8 A portfolio system of climate treaties

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Introduction

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

This is a radically different concept from the arrangement developed thus far. Under the Kyoto Protocol, emission reduction obligations apply to entire economies, not to individual sectors; reforestation (which sequesters and therefore removes carbon dioxide or CO_2 from the atmosphere) is allowed to substitute for abatement (which reduces greenhouse gas [GHG] additions to the atmosphere, relative to "business as usual"); the emissions of different countries can be traded; and increases in the emission of one gas can be offset by reductions in the emission of another. This approach has one great virtue: it promotes cost-effective abatement.

Unfortunately, this approach has also (so far, at least) failed to address the more important objective, which is to reduce GHG emissions and ultimately to stabilize atmospheric concentrations. There may be different explanations for this. My diagnosis is that this failure is due to a lack of robust enforcement. So, why not add an enforcement capability? As I shall explain in this chapter, it may not be possible to enforce the current treaty design.[1] If enforcement is important—and I shall argue here that it is essential—then a better strategy may be to break up the problem, treating different sources and types of gases separately. This strategy may succeed better at reducing emissions overall.

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1 For a discussion of the possible trade off between cost-effectiveness and enforcement, see Barrett and Stavins (2003).

Of course, in breaking things up, cost-effectiveness may be compromised—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 is, by design, linear. 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; followed by another that 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 anthropogenic interference with the climate system."

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. Investments in R&D and emissions 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 GHG 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 policy 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," which involves the use of technologies for scattering solar radiation to counteract the effect of rising atmospheric GHG concentrations on the climate. Geoengineering has the potential to limit climate change risk, but its use will introduce new risks. We may therefore also want to reduce the risks associated with deploying geoengineering measures. One way to do this, of course, is to limit GHG concentrations so that geoengineering need never be attempted. However, it may not be possible to reduce the probability of abrupt and catastrophic climate change to zero. Another way to reduce risk is to develop the capability to reduce concentrations rapidly after geoengineering has been tried and found, possibly, to be wanting. We can potentially do this by means of another new technology: "air capture," which involves removing GHGs from the atmosphere directly. Finally, many of the approaches to reducing emissions entail risks of their own—examples include long-term storage of nuclear waste and long-term sequestration of CO_2 in underground geologic formations. The current regime does not provide a means for balancing these risks. To do that requires a *portfolio* of agreements.

These, then, are my three main conclusions: first, that a different treaty design, comprising a system of agreements, could potentially achieve greater emission reductions overall than the current design; second, that these individual agreements must be coordinated to promote cost-effectiveness; and third, that this coordination must also manage overall risk, by developing a portfolio of approaches to climate change. In short, and as the title of this chapter indicates, my proposal is for a portfolio system of climate treaties. Subsequent sections of this chapter develop the analysis behind these conclusions.

Overview

I begin with a critical review of the Kyoto Protocol. It may be widely believed today that Kyoto is inadequate and that there is no need, therefore, for further critiques. However, even if there were widespread agreement that Kyoto has failed, there may be many incompatible explanations for *why* it has failed. If we misunderstand the reasons for Kyoto's failure, we may end up repeating the same mistakes. In the next section of this chapter I argue that enforcement is the most essential challenge for an international climate agreement and that Kyoto's greatest flaw is that it lacks effective enforcement.

I am not alone in making this diagnosis. The most popular suggested remedy is to leave the basic architecture of Kyoto unchanged and to incorporate trade restrictions as the primary means for enforcement in a post-2012 agreement. In a later section I explain why this remedy may not work—and why a different architecture may work better.

The problem, as I see it, is that a treaty's architecture and its enforcement mechanism need to be *co-determined*. Not every desirable outcome can be enforced internationally. Kyoto's architecture may be commendable, provided enforcement can be assured. But if Kyoto's architecture makes enforcement difficult, then we may be better off using a different architecture—even one that would be theoretically inferior in a world in which enforcement was assured.

This chapter begins to outline an alternative architecture for a post-2012 agreement. The focus here is on the logic of negotiating sector-specific agreements rather than a single, all-encompassing, economy-wide agreement. Later sections extend this argument to propose having different agreements for different gases and return to the earlier topic of trade restrictions. I explain here that while trade restrictions may fail to enforce economy-wide targets of the type prescribed by Kyoto, they may be effective in enforcing sector- and gas-specific agreements.

To reduce emissions dramatically, new technologies are needed; and, to develop these new technologies, increased spending on R&D is needed. In the second half of this chapter I explain how R&D agreements should be structured, and how they ought to relate to other agreements within a broader system of agreements.

I then discuss other components of a portfolio system of agreements for limiting climate change risk, including adaptation, geoengineering, and air capture. The last section of the chapter concludes with some final thoughts.

Kyoto's enforcement challenge

The Framework Convention on Climate Change was negotiated years before Kyoto, but because it is linked to Kyoto, 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] The UNFCCC's framing of the challenge, thus, has not helped. Of course, from the perspective of the climate, only global emissions matter, and so there is a logic to expressing the collective goal in these terms. The problem is that this approach 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: its purpose was to establish 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 country- or source-specific emission limits. This is how Title IV of the US Clean Air Act Amendments of 1990 is designed. This law establishes a total cap on sulfur dioxide emissions for all large power plants in the United States (the initial cap was set to 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 sulfur dioxide allowances. 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, other features of the US sulfur dioxide program are more important. Participation in Title IV is mandatory 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 is successful because it is enforced centrally, by the US government.

[2] www.mofa.go.jp/announce/speech/un2008/un0810-2.html.
[3] See http://cdiac.ornl.gov/ftp/ndp030/global.1751_2005.ems.
[4] For a summary of the acid rain program, see www.epa.gov/airmarkets/progsregs/arp/index.html.
[5] See www.epa.gov/airmarkets/progress/docs/2006-ARP-Report.pdf, p. 11.

An international 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, states participate in a treaty (such as Kyoto) on a voluntary, not mandatory, basis. Customary law says that states must comply with their treaty obligations, but this does not create an incentive for compliance. It creates an incentive to negotiate obligations that countries will want to meet anyway, treaty or no treaty. If a treaty is to sustain international cooperation, it must create incentives for parties to comply. Of course, to be effective, it must also create incentives for states to participate.

Kyoto lacks both arrangements. It provides no incentive for participation, which explains why the United States is a non-party. It also provides no incentive for compliance, which is why Canada—a party to the Protocol— has declared that it will emit much more than allowed by Kyoto.

The problem is not with these 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 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 United States, 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 between actual emissions and its Kyoto limit of any country. Denmark is well off its individual target. However, thanks to the European "bubble" and substantial reductions by other EU member states (in part for reasons having nothing to do with their climate change policies), Spain and Denmark are not bound by their individual limits so long as the original fifteen members of the European Union meet their collective limit. Australia recently ratified the Kyoto Protocol, but because of the Protocol's provisions for land use, land-use change, and forestry (known to climate insiders as LULUCF), Australia is within its Kyoto limit and 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.

Trade restrictions in a post-2012 agreement?

President Sarkozy of France has suggested that trade restrictions be considered for enforcing a new international climate agreement. Nobel-prize-winning economist Joseph Stiglitz (2006) has likewise recommended this approach. Should it be used?[7]

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).

For example, leakage can be addressed by "border tax adjustments." Parties to a new treaty would agree to impose a tariff on imports from non-parties and give a rebate on exports to non-parties, where the tariff and rebate would equal the cost of meeting treaty obligations, as embodied in the price of traded goods. How would these values be determined? Calculating the emissions released in the manufacture of a particular 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 to the manufacturing process was generated). Cruder calculations might be contemplated (and most policy proposals have simplified the issue by focusing on the most trade-sensitive and energy-intensive sectors), but sector-specific taxes aimed at reducing leakage would also be hard to calculate.[8] Moreover, as trade restrictions became cruder, they would be less effective at reducing leakage.[9] Finally, crude border tax adjustments could serve as a disguise for protectionist measures.

[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] 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).

[8] For example, Hoel (1996) shows that there is no simple relationship between fossil-fuel intensity and the optimal sector-specific carbon tax.

[9] See Oliveira-Martins *et al.* (1992).

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 trade restrictions 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, trade restrictions would have to be severe. But the threat to impose them would also have to be credible. That is, participating countries would have to be better off imposing the punishment than not imposing it in a situation where participation is less than full. The reason this may not be credible is that trade restrictions harm the countries that impose them as well as those on the receiving end. Worse, punishments typically become less credible as they become more severe.[10]

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 United States 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 its economic development is the greater priority or that the rich countries are primarily responsible for the accumulation of GHGs to date? Trade restrictions that lack legitimacy may only spur retaliation—and lead to trade wars. Britain's efforts to bring the topic of climate change up for debate at the United Nations Security Council in 2007 hints at the reactions that might follow the inclusion of trade punishments in a climate change treaty. Countries without permanent representation on the Security Council 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 would seem possible if not likely.

[10] See Barrett (2005).

To be effective, trade restrictions would need to enforce compliance as well as participation. Otherwise, countries could participate and then choose not to comply to avoid both the trade restrictions and the need to reduce emissions. Will parties to a future climate treaty agree to this? Would Kyoto's current parties agree to trade restrictions as an enforcement mechanism when some of them are already at risk of not complying?

Finally, it cannot be assumed that every other aspect of a treaty would remain unaltered if trade restrictions were used for enforcement. Countries might insist that their obligations be weakened as the price for accepting trade restrictions. If so, then the adoption of trade restrictions will not have achieved very much.

I want to conclude here by saying that the case for (or against) incorporating trade restrictions is far from obvious. We have seen what happens when there is no enforcement mechanism—global emissions have kept on rising. But we haven't seen what happens if trade restrictions are used for this purpose. It might be that they will improve matters. It might be that they will make no difference. Or it might be that they will make matters worse—failing to help the climate while at the same time depriving countries of some of the gains from trade.

Indeed, I shall argue later that trade restrictions may be more helpful in enforcing a different kind of agreement—one that focuses on limiting the emissions of individual sectors rather than of whole economies.

The logic of sectoral agreements

Earlier I explained that it makes scientific but not political sense to limit global emissions. It makes scientific sense because only global emissions matter for the climate. It does not make political sense because there is no world government able to enforce a global limit. Now I want to extend this argument to say that it may not make political sense to limit emissions at the national level either. This is because national, economy-wide limits are difficult for a state to enforce. It is easier for states to enforce limits on the emissions of individual sectors.

Consider how states have chosen to implement Kyoto. No country has a single, economy-wide policy for meeting its Kyoto obligations, even though those obligations apply to entire economies. The European Union Emission Trading Scheme (EU ETS), for example, covers less than half of EU emissions.[11] Sweden arguably has the most well developed climate change policy of any country, but its approach involves both "sector integration" (every sector plays a part towards meeting the overall goal) and "sector responsibility" (different sectors have different obligations). In other words, 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]

To be sure, it is *feasible* to limit an economy's total emissions. Proposals in the United States for an upstream cap-and-trade program are economy-wide in their reach. However, other proposals in the United States target individual sectors (as was done in the previously mentioned Title IV program for sulfur dioxide emissions), and it is not obvious which type of proposal will eventually become law. A key issue is likely to be the possible vulnerability of trade-sensitive industries under an economy-wide cap. If firms that compete with US firms are based in countries that do not limit emissions, comparative advantage my shift towards these countries, harming the "competitiveness" of US companies. This means that the emissions of these other countries may increase as a consequence of the United States restricting its own emissions—a phenomenon known as "leakage." Concern about leakage is the reason that Sweden offers its energy-intensive industries relief from its carbon tax.

To be clear, an economy-wide policy would be cost-effective, but it would not be efficient from the perspective of a country acting to limit emissions unilaterally—not if leakage were significant.

Though Kyoto is an economy-wide agreement, it makes exceptions.

[11] It is worth noting that Title IV, discussed previously, is also a sectoral policy.

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

[13] The American Clean Energy and Security Act of 2009, which was approved by the United States House of Representatives, contains an economy-wide, cap-and-trade component, but also numerous sectoral policies, such as performance standards for new coal-fired power plants, investment in an electric vehicle infrastructure, efficiency standards for appliances, emission standards for automobiles, and so on.

It excludes emissions from aviation and marine transport. One reason 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)? 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.

Article 2.2 of the Kyoto Protocol says that emissions from aviation and marine transport should be reduced, but through arrangements made outside the Protocol, by the parties "working through the International Civil Aviation Organization and the International Maritime Organization, respectively." So far, parties to both organizations have failed to act, but the motivation for treating marine and aviation emissions outside of Kyoto remains compelling. These are international transportation *systems*. In systems it is imperative that 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 GHG emissions from their respective sectors.

For example, Farrell, Keith, and Corbett (2003) have suggested that marine transport may offer attractive opportunities for switching to hydrogen fuel. One reason for this is that ports are often located near refinery operations, where hydrogen is already produced and where cargo vessels already refuel. Such network effects have already transformed other aspects of ocean shipping, such as standards for oil tankers, which initially required separate oil and ballast water tanks but later evolved to require 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 are not powered by hydrogen. As more countries impose this standard, the incentives for others to do likewise would increase.

Notice that marine transport can be made carbon neutral in this way (assuming that hydrogen production is carbon-free) without needing to agree on an allocation of property rights. Even more importantly, so long as the network effects are strong, the arrangement described above will be self-enforcing. We have some assurance that this arrangement can work in the marine shipping context because it has worked to limit damage to the oceans from deliberate and accidental releases of oil.

The same logic can apply to those parts of the economy that *are* included under Kyoto emission caps, such as road transport. The economics of hydrogen for automobile transportation are currently unattractive because of the need to change 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. Plug-in hybrids are similar to hybrids on the road now insofar as 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 (which, given current battery technology, continues to suffer from restricted driving range between charges), plug-in hybrids can 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 extended travel in electric mode will also increase. Both of these developments will improve the economics of the all-electric car.

As with international marine and aviation transport, the road transportation systems of different (especially contiguous) countries must be compatible. Plug-in hybrids are compatible with existing infrastructure. Their use can spread to new geographic regions under current conditions. Wider adoption by more countries will allow economies of scale and learning to be exploited, helping to increase market penetration further. In short, the adoption of plug-in hybrid vehicles may spread without the need for international cooperation. By contrast, the all-electric vehicle may fail to take off without an international agreement. At minimum, an international agreement may be needed to facilitate the transition to an all-electric vehicle future.[14] Note as well that technical standards create an automatic trade restriction that is legal (so long as the standards are non-discriminatory) and easily administered. This also helps to encourage the proliferation of common standards. It is by this means that the catalytic converter coupled with the use of unleaded gasoline became a global standard.

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

Another sector excluded by Kyoto is deforestation. This is an important omission since deforestation is estimated to be responsible for around 18 percent of global GHG emissions (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 also good reasons why avoided deforestation was left out of the Kyoto Protocol in the first place. Forest loss is sometimes beyond the control of individual parties (as in the case of forest fires), the potential for leakage is huge, the benefits of avoided deforestation are reversible, and establishing a baseline for the purpose of calculating credits is fraught with difficulties. Policies to reduce deforestation are needed, but they will be imperfect.

Indeed, while afforestation and reforestation (tree planting, essentially) are counted by Kyoto, "trade" in forestry-based credits between developing (non-Annex I) countries and developed (Annex I) countries under the Clean Development Mechanism (CDM) has been very limited. So far, only one such project has been approved, and this project has been unable to find a buyer. As noted by Basu (2009: 146), "Because of their uncertain environmental value, forest-generated

[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 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 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."

credits are expected to fetch only \$4–\$5 apiece in the global markets, compared with the \$20–\$25 fetched by carbon credits from other offset schemes." The EU currently does not allow forestry credits such as these to be traded within its Emission Trading Scheme, thus voting with its feet, as it were, to ring-fence forestry, so as not to allow forestry activities to contaminate other efforts to reduce net emissions (other CDM projects are allowed).

To sum up this section, the Kyoto Protocol's limits are not truly economy-wide, and while there have been proposals to develop a more comprehensive agreement, there was a logic in the original design, which treated different sectors—notably marine and aviation transportation, and deforestation—differently. This logic could also be extended to other sectors that are presently included in Kyoto's emission caps. I take up the question of whether a more fragmented approach should substitute for a broader agreement, or be additional to a broader agreement, in a later section.

Separate agreements for different gases

The logic of breaking the global mitigation challenge up into pieces can also be extended to the different types of GHGs. Indeed, one of the six gases controlled by Kyoto has already been addressed under 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 concluded 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 GHG emissions by 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 hydrochlorofluorocarbons (HCFCs) was accelerated. HCFCs

[16] See Velders *et al.* (2007). Ozone-depleting substances also have a warming effect in the atmosphere, but so does stratospheric ozone itself and so do many of the substitutes for ozone-depleting substances.

are a category of GHGs, though they are not regulated by Kyoto (for the reason 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 GHG but *not* an ozone-depleting substance) *are* controlled by Kyoto. This new agreement thus adds to the Montreal Protocol's earlier achievement.

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

Why has the Montreal Protocol succeeded where the Kyoto Protocol has failed? An important reason is that climate change and ozone depletion are different problems. Ozone depletion threatens human health directly, and can be avoided at relatively low 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 the potential for emissions leakage through trade. 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 CDM; as discussed earlier, it lacks an enforcement mechanism.

The lesson is not that an international climate agreement ought to have the features of the Montreal Protocol. These are different problems; they will have different solutions. The lesson is that, by pooling all gases and sources together, Kyoto loses the leverage that can be brought to bear in controlling, in this instance, one type of GHG independently of others. Montreal has shown us that a different design would have achieved much more.

[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.

Sectoral agreements again

Although the Montreal Protocol's production and consumption limits are economy-wide, they are determined with a view to how individual sectors can substitute away from controlled chemicals, and they take into account the benefits to be derived from these changes. For example, the adjustments agreed in late 2007 were grounded in a very detailed analysis of individual sectors, including refrigeration and air conditioning, foams, medical aerosols, and fire protection.[18] The Technology and Economic Assessment Panel (TEAP) that advises parties to the Montreal Protocol includes members who are "influential in technical standards organizations, industry associations, and private and public regulatory authorities" (Anderson and Sarma 2002, p. 441). The members from environment ministries "use knowledge of emerging technology to time regulatory approval with commercialization," while industry experts are "influential in crafting regulatory incentives necessary to stimulate investment and rapidly achieve economies of scale" (Anderson and Sarma 2002, p. 441).

A consequence of this process is that, by the time treaty parties approve TEAP recommendations, the political, economic, and technical feasibility of their implementation is virtually assured. As explained by Parson (2002), Montreal's "success was not achieved by the control measures in the original treaty. Instead, it was achieved by rapid adaptation of the controls and the flood of innovations that followed. The protocol's novel process of assessing alternatives to ozone-depleting chemicals was central to this adaptation." Parson adds, "These linked processes of assessment, innovation, and diffusion were so powerful they almost made the regulations appear superfluous, as private reduction efforts stayed consistently ahead of regulatory requirements."

[18] Seehttp://ozone.unep.org/teap/Reports/TEAP_Reports/TEAP-TaskForce-HCFC-Aug2007.pdf.

For climate change, Parson suggests that more progress might be made if technology-based assessments were undertaken in key industrial sectors such as steel, smelting, chemicals, and pulp and paper, and in other areas that offer significant abatement potential, such as improving the fuel efficiency of vehicles; developing power-plant carbon capture and storage; and reducing industrial emissions of HFCs, perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

This process of technology assessment was made effective by structural features of the Montreal Protocol. Several of these features could—and, I would argue, should—feature in a new climate treaty regime.

First, a climate treaty's obligations, whether for an individual sector or a particular type of gas, should apply globally. Developing countries should not be exempted from meeting new global standards, as they were from reducing their emissions under Kyoto (though, as with the Montreal Protocol, it may be desirable in some cases to establish a different transition path for developing countries).

Second, developing countries should be offered financial assistance to reward their participation and 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 and complying as compared with an alternative scenario where the agreement did not exist. In contrast to Kyoto, payments would not be made for "hot air." Nor would surpluses be paid (as they are, except at the margin, under a trading system). This arrangement will lower the cost to rich countries of achieving emission reductions in poor countries and thus encourage greater action to limit emissions.

Third, trade restrictions should be used to enforce agreements for trade-sensitive sectors. Since developing countries would be compensated for participating in and complying with these agreements, and since the aim of the 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 of trade restrictions should also have a high chance of being credible, since parties to such sectoral agreements would not want non-parties to have an "unfair" advantage in international trade. Moreover, the trade-sensitive sectors are, by definition, especially vulnerable to leakage. Applying trade restrictions to non-parties would help to reduce leakage, thus making credible the threat to apply restrictions (Barrett 2005).

Finally, treaty obligations should be expressed in terms of consumption and not only production. Importing countries should agree to import only goods that were produced by methods that meet global standards. This measure reduces the market for non-participants and increases the market for participants. It thus encourages participation.

The aluminum sector is a prime candidate for a sectoral agreement.[19] 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 aluminum scrap, which is 95 percent less GHG-intensive than primary aluminum production. Finally, twenty-six companies, making up 80 percent of world output, belong to the International Aluminium Institute, which has already adopted voluntary energy intensity targets. There exists a basis here for negotiating new global standards for the industry, in a manner similar to the TEAP, 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—demonstrating the value, again, of technology assessment. 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 limit upstream emissions associated with electricity inputs to the production process. 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.[20] Other obvious candidates for sectoral agreements include steel and cement.[21]

A final question is whether sectoral and individual gas agreements should substitute for an economy-wide, multi-gas agreement or whether the different types of agreement should coincide. The latter possibility may be more cumbersome, but it has the advantage of being more evolutionary. Over time, we can shed the agreements that prove superfluous or ineffective.

[19] I am drawing here from the excellent study by Bradley *et al.* (2007), especially pp. 37–8.

[20] Watson *et al.* (2005) p. 12.

[21] Again, see Bradley *et al.* (2007).

R&D

An area where linkage is certainly needed concerns policies to reduce emissions and promote R&D.

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

Preferably, and as noted previously, the obligations expressed in a treaty should hold indefinitely and thus prevent backsliding. Future adjustments and amendments can ratchet up the actions required. It may be difficult for a climate treaty to do this if the goals are expressed as emission limits—in that case the question arises, would permanent limits be credible? It may be easier if goals are expressed in some other way—as technology standards, for instance. It is sometimes claimed that technology standards have the opposite problem of "locking in" a given level of performance. However, there is evidence to counter this claim. The oceans have been protected from oil releases by a succession of technology agreements, each one more demanding than the last.[22]

The Kyoto Protocol has the additional shortcoming that it 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, the production of 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 UNFCCC was adopted in 1992; it changed little after Kyoto was negotiated; and it has remained steady since Kyoto entered into force.[23] Kyoto's design does not promote R&D directly.

Failure to stimulate R&D makes long-term 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

[22] Barrett (2007a).
[23] See Doornbosch and Upton (2006).

change. Reducing emissions dramatically will require a technological revolution.

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 GHG emissions).

We know that the incentives to conduct research into nuclear fusion are strong, because countries have already cooperated in this research.[24] Fusion power, however, promises to yield benefits unrelated to climate change, in addition to climate benefits. The incentives to undertake R&D into carbon capture and storage, by contrast, 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 in turn on the strength of future incentives for countries to cut their GHG emissions (Barrett 2006). As noted previously, these incentives are likely to remain weak even with an international climate agreement unless a way can be found to address the enforcement challenge.

Electricity is not usually traded (that is, it is mostly generated in the country where it is consumed), and so the emissions from this sector cannot be controlled in the same way as emissions from sectors like aluminum and transport. This, of course, is another reason why it makes sense to break the larger problem up to accommodate 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. Recall that Title IV of the Clean Air Act Amendments of 1990, which limits power plant emissions of sulfur dioxide, was adopted as a US law. It was incorporated within a bilateral agreement with Canada, but only after being passed as domestic legislation. This law did not make any provision for trade restrictions because leakage was not a problem. Nor was free riding, because the domestic benefits of Title IV outweighed the costs.

[24] 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.

A climate change treaty requiring, say, that all new coal-fired power stations be fitted with carbon capture and storage would need to overcome free rider incentives.

How might this be done? One possibility is to make the policies of different 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 (this is because capture requires energy). It will never be something countries implement on a major scale unilaterally. A way must therefore be found to enforce participation in an agreement that mandates the use of this technology (or that prescribes emissions constraints 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 advance both carbon capture and geologic carbon storage. 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 storage. Because the benefits of this R&D lie entirely in supplying the global public good of climate-change mitigation, this research will need to be coordinated. Indeed, there is almost certainly a need for international cooperation in financing R&D in this area. The Carbon Sequestration Leadership Forum

(with twenty-one member states) is a "framework for international cooperation in research and development for the separation, capture, transportation and storage of carbon dioxide."[25] The Forum does not undertake R&D. Its purpose is to share information. About twenty large-scale carbon capture and sequestration demonstration projects are now being planned, but 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."[26] 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 and six other countries. Countries contribute to an effort like this when they benefit from the fruits of the 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 greater benefit when a country is engaged in complementary research programs. In these situations, other countries may free ride, but their free riding need not undermine the provision of knowledge-based public goods (Barrett 2007a). High participation levels are important only for agreements that aim to reduce emissions.

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, and they have incentives to adapt in *anticipation* of climate change, to insure against future damage.

[25] See www.cslforum.org/publications/documents/CSLFcharter.pdf.

[26] 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 www.nytimes.com/2008/01/31/business/31coal.html?ref=environment&pagewanted=all. Recently, the Obama adminstration reversed this decision.

In contrast to mitigation, the benefits of adaptation are excludable—they need not be shared with outside parties. Much adaptation will therefore be done "automatically" by the market. Much of the rest will require governments to invest in local public goods (such as augmenting the Thames Barrier), 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.

Mitigation will depend mostly on the efforts of the richest countries (not only as regards their own abatement but also their willingness to finance 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.

Compassion might move rich countries to offer assistance to the poor: 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 poor countries with adaptation. Article 3 of the UNFCCC 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 the obligation of rich countries to assist the poor. It established an adaptation fund, financed by a levy on CDM 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 the Kyoto Protocol, its obligation to assist developing countries (an obligation it accepted under the UNFCCC) cannot be fulfilled by the CDM. For all three reasons, a different approach is needed.

What 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 (CGIAR) 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 a mosquito is non-linear. Small changes in temperature can thus lead to large changes in malaria incidence.[27] Of course, even leaving direct climate-disease interactions aside, we can be sure that countries will be better able to adapt to the myriad impacts of climate change if they are relieved of their crushing disease burden. Much of this burden can be erased using existing medical products, but R&D into the tropical diseases has also been lacking. One way to help developing countries adapt is thus to invest in R&D on infectious diseases.

[27] 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.

The important design question is whether and how contributions to adaptation and R&D should be linked to other actions in the treaty system. Much future climate change can be attributed to historical emissions. Even more climate change will be due to future emissions. The more we succeed in reducing emissions, the less we will need to spend on adaptation. This suggests that a component of each country's contribution to adaptation should be linked to its role in reducing future emissions.

Geoengineering

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

There are many different ideas for how this might be done. The most prominent option involves throwing particles (sulfates or particles engineered specifically for this purpose) into the stratosphere. This would have a similar effect to 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. Putting large volumes of particles in the atmosphere 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 available option for lowering global temperature quickly. Reducing (net) GHG 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.[28]

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

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 discrete action—in other words, a number of countries could deploy this option 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 try geoengineering may be "too easy." Indeed, the international challenge is not to get countries to use geoengineering but to get them *not* to use it if other countries object.[29]

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

The situation in which "gradual" climate change is occurring is more complicated. William Cline (2007) has shown that the effects of gradual change on agriculture, within this century, are likely to be mixed. Some countries will probably lose substantially. In Cline's analysis, a "business as usual scenario" that leads to an increase in mean global temperature of 3 degrees Celsius by around the year 2080 causes India's agricultural capacity to fall by nearly one-third. This is a huge loss for a country where many 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 7 percent. In Russia it rises 6 percent; in the United States, 8 percent. The overall or aggregate effect of climate change in 2080 is small—global agricultural capacity falls by only

[29] For a discussion of this challenge, see Barrett (2008a). An anonymous referee suggested that an expectation that geoengineering could stimulate conflict may create an additional motivation for states to reduce their emissions. Others have suggested the opposite—that the possibility of geoengineering reduces the incentive for states to cut their emissions.

about 3 percent, an amount so small as to be within the "noise" given the uncertainty in these estimates and the number of things that can change over a period of 75 years. What stands out is the variation of impacts across countries.

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

What else to do now? R&D in the area of geoengineering is certainly needed—to explore whether this approach is likely to work, how it should be deployed, and what the harmful consequences may be. Because individual countries may have the incentive to deploy geoengineering, they have an incentive to undertake related R&D unilaterally. However, because the consequences of geoengineering would be global, my view is that R&D on this option should be undertaken cooperatively and openly.

Air capture

Of course, R&D cannot tell us everything we need to know about geoengineering—only after this option were used at scale and over a sustained period of time would we 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 geoengineering works and does not result in serious adverse consequences. Then we can continue to use it. Suppose, however, that we discover geoengineering is effective 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 GHG concentrations, so that we can slowly wean

ourselves away from geoengineering. We could do this more quickly and at lower cost if we invest much earlier in R&D to advance new low-carbon technologies. Even so, however, reducing GHG emissions is a slow way to reduce atmospheric concentrations.

A faster approach is "air capture." This involves removing CO_2 directly from the air. Of course, the process of photosynthesis does this naturally, 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 attempting ocean fertilization on a large scale—in fact, parties to the London Convention, an international treaty for the protection of the oceans, recently cautioned against large-scale experiments of this kind.[30]

Industrial air capture involves bringing air into contact with a chemical "sorbent"—an alkaline liquid that would absorb the CO_2 in the air. The CO_2 could then 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 and would offer the fastest way to reduce atmospheric concentrations.

Air capture is also extremely expensive, however. 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

[30] In 2007, the eighty-four 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 parties to the UNFCCC. Restricting ocean fertilization may be to the benefit of the oceans, which are the primary concern of parties to the London Convention. However, the choice is not whether 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 could have been avoided by implementing ocean fertilization. The parties to the Framework Convention must surely play a role in making this judgment.

situation that is most likely to arise when the case for implementing geoengineering is also strong and when air capture can be deployed to directly reduce atmospheric GHG concentrations so that geoengineering interventions can be scaled back or stopped. Currently, our knowledge of this technology is in its infancy. R&D should be undertaken now to develop air capture and lower its costs, so that we will be ready to deploy this technology should we feel the need to do so in the future.[31]

Conclusions

In this chapter 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 of such a treaty system might be developed and I have examined their potential 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 viable alternatives. In making this comparison, it is essential that the alternatives 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, do not offer viable alternatives.

There are two fundamental problems with the approach taken so far to reduce GHG emissions. The first is that it lacks an effective enforcement mechanism. The approach outlined here 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 the approach taken thus far is that it largely neglects other opportunities for reducing climate change risk.

[31] 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."

Adaptation is also important. So, ultimately, may be geoengineering and air capture. We need a portfolio of approaches, one that allows for changes in the mix of measures used to manage climate change as we learn more about the problem and our ability to address it.

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PART II

Negotiation, assessment, and compliance