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A Portfolio System of Climate Treaties

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THE HARVARD PROJECT ON INTERNATIONAL CLIMATE AGREEMENTS

The goal of the Harvard Project on International Climate Agreements is to help identify key design elements of a scientifically sound, economically rational, and politically pragmatic post-2012 international policy architecture for global climate change. It draws upon leading thinkers from academia, private industry, government, and non-governmental organizations from around the world to construct a small set of promising policy frameworks and then disseminate and discuss the design elements and frameworks with decision-makers. The Project is co-directed by Robert N. Stavins, Albert Pratt Professor of Business and Government, John F. Kennedy School of Government, Harvard University, and Joseph E. Aldy, Fellow, Resources for the Future. For more information, see the Project's website:
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Abstract

The current climate regime, which focuses on reducing (net) emissions, can be improved in two ways. First, by breaking up the problem, and addressing each part separately, but treating all parts as a *system* of agreements, new possibilities emerge for enforcement. Second, by incorporating adaptation, "geoengineering," and the risks associated with mitigation options (such as long term storage of nuclear waste and carbon dioxide) in a *portfolio* of agreements, more opportunities open up for risk management. A portfolio system of climate treaties would be superior to today's single-track architecture.

A Portfolio System of Climate Treaties

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1. Introduction

Climate change is so fundamental a challenge that it must be addressed from a multiple of perspectives, using a multiple of approaches.

This is a radically different concept from the arrangement developed thus far. The current regime strains to develop a unified approach to addressing climate change. It focuses on net emissions—flows that both add to and subtract from the stock of atmospheric concentrations. Under the Kyoto Protocol, reforestation (which sequesters and therefore removes carbon dioxide or CO_2 from the atmosphere) can substitute for abatement (which reduces additions to the atmosphere, relative to "business as usual"); the emissions of different countries can be traded; and reductions in the emission of one gas can offset increases in the emission of another. This approach has one great virtue: it promotes cost-effective abatement.

Unfortunately, this approach has so far failed to address the more important objective, which is to reduce greenhouse gas emissions and ultimately to stabilize atmospheric concentrations.[1] In this paper I explain why a strategy of breaking up the different sources and types of gases and addressing many of them separately may succeed better at reducing emissions overall.

Of course, in breaking things up, cost-effectiveness may be compromised somewhat, but this is why the different approaches need to be linked. We don't simply need a number of agreements; we need a *system* of agreements.

The existing regime comprises a linear series—a framework convention linked to a short-term protocol. The United Nations Framework Convention on Climate Change (UNFCCC) establishes a collective, long run goal and lasts indefinitely (of course, this treaty, like all treaties, can always be revised or dissolved or replaced). The Kyoto Protocol, by contrast, establishes short term, individual country emission targets and lasts only through 2012. Kyoto was supposed to be succeeded by a series of follow-on agreements—one that established individual country targets for 2013-2017; one that, after this, established targets for 2018-2022; and so on *ad infinitum*. The ultimate aim of this series of protocols was to meet the collective goal expressed in the Framework Convention—to ensure that concentrations would be stabilized "at a level that would prevent dangerous interference with the climate system."

* I am grateful to Joseph Aldy and Robert Stavins for comments on a first draft.

[1] Zero abatement is cost-effective but achieves nothing. For a discussion of the possible trade off between cost-effectiveness and enforcement, see Barrett and Stavins (2003).

There are a number of problems with this design. The short-term nature of each protocol creates little incentive for countries to innovate and invest. Also, by not promoting R&D, Kyoto fails to generate the knowledge that will be needed to reduce emissions dramatically in the future. R&D and emission reductions are complements. Not only are both needed; both need to be considered jointly.

A focus on emissions alone is also inappropriate because of climate change uncertainty. We don't know the concentration level that will prevent "dangerous interference." We might guess wrong. We might guess right but, for the reasons already mentioned, be unable to use Kyoto to stop the world from exceeding the target concentration level. The objective of a climate change regime should be to reduce climate change *risk*.

Of course, limiting emissions will reduce risk, but there is more we can and should do. Perhaps most importantly, countries must be made less vulnerable to the climate change that is not or cannot be avoided by reducing emissions. One way to do this is by adapting to climate change. Many countries are capable of adapting on their own, but many are not, and those that are not must be helped. The Framework Convention and the Kyoto Protocol both acknowledge this need, but neither adequately addresses it.

Another approach to reducing climate change risk is not even mentioned in these agreements. This is "geoengineering," a technology that would scatter solar radiation to counteract the effect of rising atmospheric concentrations on the climate. Geoengineering has the potential to limit climate change risk. Its use, however, will introduce new risks. We may therefore also want to develop a capability to reduce concentrations rapidly by means of another new technology, "air capture." How should these technologies figure into an overall strategy for reducing climate change risk? More generally, many of the approaches to reducing emissions entail risks of their own—examples include long-term storage of nuclear waste and storage of CO_2, underground or perhaps in the deep oceans. Risk management requires a *portfolio* of agreements.

1.1 Conclusions

Let me summarize my three main conclusions:

First, we need a multiple of agreements. This is because by combining every sector and gas in a single agreement the ability to enforce the entire agreement depends on the weakest component. (This is why it made sense not to address deforestation in the Kyoto Protocol.) It is also because the approach to enforcement must be designed to suit the unique features of each gas and sector. (Trade restrictions may work for some sectors; they are unlikely to work for enforcing economy-wide emission limits.)

Second, we need a system of agreements rather than simply a collection of agreements. This is because the different parts are technically inter-connected. (For example, a shift towards the use of electric or hydrogen cars will succeed in reducing emissions only if the electricity and hydrogen are produced without emitting CO_2.) It is also because the different parts are strategically interrelated. (For example, if hydrogen is produced from fossil fuels, the economics of carbon capture and storage will improve, since hydrogen production yields a stream of pure CO_2, which is easier to capture.) Finally, it is because cost-effectiveness requires that the marginal costs of reducing emissions be uniform as between the different sectors and gases.

Third, we need a portfolio of agreements to limit climate change risk. Reducing emissions will limit risk, but we can also limit risk by investing in adaptation and by being prepared to use, should the need ever arise, a form of geoengineering to offset the effect of rising concentrations.

The title of this paper may be awkward but it conveys the essential message—that we need a portfolio system of climate treaties.

1.2 Overview

These conclusions emerge from the analysis developed in the sections that follow. Here I summarize these.

I begin with a critical review of the Kyoto Protocol. It may be widely believed today that Kyoto is an inadequate treaty, and that there is no need, therefore, to criticize it. However, even if there were widespread agreement that Kyoto has failed, there may be many incompatible explanations as to *why* it has failed. Agreement that Kyoto has failed may ensure that we do not make the same mistake again. It is no guarantee that we will not make a different mistake. My concern is that we may make a different mistake because we misunderstood the reasons Kyoto has failed. In the next section of this paper I argue that enforcement is the most essential challenge to addressing climate change fundamentally and that Kyoto has failed because its design makes enforcement very difficult if not impossible.

I am not alone in making this diagnosis, and the most popular suggested remedy is to incorporate trade restrictions in a post-2012 agreement. In Section 3 I explain why I believe this remedy may not work to enforce economy-wide emission limits.

In Section 4 I begin to develop an alternative architecture for a post-2012 agreement. The focus here is on the logic of negotiating sectoral agreements rather than a single, economy-wide agreement. Section 5 extends this argument to having different agreements for different gases. Section 6 returns to the earlier topic of trade restrictions. I explain here that trade restrictions are needed and are likely to be effective in enforcing some sectoral or individual gas agreements.

To reduce emissions dramatically, new technologies will be needed, and these will only emerge with increased spending on R&D. In Section 7 I explain how R&D agreements need to be structured, and how they ought to relate to the other agreements within the broader system of agreements.

The next three sections discuss the other components of a system of agreements intended to limit climate change risk. The first component, discussed in Section 8, is adaptation. The second, discussed in Section 9, is geoengineering. The third, discussed in Section 10, is air capture. This is a means for reducing concentrations directly. Air capture could be used to offset emissions, but it is an expensive means for doing so—a "backstop technology." Air capture's great advantage is not its costs but its ability to reduce concentrations directly and, if scaled up dramatically, quickly. It can thus play a role in limiting the risks associated with geoengineering.

In the paper's last section I conclude with some final thoughts.

2. Kyoto's enforcement challenge

The Framework Convention was negotiated years before Kyoto, but because it is linked to Kyoto, the parties to the Convention have sought to define its collective goal in terms that are compatible with Kyoto. At the G8 summit held in Hokkaido, Japan in July 2008, the G8 members agreed that they would "share with all Parties to the UNFCCC the vision of, and together with them to consider and adopt in the UNFCCC negotiations, the goal of achieving at least 50% reduction of global emissions by 2050…."[2]

Climate negotiations have been going on for so long that history is beginning to repeat itself. In 1988, at a quasi-political conference held in Toronto, participants concluded that global CO_2 emissions should be reduced 20 percent from the 1988 level by 2005. Through 2004, however, global emissions *increased* 32 percent.[3] This conception of the challenge has thus not helped. Of course, from the perspective of the climate, only global emissions matter, and so there is a logic to expressing a goal in these terms. The problem is that such a goal creates no incentives for countries to limit their emissions. It is easy to reach agreement on a collective goal. If everyone is responsible for meeting it, no single country is responsible for meeting it. This is why the Kyoto Protocol was needed: it establishes individual country emission limits.

Setting a global emissions target only helps if a way can be found to disaggregate the overall target and to enforce these source-specific emission limits. This is how Title IV of the Clean Air Act Amendments of 1990 is designed. This U.S. law establishes a total cap on sulfur dioxide emissions for all large plants (about 50 percent of the levels emitted in 1980).[4] It then allocates this total to individual plants. Finally, it allows the operators of these plants to trade their allocations. Trading creates an incentive for operators to meet the overall emissions target at minimum cost.

Though the trading arrangement in this law inspired Kyoto's design, two other features of Title IV are more important. Participation in Title IV is involuntary and non-compliance is penalized severely. Indeed, the penalty for non-compliance is so severe that, in 2006, compliance was 100 percent.[5] Title IV's success is due to it being enforced centrally, by the U.S. government.

A climate change treaty cannot be enforced in the same way. There is no world government; there are, instead, nearly 200 governments, each accorded sovereign equality in international law. Under the rules of international law, participation by states in a treaty (such as Kyoto) is voluntary. Customary law says that states must comply with their treaty obligations, but treaties seeking to sustain international cooperation must usually create internal incentives for compliance. They must also create incentives for participation.

Kyoto lacks both arrangements. It provides no incentive for participation, which explains why the United States is a non-party. It provides no incentive for compliance, which is why Canada, a party, has declared that it will not comply.

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[2] http://www.g8summit.go.jp/eng/doc/doc080714__en.html.
[3] See http://cdiac.ornl.gov/ftp/ndp030/global.1751_2004.ems.
[4] For a summary of the acid rain program, see http://www.epa.gov/airmarkets/progsregs/arp/index.html.
[5] See http://www.epa.gov/airmarkets/progress/docs/2006-ARP-Report.pdf, p. 11.

The problem is not with individual countries but with the design of the agreement. China is a party to the Kyoto Protocol and it will comply, but that is only because Kyoto does not require that China reduce its emissions. Russia is a party and it will also comply, but that is only because Russia's Kyoto limits are so generous that they do not bite. Other parties, like Japan and New Zealand, face emission limits that do bite, but it is not yet clear whether these countries will ultimately comply. They could comply easily by purchasing surplus credits from countries like Russia, but then their compliance would not help to reduce global emissions. What would be the point? They could comply at some cost, but why should they do that when other countries (like the U.S., Canada, China, and Russia) are not reducing their emissions? Compliance by some members of the European Union also appears challenging. Spain has the largest gap of any country. Denmark is well off its individual target. However, thanks to the European "bubble," and substantial reductions by other EU countries (in part for reasons having nothing to do with their climate change policies), these countries are not bound by their individual limits so long as the original 15 members of the European Union meet their collective limit. Australia recently ratified the Kyoto Protocol, but because of the provision for land use, land-use change, and forestry (known to climate insiders as LULUCF), Australia is within its Kyoto limit; Australia will have to do very little if anything to comply.[6]

One current strategy is to make Kyoto's emission reduction obligations more stringent, but if that is all that is changed, the effect will be the same. A means must also be found to enforce a new agreement.

3. Trade restrictions in a post-2012 agreement?

President Sarkozy of France has suggested that trade restrictions be considered for this purpose. Nobel-prize-winning economist Joseph Stiglitz has recommended that they be used.[7] Should they be used?[8]

Trade restrictions can serve two purposes. They can be used to correct leakage. They can also be used to promote participation (that is, deter free riding).

Leakage can be corrected by "border tax adjustments." This would involve parties to the agreement imposing a tariff on imports from non-parties, and giving a rebate on exports to non-parties, equal to the cost of meeting the treaty's obligations, as embodied in the price of traded goods. How would these values be determined? Calculating the emissions released in the manufacture of a good is difficult. Two identical products, manufactured in the same country, might have very different "carbon footprints" (depending, for example, on how the electricity used as an input was generated). Cruder calculations might be contemplated (and most policy proposals have focused on the trade-sensitive, energy-intensive sectors), but sector-specific taxes aimed at reducing leakage would also be hard to calculate.[9] Moreover, as trade restrictions became cruder, they would be less effective at

[6] LULUCF is normally treated differently from emissions because of various accounting and incentive problems. For example, carbon accumulated in forestry may later be released.
[7] Stiglitz (2006).
[8] See Jeffrey Frankel's paper on this subject in the same series for the Harvard Project on International Climate Agreements. See also Houser *et al.* (2008).
[9] For example, Hoel (1996) shows that there is no simple relationship between fossil fuel intensity and the optimal sector-specific carbon tax.

reducing leakage.[10] Finally, crude border tax adjustments could serve as a disguise for protectionist measures.

Trade restrictions intended to promote participation can be blunt. Indeed, ideally, they would not need to be imposed at all; the credible threat to impose them would suffice to make all countries want to participate. Better still, if they impelled all countries to participate, not only would free riding be eliminated, but so too would leakage.

Unfortunately, blunt punishments cannot be relied upon to work this way. To make countries want to participate, the restrictions would have to be severe in addition to being credible, and punishments typically become less credible as they become more severe.[11]

The legitimacy of using trade restrictions to enforce an agreement may also be challenged. Who should decide what a particular country should be required to do? Who should decide the punishment that is appropriate should that country fail to fulfill this obligation? Suppose trade restrictions were to be imposed against the United States for not ratifying Kyoto. Might not the U.S. claim that Kyoto's base year (1990) favored Europe, or that its own efforts to promote R&D were at least as helpful in addressing climate change? Suppose that China were to be the target of trade restrictions. Might not China argue that development is the greater priority or that the rich countries were responsible for the accumulation of greenhouse gases? Trade restrictions lacking legitimacy may only spur retaliation—a trade war. Britain's efforts to bring the topic of climate change for debate at the United Nations Security Council hints at the possible reaction to adopting trade punishments in a climate change treaty. Countries without permanent representation on the Security Council were angry; they felt that the issue should have remained with the General Assembly, where every country has one vote. The meeting ended without even a statement let alone a resolution. Were one group of countries to seek to impose a climate agreement on others, backed by the threat of trade restrictions, an even stronger response seems possible if not likely.

Finally, trade restrictions would also need to be used to enforce compliance. Otherwise, participation would become a route for avoiding having to reduce emissions. Will parties to a future climate treaty agree to do this? Would Kyoto's current parties agree to do this, when some of them are already at risk of not complying?

4. The logic of sectoral agreements

If economy-wide obligations cannot be enforced by trade restrictions or any other means, perhaps a different approach should be tried—one that focuses on individual sectors.

We can understand the problem with economy-wide approaches by looking both at how Kyoto has been implemented and at how Kyoto was designed.

First, consider how countries have chosen to implement the treaty. No country has a single, economy-wide policy for meeting its Kyoto obligations. The European Emissions Trading Scheme covers less than half of EU emissions. Sweden arguably has the most well developed climate change

[10] See Oliveira-Martins *et al.* (1992).
[11] See Barrett (2005).

policy of any country, and its approach involves both "sector integration" (every sector plays a part towards meeting the overall goal) and "sector responsibility" (different sectors play different parts). Even Sweden's economy-wide policies differentiate by sector. Its carbon tax, for example, offers relief for energy-intensive industrial operations.[12] The mismatch between the approaches taken to implement Kyoto and the way in which the protocol's obligations were expressed hints that a different design, focused on individual sectors, would work better.[13]

Second, consider Kyoto's design. It is an economy-wide agreement but there are exceptions. It excludes emissions from aviation and marine transport—and for good reasons. One is that it isn't obvious how the responsibility for lowering these emissions should be allocated. Take the case of ocean shipping. Should the state where a ship refuels be responsible? Or should the responsible state be the one in which the operator is based, or the owner resides, or the ship is registered (these are often three different states)? (There are other possibilities.) Another reason for excluding aviation and marine transport is that, no matter how responsibility is assigned, restricting emissions at the country level creates an incentive for unwanted behavioral change—for ships to re-register with a non-party, for example. This is an extreme version of "trade leakage." Trade leakage is also a problem for other sectors but not all. It is the reason that Sweden offers carbon tax relief for its energy intensive industries.

Article 2.2 of the Kyoto Protocol says that emissions from aviation and marine transport should be reduced, but that the arrangements for doing so should be developed outside of this agreement—by the parties "working through the International Civil Aviation Organization and the International Maritime Organization, respectively." Treaties limiting these emissions have not yet been developed, but the motivation for treating the emissions arising from aviation and marine transport outside of Kyoto is compelling. These are international transportation *systems*. In systems it is imperative that the different parts be compatible. The reason the above two organizations were formed in the first place was to provide a forum for choosing global standards. (Under rules established by the International Civil Aviation Organization, for example, pilots flying internationally must speak either the local language or English, while controllers must be able to speak both languages. This rule ensures that pilots and controllers can always communicate in the same language.) Both organizations could play a role in choosing standards for reducing greenhouse gas emissions.

Farrell, Keith, and Corbett (2003), for example, have suggested that marine transport may be an attractive candidate for switching to hydrogen fuel. One reason for this is that ports are often close to refinery operations, where hydrogen is already produced and where cargo vessels already refuel. Helped by network effects, ocean shipping has already been transformed. For example, the standard for oil tankers has evolved—first, by requiring separate oil and ballast water tanks; and, second, by requiring double hulls (Barrett 2007a). Parties to the International Maritime Organisation could establish a new standard for hydrogen-powered container ships. This would require that ports make the fuel available and that individual governments ban ships (above a certain size) that were not

[12] See Ministry of Sustainable Development (2005). *The Swedish Report on Demonstrable Progress Under the Kyoto Protocol*. Available at http://www.sweden.gov.se/content/1/c6/05/47/62/24057533.pdf.

[13] To be sure, there have been proposals for economy wide approaches to limiting greenhouse gas emissions (for the U.S. proposals, see http://www.pewclimate.org/docUploads/Cap-and-Trade-Chart.pdf), but many of these are incompletely developed and some are economy-wide in disguise (with "upstream" approaches for some sectors or fuels and "downstream" approaches for others). Most importantly, none has been adopted yet.

powered by hydrogen. As more countries imposed this standard, the incentives for others to impose it would increase.

This same logic could be extended to those parts of the economy that *are* included in the Kyoto caps, such as road transport. The economics of hydrogen for automobile transportation are currently unattractive because of the need to change the transportation infrastructure—especially the fuel distribution system, refuelling stations, and vehicles. Currently, electric vehicles seem to have the edge, especially as the plug-in hybrid could possibly act as a bridge to an all-electric future. The plug-in hybrid is similar to hybrids on the road now; they run on electricity and gasoline. The difference is that plug-in hybrids have bigger batteries that can be recharged from the grid. People with garages can charge them at home now. In contrast to the all-electric car (given current battery technology), plug-in hybrids can also be driven long distances, making use of the existing refuelling infrastructure. Some people (depending on relative prices) may want to purchase these cars now. As plug-in hybrids penetrate the market, the number of electrical outlets for recharging will increase. The incentive to improve batteries for long-haul travel will also increase. Both of these developments will improve the economics of the all-electric car.

Like international marine and aviation transport, the road transportation systems of different (especially contiguous) countries must be compatible. Plug-in hybrids are compatible with the existing infrastructure. They can spread spatially under current conditions. Wider adoption by more countries will allow economies of scale and learning to be exploited, helping spread even more. The plug-in hybrid may spread without the need for international cooperation. By contrast, the all-electric vehicle may fail to take off without an international agreement. At a minimum, an international agreement may be needed to facilitate transition to an all-electric future.[14] Note that technical standards create an automatic trade restriction that is legal (so long as the standards are non-discriminatory) and easily administered. This will also help spread.

Of course, a switch to electric vehicles (or hydrogen) makes it even more imperative that emissions from electricity generation be cut very substantially. I discuss this sector later in this paper.

Let me conclude this section by making one more point. I have so far stressed that a sectoral approach could achieve more than an economy-wide approach. The sectoral approach has another advantage: it prevents cross-contamination. If efforts to reduce the emissions arising from one sector falter, the other efforts won't be pulled down with it.

The Kyoto Protocol does not provide credits for avoided deforestation—an arrangement that has been criticized with some justification since deforestation is responsible for around 18 percent of global emissions of greenhouse gases (Bradley *et al.* 2007: 44). There is wide agreement that the deforestation "loophole" needs to be closed, and there are proposals for doing so by creating "credits" for avoided deforestation.[15] However, there are good reasons why avoided deforestation was left out of the Kyoto Protocol in the first place. Forest loss is sometimes beyond the control of

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[14] We already have an agreement for harmonizing automobile standards—the Agreement Concerning the Establishing of Global Technical Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or Used on Wheeled Vehicles. See http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29glob/globale.pdf. An agreement on new automobile standards could be negotiated as an amendment to this agreement.

[15] See, for example, Scott L. Malcomson, "Leafonomics," *New York Times*, 20 April 2008, at http://www.nytimes.com/2008/04/20/magazine/20wwln-essay-t.html?partner=rssnyt&emc=rss. The UN's Reduced Emissions from Deforestation and Forest Degradation Program, or UN-REDD, also creates emission "credits."

individual parties (forest fires), the potential for leakage is huge, the benefits of avoided deforestation are reversible, and establishing a baseline for agreement is tricky business. Policies to reduce deforestation are needed but they will be imperfect. They should be ring-fenced so as not to contaminate other efforts to reduce net emissions.

To sum up this section, the Kyoto Protocol does leave out some sectors, and while there have been proposals to incorporate these in an even more comprehensive agreement, there was a logic to leaving them out, and this logic can also be extended to other sectors. In Section 6 I shall discuss whether a more fragmented approach should substitute for a broader agreement or be additional to a broader agreement.

5. Separate agreements for different gases

The logic of breaking the challenge up into pieces can also be extended to the different greenhouse gases. Indeed, one of the six gases controlled by Kyoto has already been limited by a different agreement—the Montreal Protocol, which was created to protect the ozone layer, not to limit climate change.

Protection of the ozone layer has both positive and negative implications for climate change, but a 2007 study has shown that, overall, the Montreal Protocol has been very effective in mitigating climate change.[16] Indeed, the study calculates that the Montreal Protocol has done more to address global climate change than the Kyoto Protocol, even assuming that Kyoto worked as originally intended. Already, this study estimates, the Montreal Protocol has reduced the emission of greenhouse gases four times as much as the Kyoto Protocol planned to do.

In late 2007, months after the above study was published, the Montreal Protocol was revised again. This time, an earlier agreement to phase out HCFCs was accelerated. HCFCs are a greenhouse gas, though they are not regulated by Kyoto (the reason being that they were already controlled by the Montreal Protocol). However, the manufacture of HCFCs produces HFCs (hydrofluorocarbons) as a byproduct, and HFCs (which are a greenhouse gas but *not* an ozone-depleting substance) *are* controlled by Kyoto. This new agreement thus adds to Montreal's earlier achievement.

The implication is that, had HFCs been addressed in a separate agreement, outside of Kyoto, they could have been cut dramatically and perhaps phased out, and not only by the Annex I countries but *globally*. By pooling HFCs with the other greenhouse gases within Kyoto's structure, less was achieved.[17]

Why has Montreal succeeded where Kyoto has failed? An important reason is that climate change and ozone depletion are different problems. Ozone depletion threatens human health directly, and

[16] See Velders *et al.* (2007). Ozone-depleting substances are greenhouse gases, but so is stratospheric ozone itself and so also are many of the substitutes for ozone-depleting substances.

[17] Indeed, there is evidence that Kyoto might actually have created incentives for HFC production to *increase*. According to Michael Wara (2007: 596) producers of HCFCs can earn more from Clean Development Mechanism (CDM) credits for the HFCs produced as a byproduct than from the HCFCs themselves. This is an illustration of one problem with the CDM—establishing a baseline.

can be avoided at relatively little cost. There are, however, other reasons—reasons having to do with the design of these treaties and how these designs address the underlying challenges.

Four observations are especially important. First, Montreal requires that *all* countries cut their emissions, whereas Kyoto only limits the emissions of Annex I countries. Second, Montreal controls production *and consumption* whereas Kyoto only limits the emissions arising from production. By restricting consumption (defined as production plus imports minus exports), Montreal dampens trade leakage. Third, the Montreal caps are *permanent*, whereas Kyoto's last only five years. Permanent limits create an expectation of a fundamental shift in global demand, stimulating innovation. Finally, Montreal created strong incentives for both participation and compliance—"carrots" in the form of financial payments from rich to poor countries, and "sticks" in the form of trade restrictions between parties and non-parties to the agreement. Kyoto only offers financial assistance through the faulty Clean Development Mechanism; as discussed earlier, it lacks an enforcement mechanism.

The lesson is not that Kyoto ought to have Montreal's features. Those features cannot support the ambitions of the Kyoto Protocol. The lesson is that, by pooling all the gases and sources together, Kyoto loses the leverage that can be brought to bear on controlling, in this instance, one of the greenhouse gases.

6. Sectoral agreements again

Though climate change and ozone depletion are very different problems, the logic of the Montreal Protocol can help with the development of sectoral agreements. First, these agreements ought to establish global standards. Developing countries should not be exempted from meeting these standards (as they were from reducing their emissions under Kyoto). Second, developing countries should be offered financial assistance, to aid their compliance. This assistance should be based on the principle of "incremental cost," meaning that developing countries should not be made worse off for participating as compared with the alternative where the agreement did not exist. Third, trade-sensitive sectoral agreements should be enforced using trade restrictions. Since developing countries would be compensated for participating in these agreements, and since the aim of these agreements would be to create universal standards for a "level playing field," the use of trade restrictions in this context would have legitimacy. The threat to restrict trade should also have a high chance of being credible, since parties to such an agreement would not want non-parties to have an "unfair" advantage in international trade. Moreover, by definition, these sectors would be especially vulnerable to leakage, and trade restrictions applied to non-parties would help to reduce leakage, making credible the threat to apply the restrictions (Barrett 2005). Finally, the treaty's obligations should be expressed in terms of consumption and not only production. Importing countries should only import goods that were produced by methods that met the global standards.

The aluminium sector is a prime candidate for a sectoral agreement.[18] It is a concentrated industry: twelve countries account for 82 percent of global production; ten companies produce more than half of world output. The industry employs just two smelting technologies, and emissions can be reduced substantially by re-melting aluminium scrap (the former is 95 percent less greenhouse-gas-

[18] I am drawing here from the excellent study by Bradley *et al.* (2007), especially pp. 37-38.

intensive than primary aluminium production). Finally, twenty-six companies, making up 80 percent of world output, belong to the International Aluminium Institute, which has already adopted voluntary intensity targets. There exists a basis here for negotiating new global standards for the industry, backed by international enforcement. The precise nature of such an agreement would need to be worked out by the parties, in association with the industry. One possibility is to require that all smelters employ the more efficient Prebake smelting technology (some facilities in developing countries still rely on the less efficient Söderberg technology). Another possibility is to require that the electricity input be produced with zero emissions. A final possibility is for an agreement to reduce emissions of PFCs. There is tremendous variation among aluminum plants in the amount of this gas that is emitted—and opportunities, therefore, for the lower emission rates to serve as an industry standard.[19] Other candidates for sectoral agreements include steel and cement.[20]

7. R&D

Another area in which linkage is needed is between policies to reduce emissions and R&D.

The Kyoto Protocol lasts just five years—too short a period to provide incentives for firms to make major investments for reducing emissions. Patents typically last 20 years. If a treaty is to create incentives for industry to innovate, a treaty's obligations must last at least as long.

Preferably, the obligations should hold indefinitely. A treaty should ratchet up the actions required and minimize the risk of backsliding. This is what the Montreal Protocol did. It may be difficult for a climate treaty to do this if the goals are expressed as emission limits (would permanent limits be credible?). It may be easier if the goals are expressed in some other way—such as technology standards. It is sometimes claimed that technology standards have the opposite problem: lock in. However, there is evidence to counter this claim. The oceans have been protected from oil releases by a succession of technology agreements.[21]

Kyoto also creates little incentive for countries to invest in R&D. The product of basic research is knowledge, and knowledge (by social choice) cannot be patented. Instead, basic research must be stimulated by public financing—by national laboratories undertaking research directly, by research grants being awarded on a competitive basis to universities, by research subsidies being paid to industry, or by prizes being awarded for research success. Energy R&D spending was flat after the Framework Convention was adopted in 1992; it changed little after Kyoto was negotiated; it has remained steady since Kyoto entered into force.[22] Kyoto's design does not promote R&D directly.

Failure to stimulate R&D makes progress in reducing emissions difficult. Basic knowledge and technology development are complements. The returns to each activity increase in the level of the other activity. Both activities are also crucial to addressing climate change. Reducing emissions dramatically will require a technological revolution.

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[19] Watson *et al.* (2005: 12).
[20] Again, see Bradley *et al.* (2007).
[21] Barrett (2007a).
[22] See Doornbosch and Upton (2006).

Knowledge is a global public good. Countries—especially large, rich countries—have incentives to invest in R&D, individually in some cases and collectively in others. However, in the case of climate change, the returns to supplying one global public good (knowledge) depend on the returns to supplying the other (using the knowledge to reduce greenhouse gas emissions).

We know that the incentives to conduct research into nuclear fusion are strong, because countries have already cooperated in this research.[23] Fusion power, however, would yield benefits unrelated to climate change, in addition to climate change benefits. The incentives to undertake R&D into carbon capture and storage are much weaker. They depend entirely on the prospects of the knowledge emerging from this research being embodied in new technologies that are actually diffused, and these prospects depend on the incentives for countries to cut their emissions (Barrett 2006). As noted previously, the latter incentives are weak unless a way can be found to address the enforcement challenge.

Electricity generation is not usually traded, and so the emissions from this sector cannot be controlled in the same way as sectors like aluminum and transport. This, of course, is another reason why it makes sense to break the larger problem up—different approaches for different sectors.

Though trade restrictions cannot be used to enforce an agreement on electricity generation, at least we do not need to worry about leakage compounding free rider incentives. But how can these incentives be shut off? An agreement may be able to help, by making the policies of countries contingent. For example, an agreement could require that all new coal-fired power stations be fitted with carbon capture and storage, with this obligation being binding on individual countries only so long as the treaty's minimum participation condition was met. This arrangement would address one of the motivations for free riding—the fear that, should your country cooperate, others will not, with the consequence that your country helps free riders but is made worse off itself compared with a situation in which cooperation fails completely (Barrett 2005). To provide additional reassurance that other parties really will adopt the new standard, the agreement could require that parties adopt domestic legislation mandating the technology standard. This would shift the compliance burden onto domestic institutions (participation would still need to be enforced internationally, but that would be the purpose of the minimum participation clause noted above).

Two problems with carbon capture and storage cannot be avoided. The first is that it is more costly and results in more local pollution emissions than an equivalent plant without carbon capture (capture requires energy). It will never be something countries will do on a major scale unilaterally. A way must therefore be found to enforce participation in an agreement mandating its use (or prescribing an emissions constraint that can only be met using carbon capture and storage). Second, geologic storage will introduce new risks, particularly if done on a substantial scale. Some of these risks are local (harm to groundwater, for example). Some are global (leakage of CO_2 into the atmosphere). (Deep ocean storage introduces other risks.)

A priority for action now must be to undertake R&D into both of these matters. R&D must demonstrate the economics of large scale, integrated power plants with carbon capture, and find ways to lower costs and improve efficiency. It must also demonstrate the safety of underground

[23] The International Thermonuclear Experimental Reactor, being built now in France, is a cooperative endeavour, supported by the European Union, China, India, Japan, South Korea, Russia, and the United States—the same countries that will need to cooperate in addressing climate change.

storage. Because the benefits of this R&D lie entirely in the supply of the global public good, this research will need to be coordinated. Indeed, there is almost certainly a need for international cooperation in financing this R&D. There are international initiatives in this area, including the Carbon Sequestration Leadership Forum (with 21 member states), but this is a "framework for international cooperation in research and development for the separation, capture, transportation and storage of carbon dioxide."[24] The Forum does not undertake R&D. There are about 20 large-scale demonstration projects now being planned. However, as noted by the International Energy Agency (IEA 2008: 276), the list of such plants is "changing rapidly…due to a number of project cancellations as well as new projects being announced."[25] We should be able to rely more on R&D in this vital area.

R&D agreements do not require universal participation or even a high level of participation. They can involve a small number of countries. The ITER nuclear fusion project, for example, is supported by the European Union, China, India, Japan, South Korea, Russia, and the United States. Countries contribute to an effort like this when they benefit from the fruits of this research and their contributions are pivotal to the project going ahead. They also contribute so that their scientists can learn from colleagues based in other countries—a benefit that is higher when a country is engaged in complementary research programs. In these situations, other countries may free ride, but their free riding need not undermine provision of the public good of knowledge (Barrett 2007a). High levels of participation are important only for agreements aiming to reduce emissions.

8. Adaptation

Countries have exceptionally strong incentives to adapt. They have incentives to adapt in response to climate change, to limit the damage from climate change. They also have incentives to adapt in anticipation of climate change, to insure against the consequences of future climate change.

In contrast to mitigation, the benefits of adaptation are excludable. Much adaptation will be done "automatically" by the market. Much of the rest will require the supply of local public goods (augmenting the Thames Barrier is an example), the benefits of which will be largely internal to the countries that supply them.

Poor countries are especially vulnerable to climate change. This is partly because of their geography (Mendelsohn, Dinar, and Williams 2006). It is also because poor countries lack the capability to adapt. Adaptation requires the same institutions as development. Poor countries have weaker market institutions, and their governments routinely undersupply basic local public goods (like immunization). Poor countries are also less accustomed to cooperating with each other to address cross-border challenges like malaria, which may become an even greater threat with climate change.

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[24] See http://www.cslforum.org/documents/CSLFcharter.pdf.

[25] The United States had planned to build a "clean coal" pilot project called FutureGen. The plant was to produce hydrogen and electricity from coal while using carbon capture and storage to sequester the CO_2 underground. The initiative was launched in 2003. In December 2007, a site was selected. A month later, the project was cancelled, ostensibly because the cost had risen from $1 billion to $1.8 billion. See M.L. Wald, "Higher Costs Cited as U.S. Shuts Down Coal Project," *New York Times*, January 31, 2008; available at http://www.nytimes.com/2008/01/31/business/31coal.html?ref=environment&pagewanted=all.

Mitigation will depend mostly on the efforts of the richest countries (not only as regards their own abatement but also their financing of abatement by other countries). However, these countries are also more capable of adapting. The rich countries may, therefore, substitute the local public good of adaptation (the benefits of which are captured locally) for the global public good of mitigation (the benefits of which are distributed globally), leaving poor countries more vulnerable still. Climate change thus has the potential to widen existing inequalities.

Rich countries might offer assistance to the poor for reasons of compassion, but there is a more powerful motive. The rich countries are responsible for the poor needing to adapt.

Rich countries have already accepted that they are obligated to assist the poor to adapt. Article 3 of the Framework Convention on Climate Change says that rich country parties to the convention shall "assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects." However, the agreement does not say how much money the rich countries ought to provide or the basis for determining this amount. Nor does it mention burden sharing. How much should each rich country contribute?

The Kyoto Protocol made a first attempt to define and implement this obligation. It established an adaptation fund, financed by a levy on Clean Development Mechanism transactions (the CDM allows rich countries to fulfill their emission reduction obligations by obtaining credit for emission reductions they finance in poor countries). However, there are three problems with this arrangement. First, the amounts of money that will be needed for adaptation bear no relation at all to the amounts raised by CDM transactions. Second, taxing CDM transactions penalizes efforts to supply the global public good of mitigation. Finally, since the United States is not a party to this treaty, its obligation to assist developing countries (an obligation it accepted under the Framework Convention) cannot be fulfilled by this mechanism. For all three reasons, a different approach is needed.

The form this new approach might take is presently unclear. The priority at this time should be to make investments in development that will reduce future vulnerability. An obvious area for investment is agriculture. The Consultative Group on International Agricultural Research is currently undertaking research that could reduce future vulnerability dramatically. This includes developing "climate-ready" crops capable of withstanding climate change—examples include heat-tolerant crops, "drought-escaping" rice (varieties that can grow over a shorter cycle), and "waterproof" rice (varieties that survive prolonged flooding). Industrialized countries pay about 70 percent of the CGIAR's budget (multilateral and regional development organizations finance most of the balance). They should increase their contributions to finance an expanded climate-related research program.

Another obvious area for investment is tropical medicine. The link between climate change and infectious diseases is complex and uncertain but there are reasons to be concerned. For example, the relationship between temperature and the number of days it takes for the malaria parasite to develop within the mosquito is non-linear. Small changes in temperature can thus result in big changes in malaria incidence.[26] Of course, these matters aside, we can be sure that countries will be better able to adapt to climate change if they are relieved of their crushing disease burden. Much of this burden

[26] See Patz and Olson (2006). Of course, rainfall patterns are also important, and the phenomenon of "biological amplification" described here depends on a number of things, including the existing level of transmission.

could be erased using existing medical products, but there is also a lack of R&D into the tropical diseases. One way to help developing countries adapt is thus to invest in this R&D.

The important design question is whether and how contributions of the kind just discussed should be linked to other actions in the treaty system. Much future climate change can be attributed to historical emissions. If serious action is not taken soon, however, even more climate change will be due to future emissions. The more we succeed in reducing emissions, the less adaptation will be needed. This suggests that a component of contributions to adaptation should be linked to each country's role in reducing emissions—or not, as the case may be.

9. Geoengineering

Two fundamental forces determine the Earth's climate: the amount of solar radiation that strikes the Earth and the amount of this radiation that is trapped by greenhouse gases in the atmosphere. So far, international negotiations have focused on the latter force—the concentration of greenhouse gases. Geoengineering is a radically different approach. Its aim is not to limit climate change by limiting greenhouse gas concentrations but to limit climate change by altering the amount of solar radiation that reaches the Earth.

How could we do that? There are many different ideas. The most well established proposal is to throw particles (sulfates or particles engineered specifically for the purpose) into the stratosphere. These would have a similar effect as some volcanic eruptions—the particles would scatter sunlight, cooling the Earth. Of course, this is a Band-Aid, not a solution that gets at the root of the problem; but there are other problems with the proposal. It fails to address the allied problem of ocean acidification. It may not maintain the current distribution of climate. It may increase stratospheric ozone depletion. It may create other risks as yet unknown. There are many reasons why geoengineering should never be tried.

Geoengineering is also the only way in which temperature could be reduced quickly. Reducing (net) emissions takes decades to translate into temperature changes. Geoengineering could cool the Earth within months. Suppose, then, that a low probability but high consequence climate event started to unfold. Would we want to have the option to use geoengineering then? Certainly many people would say yes—as a last resort.[27]

Two other aspects of geoengineering are crucial. First, geoengineering is relatively cheap in financial terms. How cheap? According to David Keith (2000: 263), the cost is sufficiently low that "it is unlikely that cost would play any significant role in a decision to deploy stratospheric scatterers…." Second, geoengineering can be undertaken as a single project. A number of countries could deploy a geoengineering technology unilaterally.

This means that an international agreement is not really needed to finance deployment (alternatively, such an agreement should be easy to reach). If getting countries to reduce their emissions is "too hard," getting countries to use geoengineering is "too easy." Indeed, the international challenge is

[27] See, for example, Stephen Schneider's (2008) recent paper on this question.

not to get countries to use geoengineering but to get them *not* to use it when other countries object to them using it (Barrett 2008a).

The situation in which "abrupt and catastrophic" climate change appears imminent and can be prevented by geoengineering is easy to analyze. Under these circumstances, many countries will want to use this technology. Since no country gains from this kind of climate change, few if any countries are likely to oppose deployment. We can expect that geoengineering will be used, and that this will be desirable, at least from an *ex ante* perspective.

The situation in which "gradual" climate change is occurring, and in which there are winners and losers, is more complicated. William Cline (2007) has shown that the effects of this kind of climate change on agriculture are likely to be mixed. Some countries lose substantially. In Cline's analysis of climate change for a "business as usual scenario," leading to a 3° C mean global temperature increase by around the year 2080, India's agricultural capacity falls by nearly one-third. This is a huge loss for a country for which millions of people rely on agriculture for their livelihood. The losses in equatorial Africa are even larger—over 50 percent. However, other countries gain. Agricultural capacity in China rises nearly seven percent. In Russia it rises six percent, in the U.S. eight percent. The total effect of climate change in 2080 is small—global agricultural capacity falls by only about three percent, an amount so small as to be interpreted as "noise" given the number of things that can change over a period of 75 years. It's the variation among countries that stands out.

India already has space and nuclear programs. It would certainly have the capability to use geoengineering in an attempt to reverse the damage caused by "gradual" climate change, should it choose to do so. But, plainly, other countries would object if India were attempt this. In this situation, conflict seems likely. How will it get resolved? That is hard to say, but because conflict can be anticipated, an incentive exists for it to be made less likely to emerge—another reason why it is essential that rich countries not only work to reduce emissions but also help poor countries to adapt by making investments in areas like agriculture. Potentially, improvements in agriculture could more than offset declines in productivity caused by climate change.

What else to do now? We certainly need to undertake R&D into geoengineering. The aim of this R&D would be to learn whether it would work, and how it would work. R&D should also learn about the full consequences of using geoengineering. Because individual countries may have the incentive to deploy geoengineering, individual countries should also have the incentive to undertake this R&D. However, because the consequences of geoengineering would be global, my view is that it is best that this R&D be undertaken cooperatively and openly.

10. Air capture

Of course, R&D into geoengineering cannot tell us everything we need to know. It is not until geonengineering is used at scale and over a sustained period of time that we will learn its full consequences.

Suppose, then, that geoengineering is deployed in the hope that it will reduce the chances of imminent catastrophe. Suppose further that, upon deploying this technology, we learn that geonengineering works and does not result in serious adverse consequences. Then we can continue to use it. Suppose, however, that we discover that it works at lowering global mean temperature but that it has other, adverse consequences—perhaps consequences that were previously unforeseen; then what? At this point we will want to reduce atmospheric concentrations, so that we can slowly wean ourselves off of geoengineering. We could do this quicker and at lower cost if we had invested in R&D into new technologies much earlier. Even so, however, reducing emissions is a slow way to reduce concentrations.

A faster approach is "air capture." This involves removing CO_2 from the air. Of course, the process of photosynthesis does this, which is why Kyoto acknowledges the role of afforestation and reforestation. However, there are limits to reducing concentrations in these ways.

Another approach is to fertilize iron-limited regions of the oceans, to stimulate phytoplankton blooms. This has already been done on an experimental basis, but the potential for this kind of air capture is also limited. Moreover, there are concerns about the consequences of doing this on a large scale. International treaties outside of the climate regime recently cautioned against large-scale experiments of this kind.[28]

Industrial air capture would bring air into contact with a chemical "sorbent"—an alkaline liquid that would absorb the CO_2 in the air, allowing it to be sequestered in the same way as CO_2 removed from a power plant's stack gases. This technology can be scaled up to any level. It would be the fastest way to reduce atmospheric concentrations.

It is also extremely expensive. In contrast to geoengineering, it is very unlikely that any country would choose to deploy this technology on a massive scale unilaterally. It is possible that a number of countries would be willing to do so collectively, but only if the damages avoided were at least as large as the cost—a situation that is most likely to arise when the case for deploying geonegineering is strong and when air capture can be deployed to reduce concentrations so that geoengineering can be reduced or stopped. Currently, our knowledge of this technology is in its infancy. Should R&D be undertaken to develop this technology, and lower its costs, so that we will be ready to deploy it should we choose to do so under the circumstances outlined above? The economics of R&D as a hedge against uncertainty are remarkably complicated, but there does seem to be a case for undertaking this R&D, now.[29] R&D is thus of value not only as part of a system for reducing emissions but also for reducing climate change risk.

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[28] In 2007, the 84 parties to the London Convention/Protocol endorsed a "statement of concern" about ocean fertilization, and urged parties "to use the utmost caution when considering proposals for large-scale ocean fertilization operations." (See OSPAR Decision 2007/02 on Storage of Carbon Dioxide Streams in Geological Formations, June 2007.) They also agreed that they would consider regulating this technology. This should be of concern to the parties to the Framework Convention on Climate Change. Restricting ocean fertilization may be to the benefit of the oceans, the concern of the parties to the London Convention, but the choice is not whether or not to allow such an experiment. It is whether to allow such an experiment or to do *something else* to reduce concentrations or to accept the damage from climate change that is not avoided by the experiment. The parties to the Framework Convention must surely play a role in making this judgment.

[29] In a recent analysis of a similar but not identical situation, Baker, Clarke, and Weyant (2006: 173) conclude that, "from a policy perspective, the more likely we believe dramatic emissions reductions will be necessary, the more R&D funding should be pushed toward technologies that will reduce the costs of these reductions."

11. Conclusions

In this paper I have outlined a different approach to addressing climate change, building on my earlier proposal for a "multitrack climate treaty system" (Barrett 2007b). I have provided more details about how the individual parts might be developed. I have also examined their interconnections, including their implications for managing climate change risk. I am not claiming here that my approach is ideal. Plainly, it is not. My proposal should be judged relative to the relevant alternatives. The alternatives that are relevant must, like my own proposal, be shown to be self-enforcing. Proposals that either ignore the need for enforcement, or that assume that enforcement will appear out of thin air, are not viable alternatives. They are, to my mind, fantasies.

There are two fundamental problems with the approach of controlling the aggregate of all gases and sectors. The first is that it undermines enforcement. The ability to enforce the entire regime is only as strong as its weakest part. Disaggregation ensures that the weakest part does not pull down the whole system. It also allows us to use different means to enforce different parts. We know this alternative approach could do better because we have seen it do better—the latest adjustment to the Montreal Protocol is proof. We also know that this approach could not do worse than the existing arrangement, since separate agreements for individual sectors and gases could be developed as supplements or additions to the approach tried thus far.

The second problem with this approach is that it ignores opportunities for reducing climate change risk. It focuses almost exclusively on the need to reduce emissions. Adaptation is also important. So, ultimately, may be geonengineering and air capture. We need a portfolio of approaches, one that changes the mix as we learn more about climate change and our ability to address it.

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