) and one for the outlook subsequent to the GFC made in late 2009, prior to COP15 (MEP2030-GFC). Thus the difference between the first two paths can be used to estimate of the impact of policy changes between 2006 and 2008 on future emissions, while that between paths two and three is a measure of the impact of the GFC on emissions. The fourth projection, MEP2030-COP15, incorporates the Copenhagen Accord commitments to 2020 and where possible their extension to 2030. Hence the difference between paths three and four estimates the effect of the COP15 commitments using a consistent set of assumptions to 2100. The fifth projection, applying an MEP from 2020 is MEP2020-COP15.

While the economic assumptions are the same for the three post-GFC cases, there are some differences between them for the 2006, 2008 and GFC cases. Estimated global GDP in constant PPP terms in 2030 is reduced by 9.6% (from \$180.0 trillion to \$162.7 trillion) between MEP2030-2006 and MEP2030-2008, the major factor being a reduction in China’s projected growth rate from 8.5% per annum to 7.8% per annum over 2006–2030. While revised growth rate assumptions reflect many factors, they cannot be assumed to be entirely independent of climate policy. For example, China’s plans in the 11th Five Year Plan (2006–10) and beyond to shift the economy to a more energy efficient and welfare generating path involve restraining over-rapid growth driven by heavy industry and fixed asset investment. Between the 2006 and COP15 cases global emissions in 2030 have fallen by 28%, with about one-third of this due to reduced GDP growth projections and two-thirds due to reductions in emissions intensity of growth, changes in the fuel consumptions mix and other factors.

Simple climate model

Climate-related risks associated with the reference path are explored using the simple climate model, MAGICC V5.3 (Wigley 2008; see also http://www.cgd.ucar.edu). MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models and has been used extensively to compare the global climate implications of different emissions scenarios and to explore the sensitivity of results to different model parameters. The model estimates greenhouse gas concentrations, radiative forcing changes and mean global warming. All the projections shown in this paper are assessed using the IPCC's (2007) median estimate of climate sensitivity of 3.0°C and default model settings.

Climate policy and economic change since 2005 – results

The global emissions paths to 2030 for the five projections are summarised in Table 2. As noted earlier, global emissions are expected to see renewed rapid growth in the post GFC recovery. As shown in Table 1, for this case (2008 Post GFC) global emissions are projected to rise by 2.6% per annum over 2009–15, with emissions in advanced countries flat over this period and those in developing countries rising by 5.0% per annum. Over the whole period 2005–30 emissions are projected to rise by 1.8% per annum from 12.4 Gt C in 2005 to 19.4 Gt C in 2030 (Table 2). By contrast, if the COP15 commitments are implemented global emissions in 2030 are expected to be 16.3 GtC, a 16% reduction from the post GFC projection and a 28% reduction from the 2006 projection. Applying an MEP from 2020 reduces emissions in 2030 by 30% from the 2006 base case.

Table 2: Projections of global emissions to 2030

	1990	2005	2020	2030	2005-20	2020-30	2005-30
		(GtC-e)				Growth rate (%pa)	
MEP2030-2006	10.4	12.4	18.4	22.7	2.7	2.1	2.4
MEP2030-2008 (Pre GFC)	10.4	12.4	17.0	20.2	2.1	1.7	2.0
MEP2030-GFC (Post GFC)	10.4	12.4	16.5	19.4	1.9	1.6	1.8
MEP2030-COP15 (Post COP15)	10.4	12.4	15.0	16.3	1.3	0.8	1.1
MEP2020-COP15	10.4	12.4	15.0	15.8	1.3	0.5	1.0
Ratio to MEP2030-2006							
MEP2030-2008	1.00	1.00	0.92	0.89			
MEP2030-GFC	1.00	1.00	0.90	0.85			
MEP2030-COP15	1.00	1.00	0.82	0.72			
MEP2020-COP15	1.00	1.00	0.82	0.70			

The following discussion concerns results in 2100, even though we are contrasting a range of projections through to 2030, then producing MEPs that apply the same rates of reduction after 2030 (2020 in the case of MEP2020-COP15). This is based on the assumption that increased learning to 2030 will be transmitted over the longer term.

Climate implications of the projection paths

Figure 1 and Table 3 show the results for emissions, atmospheric concentration of Kyoto gases as CO_2e and mean global warming for the five projections to 2100. The major differences are between the 2006 and 2008 policy cases and the post GFC case and the COP15 cases. The impact of the GFC itself is relatively small. The atmospheric concentration of Kyoto gases at 2100 is reduced by about 100 ppm CO_2e between the 2006 and 2008 MEPs and the 2008 and GFC MEPs, while the impact of the GFC itself is an estimated reduction of less than 40 ppm. For mean global warming of 3.9°C at 2100, the estimated reduction is 0.34°C between the 2006 and 2008 MEPs and 0.42°C between the post GFC and COP15 MEPs, but only 0.15°C for the GFC itself. The final case, MEP2020-COP15, showing a more realistic continuation for policy after 2020, reduces warming in 2100 to 2.6°C by 0.28°C from the MEP2030-COP15 case and by 1.29°C from the MEP2030-2006 case. All temperatures are warming from the pre-industrial baseline and are calculated with the IPCC median climate sensitivity of 3.0°C.

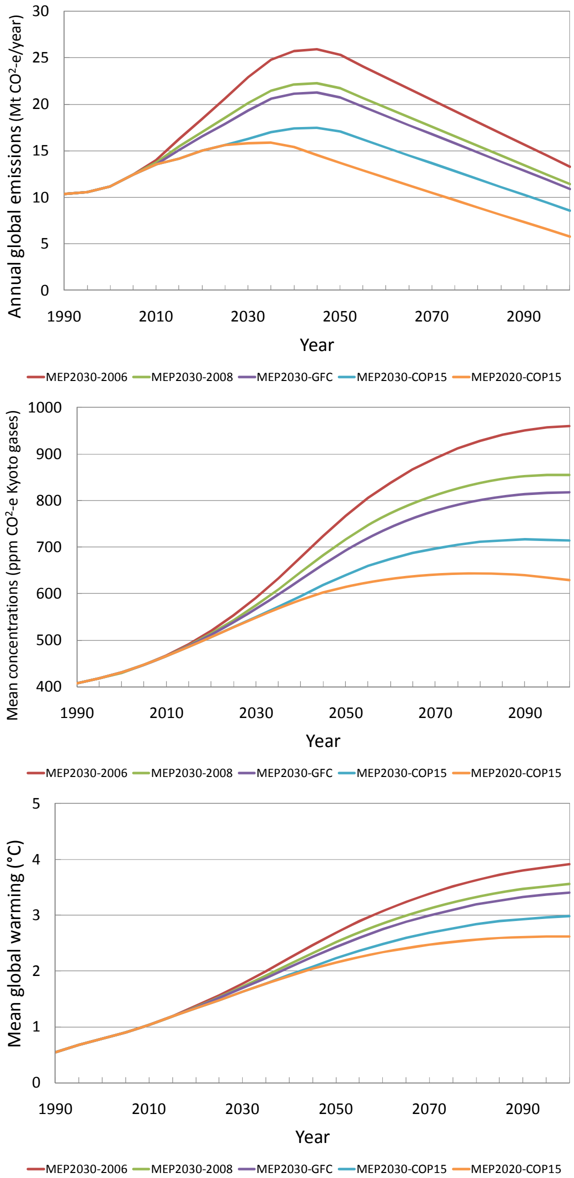

Figure 1. (Top) Emissions (GtC-equivalent/year), (Centre) concentrations for the Kyoto gases (ppm CO_2-equivalent), (Bottom) mean global warming from pre-industrial (°C) MEP projections.

Table 3. Values and differences from the MEP2030-2006 emission projection for emissions, concentrations and global mean warming from a pre-industrial baseline.

Projection	2020	2050	2100	2020	2050	2100	2100
				Difference from MEP2030-2006			(%)
Emissions (Gt C/year)							
MEP2030-2006	18.2	25.2	13.3				
MEP2030-2008	17.0	21.7	11.4	-1.1	-3.5	-1.9	-14
MEP2030-GFC	16.6	20.7	10.9	-1.6	-4.5	-2.4	-18
MEP2030-COP15	15.0	17.1	8.6	-3.1	-8.1	-4.7	-35
MEP2020-COP15	15.0	13.7	5.8	-3.1	-11.5	-7.5	-56
Concentrations (ppm CO_2-e)							
MEP2030-2006	517	763	957				
MEP2030-2008	514	717	855	-3	-47	-102	-11
MEP2030-GFC	512	693	817	-6	-70	-140	-15
MEP2030-COP15	506	640	716	-11	-123	-241	-25
MEP2020-COP15	506	615	629	-11	-149	-329	-34
Warming (°C)							
MEP2030-2006	1.36	2.67	3.90				
MEP2030-2008	1.36	2.51	3.56	-0.01	-0.16	-0.34	-9
MEP2030-GFC	1.35	2.43	3.41	-0.01	-0.24	-0.49	-13
MEP2030-COP15	1.33	2.23	2.99	-0.03	-0.45	-0.91	-23
MEP2020-COP15	1.33	2.15	2.62	-0.03	-0.52	-1.29	-33

Overall, the atmospheric concentration of Kyoto gases at 2100 is estimated to fall from 957 ppm CO_2e in MEP2030-2006 to 716 ppm CO_2e in MEP2030-COP15, a decline of 25%. Warming in 2100 is estimated to drop from 3.9°C to 3.0°C, a decline of 23%. About 4 percentage points are due to the GFC, and a slightly larger proportion to non-policy related changes to economic assumptions. Thus we conclude that over the four years 2006–2010 climate policy changes, both prior to and associated with COP15, have reduced projected atmospheric concentration of Kyoto gases and mean global warming at 2100 by about 15–18% everything else being equal. These figures are comparative only and do not claim to adequately manage risk or otherwise – alternative ways of extending the projections to 2030 out to 2100 would estimate different GHG concentrations and mean warming. But it is clear that substantial reductions in prospective warming levels have been secured by policy change over the past four years, and that similar progress over the next 4–5 years would bring the world within reach of the <2°C target. This is a comparative statement only and makes no claim as to how easy or difficult that may be.

Learning implications of the 2°C commitment

If COP15 commitments as represented here are implemented to 2020 and further reductions from that that date are made (MEP2020-COP15), the atmospheric CO_2-e concentration peaks at about 640 ppm in 2080 with peak warming of 2.6°C late in that decade. While an earlier reduction in emissions should indeed be sought if the 2°C target is to be avoided, this implies the virtual necessity of a peak-and-decline path in order to hold peak warming at <2°C, although the atmospheric CO_2-e concentration would peak at well above the stabilisation level for <2°C warming (about 450 ppm) and then declining. Other simulations with alternative paths, not reported here, further confirm this conclusion.

Several things follow from this conclusion. First, the world will see increasing mean global temperatures over the next two decades at least, with a range of different impacts being felt across different countries and communities. There will, in other words, be a major process of learning about the incidence and scale of climate impacts. Secondly, the IEA has recently concluded that there are “early signs that a (clean) energy technology revolution is already underway” (IEA, 2010, p45), but that massive further investments across a wide range of technologies – in R&D, in commercial testing and scale-up and in associated policy and infrastructural frameworks – for significant reductions in emissions to be achieved. The acceleration in such investments by governments, firms and research groups will not only contribute to economic growth but will provide vital new information on the timing, effectiveness and cost in such technologies, and their likely impact on global patterns of competitiveness.

Thirdly, to achieve a decline in the atmospheric CO_2-e concentration from peak levels requires global emissions to be reduced to levels below the net removal of GHGs from the atmosphere. Given slower reductions in emissions in developing countries, this effectively means moving close to zero net emissions in developed countries. Thus a serious commitment to the <2°C target implies substantially investment in, and learning about, R&D and commercial development of the technologies consistent with a zero emissions economy (such as carbon capture and storage, biosequestration and direct removal of CO_2 from the atmosphere).

Thus the attempt to meet the 2°C target will involve fundamental changes in technology and industrial structures, to be pursued in the face of rising temperatures and severe impacts in many communities. This will imply many forms of learning: about the actual impacts of rising global mean temperatures, about the pace of development of many different technologies and about their competitive position, about the scale of investment involved in moving to a low carbon economy and about the impact of these factors on the competitive position of different countries and regions. Given the historic scale of this learning it seems appropriate to develop an international agreement framework that allows countries to adjust their strategies over time, within the global commitment to hold peak warming to <2°C, as they learn more about the many factors involved.

Conclusions and qualifications

This paper contrasts two ways of seeking to achieve the objective enshrined in the Copenhagen Accord, to hold global warming to <2°C. One, which we call *the one-shot approach*, involves a universal, legally binding agreement on emissions paths that will stabilise the atmospheric concentration of GHGs at an appropriate level. The other, *the learning-by-doing approach*, involves the major nations entering into an evolving process to contain warming to the target level, by adopting and acting on emissions reduction targets that in some cases are non-binding and are reviewed over time.

The paper reaches three conclusions about these approaches. First, there is no assurance in either theory or practice that a one-shot agreement can be achieved at a level consistent with the warming target, or that this approach is to be preferred to the learning-by-doing approach. The putative benefits of the one-shot, binding approach – avoidance of free-riding, encouragement of country commitments and certainty of outcomes – might be equally well achieved under a learning-by-doing approach, and there are grounds for the view that a reflexive, learning by doing approach might be more effective in dealing with such complex strategic interaction. Secondly, good but still insufficient progress towards reducing future emissions and global warming has been made in recent years by using a learning-by-doing, bottom-up approach. Comparing a range of emissions paths associated with different policy settings, from the policies in place in 2006 to those implicit in the Copenhagen Accord, we find that policy changes over that time have reduced the estimated atmospheric concentration of Kyoto gases and mean global warming at 2100 by about 15–18%. This contrasts with the impact of the GFC, which was to reduce the 2100 value of these variables by about 4%. Thirdly, the attempt to meet the <2°C target will involve fundamental changes in technology and industrial structures, to be pursued in the face of rising temperatures and severe impacts in many communities. This will imply many forms of learning: about the actual impacts of rising global mean temperatures, about the pace of development of many different technologies and about their competitive position, about the scale of investment involved in moving to a low carbon economy and the impact of these factors on the competitive position of different countries and regions.

These findings show that it is important to view the development and application of climate policy as a dynamic, multi-stage process of adjustment to the risks posed by climate change, in the context of many dimensions of ongoing learning and of continued strategic interaction of the parties involved. Many steps will be required to establish a learning-by-doing approach to meeting the <2°C target, including the following:

- complete such an agreement, if possible at the UNFCCC meeting in Cancun in December 2010, both locking in and enhancing existing commitments and extending the number of countries making commitments;
- establish periodic processes (perhaps biannually) for formal reporting on and review of progress against commitments;
- establish agreed methods for comparing commitments across countries and estimating the climate implications of any given set of commitments;
- request the Intergovernmental Panel on Climate Change to examine in detail the warming and damage implications of potential paths under the agreement, and to review the climate implications of maintaining the <2°C target;
- provide extensive support from advanced countries to developing ones for technology development and transfer to assist the achievement of their targets, as well as for adaptation to the inevitable process of global warming implicit in the <2°C target; and
- support the urgent development of improved scientific knowledge about the likely physical response of the Earth system to peak-and-decline emission pathways.

The last point relates to the major qualification to be made to this paper, which relies on a simple climate model for its climate analyses. The rate and direction of warming in a peak and decline scenario are highly contingent on the diffusion of heat into the oceans and where that heat goes. In MAGICC, this process is highly parameterised and needs to be updated; however, few experiments have been run testing peak and decline scenarios in fully coupled earth system models. For example, the transport of warm water into the southern high latitudes has the potential to render the West Antarctic Ice Sheet unstable (Naish et al., 2009; Pollard and DeConto, 2009) and may persist in those latitudes for some time. The likelihood of large-scale instabilities such as this is much lower at reduced levels of warming, but may still be possible (The Copenhagen Diagnosis, 2009). The new IPCC scenario process has one representative concentration pathway, RCP2.6, which peaks at 490 ppm CO_2e then declines; it is currently being modelled in preparation for the IPCC's Fifth Assessment Report (Moss et al., 2010). Assessment of this and similar pathways is urgently needed.

The current policy impasse is implicitly trading on a range of risks across the climate, climate policy and political risk domains. We have shown here that learning on climate policy progressed rapidly over the period 2006–2010. The knowledge of climate risks is also progressing very rapidly, raising concerns of serious risks even at comparatively low levels of global warming (The Copenhagen Diagnosis, 2009). The development of policy mechanisms, institutional frameworks and assessment systems that can use learning in all of these risk domains remains the best hope of achieving the ultimate goals of climate policy.

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