WPS5164

Policy Research Working Paper 5164

Contrasting Future Paths for an Evolving Global Climate Regime

Scott Barrett
Michael Toman

The World Bank
Development Research Group
Environment and Energy Team
January 2010

Policy Research Working Paper 5164

Abstract

This paper explores two different conceptions of how an emerging climate regime might evolve to strengthen incentives for more vigorous cooperation in mitigating global climate change. One is the paradigm that has figured most prominently in negotiations to this point: the establishment of targets and timetables for countries to limit their aggregate greenhouse gas emissions. The other approach consists of a variety of loosely coordinated smaller scale agreements, each one of which addresses a different aspect of the challenge, and is enforced in its own way. The primary conclusion is that an agreement of the first type may be more cost-effective, but that a system of agreements of the second type would likely sustain more abatement overall.

This paper—a product of the Environment and Energy Team, Development Research Group—is part of a larger effort in the department to investigate the risks of climate change and options for responding to those risks. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at mtoman@worldbank.org.

Contrasting Future Paths for an Evolving Global Climate Regime

Scott Barrett
Columbia University

Michael Toman
World Bank

Contrasting Future Paths for an Evolving Global Climate Regime

1. Introduction

There is growing international concern, even alarm, about the future threats posed by ongoing changes in the global climate system due to the release of greenhouse gases (GHGs) into the atmosphere. These include CO_2 from burning fossil fuels; emission of other GHGs, such as methane, from agriculture and other sources; and deforestation, which adds to net CO_2 releases. The effect of accumulating long-lived GHGs is to trap heat energy that otherwise would radiate back into space. The resulting climate change is expected to lead to a number of impacts in the climate system in terms of temperatures, rainfall patterns, and extreme weather events. The consequences of unchecked climate change for human well-being, including impacts on economic development, human health, and ecosystem integrity, would be profound.[1]

This growing concern has not yet been accompanied by major actions "on the ground" to limit global emissions. Under the 1992 UN Framework Convention on Climate Change (UNFCCC), an initial set of agreements for action were negotiated in the 1997 Kyoto Protocol (see also www.unfccc.int for further information). After several more years of tumultuous negotiations, the Protocol entered into force in 2005. A central feature of the Protocol is a set of national emission targets to be met by a set of more advanced industrialized countries over 2008-2012. However, both during and after the negotiation of the Protocol, there have been complaints from many quarters that the targets are not nearly tough enough to avoid dangerous human-caused climate change.[2] Further negotiations culminating in a December 2009 international meeting in Copenhagen are intended to establish the design of a post-2012 follow-on to Kyoto. While the results of that meeting are not known as of this writing, the information about the negotiating process as of October 2009 highlighted that countries remain sharply divided over how best to go forward.[3]

In this paper we explore two different conceptions of how an emerging climate regime might evolve to strengthen incentives for more vigorous cooperation in mitigating GHGs.[4] We first discuss the root of the challenge – that mitigating global climate change is a

---

[1] See Schneider et al (2007). Adaptation is the other important side of climate change policy, with difficult debate over the extent and form of financial transfers to more vulnerable countries. Our focus in thie paper is entirely on mitigation.

[2] Aside from the fact that the U.S. did not ratify the Protocol and rejected it outright in 2001, there are concerns that other industrialized countries will overshoot their targets and that the targets themselves were watered down through adoption of various measures.

[3] The challenges are highlighted by the 15 September 2009 version of the draft negotiating text, available at http://unfccc.int/resource/docs/2009/awglca7/eng/inf02.pdf. The reporting by the International Institute for Sustainable Development on the 28 September – 9 October negotiations in Bangkok (available at http://www.iisd.ca/climate/ccwg7/) indicated that some progress was made in areas such as technology and capacity building, but "deep divides" lingered over mitigation and finance.

[4] A range of alternative architectures for agreement, including the ones examined here, can be found in Aldy and Stavins (2007).

colossal collective action problem. In Section 3 we describe some basic characteristics that need to be satisfied for an international agreement limiting GHGs to be successful – defined here as achieving a *high level of global participation*, *high levels of participant compliance*, and *substantial reductions in global emissions* to ameliorate climate change.

In section 4 we describe and compare, against these criteria, two approaches to establishing an international GHG mitigation regime. One is the paradigm that has figured most prominently in negotiations to this point: the establishment of targets and timetables for countries to limit their aggregate GHG emissions. The other approach consists of a variety of loosely coordinated smaller scale agreements, each one addressing a different aspect of the challenge, and enforced in its own way. The two approaches are not mutually exclusive, as discussed further below. In particular, smaller scale agreements could complement an agreement on national emission reduction targets and timetables (see also Stern 2009, chapters 8-9). Conversely, a portfolio of smaller agreements could be modified over time to converge toward agreement on national targets and timetables, though this is likely to be more challenging.

Our primary conclusion is that an agreement of the first type, should it be established and implemented fully, would likely be more cost-effective than piecemeal agreements; however, the second approach is more likely to succeed in reducing global emissions, even if implementation of this agreement would be less than fully cost-effective.[5] In Section 5 we conclude the paper with reflections on practical opportunities for moving in this direction.

2. The Challenge of Collective Action for Addressing Global Climate Change

To mitigate climate change, the long-term concentration of GHGs in the atmosphere must be constrained, and this requires limiting *global* emissions. Given the large quantity of global emissions relative to the national emissions of even the largest emitters (e.g., China and the U.S.), no country can adequately limit concentrations by its own actions; international cooperation is needed. Given that the rules of international relations respect national sovereignty, the prospects of international cooperation succeeding depend on the *incentives* states have to cooperate. Even when benefits for each country from global abatement are high, the incentive for each country to contribute significantly to global abatement may be weak since each country gets back just a fraction of the total benefit of its own abatement. Incentives to contribute are especially weak when the costs of abatement increase steeply with the level of abatement.

To illustrate, suppose first that damages were anticipated to increase precipitously as some known "threshold" level of this stock was approached. Because limiting concentrations

[5] That there may be a trade-off between cost-effectiveness and overall emission reductions is discussed in Barrett and Stavins (2003).

requires reducing net GHG emissions globally to zero,[6] reducing every country's emissions would become pivotal to the collective effort to avoid catastrophe. Every country would thus have a strong *individual* incentive to limit emissions, so long as it were assured that all others would reduce their emissions as well. In the face of a highly probable catastrophe, such mutual assurance would likely develop as countries visibly changed their GHG-emitting behavior, with negotiations focusing more on coordination of efforts than on the sanctioning of backsliders.

In practice, however, the climate change problem is more complicated. The risk of severe or catastrophic climate change remains quite uncertain as to the mechanisms and potential timeline of occurrence.[7] More gradual and still uncertain climate change damages occurring over a longer period are less likely to galvanize an easily maintained collective response. The reduction of each country's GHG emissions would not be pivotal to mitigating risks.[8]

In this situation, individual countries will see limited benefit to reducing their own emissions in the absence of international agreements that provide adequate assurance of effective participation by others.[9] Moreover, benefits would be realized mainly in the longer-term future, thus reducing their salience relative to more immediate concerns. Indeed, individual incentives to act will depend to a large extent on how the current generation views its interests in, and its obligations towards, unknown future generations facing uncertain baseline circumstances. Further complicating this international distribution issue is that per capita benefits relative to income likely would accrue more to poorer states that can do relatively little to reduce global emissions in the near to medium future.

The incentives to reduce national emissions also depend on the anticipated cost – the higher the cost, the stronger the incentives to free ride. There is considerable debate over the cost of emissions reduction, depending on a variety of analytical assumptions and judgments. As one rough guide to the costs, the Intergovernmental Panel on Climate Change (IPCC) indicates in its Fourth Assessment Report that stabilization of GHG concentrations below a doubling of pre-industrial levels could cause global GDP in 2050 to be roughly 5% below its baseline value (Fisher, Nakicenovic et al. 2007).[10] The IPCC figures also reflect ideal conditions for policy implementation. If more realistic assumptions of less

---

[6] "Net" emissions means total emissions minus those withdrawn by natural or human-engineered sequestration, and the natural breakdown of GHGs in the atmosphere over time.

[7] For a review of policy implications of catastrophic climate change, see Kousky et al. (2009).

[8] For at least some moderate degree of change, moreover, there can be both winners and losers even if the aggregate impact is adverse. See, for example, Cline's (2007) analysis of agricultural impacts.

[9] One factor that erodes the benefits from cutting emissions without broad participation by other countries is various forms of international emissions "leakage." If a subset of countries reduces emissions, this will tend to lower the relative cost of GHG-producing activities in other countries, inducing *their* emissions to increase. Similarly, if one group of countries reduces its consumption of internationally traded fossil fuels to cut its emissions, international prices of these fuels will fall, causing other countries to increase their consumption and emissions.

[10] See also Stern (2007) and Nordhaus (2008) for significantly contrasting estimates.

cost-effective policy measures are made, the cost could be significantly larger. Moreover, if emissions reductions are attempted by only a subset of countries the resulting cost will be significantly higher than the cost of achieving the same reductions with broader participation (Nordhaus 2008: 116-122).[11] The substantial reductions in emissions needed to stabilize GHG concentrations at levels seen as needed for adequately mitigating climate change risks thus seem likely to be costly, at least in the absence of major breakthroughs in energy and other GHG-related technologies (Barrett 2009).

Because incentives for unilateral action and ad hoc cooperation are limited, while the collective gains to cooperation are likely to be very large, international treaties are needed that change the rules of the game to increase the incentives countries have to reduce their emissions. For climate change, an effective treaty must achieve three things. First, it must achieve a high level of participation. Second, it must achieve a high level of compliance. Finally, it must require that parties reduce their emissions substantially.

It is relatively easy to design a treaty capable of meeting one or two of these requirements, but accomplishing all three of the needed conditions is more difficult. A treaty that asks countries to do no more than they would do in the absence of the treaty will attract high participation and compliance, but to no effect. A treaty that demands that countries do a lot, and that is backed up by strong compliance enforcement may fail to attract participation. Alternatively, it may attract high participation on paper, but then collapse if enforcement mechanisms lack credibility or are ineffective. The usual approach to sustaining cooperation is reciprocity. However, when mitigation benefits are high and other countries seek to punish a free rider by reducing their own abatement, they harm themselves in the process. This undermines the credibility of a threat to enforce substantial reductions in emissions using reciprocity (Barrett 2005).

3. Basic Characteristics of a Successful GHG Mitigation Agreement

Here we identify five characteristics for a *successful* international agreement to mitigate GHGs – one reflecting a high level of participation, a high level of actual compliance, and substantial emission reductions.[12]

[11] Bosetti et al (2009) use simulation modeling to conclude that in the face of prospects for emissions reductions by developed countries, developing countries are likely to be better off anticipating tighter future global limits on emissions and initiating emission-reduction investments as well, versus participating only after a delay. However, in this analysis the long-term targets for GHG stabilization are taken as invariant with respect to participation decisions. A different conclusion would arise if the long-term goal was made endogenous to the participation decisions.

[12] These points have been identified in previous contributions to the literature on international agreements. See, among other sources, Carraro and Siniscalco (1993), Hoel (1994), Finus (2001), Sandler (2004), and Barrett (2005).

a. Global benefit should exceed global cost

This is a minimal condition; if an agreement cannot produce a net benefit for the world, it will not be sustained. One practical issue is determining the perspective from which we should judge potential improvements from agreement. A relevant reference point is the outcome that would arise were countries not to cooperate at all—the non-cooperative outcome. The maximum potential global gain to cooperation then is the improvement that would arise were countries to cooperate fully. Unfortunately, full cooperation may not be possible for reasons explained previously. At the very least, however, we should require that any agreement improve upon the non-cooperative outcome—that is, relative to this outcome, the agreement should yield a positive global net benefit.

b. Every country should gain individually from an agreement

So long as countries are motivated by self-interest, every participating country must see itself as gaining from an agreement.[13] Since the potential gains from mitigating global warming are spread unevenly, and the incremental costs of limiting GHGs also differ greatly across the world, it is unlikely that simply establishing various national limits on emissions, unsupported by other policies, can ensure that this requirement will be met. If the world as a whole gains from an agreement, however, then financial transfers can ensure that every country also gains from the agreement. The question is how to do this in practice.

One possibility already incorporated in the current architecture is to allow participating countries to buy and sell entitlements or allowances to emit greenhouse gases. Once an initial allocation of allowances is made, trading in allowances will result in financial transfers. The extent of these transfers must be limited, however, to ensure that net buyers of allowances as well as net sellers gain by participating in the agreement. A different approach is for financial transfers to be negotiated directly. The successful Montreal Protocol on Substances that Deplete the Ozone Layer adopted this second approach.

c. Participation should be very broad

As noted, cost-effectiveness increases with the level of international participation. The incentive to save costs is a powerful reason for preferring a "broad but shallow" treaty to a "narrow but deep" treaty (Barrett 2005). Broad participation also will stem leakage. Procedurally, universal (or close to universal) participation helps legitimize the process by giving every country a voice in decision-making.[14]

---

[13] This is a necessary but not sufficient condition. The essence of the collective action challenge is that every country gains if all cooperate, but none has a strong incentive individually to cooperate.

[14] Not every aspect of climate change policy has to involve (nearly) universal participation. This is needed for GHG mitigation for reasons explained previously, but an agreement to coordinate R&D into breakthrough technologies would require only a relatively small number of countries to be effective. The problem is that the returns to this R&D depend on the prospects of these technologies being diffused, which depends of course on achieving very broad participation; see Barrett (2006).

A key feature of an international agreement in practice is the minimum participation level—the number of countries that must ratify an agreement for it to enter into force, and thus be legally binding, on all its parties. The minimum participation level needs to be set low enough that a small number of countries do not essentially have a veto, but high enough that countries derive significant benefits by participating. In some cases, the minimum participation level can serve as a coordinating device, causing participation to "tip" towards full participation.[15]

d. Obligations should be permanent, though subject to periodic revision

Expectations of permanent and increasingly stringent emissions limits is necessary to stimulate the required investment, both in R&D and new capital, in order to stabilize GHG concentrations and limit temperature change. The Montreal Protocol imposed a permanent system of restrictions that were ratcheted upward over time. For climate change, there are strong economic arguments – including uncertainty about compliance costs and a desire to ameliorate adjustment costs – for increasing the stringency of GHG mitigation targets and/or policies and measures over time. One challenge is to devise ways in which countries can make credible their *ex ante* commitments to follow subsequent more-stringent targets. Another challenge is to put developing countries on a new development path, rather than have these countries follow the same development path as the rich countries, and *then* to transition to a new technology base.

e. Agreements should be enforced using credible mechanisms

"Free riding" by not participating and not complying must be discouraged. To enforce a norm to participate in or to comply with an international agreement, the punishment must be *severe* enough that countries are necessarily made worse off for deviating from the norm, given that the punishment is imposed. The punishment must also be *credible* (Schelling 1960). The countries expected to carry out the punishment must be better off doing so as compared with not doing so, given that a country has deviated from the norm. As punishments must become more severe to enforce a behavior, they usually also become less credible.

A precondition for enforcement is that, in the jargon of current debates over climate change action, obligations must be "measurable, reportable, and verifiable." To illustrate the challenge in meeting these conditions, measuring net emissions associated with avoided deforestation is particularly difficult since it involves both measurement of forest cover change and establishment of an agreed baseline over time. Implementation of technology standards, by contrast, is relatively easy to measure and verify.

---

[15] The Obama administration has been working with a "major emitters group" comprising 16 countries that together account for about 80 percent of global emissions. It is certainly easier to negotiate among 16 states than 190, and it is fairly likely that an agreement approved by these states would end up being acceptable to most others.

f. Discussion

Recent numerical simulation work by Bosetti et al (2008) and Carraro et al (2009) illustrates the importance of all these criteria. Their analyses start with assumptions about sizes of damages and inter-temporal discount rate such that significant global mitigation (to a concentration target of 550 ppm CO_2-eq) is in the collective interests of all states. Thus by construction our first condition above is satisfied. They also assume that a country's participation decision is permanent, which roughly satisfies our fourth condition – though in practice participation decisions certainly could vary over time. Their analysis is particularly helpful in understanding the importance of the other three criteria.

First, they show that the 550-ppm-CO_2-eq. target can only be met by very broad participation. Action by industrialized countries alone cannot limit concentrations to this level. Indeed, participation by nearly every region of the world is necessary to meet this target (the exception is sub Saharan Africa, the emissions of which are very low). This underscores the importance of our third condition.

Second, they find that China and non-EU Eastern Europe (this region includes Russia) both lose under the arrangement in which the 550 ppm CO_2-eq target is met cost-effectively. This is mainly because both of these regions benefit from climate change through most of this century. To ensure that these countries also gain from the agreement, compensation must be paid. The amount needed, however, would be huge—on the order of three percent of OECD GDP. This is a politically unimaginable scale of transfer.

Finally, this analysis also examines the "stability" of a cooperative agreement. This is a crude way of examining the importance of enforcement. Under their analysis, the only stable coalition of countries consists of the OECD countries. Recall, however, that an agreement comprising only these countries cannot meet the 550-ppm-CO_2-eq. target. This underscores our point that in a world of sovereign countries, it may not be possible to sustain a "first best" climate policy. Carraro et al (2009) suggest that the best way forward might be to negotiate an agreement among the OECD countries, and to make R&D into new "breakthrough" technologies a cornerstone of such an agreement. The advantage here is that such technologies may diffuse globally, causing non-parties to the climate regime to cut back their emissions (relative to business as usual) over time—a kind of negative leakage. Our own analysis similarly can be interpreted as looking at alternative formulations for a "second best" climate regime.

4. Illustrative Comparison of Alternative Approaches for International GHG Mitigation Agreements

In this section we consider two approaches to international agreement for limiting GHGs. Although these models are conceptually very different, as already noted there can be substantial overlap and complementarity between them.

The first is a comprehensive set of national economy-wide targets and timetables for reducing global emissions, implemented with the support of international trading of emission allowances. The approach also can include complementary and subsidiary agreements, in particular for development of safe and effective low-GHG technologies and targeted support for their dissemination. However, the heart of the international agreement is assumed to be the targets and timetables.

The second alternative is a portfolio of more specific and loosely coordinated agreements for GHG mitigation. These would apply to various sources and sectors, potentially incorporating technology as well as performance standards. The approach also can include technology development and diffusion agreements – in fact we assume that these would play a larger role in the absence of some comprehensive global system for carbon pricing. In this setting, the role for allowance trading would be more limited.

a. International Economy-wide Targets and Timetables With Emissions Trading

In this approach, participating countries negotiate economy-wide GHG emissions limits that decline over time. As in the Kyoto Protocol, different GHGs could be treated as interchangeable for purposes of compliance based on certain "global warming potentials."[16] Avoided deforestation could be incorporated in an economy-wide, international cap and trade treaty by creating "credits" for avoided deforestation.[17] However, successful achievement of this goal requires overcoming several challenges discussed later in our paper.

Countries would bargain over the size and timing of their emission limits. In doing so, they would anticipate the effect that international emissions trading will have on their net benefits. Trading would reduce costs overall, but it will also result in financial transfers. Since the limits are negotiated by sovereign states with widely varying levels of income and patterns of energy use, one can expect differentiation in the size and timing of obligations across countries—as well as problems in establishing "comparability." Along with negotiated targets and timetables, an agreement would need to establish practices for monitoring, reporting and verifying national emissions. It would also require provisions for deterring free-riding by punishing both non-participation and non-compliance with agreed national emission limits.

The Kyoto Protocol is a particular expression of this model, one that could be elaborated upon further in follow-up negotiations under the Framework Convention. Kyoto was in fact an incomplete agreement in terms of the above description since it dealt with emissions only over a short period (2008—2012) and because it contained no agreed principles for how non-Annex B countries would assume differentiated but binding

[16] The European Emissions Trading System currently limits only CO_2, but there are plans to extend the existing arrangement to include other gases, including N_2O from adipic acid production and PFCs from the aluminum sector. See http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/08/35&format=HTML&aged=0&language=EN&guiLanguage=en.

[17] See in particular http://unfccc.int/methods_science/redd/items/4531.php.

emission limits over the longer term. Moreover, it did not establish an enforcement mechanism that could be relied upon to be credible and effective. On the other hand, the Kyoto "flexibility mechanisms" for international emissions trading, while hardly perfect, represent an important innovation.

b. Portfolio of specific agreements

This approach would consist of multiple sets of commitments and corresponding measures that would operate concurrently, but could be developed at different times. Their scope, design and operation would vary, as might the level of participation. All the agreements also would be subject to provisions for monitoring, reporting, and verification, and for deterring non-participation and non-compliance. The following elaboration provides one illustrative portfolio of agreements. [18] It is motivated in part by key features of two international environmental agreements crafted broadly along these lines: the Montreal Protocol, mentioned previously, and the International Convention for the Prevention of Marine Pollution from Ships, known today as MARPOL 73/78.[19]

First, emissions from international aviation and international maritime transport would be controlled under separate agreements. Emissions from international aviation would be addressed with the support of the International Civil Aviation Organization (ICAO); an approach to limiting emissions from international maritime transport would be negotiated under the auspices of the International Maritime Organization (IMO).[20] Kyoto proposed this same arrangement, since incorporating these sectors in a system of national emission limits would have been difficult. However, progress has been very slow; so far, neither of these international organizations has developed an agreement.[21]

Second, different agreements would limit the emissions of different greenhouse gases. For example, HFCs could be controlled under the Montreal Protocol or a similar new agreement; the emission of perfluorocompounds (PFCs) and sulfur hexafluoride (SF_6)

---

[18] The Waxman-Markey bill, passed by the United States House of Representatives in June 2009, covers the vast majority of CO_2 emissions, but not all, and while cap-and-trade is a centerpiece provision it also incorporates numerous associated policies, such as renewable energy, energy efficiency, and low carbon fuel standards as well as provisions for forest protection and HFC limitation.

[19] See Barrett (2005) for a broad review of literature with respect to these agreements and an evaluation of them.

[20] MARPOL 73/78 already limits pollution from ships (under Annex VI); it could be revised to incorporate new standards for greenhouse gas emissions. ICAO has proposed an "aspirational" goal for improving the fuel efficiency of aircraft (see http://www.icao.int/icao/en/nr/2009/PIO200907_e.pdf); these or other measures could be made mandatory. The European Union has proposed a different approach—incorporating international aviation, including flights into and out of the European Union, within its Emissions Trading System (http://ec.europa.eu/environment/climat/aviation_en.htm). But this is not a global approach (United States Government Accountability Office 2009).

[21] Partly for this reason, Europe has taken steps to incorporate these two sectors within the economy-wide targets and timetables approach. This is an example of how the current, nascent regime could evolve in either direction—towards greater consolidation or fragmentation.

could be restricted in similar fashion (see also Box 1).[22] Other specific agreements likely would be required to limit the emissions of methane, or CH_4, which is emitted from many sources, including landfills, fossil fuel systems, wastewater treatment, some industrial processes, livestock, and agriculture. Similarly, nitrous oxide, or N_2O, is emitted by numerous sources, including the production of adipic acid, a feedstock for producing some forms of nylon. In developed countries, these emissions have been reduced 90 percent, through voluntary efforts (Wara 2006). As the feasibility of reducing emissions has already been demonstrated, these same standards could be made universal by international agreement. In all these cases, the industries that would be affected should be engaged in the process, just as they were under the Montreal Protocol, to establish realistic but effective timetables for significantly reducing (and eliminating to the extent practicable) the production of these gases.

Third, for CO_2, various sector-specific agreements would be negotiated. These could take a variety of forms tailored to the particular circumstances of each sector, including technical and performance standards as well as sector-level emission targets and timetables. Trade-sensitive sectors (those in which differences in energy costs can especially affect competitiveness) would be treated separately from the less trade-sensitive sectors. Transportation also has certain features that would benefit from separate treatment. This differentiated approach also could be applied selectively to other GHGs whose emissions are relatively easy to monitor (e.g., industrial methane). The sector-specific approach could include some domestic emissions trading (including intra-EU trading), but the scope for doing so would be determined sector-by-sector based on the nature of the nature of the sectoral constraints imposed.[23]

Fourth, other agreements would cover net emissions related to changes in land use and forest cover. Deforestation, discussed in more detail later, is left out of Kyoto, though emission reductions from afforestation and reforestation are counted. There is broad agreement that this omission needs to be corrected—deforestation is responsible for around 18 percent of global emissions of greenhouse gases (Bradley *et al*. 2007: 44). Under the portfolio approach, these sources of net emissions would be addressed separately.[24]

c. The approaches compared

We now compare the alternatives against the five criteria noted before. Our emphasis in this discussion is on the interactions among the various criteria.

---

[22] PFCs are primarily emitted by the aluminum and semiconductor industries, SF_6 by the electric power, magnesium smelting, and semiconductor industries. All these industrial gases could be controlled under a combined agreement, or under separate agreements.

[23] The European Emissions Trading System covers less than half of the EU's CO_2 emissions. The EU is planning to extend the arrangement, to include more sectors—in particular, petrochemicals, ammonia, and aluminum. See the reference given in the previous footnote.

[24] The EU has so far decided to keep the arrangements for land use, land use change, and forestry, including deforestation, separate from the Emissions Trading System.

Global benefit should exceed global cost

The magnitude of the global net benefit produced by an agreement depends on (1) the overall level of mitigation, and (2) cost-effectiveness. Both of these dimensions, however, depend on participation being broad, which depends in turn on each country gaining individually from an agreement and on participation and compliance being enforced. We therefore cannot fully evaluate this criterion without considering the others. We can observe that a successfully implemented targets-and-timetables approach is likely to be more cost-effective than the portfolio approach because it provides a uniform international price signal for GHG mitigation. This approach also will provide a strong stimulus to demand for new lower-GHG technologies that reduce the long-run cost of increasingly stringent targets. On the other hand, the portfolio approach still can provide incentives for adopting new technology, as well as providing a means for integrating R&D initiatives into sector-based emission control programs. Ultimately, the strength of the portfolio approach depends on a capacity to deliver larger and more reliable global GHG emissions compared to targets-and-timetables.

Every country should gain individually from an agreement

The ability of the targets-and-timetables approach to make every country better off depends critically on the income transfers ("side payments") effectuated through allocations of emissions allowances. The targets-and-timetables approach provides enormous flexibility on this score – perhaps too much. Debate over the structure and size of transfers has permeated international discussion and negotiation over GHG mitigation for years, and it remains a contentious issue. While many possible approaches for international allowance allocation have been put forward based on various combinations of efficiency and equity criteria, there is nothing approaching consensus today on an approach to this issue and no clear candidate solutions in sight.[25] Even the limited attempt to create shared benefits through the Clean Development Mechanism (CDM) has run up against questions about the mechanism's environmental effectiveness and transactions costs.

A portfolio of agreements also can allow a range of approaches for addressing burden sharing, though these must be established across different sources and sectors. A technology performance standard for carbon emissions that represents some kind of evolving best practice for a sector like power or vehicles may require more technology upgrading in lower-income than higher-income countries, but it legitimately can be represented to stakeholders as enhancing capital stocks to contribute to economic development, as well as providing environment benefits (and potentially expanding markets for new technology). Since capital stock expansion and enhancement can be

[25] To illustrate: an approach that would have rich and poor countries converge toward a common size of emissions per capita would involve very large North-South transfers given the population differences and the differences in levels of economic development that give rich countries today much higher per-capita emissions than poor countries. An approach that would start with status quo emissions and converge toward a common figure of emissions per unit of GDP would allow the North to phase in mitigation starting at its higher emissions levels, while the South would need to do proportionately more to curb emissions intensity as economic growth progressed. For further discussion of alternative allocations strategies see Barrett (1992) and Rose et al (1998).

expected to occur anyway as part of economic development, agreed performance standards do not involve the same zero-sum political economy as allowance allocations. Further nuance in the burden sharing can be introduced in phasing in requirements for richer and poorer countries, as occurred in the Montreal Protocol.[26]

A related advantage of negotiating measures such as technical standards as opposed to emission quotas is that developing countries can be compensated for based on estimates of the incremental costs of meeting new global standards, rather than on the basis of transfers of allowances for emissions. This approach also has been used under the Montreal Protocol, though incremental costs likely would be more complex to assess under at least some of the specific GHG agreements we are suggesting. Direct compensation reduces the magnitude of transfers (to inframarginal suppliers) that can arise in market trading of allowances. Wara (2006, 2007) has described how, under the CDM, HFC emissions were reduced at a price far in excess of the actual cost. Paying above cost means that a given amount of financial resources achieves less in terms of emission reductions. A further advantage of direct compensation is that it creates a more direct and observable linkage between transfer and outcome. For both reasons, compensation for additional costs seems likely to be more politically acceptable to paying countries than purchases of previously allocated emissions allowances.

Participation should be very broad

Participation necessarily is very broad for a successful targets-and-timetables based agreement. However, there is a potential gain from a more direct focus on technologies due to the possibility to broaden participation through the operation of different "network externalities." These arise when one country's net benefit from adopting a standard increases with a rise in the number of other countries that adopt the standard. Network externalities help to explain MARPOL's success. A similar logic could commend the establishment of technical standards for the international marine transport sector.[27] International air travel also comprises a network whose emissions could be regulated under a global agreement establishing new technical standards.

Road transport interconnections are more local than global, but vehicle manufacture is subject to economies of scale, which also encourages standardization. Moreover, since road transport is a system requiring compatibility of consisting of vehicles and refueling stations, standardization of the former also can increase benefits from standardization of the latter. In this context, network externalities also can promote *negative* leakage—that is, they can help spread climate-friendly technology.

Obligations should be permanent, though subject to revision

An effective climate change treaty must create incentives for innovation, and the diffusion of innovation. Economy-wide targets of limited duration may not stimulate enough of the required innovation or allow enough development of markets for new technology to

[26] Edmonds and Wise (1997) provided an early and still highly relevant example of these approaches.

[27] Farrell, Keith, and Corbett (2003) use the logic of network externalities to explain how marine transport could shift to hydrogen fuel.

facilitate diffusion. Yet, targets with a longer duration may lack credibility.[28] If the market believes that these targets will not ultimately be enforced, then investments in R&D and new technologies will suffer. As a consequence, the costs of meeting ambitious mitigation targets will remain high, and the belief that the targets would not be enforced will be self-fulfilling.

A portfolio approach, focusing more on individual technologies, gases, and sectors can provide lasting obligations to reduce emissions while incorporating and motivating R&D. Where appropriate, technology performance standards can be adjusted to reflect the best information available about the prospects for technical advance over time in different parts of the economy in which they are applied. As the performance standards begin to take hold and to shape both investment plans and applied innovation within the various sectors, they are likely to become more self-enforcing over time by the longer-duration resource allocations they are shaping.

An important difference with CFC phase-out in the Montreal Protocol, for which affordable substitutes were available, and significant GHG mitigation is that the process of negotiating credible and achievable climate change standards must be accompanied by promotion of major advances in GHG-reducing RD&D. For example, deep cuts in emissions in the electricity sector will require realizing to the maximum extent practicable the possibility of carbon capture and storage. New plants can be built with technical standards (siting, layout, configuration) facilitating later incorporation of CCS. However, we first need to know if this technology can work on a large scale, as well as its costs, its safety, and its effectiveness. This knowledge is another global public good. It is likely to require international cooperation, though not on a grand scale. It is only essential that "enough" countries cooperate to provide the needed finance. Cooperation in this case will be relatively easy provided parties can be confident that the technologies resulting from this R&D can and will be diffused globally (Barrett 2006).

Agreements should be enforced using credible mechanisms

As we have seen, economy-wide targets and timetables are difficult to enforce internationally. After Kyoto's targets and timetables were agreed, a compliance mechanism was developed, but it was never adopted. It would not have worked in any event (Barrett 2005). The mechanism required that a country that exceeded its allowed emission limits during the first commitment period (2008-2012) make up for this shortfall in the next period, and pay a penalty on top of this. The problem with this arrangement is that it relies on countries punishing themselves. The punishment is easily avoided. For example, a country can always insist on a high future target for emissions (so that the punishment never applies) as the price for its participation.

[28] For a general discussion of the credibility challenge with climate change policy, see Montgomery and Smith (2007).

Proposals have been offered to enforce a future agreement using trade restrictions, but none, so far, has been adopted.[29] Trade restrictions pose a number of challenges. If the purpose were to prevent trade leakage of emissions, the trade restrictions would need to apply to products based on the emissions associated with their manufacture, This would be difficult to do. Indeed, the Montreal Protocol had originally allowed trade to be restricted based on the method of manufacture, but upon further inquiry the parties discovered that this would be almost impossible to do with accuracy. If the purpose of the trade restrictions were to deter free riding in general, on the other hand, then blunt trade restrictions can be threatened.[30] To be effective, however, trade restrictions would need to be severe. Blunt trade restrictions imposed by a climate treaty to enforce economy-wide limits would likely not be credible because the loss in the gains from trade would be large, while the benefits in avoided leakage would be small.[31]

Trade restrictions also lead to debates over their legitimacy that could further aggravate the risk of a broader trade war. Suppose trade restrictions were imposed against the United States for not ratifying Kyoto. The U.S. might then claim that Kyoto's base year (1990) unfairly favored Europe, or that its own efforts to promote R&D were at least as helpful in addressing climate change. Suppose instead that trade restrictions were imposed against China for not agreeing to be bound by emission caps in a future agreement. China might argue that the restrictions are a disguised form of protectionism, as well as noting that the rich countries are responsible for initially reducing emissions under the Framework Convention.[32]

An advantage of the portfolio approach is that it allows different agreements to be enforced in different ways. The targeted mechanisms used to enforce Montreal could be used to enforce restrictions on HFCs. Such an agreement should also include consuming (that is, importing) states as well as producing (exporting) states. To ensure legitimacy, financial assistance can be offered to poor countries for participating in such agreements.

Similar approaches also may be highly relevant for addressing emissions of CO_2 in some highly trade-sensitive sectors. Because leakage potential is particularly high for these sectors, the threat to impose trade restrictions should be credible. A verifiable and

[29] See Frankel (2009) for a recent review of the literature and arguments, as well as an argument in favor of trade restrictions.

[30] This is how Montreal and MARPOL are enforced. Under Montreal, trade between parties and non-parties in ozone destroying chemicals and products containing them are simply banned. Under MARPOL, ships violating the standards are prohibited from entering the ports of parties to the agreement.

[31] Recall that for a punishment to be credible, countries must be better off imposing the punishment than not doing so, given the behavior of the country that is the target of their enforcement. The cost of imposing the punishment is the loss in the gains from trade. The benefit, given the behavior of the target country, is the reduction in leakage. The restrictions underpinning Montreal are credible because of the concern about leakage (the trade ban offers a direct benefit in the form of reduced emission of ozone depleting chemicals) and because their broader impact is limited. MARPOL's restrictions are credible because of the domestic benefit of enforcing the ban for coastal states.

[32] Just such a problematic situation could arise under the Waxman-Markey bill, which includes provision for future application of "border adjustment taxes" on countries that are not sufficiently active in reducing their emissions.

harmonized system of technology and performance standards for the carbon-intensity of outputs in these sectors could be coupled with agreement to impose trade restrictions on any countries not meeting the standards.

Limits on the emissions of less trade-sensitive sectors, including electricity generation, require a somewhat different approach. As noted previously, one example would be an agreement requiring that power sectors converge over time toward common carbon-intensity milestones, reflecting country-specific net effects of improved thermal efficiency in generation, reduced losses in transmission and distribution, increased use of renewable energy, and use of carbon capture and storage. One component of such an agreement could require that the standards be adopted by each party's own domestic law so that domestic institutions have a responsibility to enforce compliance.[33] The agreement could contain the provision that it would not enter into force until ratified by a minimum number of other countries (possibly accounting for a minimum share of global coal-fired electricity generation). To encourage the participation of developing countries, developed countries would agree to help co-finance the incremental costs. Negotiation could then focus on how the co-financing would be undertaken (e.g. directly or through trading of carbon-intensity credits). Co-financing would not provide lump-sum remuneration for capital costs, in order that there be some ongoing incentives for maintaining progress.

5. Conclusions

Concern about the threats of climate change has risen with each new edition of the IPCC Assessment Reports, and this concern has engendered an increased sense of urgency among climate change negotiators as well as national stakeholders in developed and developing countries. Even more than before, the broad goals laid out by the Framework Convention seem salient: limit dangerous human-induced climate change; approach the problem with awareness of the differences in capacities and priorities of countries, including the need for leadership in mitigation by richer countries; and strive toward best practices to efficiently limit emissions in all countries.

To respond effectively to this sense of urgency and realize the goals of the Convention, it is necessary for leaders and their technical advisers in developed and developing countries, as well as in international development institutions supporting the process in different ways, to consider a range of possible paths forward. A focus on cost-effectiveness to reduce the overall cost of a global deal is very desirable, as are efforts to increase synergies between GHG mitigation and sustainable development for poor countries and to stimulate expansion of low-carbon technologies and growth opportunities for all. Debate is not over the virtue of these objectives, but rather on how successfully they can be realized in

[33] Even if countries just declared goals for limiting emissions from these sectors, the agreement would lack hard enforcement but would allow benchmarking of the goals of different countries. Transparency in verification—a prerequisite for "naming and shaming"—would at least create modest incentives for enforcement. At least as important, pledges to meet goals in an international agreement would create expectations that parties to the agreement will adopt domestic legislation for meeting those goals.

practice in a complex world with many differences in the circumstances and goals of sovereign countries; relatively weak institutions for executing international agreements and establishing effective mechanisms for cost-effective action; and a lack of common understanding and allegiance to a concept of what is fair in the context of burden-sharing for sharp limits in future GHG emissions.

We have presented and analyzed two different stylized conceptions of a future climate agreement regime. The comprehensive targets and timetables approach represents an extended and idealized version of the climate regime embodied in Kyoto. The other approach consists of a portfolio of agreements, with each agreement in the portfolio having its own structures and enforcement mechanisms.

We have argued that the portfolio approach has strong advantages for addressing the challenges of motivating adequate action and providing for effective enforcement. This approach is weaker in promoting cost-effectiveness. The seriousness of this problem depends on how different the shadow price of carbon ends up being across sources, sectors, and countries.[34] We believe there will be strong incentives towards cost-effectiveness under the portfolio approach as well. It will be important to design measures that can provide transparency in actions taken and thus a capacity to assess marginal costs in different agreements. This will help draw attention to possible improvements in cost-effectiveness, whether by formal or informal mechanisms. [35]

Although we have discussed these two conceptions of a future regime as alternatives, they are not mutually exclusive. As we have explained, existing arrangements reflect some hybridization of these approaches. The current regime could evolve in various directions. For example, even if a new economy-wide, multi-gas, targets-and-timetables agreement were negotiated as a successor to Kyoto, the Montreal Protocol could be amended to control the production and consumption of HFCs. Similarly, a new agreement also could be negotiated along the lines of Montreal to control all the industrial greenhouse gases. At worst, these additional agreements would reinforce the economy-wide agreement. At best, they will help achieve more by using different mechanisms to limit the emissions of different gases and sectors. Of particular importance, we believe, will be effective measures to substantially increase global investment in developing low-cost, low-carbon technologies in order to overcome disincentives to sharply reduce GHG emissions over time.

No country has addressed the implementation of Kyoto using only a single economy-wide policy. Instead, each has adopted a range of policies and measures. The portfolio approach

[34] It thus also depends on the extent to which sectoral special interests can "capture" and manipulate various standards and other requirements. We are grateful to a referee for drawing this to our attention.

[35] Imagine that emissions from the electricity sector were controlled by domestic cap and trade arrangements. Then marginal costs will be revealed in the prices of traded allowances. Under a formal arrangement for international trading, the caps (which determine domestic prices) will be taken as given, and trading will eliminate differences in marginal costs. Under an informal arrangement, countries with lower marginal costs might be pressured into reducing their caps, to bring their marginal costs into alignment with the other countries.

seeks to build a treaty architecture that is consistent with this practice. Relying too heavily on the development of economy-wide approaches could be a risky strategy.

Acknowledgments and disclaimer: Financial support from the World Bank Knowledge for Change fund is gratefully acknowledged, as are helpful comments from three anonymous referees. Any remaining errors are our own. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

Box 1: The Montreal Protocol's contribution to addressing climate change

The relationship between stratospheric ozone depletion and climate change is complex. Ozone in the stratosphere is a greenhouse gas (protecting the ozone layer will thus add to climate change), but so are the chemicals that deplete stratospheric ozone (reducing these emissions will thus help mitigate climate change). Making matters more complicated, some of the substitutes for these ozone-destroying gases are also greenhouse gases. The Montreal Protocol on Substances that Deplete the Ozone Layer, which aims to protect stratospheric ozone by banning ozone-depleting gases, could thus dampen or aggravate global climate change.

A study by Velders *et al*. (2007) has calculated the overall effect. According to this research, the Montreal Protocol has reduced greenhouse gas emissions four times as much as the Kyoto Protocol aspired to do.

In September 2007, the Montreal Protocol was adjusted again to accelerate and expand the phase out of HCFCs, an ozone-depleting substance that happens also to be a greenhouse gas. HCFCs are especially important because the manufacture of these compounds produces hydrofluorocarbons (HFCs) as a byproduct. HFCs do not deplete the ozone layer, and are not regulated by the Montreal Protocol, but they are a very potent greenhouse gas, covered under the Kyoto Protocol. By one estimate, the adjustment negotiated in Montreal in September 2007 will have about the same impact on the climate as the Kyoto Protocol was designed to achieve (Kaniaru *et al*. 2007: 4). This is on top of the larger effect Montreal has already had in reducing the concentration of greenhouse gases.

References

Aldy, J.E. and R.N. Stavins (eds.) (2007), *Architectures for Agreement: Addressing Global Climate Change in the Post-Kyoto World*, Cambridge: Cambridge University Press.

Barrett, S. (1992). "'Acceptable' Allocations of Tradeable Carbon Emission Entitlements in a Global Warming Treaty," in UNCTAD (ed.), *Combating Global Warming: Study on a Global System of Tradeable Carbon Emission Entitlements*, New York: United Nations, pp. 85-113.

Barrett, S. (2005). *Environment and Statecraft: The Strategy of Environmental Treaty-Making*, Oxford: Oxford University Press (paperback edition).

Barrett, S. (2006). "Climate Treaties and 'Breakthrough' Technologies." *American Economic Review* (*Papers and Proceedings*), **96**(2): 22-25.

Barrett, S. (2009). "The Coming Global Climate-Technology Revolution." *Journal of Economic Perspectives* 23(2): 53-75.

Barrett, S. and R. Stavins (2003), "Increasing Participation and Compliance in International Climate Change Agreements," *International Environmental Agreements: Politics, Law, and Economics*, **3**(4): 349-376, 2003.

Bosetti, V., C. Carraro, A. Sgobbi and M. Tavoni (2008). "Modelling Economic Impacts of Alternative International Climate Policy Architectures: A Quantitative and Comparative Assessment of Architectures for Agreement." Nota Di Lavoro 85.2008, Fondazione Eni Enrico Mattei, October. Available at: http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm.

Bradley, R., K.A. Baumert, B. Childs, T. Herzog, and J. Pershing (2007). *Slicing the Pie: Sector-Based Approaches to International Climate Agreements*, Washington, DC: World Resources Institute.

Carraro, C. and D. Siniscalco (1993), "Strategies for the International Protection of the Environment," *Journal of Public Economics*, **52**: 309-28.

Carraro, C., E. De Cian, R. Duval, E. Massetti, and M. Tavoni (2009). "On the Incentives to Participate in and the Stability of Climate Coalitions: A Global Assessment," presentation given at the workshop on Coalitions for Climate Cooperation: A Game-Theoretic Analysis of Post-2012 Climate Policy, Venice, Italy, 15-16 June 2009.

Cline, W. R. (2007). *Global Warming and Agriculture: Impact Estimates by Country*. Washington, DC: Peterson Institute for International Economics.

Edmonds, J. And M. Wise (1997). "Exploring a Technology Strategy for Stabilizing Atmospheric CO_2." Unpublished manuscript, Pacific Northwest National Laboratory, Washington DC (August 27).

Farrell, A.E., D.W. Keith, and J.J. Corbett (2003). "A Strategy for Introducing Hydrogen into Transportation." *Energy Policy* 31: 1357-1367.

Finus, M. (2001). Game Theory and International Environmental Cooperation. Cheltenham: Edward Elgar.

Frankel, J. (2009). "Global Environment and Trade Policy," Discussion Paper 09-01, Belfer Center for Science and International Affairs, Harvard Kennedy School.

Hoel, M. (1994). "Efficient Climate Policy in the Presence of Free-Riders." Journal of Environmental Economics and Management, 27: 259-274.

Kaniaru, D., R. Shende, S. Stone, and D. Zaelke (2007). "Strengthening the Montreal Protocol: Insurance Against Abrupt Climate Change, *Sustainable Development Law & Policy*, **3**: .

Kousky, C., O. Rostopshova, M. Toman, and R. Zeckhauser (2009). "Responding to Threats of Climate Change Catastrophes," draft, World Bank, May 8.

Mitchell, R. (1994). *Intentional Oil Pollution at Sea: Environmental Policy and Treaty Compliance*. Cambridge, MA: MIT Press.

Montgomery, W.D. and A.E. Smith (2007). "Price, Quantity, and Technology Strategies for Climate Change Policy." In M. Schlesinger, H. Kheshgi, J. Smith, F. de la Chesnaye, J.M. Reilly, T. Wilson, and C. Kolstad (eds.), *Human-Induced Climate Change: An Interdisciplinary Assessment*, Cambridge: Cambridge University Press.

Nordhaus, W. (2008). *A Question of Balance: Weighing the Options on Global Warming Policies*. New Haven: Yale University Press.

Rose, A., B. Stevens, J. Edmonds and M. Wise (1998). "International Equity and Differentiation in Global Warming Policy," *Environmental and Resource Economics* 12(1): 25-51.

Sandler, T. (2004). *Global Collective Action*. Cambridge: Cambridge University Press.

Schelling, T. (1960). *The Strategy of Conflict*. Cambridge, MA: Harvard University Press.

Schneider, S. H., S. Semenov, A. Patwardhan, I. Burton, C. H. D. Magadza, M. Oppenheimer, A. B. Pittock, A. Rahman, J. B. Smith, A. Suarez and F. Yamin (2007). "Assessing Key Vulnerabilities and the Risk from Climate Change." In M. L. Parry, J. P. Canziani, J. P. v. d. L. Palutikof and C. E. Hanson (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability; Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, UK, Cambridge University Press.

Stern, N. (2009).*The Global Deal: Climate Change and the Creation of a New Era of Progress and Prosperity*. London: Bodley Head/Random House.

United States Environmental Protection Agency (EPA) (2009). "EPA Preliminary Analysis of the American Clean Energy and Security Act of 2009 in the 111th Congress, HR 2454," 23 June 2009; at http://www.epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf.

United States Government Accountability Office (2009). Aviation and Climate Change. GAO-09-554; at http://www.gao.gov/new.items/d09554.pdf.

Velders, G.J.M., S.O. Anderson, J.S. Daniel, D.W. Fahey, and M. McFarland (2007). "The Importance of the Montreal Protocol in Protecting Climate." *Proceedings of the National Academy of Sciences*, 104(12): 4814-4819.

Velders, G.J., H. Slaper, D.W. Pearce, and A. Howarth (2000). "Technical Report on Stratospheric Ozone Depletion in Europe: An Integrated Economic and Environmental Assessment." Rijksinstituut voor Volksgezondheid en Milieu, Biltoven, the Netherlands, RIVM Report 481505011.

Wara, M. (2006). "Measuring the Clean Development Mechanism's Performance and Potential." Working Paper No. 56, Program on Energy and Sustainable Development, Stanford University; at http://iis-db.stanford.edu/pubs/21211/Wara_CDM.pdf.

Wara, M. (2007). "Is the Global Carbon Market Working?" *Nature* **445**: 595-596.