
APPENDICES

Appendix A

Four Big Uncertainties

This appendix summarizes four major uncertainties in the realm of climate change. The purpose is not to question calls to action but rather to recite these uncertainties in order to argue that “policy autopilot” would be a mistake. Climate change may prove more or less severe than contemporary estimates, damages could be inflicted in unexpected ways or on unsuspecting locations, and technology might or might not ride to the rescue.

Reaching agreement on a collective action plan and assigning targets to the principal emitting countries will be difficult. The corresponding temptation may be to engrave the agreed-upon plan in stone, making future amendments difficult. But scientific and economic uncertainties require a flexible approach and room for periodic revision—for example, requiring a consensus among the principal emitting nations to renew the original action plan every decade.

On the other hand, trading system rules with respect to climate change measures should be designed for the long haul. The key rules should accommodate a wide range of climate outcomes and mitigation measures while preserving the basic precepts of national treatment, most favored nation treatment, subsidy disciplines, and the legal stability of commercial relations.

Average Temperature Projections

Al Gore’s movie *An Inconvenient Truth* in 2006 became an amazing box office hit, attracting enormous public attention to the dangers of climate

change. Contributing to the movie's success were striking images that showed, for example, shrinking ice and snow on Mount Kilimanjaro and in Glacier National Park, and the famous "hockey stick" chart of Northern Hemisphere temperatures over the past thousand years.

In its Fourth Assessment Report (IPCC AR4), issued in 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that the average temperature of the Earth's surface has definitely warmed: The observed surface temperature has increased by about 0.74°C (Celsius) over the past hundred years, with most of the increase occurring over the last three decades. The IPCC stated that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."¹ According to the IPCC AR4, global average sea level rose at an average rate of 1.9 millimeters per year over four decades between 1961 and 2003 and 3.1 millimeters per year over the decade between 1993 and 2003. Satellite data show a 2.7 percent decrease per decade in annual average Arctic Sea ice extent.

Under various emissions scenarios and different assumptions, future global warming is widely predicted. William Cline (1992) summarized climate change projections made by three teams of well-known modelers—Nordhaus-Yohe, Reilly-Edmonds, and Manne-Richels²—and found that those models were surprisingly close. Subsequent estimates are often very similar as well. Virtually all studies point to global warming trends.

The IPCC (2007a) estimated that the Earth's average temperature would increase by 2°C to 6°C and that the sea level would rise by 0.18 meters to 0.60 meters by 2100, relative to 1980–90.³ The IPCC also raised its estimated range of "climate sensitivity" to 2°C to 4.5°C, with a best estimate of about 3°C.⁴ The previous range of climate sensitivity, reported in the 1990 IPCC report, was the range of 1.5°C to 4.5°C, with a best estimate of 2.5°C.

Other recent studies have predicted similar changes in global tem-

1. Using expert judgment, the following terms have been used in the IPCC AR4 to indicate the assessed likelihood of an outcome or a result: virtually certain >99 percent probability of occurrence; extremely likely >95 percent; very likely >90 percent; likely >66 percent; more likely than not >50 percent; unlikely <33 percent; very unlikely <10 percent; and extremely unlikely <5 percent. For more details, see IPCC (2007a).

2. Data of those three models are specified at sensitivity 2.5, which was a best estimate of the IPCC report at the time.

3. The IPCC has devised scenarios that are called the "Emission Scenarios of the IPCC Special Report on Emission Scenarios." Each scenario starts with a different future emissions range, depending on demographic, technological, and economic developments.

4. "Climate sensitivity" is an important concept in climate change modeling: It measures how the climate system responds to sustained radiative forcing, defined as the equilibrium global average surface warming following a doubling of CO₂ concentrations.

perature.⁵ CO₂ abundances rose to about 380 parts per million (ppm) in 2005 compared with about 280 ppm in preindustrial periods (around 1750). The predictions commonly assume that, in the absence of action, the level of greenhouse gas concentrations will reach 550 ppm by 2050, almost double preindustrial levels. In turn, the models predict that this will commit the Earth's average temperature to a rise in the range of 2°C to 5°C. Dr. James Hansen, director of the NASA Goddard Institute for Space Studies, claimed that the goal of keeping global warming less than 2°C, which is often adopted by other studies, is “a recipe for global disaster,” not “salvation,” and that our planet is near a “tipping point” at which greenhouse gases reach a level where major climate changes can proceed mostly under their own momentum, without adding more greenhouse gas emissions. The safe level of atmospheric CO₂, according to Hansen, is no more than 350 ppm, a figure slightly below the 2005 level.⁶

Despite the reigning consensus and Hansen's more alarming views, it would be a mistake to think that the scientific debate has been settled. To illustrate how scientific opinion can change, it is worth recalling the views of a few decades ago, when respected scientists were forecasting an episode of global cooling. In reviewing the earlier literature on climate change, Thomas C. Peterson, William M. Connolley, and John Fleck (2008) note that in the 1970s there was widespread concern about global cooling (escalating to fears of another ice age), prompted by a temperature drop in the 1950s and 1960s in the Northern Hemisphere. One of the articles they reviewed is a 1971 paper by S. Ichtiaque Rasool and Stephen H. Schneider that suggested that the increase by a factor of four in global aerosol concentrations could be enough to trigger an ice age and that the cooling effect by the dirty air could outweigh the warming effect of carbon dioxide.⁷

A *Newsweek* article in 1975 brought the global cooling debate to public attention, citing the work of respected climatologists and meteorologists. The article conveyed a similar tone to contemporary popular articles on global warming, quoting scientists who warned that global cooling could lead to major climatic changes and cause local weather extremes that could

5. Stern (2006) summarized some studies on temperature projections at different stabilization levels (parts per million). Ranges of temperature increase at the stabilization level of 550 ppm CO₂e are 1.5°C to 4.4°C, 2.4°C to 5.3°C, and 1.2°C to 9.1°C (some 11 studies).

6. See Dr. James Hansen, “Global Warming Twenty Years Later: Tipping Points Near,” briefing before the US House of Representatives Select Committee on Energy Independence and Global Warming, June 2008, available at www.columbia.edu.

7. Peterson, Connolley, and Fleck (2008) note that Rasool and Schneider's paper received a lot of criticism at the time for overestimating cooling while underestimating greenhouse warming and that Rasool and Schneider acknowledged flaws in subsequent papers. For more details, see Peterson, Connolley, and Fleck (2008), who also listed other cooling papers by McCormick and Ludwig in 1967, Barrett in 1971, Hamilton and Seliga in 1972, Chýlek and Coakley in 1974, Bryson and Dittberner in 1976, and Twomey in 1977.

severely diminish food supplies, which in turn would force economic and social adjustments on a global scale. *Newsweek* added that scientists were very pessimistic that the government would take appropriate action.⁸

In light of current scientific knowledge, the global cooling forecasts can be faulted for inadequate evidence and primitive models. Peterson, Connolley, and Fleck (2008) described the “myth” propounded by the 1970s studies on global cooling by saying that “...when climate researcher Reid Bryson stood before the members of the American Association for the Advancement of Science in December 1972, his description of the state of scientists’ understanding of climate change sounded very much like the old story about the group of blind men trying to describe an elephant.”

But if climate is an elephant and scientists in the 1970s were blind men, how can we be so sure that today’s scientists will not be faulted by their successors? Writing in the *Washington Post* in 2003, James Schlesinger, former US secretary of defense, secretary of energy, and director of the CIA, pointed out that only slow progress has been made in understanding the underlying science, even though many scientists feel pretty certain about the causes, effects, and extent of climate change.⁹

The reason the debate continues is that climate change entails very complex calculations, covering many factors that are hard to measure, hard to forecast, and often interact with one another. For example, some observers argue that there has not been much increase in temperature since 1998, when the El Niño warmed the globe. Some scientists found that natural climate variability can mask the global warming effect of greenhouse gases and that a simulation that looks into a short period—one or two decades into the future—forecasts short-term cooling effects in some regions in the next decade. Such effects may override the long-term contribution of rising greenhouse gases. For example, temperatures may rise or fall due to variation in the Gulf Stream, even in the absence of human interference (Kerr 2008, 595).

The brief review indicates that climate change skepticism has not disappeared, even though some of the debate has moved underground.¹⁰ In

8. The article also acknowledged uncertainties arising from gaps in the scientific evidence. See “The Cooling World,” *Newsweek*, April 28, 1975, www.washingtontimes.com (accessed on January 12, 2009).

9. See James Schlesinger, “Climate Change: The Science Isn’t Settled,” *Washington Post*, July 3, 2003, A17, www.washingtonpost.com (accessed on January 12, 2009).

10. An example is the Petition Project run by the Oregon Institute of Science and Medicine, which released a signatory list of knowledgeable persons who reject the assertion that global warming has reached a crisis stage or that it is caused by human activity. The current list includes 31,072 Americans with college degrees in science, including 9,021 with PhD degrees in various scientific fields. For more details, visit the Petition Project website at www.petitionproject.org (accessed on January 12, 2009).

our view, an upward trajectory of average temperatures on account of rising greenhouse gas concentrations is the most certain of our “four uncertainties.” That said, we do not subscribe to the view that the debate has been settled or that mitigation targets agreed to at the Copenhagen conference in 2009 will necessarily seem appropriate in 2019.

Projections of Extreme Events

Extremes are characteristic of the climate system. Two recent extreme weather events raised popular awareness of this basic fact. In 2003 Europe was hit by a wave of unusually hot days that caused about 20,000 deaths.¹¹ In August 2005 Hurricane Katrina devastated areas along the north-central coast of the Gulf of Mexico, causing a reported \$125 billion in economic losses, more than 1,300 deaths, and temporary displacement of millions of people.¹² These two events symbolize the scary climate change scenarios emphasized in reputable studies, including the Stern Review (Stern 2006) and the IPCC AR4: that extreme events are likely to be more intense, more frequent, and longer lasting. In turn, this is the peg for advocating bold if costly action against greenhouse gas emissions as a “global insurance payment.” In the absence of concerted greenhouse gas control measures, it is said, extreme weather events, triggered by the rise in average temperatures, may inflict enormous damage. If the risk of these events and the associated damage can be mitigated at the cost of a few percent of GDP, the reasoning goes, then it makes eminent sense to spend that money, just like insuring against more common hazards such as fire.¹³

Again, despite the prevailing consensus, it remains a major uncertainty whether rising average temperatures will increase the frequency and intensity of extreme events. To be sure, there is strong evidence of a causal connection. According to a recent study of US weather by the US Climate Change Science Program (2008), conducted under the auspices of the National Oceanic and Atmospheric Administration, extreme precipitation, defined as the heaviest 1 percent of daily precipitation totals, increased by 20 percent over the past century while total precipitation increased by only 7 percent. The study also found a strong connection over the past 50 years between tropical Atlantic Sea surface temperatures and Atlantic hurricane activity. Extrapolating from these observations, extreme episodes such as hot days, heavy precipitation, droughts, and storms may become more frequent and intense as average temperature rises.

11. For more details, see Munich Re (2004).

12. For more details, see Munich Re (2006).

13. As a matter of comparison, in the United States, net written premiums for property and casualty insurance were about \$430 billion, about 3.5 percent of GDP in 2005. For more details, see US Census Bureau (2007).

In the same spirit, the IPCC (2007b) analyzed more than 29,000 observational data series from 75 studies covering physical phenomena (snow, ice, frozen ground, hydrology, and coastal processes) and biological systems (territorial, marine, and freshwater biological systems). The IPCC found that about 90 percent of data series are consistent with the direction of change expected as a response to average warming. Moreover, based on a range of models, the IPCC AR4 projected that it is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent and that it is likely that future tropical cyclones will become more intense, with larger peak wind speeds and heavier precipitation associated with ongoing increases of tropical sea surface temperatures (IPCC 2007a).

Even so, many scientists are reluctant to bet on extreme weather events. Using a new method of computer modeling in a recent study, well-known hurricane scientists Kerry Emanuel, Raghoth Sundararajan, and John Williams (2008) found that hurricane frequency and intensity may not substantially rise during the next two centuries even with a dramatic increase in the global average temperature. Emanuel and his colleagues argued that while global warming may raise the intensity of hurricanes, other factors are likely to moderate the impact. The new results were striking not only to other scientists but also to Emanuel himself, who had previously argued the link between global warming and stronger hurricanes. Moreover, the new results contrast with earlier studies conducted by his MIT team, which were popularly cited by Al Gore. As Emanuel noted on his website, reliable records of wind speeds in hurricanes over the open ocean go back only to around 1950, and the lack of reliable data, among other unknowns, amplifies the uncertainty of projecting future weather events.¹⁴ Even Stern (2006) and IPCC (2007a), which both project more frequent and intense extreme weather events as a general tendency, note that some regions may experience fewer tropical cyclones due to the increased stability of the tropical troposphere in a warmer climate.

In our view, extreme weather events amount to a reasonable forecast, but one characterized by large error bars. The insurance argument warrants concerted collective action; however, given the current level of uncertainty, we question whether the argument can be pushed to the point of justifying extreme measures. To be specific, while costs of 1 or 2 percent of world GDP may well be justified as an insurance premium (around \$540 billion to \$1.1 trillion annually),¹⁵ we do not think that the world trading system should be sacrificed as part of the payment.

14. See Kerry Emanuel's website at <http://wind.mit.edu/~emanuel/anthro2.htm>.

15. Based on total global GDP in 2007 (IMF 2008b).

Mitigation Costs

If extreme weather events do visit planet Earth with greater frequency, the consequences of climate change could be catastrophic, sparking mass population movements, huge levels of mortality, and large economic costs. The “catastrophic tail” of climate change outcomes has in turn prompted calls for immediate collective action. Many argue that early action at relatively small costs is like a public insurance premium against the risk of enormous future losses. As already said, we can only agree with this proposition. But how large is the insurance premium? This is our third uncertainty.¹⁶

After examining several leading models available in the late 1980s and early 1990s, Cline (1992) estimated that a carbon reduction of 50 percent from his baseline in 2050 would require a cost of about 2 percent of GNP in that year.¹⁷ As a mid-range estimate, Cline’s figure has stood up remarkably well. The IPCC (2007c) estimated that, to stabilize greenhouse gas concentrations between 710 ppm and 445 ppm CO₂e by 2050, the annual cost in 2050 would fall in the range of a net gain of 1 percent to a cost of 5.5 percent of global GDP. Stern (2006) placed the annual cost of stabilizing greenhouse gas concentrations at 550 ppm CO₂e by 2050 in the range of a net gain of 1 percent to a cost of 3.5 percent of global GDP, with a central estimated cost of around 1 percent in 2050. Recently, Stern increased his central average estimate from a cost of about 1 percent to a cost of about 2 percent of global GDP annually.¹⁸ Obviously, if the goal is to stabilize CO₂ concentrations at the current level of around 350 ppm, as urged by Hansen in his briefing before the House, the costs would be much higher, but we cannot cite a responsible estimate.¹⁹

16. For the understanding of readers, it is worth noting that targets for reducing emissions are usually set relative to a base year (commonly relative to 1990 or 2005), referred to as the baseline. Estimates of mitigation costs are often shown as a percentage of the target year’s projected GDP, unless another year is specified. For example, suppose it is asserted that, in 2030, the world should reduce its emissions by 30 percent from the baseline and that this will cost about 1 percent of global GDP. The 1 percent figure usually means 1 percent of global projected GDP in 2030.

17. Cline estimated a baseline of global carbon emissions rising from 5.6 GtC (billion tons of carbon) in 1990 to a range of 15 GtC to 27 GtC in 2100. There are two models broadly used to examine the cost of abatement: top-down and bottom-up. Top-down models use macroeconomic theory and econometric techniques to calculate economic costs. The 2 percent of GNP figure is based on a top-down model. Bottom-up models examine the characteristics of specific activities and processes, considering technological, engineering, and cost details. Based on a bottom-up model, a carbon reduction of 50 percent from his baseline in 2050 would require a cost of about 1.6 percent of GNP in that year.

18. Remarks by Lord Nicholas Stern at the Third Richard H. Sabot Lecture, Center for Global Development, June 26, 2008. See <http://blogs.cgdev.org/globaldevelopment> (accessed on January 12, 2009).

19. See footnote 6.

Differences in assumed technology pathways are a major reason for the wide range in cost estimates for stabilizing CO₂e at a level around 550 ppm. As mentioned, some estimates even contemplate net gains from liming greenhouse gas emissions. The technologies considered are either known or around the corner²⁰—both are considered in the next section along with “over-the-horizon” technologies.

McKinsey & Company (2008) introduced the concept of “carbon-productivity” in a study that stressed that any action on climate change should pursue two objectives: stabilizing greenhouse gases and sustaining economic growth. To help evaluate success in achieving both goals, carbon productivity measures the amount of GDP produced per unit of CO₂e emitted. According to McKinsey, this factor should increase tenfold by 2050—from about \$740 GDP per ton of CO₂e today to \$7,300 GDP per ton of CO₂e (in constant dollars). McKinsey argues that the annual macroeconomic costs for this degree of enhancement in carbon productivity are likely to be manageable, on the order of 0.6 to 1.4 percent of global GDP by 2030.²¹

Other studies, which strongly emphasize new technologies in the spirit of McKinsey, go so far as to suggest that significant emissions reductions can be achieved for free. They argue that, by investing in low-carbon and efficient means of producing energy, countries can generate huge “negative costs” to offset positive abatement costs. If large enough, the negative costs can, theoretically, produce the sort of net gains referenced at the outset of this section. Negative costs reflect the proposition that certain investments in energy efficiency could have positive returns regardless of the carbon impact. They are calculated by reference to alternative ways of producing or consuming a given amount of energy. For example, they assume that if companies redirect their investment from building coal power plants to building nuclear power plants, which are both cleaner and more energy efficient, then the companies will enjoy positive returns on their investment. This switch results in negative costs that offset positive abatement costs. In an earlier study by McKinsey (2007), for example, the United States is projected to achieve 40 percent of its abatement at “negative” marginal costs.

These are alluring estimates, but some scholars have questioned the

20. In a 2008 article in the *Wall Street Journal*, Bjorn Lomborg, a director of Copenhagen Consensus and also the author of the best-selling and controversial book *The Skeptical Environmentalists*, argued that many of the technologies currently discussed do not exist and that existing technologies are very expensive. According to Lomborg, policy focusing solely on mitigating emissions can only yield a small benefit at a high expense. Investing in clean energy would yield better results. See Bjorn Lomborg, “How to Get the Biggest Bang for 10 Billion Bucks,” *Wall Street Journal*, July 28, 2008, A15, <http://s.wsj.net> (accessed on January 12, 2009).

21. The annual cost is expressed as a percentage of each year’s projected global GDP.

concept of negative costs. Lawrence J. Makovich (2008) argued that such estimates reflect a seriously flawed hypothesis and, as a result, the projected costs are much too low. He argued that the logic of negative costs does not hold up in the context of an efficient market for allocating capital. Negative cost studies assume positive returns for the cleaner and more efficient energy investment. However, not all the investments with positive returns get done, owing to the scarcity of capital. An investment that might reduce greenhouse gas emissions and has a positive financial return, but does not make the cut in the marketplace and can only be undertaken with public assistance, has a net positive cost in opportunity cost terms (Makovich 2008).

In our view, an emphasis on negative costs conveys the wrong impression that greenhouse gas abatement can be done on the cheap. In turn, we think both proponents and opponents are misled. Proponents of bold action tend to say, “this won’t cost much, so let’s get started.” Opponents say, “wait a minute, let’s invest in technology for the next decade.” In our view, both conclusions are wrong. Forceful action will be costly; it will hurt. But postponing action will likely delay the search for “carbon productivity” technologies because the price signals will not be strong enough.

We draw three conclusions from this survey. First, the range between the low cost and the high cost for the “consensus” CO₂e target—namely, stabilized at 550 ppm in 2050—is at least a factor of two. At today’s world GDP, each 1 percent of GDP amounts to about \$540 billion, so the difference between a 1 percent “global insurance premium” and a 2 percent “premium” amounts to at least \$540 billion annually.²² This is no small amount. Just for perspective, the net amount of bilateral and multilateral official development assistance to developing countries was about \$100 billion in 2006.²³ Second, since the requisite CO₂e stabilization target is still a matter of debate, the cost range is substantially larger than a factor of two. Third, carbon productivity technologies are vital, just to keep costs bearable, but we are very skeptical that a free lunch will be found in emissions controls.

Technological Fixes

Will technology deliver a silver bullet to defeat climate change? Perhaps. But the International Energy Agency (IEA 2008a) observes that public- and private-sector spending on energy research, development, and deployment (RD&D) has decreased since the 1980s and now remains at a relatively low level. Even so, optimism as regards technology holds great appeal, since it promises huge reductions both in greenhouse gas emissions and costs.

22. Total world GDP in 2007 was about \$54,312 billion (IMF 2008b).

23. For more details, see UNCTAD (2008).

However, the cost studies already cited typically take into account technology options that either exist today or seem to be around the corner. In other words, only a wild optimist can envisage stabilizing greenhouse gas concentration at low or zero cost. Technology options popularly discussed include carbon (or carbon dioxide) capture and storage (CCS), nuclear power, hydrogen for heat and transport fuels, electric and hybrid cars, biofuels, and wind, solar, and tidal energy. Some of these options have a great potential to reduce carbon emissions. In some cases, the main question is whether public resistance can be overcome; in most cases, the question is whether economic incentives will be sufficient to put new technologies to work.

CCS has gained the most attention, given booming demand for coal-fired power stations.²⁴ In a special report, the IPCC (2005) estimated that a power plant with CCS could reduce CO₂ emissions by up to 90 percent. In most scenarios for stabilizing greenhouse gases at levels between 450 ppm and 750 ppm CO₂, the contribution of CCS accounts for 15 to 55 percent of the cumulative global mitigation effort, at least until 2100. Stern (2006) estimated that, without CCS, marginal abatement costs would rise from \$25 to \$43 per ton in Europe, and from \$25 to \$40 per ton in China, while global emissions would be 10 to 14 percent higher.

Uncertainty over Future Carbon Prices

Since private firms only invest in hopes of a return, and since the benefits of new technology are seldom captured in their entirety by the original investor, various policy measures are contemplated to furnish economic incentives for creating and implementing new technology. Popular measures point to a combination of subsidies for alternative energy sources and permits or taxes to boost the cost of carbon emissions. To be sure, rising oil prices also help, but they are not directly correlated with CO₂ emissions. A higher price for oil reduces energy consumption and encourages cleaner substitutes, but it also encourages the use of coal, which emits considerably more CO₂ per megawatt of power.

A favorite answer to the coal emission problem is CCS, either mandated, subsidized, or inspired by CO₂ limits. The IPCC (2005) has estimated the costs of CCS in a wide range from zero to around \$270 per ton of CO₂, depending on the fuel, location, and type of power plant. The IPCC has also suggested that CCS systems will begin to be widely deployed when

24. CCS refers to carbon dioxide as well as carbon capture and storage (or sequestration) because the capture schemes generally apply to CO₂, not pure carbon. CCS entails the separation of CO₂ from energy sources, transporting the CO₂, and storing it in a fashion that does not leak into the atmosphere. CCS has gained considerable attention for two reasons: first, because the component technologies to carry it out now exist; and second, because the use of coal, which is abundant and relatively cheap, will likely increase to meet world energy demands.

CO₂ emission prices reach about \$25 to \$30 per ton (either through taxes or tradable permits). A team from the Massachusetts Institute of Technology (2007) offers a similar estimate.²⁵ As the CCS story illustrates, the speed at which technology to reduce greenhouse gas emissions is adopted will be significantly determined by the level of CO₂ emission prices or by the public provision of subsidies.

The deployment of new technology often requires major long-term investment in infrastructure. For example, an integrated CCS system requires pipelines for transporting and facilities for storing CO₂. In the case of wind and solar power, while the technologies are already in use, little progress has been made in improving the US grid for transmitting wind and solar energy (Kopp 2008). Testifying before the Senate Homeland Security and Government Affairs Committee on July 22, 2008, Texas oil mogul T. Boone Pickens claimed that installing wind farms and solar power facilities in the midwest could produce about 20 percent of electricity consumed domestically.²⁶ He asked Congress to at least clear the path for the private sector to invest money to build a grid.

Some technology options involve safety issues. In the case of CCS, high pressure transport and safe storage of CO₂ are the main concerns. Safety issues are more acute for nuclear power. The International Energy Agency (IEA 2008a) suggested that 30 percent of global energy demand needs to be met from nuclear sources. However, a large swath of the public opposes nuclear power for a variety of reasons, and bureaucratic obstacles to building new plants, both at a federal and local level, are correspondingly severe.

Biofuels are a good example. Biofuels have gained attention both as an alternative energy source and as a means of cutting carbon emissions. Many countries have jumped on the biofuel bandwagon—notably Brazil (the pioneer), the United States, and the European Union. However, studies now find that the increase in biofuel production contributes to rising food prices, while the net reduction in CO₂ emissions may be modest. The biggest proponents of biofuels are no longer climate change experts but rather agricultural land owners. Appendix B examines issues in the biofuels debate.

“Over the Horizon” Technology and Side Effects

“Geoengineering” ideas have been advanced as one means of preventing global warming. In the context of climate change, geoengineering

25. Both the IPCC and the MIT acknowledge that their estimates of CCS costs are uncertain.

26. See Suzannes Gamboa, “Texas Oilman: Clear Path for Wind Power,” Associated Press, July 22, 2008, www.foxnews.com. For more information about the “Pickens Plan,” see www.pickensplan.com (by subscription only).

encompasses techniques to reduce atmospheric absorption of incoming solar radiation by various schemes: injecting particles of sulfur into the stratosphere; blasting clouds with chemicals; spreading iron fillings on the ocean surface to nurture plankton and sequester carbon dioxide; and installing orbital mirrors in space to reflect solar radiation. An attraction of geoengineering is its relatively cheap cost, compared with conventional means of reducing greenhouse gas emissions.²⁷ But many scientists warn that attempts to engineer the planet may cause unforeseen negative impacts both on the environment and on human health. For example, large-scale iron seeding in the ocean, or injecting particles in the atmosphere, may alter complex biological and geological processes, contribute to ozone depletion, and worsen ultraviolet levels on the Earth's surface.²⁸

Based on this survey, it appears that technology will deliver higher carbon productivity, but the pace of improvement will critically depend on the path of carbon prices, the size of government subsidies, and the severity of public mandates. To a modest extent, therefore, higher mitigation costs will self-correct by inspiring faster creation and implementation of new technology. However, we are very skeptical that new technology will deliver anything resembling a free lunch for greenhouse gas mitigation. Indeed, since most of the cost mitigation studies already assume brisk improvement of carbon productivity, we believe that the current cost estimates for mitigation in the more distant future (e.g., 2 percent of world GDP in 2030) are probably on the low side. However, we do not dismiss the prospect of geoengineering solutions, especially if extreme weather frequently visits the planet.

Conclusion

What do we conclude from these four uncertainties?

- The likelihood of a persistent rise in global average temperatures seems very high.
- Large error bands need to be placed around contemporary forecasts of extreme weather events, the calculations of future mitigation costs, and speculation about new technology “around the corner” or “over the horizon.”

27. There was considerable interest in these ideas in 2006, when atmospheric scientist Paul Crutzen, the 1995 Nobel Laureate in Chemistry, raised the possibility that releasing sulfurous debris into the atmosphere may create some cooling effects. See Bryan Walsh, “Geoengineering,” *Time*, March 12, 2008, www.time.com (accessed on January 12, 2009).

28. See Pat Mooney, “Global Warming: The Quick Fix Is In,” *Foreign Policy in Focus*, February 21, 2007, www.fpif.org (accessed on January 12, 2009).

- A plan for concerted collective action that assigns targets to the principal emitting countries should be reached at the Copenhagen conference in 2009. However, the Copenhagen action plan should build in ample room for future amendments, depending on the evolution of the Earth's climate, and on the successes, failures, and costs of meeting agreed-upon targets.
- Finally, new trading system rules should be designed both to accommodate climate mitigation measures that will be shaped and reshaped over the next several decades and to preserve the basic values of the trading system.

Appendix B

Will Biofuels Save Energy and Reduce CO₂ Emissions?

Biofuels clearly have a downside. Studies reported that soaring food prices in 2007 and early 2008 were strongly connected with the expansion of biofuel production. The International Monetary Fund (IMF 2008a) calculated that biofuel production had diverted 20 to 50 percent of feedstocks from food to biofuels, with a substantial impact on food prices. Citing a confidential World Bank report, the *Guardian* reported that biofuels have forced global food prices up by 75 percent.¹ In April 2008 UN special rapporteur Jean Ziegler strongly condemned the United States and the European Union for taking a “criminal path” by contributing to an explosive rise in global food prices through the use of food crops to produce biofuels.²

According to the Organization for Economic Cooperation and Development (OECD 2008), global production of biofuels amounts to about 62 billion liters, which equals about 2 percent of total global transport fuel consumption in energy terms. The world’s largest producers of biofuels are the United States, Brazil, and the European Union, but new players such as Canada, China, India, and Indonesia are jumping into the game. The United States and Brazil accounted for about 51 and 37 percent, respectively, of world ethanol production in 2007, while the European Union accounted for about 60 percent of world biodiesel production. Propelled by climate change concerns and the rising price of oil and gas (through mid-2008), the OECD projected that production of biofuels would double in the next decade.

1. See Aditya Chakraborty, “Secret Report: Biofuel Caused Food Crisis,” *Guardian*, July 4, 2008.

2. See “Biofuel Production is ‘Criminal Path’ Leading to Global Food Crisis—UN Expert,” UN News Center website, April 28, 2008, www.un.org (accessed on January 12, 2009).

A controversial issue in the biofuel debate is government support. The United States and the European Union have provided the greatest amount of public support to agricultural producers, accounting for 60 percent of total OECD agricultural producer support (Elliott 2006).³ The United States, the European Union, and Canada, among others, have offered public support in various forms, including subsidies, tax incentives, and consumption mandates.⁴ Making matters worse, the United States and the European Union have high import tariffs on ethanol. The World Bank (2007) warns that the current biofuels programs are not economically viable and depend excessively on government support. In the United States, more than 200 support measures (costing approximately \$5.5 billion to \$7.3 billion a year) are provided to biofuel producers.⁵

Today, the strongest proponents of these programs are not climate or energy experts but rather lobbyists who represent agricultural interests that directly benefit.⁶ In an article posted on the Center for Global Development's website, Kimberly Ann Elliott argued that the biofuels industry and corn state legislators are contesting the charge that their favorite policies are an important cause of rising food prices. Whatever the impact on food prices, it can be questioned whether the leading biofuel—ethanol—meets the two principal goals invoked by its supporters—energy security and climate change—to justify government support.⁷

3. The percentage figure is an average for the period of 2002 to 2004, based on the dollar amount of subsidies.

4. The United States passed the Energy Independence and Security Act of 2007 (originally named the Clean Energy Act of 2007), with provisions that increase taxpayer funding for the production of biofuels and increase the amount of biofuels that must be added to gasoline from 4.7 billion gallons in 2007 to 36 billion gallons by 2022. The United States signed a biofuel agreement with Brazil in March 2007 and has recently concluded a similar agreement with Colombia. Both agreements contemplate technology exchanges.

5. Such measures amount to 38 to 49 cents per liter of petroleum equivalent for ethanol and 45 to 57 cents for biodiesels. See World Bank (2007).

6. The biofuel lobby has become quite active, and the National Biodiesel Board has lobbied on a range of measures intended to expand use of biofuels. See "Biodiesel Board Spent \$384,000 to Lobby in 1Q," Associated Press, July 14, 2008, <http://bioenergy.checkbiotech.org/news> (accessed on January 12, 2009). In July 2008 a new lobby group, the Alliance for Abundant Food and Energy, was formed by Archer Daniels Midland Company, DuPont, Deere & Company, Monsanto, and the Renewable Fuels Association. Among other legislators, Senator Charles Grassley (R-Iowa) is a big supporter of biodiesel and extending the biodiesel tax incentive. See "Sen. Grassley Tells NBB He Will Continue to Champion Biodiesel Tax Incentive," National Biodiesel Board press release, June 18, 2008, www.biodiesel.org (accessed on January 12, 2009).

7. See Kimberly Ann Elliott, "Another Volley in the Battle over Biofuels," Center for Global Development, July 10, 2008, <http://blogs.cgdev.org/globaldevelopment> (accessed on January 12, 2009).

Saving Fossil Fuel Energy?

Producing ethanol involves several steps: growing, harvesting, milling, and transporting feedstock; then processing, refining, and transporting biofuels. Each step requires energy in various forms. David Pimentel and Tad Patzek (2007) estimated the energy inputs in ethanol production from sugar cane and found that approximately one kilocalorie (kcal) of fossil fuel energy is expended to produce each 1.12 kcal of ethanol energy in the United States, or 1.38 kcal of ethanol energy in Brazil. According to Pimentel and Patzek, other studies have overlooked energy inputs required for ethanol production, resulting in unrealistically low fossil fuel energy costs for each kcal of ethanol energy.

Saving Greenhouse Gas Emissions?

According to OECD (2008), ethanol based on sugarcane—the main feedstock of Brazilian production—generally reduces greenhouse gas emissions by 80 percent or more over the whole production and use cycle, relative to emissions from fossil fuels. By contrast, ethanol based on corn—the main feedstock of US production—reduces greenhouse gas emissions by less than 30 percent relative to emissions from fossil fuels.

However, neither calculation takes account of land clearing that might result from increased production of sugarcane or corn. When land is cleared, substantial amounts of CO₂ are released. In fact, some studies have found that, when land use changes are taken into account, many biofuels are worse from a climate perspective than the fossil fuels that they replace. Joseph Fargione et al. (2008) found that converting rain forests, peat lands, savannas, or grasslands to produce food-based biofuels would outweigh the carbon savings made from biofuels and create a “carbon debt” of 17 to 420 times more CO₂. This amount could take centuries to “pay back” through the growth of new vegetation. In an article in *Science*, Timothy Searchinger et al. (2008) expressed the same view, calculating that, owing to land use changes, corn-based ethanol almost doubles greenhouse gas emissions over a 30-year horizon in comparison with equivalent energy from fossil fuels. The increase in greenhouse gas concentrations, they maintained, might persist for 167 years until new vegetation absorbs the additional load of CO₂.

Appendix C

Summaries of Selected Environmental Dispute Cases

Brazil—Tyres, 2007 (DS 332): Measures Affecting Imports of Retreaded Tyres

The European Communities (EC) brought this case against Brazil's import ban on retreaded tyres. Brazil claimed that the measure had a public health and environmental purpose, namely, to prevent the accumulation of waste tyres as a breeding ground for mosquito-borne illnesses. The World Trade Organization (WTO) found that the measure violates the General Agreement on Tariffs and Trade (GATT) Article XI: 1 and is not justified by Article XX (b) because the measure did not qualify under the Article XX chapeau. It was noteworthy, however, that the Appellate Body agreed with Brazil that the import ban met the balancing test for necessity under Article XX (b). The failure of Brazil's import ban to meet the chapeau requirement stemmed in part from the fact that Brazil was importing retreaded tyres from Southern Common Market (Mercosur) countries. Because this discrimination went against the environmental purpose of the legislation, the Appellate Body concluded that Brazil was engaging in arbitrary and unjustifiable discrimination between countries and a disguised restriction on international trade. In addition, the chapeau was also being violated because of Brazilian court injunctions that permitted the importation of used tyres by domestic retread firms.

Case summaries in this appendix are arranged in descending chronological order. Further information on Panel and Appellate Body reports is available at <http://worldtradelaw.net> (accessed on September 8, 2008).

European Communities—Asbestos, 2001 (DS 135): Measures Affecting Asbestos and Asbestos-Containing Products

Canada brought this case against the European Communities with respect to a French ban on the manufacture, processing, sale, and import of asbestos and products containing asbestos, enacted pursuant to Decree No. 96-1133. While Canada argued that these measures violated the Agreement on Technical Barriers to Trade (TBT), GATT Article III: 4 and certain other articles, the EC defended the ban on the grounds that its purpose was to protect human health, pursuant to Article XX (b). The Appellate Body reversed the panel's finding against the EC and found that the TBT agreement applied to the measure viewed as an "integrated whole." However, the Appellate Body did not determine whether the measure conformed to the terms of the TBT agreement. Examining the panel's findings related to Article III:4 (the obligation not to discriminate against "like" imported products), the Appellate Body noted that the panel had excluded the health risks associated with asbestos when it determined "likeness" and that Canada failed to satisfy its burden of proving that imports and domestic goods were like products. Consequently, the Appellate Body reversed the panel's conclusion that the measure was inconsistent with Article III: 4. In determining whether the measure was justified under Article XX (b), both the panel and the Appellate Body emphasized the objective of a French ban and noted that the purpose of the measure was "both vital and important" in the "highest degree" and that no reasonable alternatives were available to achieve the same objective as the measure at issue. Therefore, the measure was "necessary" to protect human life or health, pursuant to Article XX (b). It is noteworthy that this was the first case in which the WTO accepted the respondent's defense under Article XX (b).

United States—Shrimp, 1998 (DS58) and 2001 (DS58/ Article 21.5): Import Prohibition of Certain Shrimp and Shrimp Products¹

India, Malaysia, Pakistan, and Thailand brought this case to challenge the US import restrictions on shrimp and shrimp products harvested in a manner that causes incidental killings of endangered sea turtles. The United States defended its measure as justified under Article XX (g). The WTO found that the measure violates GATT Article XI: 1 and was not justified by Article XX. With respect to Article XX, the WTO found that, while the US import ban fell within the scope of Article XX (g), it could not be justi-

1. Also known as the "shrimp-turtle" case.

fied because it failed to meet the nondiscrimination test in the chapeau of Article XX. In reaching this conclusion, the Appellate Body reasoned, in part, that the measure had a coercive effect on the policy decisions made by other member countries, without taking into consideration the different conditions prevailing in those countries. Moreover, the operating details of the measure were shaped in a unilateral way without consultation with other member countries. Later, in a compliance review case brought by Malaysia that was referred to the original panel pursuant to Article 21.5 of the Dispute Settlement Understanding mechanism, the Appellate Body rejected Malaysia's contention and found that the revised US guidelines met the conditions of the chapeau of Article XX. Under the revised guidelines, US restrictions were no longer applied in a manner that constituted arbitrary discrimination.

United States—Reformulated Gasoline, 1996 (DS2): Standards for Reformulated and Conventional Gasoline

Brazil and Venezuela brought this case against the US “gasoline rule” under its Clean Air Act, which required oil companies to reformulate the gasoline sold in the United States. The WTO agreed with Brazil and Venezuela that by applying different air pollution emissions standards, US rules treated products from foreign oil refineries less favorably than “like products” from domestic oil refineries and therefore violated Article III: 4 on national treatment. With respect to the US defense under Article XX (g), it is noteworthy that the Appellate Body determined that the measure was “related to” the conservation of exhaustible natural resources and also “made effective” in conjunction with restrictions on domestic production or consumption because the measure was imposed with respect to both imported and domestic products and therefore fell within the scope of Article XX (g). However, the Appellate Body concluded that the measure was not justified by Article XX because it constituted arbitrary and unjustifiable discrimination between countries and a disguised restriction on international trade.

United States—Taxes on Automobiles, 1994 (GATT DS31/R): Taxes on Automobiles²

This case was brought by the European Communities against the United States. The EC alleged that three US measures on automobiles—the corporate average fuel economy (CAFE) regulations, the gas guzzler tax, and the

2. The Panel Report was circulated in 1994 (during the GATT-1947 era) but not adopted. The conclusion of the Uruguay Round and the establishment of the WTO in 1995 rendered prior GATT panel reports moot. The European Union did not renew the case under the auspices of the WTO Dispute Settlement Mechanism.

luxury tax—all discriminated against EC auto exports. The panel found that the luxury tax and the gas guzzler tax were consistent with Article III: 2. With respect to CAFE regulations, the panel found that they were inconsistent with Article III: 4 because they discriminated against imported products by applying a separate fleet accounting system on imported cars in a way that differentiated between imported and domestic cars on the basis of factors unrelated to product characteristics (namely, the control or ownership of foreign producers or importers). Replying to the US defense of CAFE regulations under Article XX, the panel found that the measure was not justified under Article XX (g) because the separate fleet accounting method was not “primarily aimed at” the conservation of exhaustible natural resources.

United States—Tuna/Dolphin I, 1991 (GATT DS21/R) and United States—Tuna/Dolphin II, 1994 (GATT DS29/R): Restrictions on Imports of Tuna³

Mexico brought this case against the US import ban on tuna and tuna products from Mexico and intermediary countries handling the tuna en route from Mexico to the United States, enacted pursuant to the US Maritime Mammal Protection Act. The United States claimed that its measure had an environmental purpose, namely to protect dolphins from incidental mortality caused by methods used to capture tuna. However, the panel rejected the US assertion that its measure could be justified under Article XX (b) or (g), as it failed to meet the necessity test and could not be regarded as being “primarily” aimed at conservation of dolphins. It is important that the panel held that Article XX (b) could not justify a measure which is intended to protect something outside the territorial jurisdiction of the nation that adopted a measure. The same reasoning was applied to Article XX (g). Also, the panel found that the import prohibitions under the direct and intermediary embargoes did not constitute internal regulations within the meaning of Article III.

The second *United States—Tuna/Dolphin* case involved the same US measures as the first case but was brought by different countries, namely the European Economic Community (EEC) and the Netherlands. As in the first *United States—Tuna/Dolphin* case, the panel found that US measures were inconsistent with Article XI and not justified under Article XX. However, one important difference should be noted. In contrast to the panel’s finding in the first *United States—Tuna/Dolphin* case, the second panel held that no valid reason existed for the conclusion that the provisions of Article XX (g) would apply only to policies related to the conservation of exhaustible

3. Neither of the two panel reports was adopted.

natural resources located within the territory of the country that adopted the measure. Therefore, US measures that applied outside the United States would fall within the range of policies protected by Article XX (g). However, the panel found that US measures were not “primarily” aimed at conservation of dolphins and did not render effective restrictions on domestic production and consumption. The panel’s rationale was that Article XX did not permit governments to take trade measures so as to force other contracting parties to change their policies within their jurisdiction. Therefore, US measures were not justified under Article XX.

Thailand—Cigarettes, 1990 (GATT DS10/R): Restrictions on Importation of and Internal Taxes on Cigarettes

The United States brought this case against Thailand’s import restrictions on cigarettes. Thailand claimed that import restrictions had a public health purpose since they aimed at reducing the general consumption of cigarettes and protecting the public from harmful ingredients specifically found in imported cigarettes, and thus could be justified under Article XX (b). However, the panel found that the import restrictions violated Article XI: 1 and were not justified under Article XX (b). In determining whether the measure could fall within the exceptions of Article XX, the panel found that the measure failed to satisfy the “necessary” requirements under Article XX (b) because Thailand allowed the sale of domestic cigarettes and also because Thailand could adopt alternative measures to achieve the same objectives.

Canada—Unprocessed Herring and Salmon, 1988 (BISD 35S/98): Measures Affecting Exports of Unprocessed Herring and Salmon

The United States brought this case against Canadian export restrictions on certain unprocessed herring and salmon, pursuant to the 1976 Canadian Fisheries Act. Canada argued that these export restrictions were part of a system of fishery resource management aimed at preserving fish stocks, and therefore were justified under Article XX (g). Canada also argued that its measures fell under the Article XI: 2(b) exception that permits export prohibitions for the purposes of ensuring quality or regulations relating to the international marketing of a good. However, the panel found that export prohibitions were not justified under Article XX (g) because they were not primarily aimed at conserving salmon and herring stocks or rendering effective the restrictions on the harvesting of salmon and herring. Also, the panel found that export prohibitions could not be justified under Article XI: 2(b) because unprocessed fish was not the target of marketing or promotion.

United States—Tuna and Tuna Products, 1982 (BISD 29S/91): Prohibition of Imports of Tuna and Tuna Products from Canada

Canada brought this case against the US import ban on tuna and tuna products, enacted pursuant to the 1975 Fishery Conservation and Management Act.⁴ The panel found that the US measure was inconsistent with Article XI. And, while the United States claimed that its measure was related to the conservation of tuna, the panel found that the measure failed to satisfy the requirements of Article XX (g) because it applied to all kinds of tuna, including ones not in danger of depletion, and because the United States did not impose equivalent restrictions on domestic production.

4. In fact, the US import ban was imposed in retaliation for Canada's seizure of 19 US fishing vessels and arrest of US fishermen fishing without authorization from the Canadian government in waters considered by Canada to be under its jurisdiction.

Appendix D

Clean Development Mechanism: A Big Challenge for the Post- Kyoto Regime

Among three major “flexibility mechanisms” adopted in the Kyoto Protocol to help countries meet their emission targets (see box 4.1), the clean development mechanism (CDM) has been most widely used. One reason for its popularity is that the CDM gives emitting countries greater flexibility in achieving their targets at lower costs by financing emissions reduction in developing countries. Another reason is that substantial funds are transferred to developing countries.

Of the more than 3,000 projects in the CDM pipeline as of September 2008, about 1,160 projects had been registered by the CDM Executive Board under the mechanism, estimated to cover some 1.3 billion certified emissions reductions (CERs) in total over their lifetime.¹ By the end of 2012, when the Kyoto Protocol expires, all the projects in the CDM pipeline are expected to generate some 2.7 billion CERs over the project lifetimes, which would be worth up to about €57 billion at current market rates.²

According to the United Nations Framework Convention on Climate Change (UNFCCC), among 1,162 currently registered CDM projects, India is the largest host country with 358 projects, and China is second with 267 projects. In terms of expected average annual CERs from registered projects by host country, China is in the lead, accounting for more than 50 per-

1. Each CER is equivalent to one metric ton of CO₂ or its equivalent and corresponds to a reduction of one metric ton of CO₂e.

2. According to *Carbon Positive*, on December 9, 2008 the benchmark CER contract for December 2008 delivery closed at about €13 on the European Climate Exchange. See “CERs Find New Lows as Oil Plunges,” *Carbon Positive*, December 9, 2008, www.carbonpositive.net (accessed on January 12, 2009).

cent of the total expected annual average 220 million CERs from registered projects, followed by India (14 percent) and Brazil (9 percent).³ By region, the Asia Pacific is the largest host, covering 65 percent of total registered projects by number, followed by Latin America and the Caribbean (32 percent) and Africa (2 percent). By scope, the energy industry (both renewable and nonrenewable sources) accounts for more than 55 percent of total registered projects by number; waste handling and disposal, 20 percent; fugitive emissions from fuel production, 8 percent; agriculture, 6 percent; and manufacturing industries, 5 percent.⁴

As the CDM has flourished, its criticism has mounted. Procedural inefficiencies and regulatory bottlenecks have caused delays in registration of CDM projects and issuance of CERs. A key issue is the “additionality” test under the CDM. To avoid abuses of the CDM, industrial countries that wish to purchase credits from CDM projects must meet several requirements. An industrial country must secure the consent of a host developing country, and the project must qualify under the UN registration and issuance process. This process is meant to ensure “additionality,” as defined in the Kyoto Protocol. Under Article 12, which defines the purpose and requirements of the CDM, Article 12.5(c) states that “emission reductions resulting from each project activity shall be certified...on the basis of...(c) reductions in emissions that are additional to any that would occur in the absence of the certified project activity.”⁵

Critics argue that the concept of “additionality” on a project basis is both vague and disturbing. At the Carbon Expo trade fair in Germany in May 2008, Ken Newcombe, the former director of the World Bank Carbon Finance Unit and managing director of US Carbon Emissions Trading for Goldman Sachs, claimed that “additionality” is an impossible concept and that the associated requirements increase transaction costs, raise the burden of proof, and augment risk for the private sector—all with the result of discouraging investment.⁶ Citing an unpublished report by the United Nations, the *Guardian* claimed that “the CDM has been contaminated by gross incompetence, rule-breaking and possible fraud by companies in the

3. For comparison, the world total of CO₂e emissions in 2000 was 36 billion metric tons, while the world total of just CO₂ emissions in 2006 was 28 billion metric tons (see tables 1.1 and 1.2). In other words, the CDM as presently managed makes a very small contribution to reducing CO₂e, far less than 1 percent of annual emissions.

4. For more details, see the UNFCCC CDM website at <http://cdm.unfccc.int> (accessed on January 12, 2009).

5. Another important requirement is stated under Article 6.1(d) of the Kyoto protocol: “The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.” See the Kyoto Protocol text at <http://unfccc.int> (accessed on January 12, 2009).

6. See “Time to Rethink CDM Additionality,” *Carbon Finance*, May 7, 2008, www.carbon-financeonline.com (accessed on January 12, 2009).

developing world.” The *Guardian* also cited findings by Axel Michaelowa, a member of the CDM board of expert advisers, to the effect that, among 52 CDM projects hosted in India that were registered up to May 2006, one-third actually failed to meet the additionality test.⁷

Critics have also questioned the effectiveness of the CDM. From an environmental standpoint, the mechanism may not contribute to an overall reduction in emissions because it allows an industrialized country to emit an additional ton of CO₂e by buying one CER from developing countries. The World Bank has criticized the CDM as “most expensive and time consuming.”⁸

Controversial questions have also been asked about one specific greenhouse gas, namely hydrofluorocarbons (HFCs). According to *Scientific American*, about a third of CDM credits come from projects that focus on preventing the emission of HFC-23 (also known as trifluoromethane), a potent greenhouse gas that is a byproduct of the manufacture of refrigerant gases. HFC-23 has about 11,700 times the global warming potential (GWP) of CO₂, but it can be destroyed using relatively cheap technology.⁹ However, the CDM payment mechanism is scaled to the reduction of GWP, so the payoff from reducing a ton of HFC-23 is very high—almost 12,000 times the payoff from reducing a ton of CO₂. It is important to prevent detrimental greenhouse gases like HFC-23 from entering the atmosphere. However, it is arguable whether the CDM should pay for removing gases like HFC-23 at their GWP rate, when they can be removed at very low costs. As a perverse result of the present system, manufacturing firms in developing countries delay the installation of devices that destroy HFC-23 so that they can raise their baseline values in order to claim very large CDM credits.

Another example illustrates the flaws in the current CDM rules. Rhodia SA, the French chemical maker, is expecting to receive a billion dollar windfall by implementing CDM projects that remove nitrous oxide (laughing gas) from its own factories in South Korea and Brazil.¹⁰ Under the Kyoto Protocol, certain highly industrialized countries such as South Korea are categorized as non-Annex I countries and thus have no obliga-

7. See Nick Davies, “Abuse and Incompetence in Fight Against Global Warming,” *Guardian*, June 2, 2007, www.guardian.co.uk (accessed on January 12, 2009). According to the article, Michaelowa found evidence that some projects provided false information that was then approved without checking. The *Guardian* also cited one senior figure who suggested there may be faults with up to 20 percent of the CERs already sold.

8. See Mathew Carr, “UN Carbon Trade Expensive and Slow, World Bank Says,” *Bloomberg News*, August 26, 2008, www.bloomberg.com (accessed on January 12, 2009).

9. See David G. Victor and Danny Cullenward, “Making Carbon Markets Work,” *Scientific American*, September 24, 2007, www.sciam.com (accessed on January 12, 2009).

10. See Charles Forelle, “French Firm Cashes in Under UN Warming Program,” *Wall Street Journal*, July 23, 2008, <http://online.wsj.com> (accessed on January 12, 2009).

tion to reduce emissions. These countries have hosted many CDM projects. This conflicts with a central purpose of the CDM, which is to stimulate investment and technology transfer to poor countries. As revealed by the statistics already mentioned, CDM projects have been concentrated in certain countries—notably China, India, and Brazil. The Asia-Pacific region has hosted about 65 percent of total CDM projects, while Africa has hosted only 2 percent. The Rhodia example also raises other questions, such as whether the additionality test is appropriately conducted and whether it is justifiable that a company can earn a profit by reducing CO₂e in its own facilities located in developing countries.

In response to the many criticisms, it seems that the United Nations regulators who administer the CDM have become more cautious when approving projects. In 2007 the CDM Executive Board reportedly rejected about 9 percent of proposed projects, in contrast to previous years (2004 and 2005), when virtually all projects were approved.¹¹ However, major reforms to the CDM system seem inevitable during the course of the Copenhagen negotiations. Success of the post-Kyoto CDM regime will depend on whether it can be redesigned to cure its faults in a systemic manner. The Kyoto Protocol expires in 2012; the clock is ticking for a new and better clean development mechanism.

11. See Jeffrey Ball, "UN Effort to Curtail Emissions in Turmoil," *Wall Street Journal*, April 12, 2008, <http://online.wsj.com> (accessed on January 12, 2009).

Appendix E

Rise of Global Carbon Markets

Carbon trading markets have seen huge growth in recent years, both in value and volume. Global carbon markets were worth about \$64 billion in 2007, more than double the \$31 billion level in 2006. By trading volume, global carbon markets grew from 1.7 billion tons of CO₂e in 2006 to about 3 billion tons of CO₂e in 2007 (table E.1).¹ Growth is expected to remain strong in 2008 and beyond, since 2008 is the first year of the compliance period (2008–12) under the Kyoto Protocol and also the first year of Phase II (2008–12) of the European Union Emission Trading Scheme (EU ETS).² Over the next few years, more countries are likely to adopt their own national cap and trade schemes, which will further boost the value and volume of carbon trading.

Two distinct carbon markets are now in operation: allowance markets and credit (project-based) markets. In allowance markets, such as the EU ETS, allocated greenhouse gas emissions rights are traded, while in credit markets, notably the clean development mechanism (CDM) and the joint implementation system, “offsets” are traded that were awarded for specific projects related to greenhouse gas reductions. Each carbon market has its own operating rules and profiles, and no uniform CO₂ price yet exists, but discussions are under way to link carbon markets. This appendix provides short summaries of the major carbon markets (or schemes) now in operation.

1. The figures include both allowance and credit (project-based) markets.

2. Annex I countries that signed and ratified the Kyoto Protocol have to meet their own targets listed in Annex B.

Table E.1 Carbon markets: Volumes and values of transactions, 2006 and 2007

Market	2006		2007	
	Volume (MtCO ₂ e)	Value (millions of US dollars)	Volume (MtCO ₂ e)	Value (millions of US dollars)
Allowance-based markets				
European Union Emission Trading Scheme	1,104	24,436	2,061	50,097
New South Wales	20	225	25	224
Chicago Climate Exchange	10	38	23	72
<i>Subtotal</i>	1,134	24,699	2,109	50,393
Project-based markets				
Primary clean development mechanism (CDM)	537	5,804	551	7,426
Secondary CDM	25	445	240	5,451
Joint implementation	16	141	41	499
Other compliance and voluntary transactions	33	146	42	265
<i>Subtotal</i>	611	6,536	874	13,641
Total	1,745	31,235	2,983	64,034

MtCO₂e = million tons of carbon dioxide equivalent

Source: World Bank (2008a, table 1).

European Union: Emission Trading Scheme

By far, the EU ETS is the largest carbon trading scheme. In 2007 it covered 69 percent of the total global carbon market in volume terms and 78 percent in value terms (table E.1). The major marketplaces for EU emissions allowances (EUAs) are the European Climate Exchange, covering more than 80 percent of exchange-traded transaction volume, and the London Energy Brokers Association, covering more than 50 percent of over-the-counter activity (World Bank 2008a).

Based on Directive 2003/87/EC, which entered into force in October 2003, the EU ETS came into operation on January 1, 2005. The main objective during Phase I (a three-year trial period lasting from 2005 to 2007) was to acquire experience and build the infrastructure for success in Phase II and beyond. During Phase I, the price of EUAs fluctuated in a wide band: The

price of a future contract, for delivery in December 2007, soared to more than €30 per metric ton of CO₂e in April 2006, and then dropped nearly to zero one year later, following release of the actual 2005 emissions data that showed that emissions were below the targeted level.³ Since May 2007, the EUA price for use during the Phase II period has become less volatile. For example, the EUA contract for December 2008 delivery has moved in a price band of €20 to €25 per metric ton of CO₂e.

In light of the experience with Phases I and II, the European Commission proposed a reform package in January 2008 and the European Parliament approved the package with revised terms on December 17, 2008. Under the package, the European Union announced a more stringent overall emissions target (at least 20 percent below 1990 levels by 2020) and held open a possible 30 percent emissions reduction target if a post-Kyoto regime is agreed upon. The package includes other provisions such as permit auctions, broader coverage of energy-intensive industries, and a target of 20 percent for the share of renewable energy use. The package restricts the use of certified emissions reductions (CERs) and emissions reductions units (ERUs) in Phase III by making them contingent on the post-Kyoto regime.⁴ For a time, this restriction may undermine project-based carbon markets.

The EU ETS is valued as a successful market scheme in two respects. First, it has utilized the price mechanism for mitigating carbon emissions. EU price signals not only provide a benchmark but also motivate project developers. Second, it has furthered a multinational climate regime, embracing countries with diverse historic, economic, and political backgrounds. The number of countries participating in the ETS has increased from 15 in Phase I to 30 Phase II (including all EU-27 members and three non-EU members, Norway, Iceland, and Liechtenstein).

Citing projections made elsewhere, the World Bank (2008a) suggested that the price of the EUA would reach around €30 to €35 per ton of CO₂e by the end of Phase II and €40 at the start of Phase III. *Point Carbon* forecasts that the European carbon price will average €37 per ton of CO₂e between 2009 and 2012.⁵

3. The EU ETS did not allow banking between Phase I and Phase II, but it did allow banking within a phase. Ellerman and Joskow (2008) argue that, if there had been no trade restriction between the two phases, the EUA price for use during Phase I period would not have dropped to zero.

4. CERs are issued under the CDM, while ERUs are issued under the joint implementation system.

5. See "Carbon Market Analyst Raises 2009–2012 EU Allowance Price Forecast," *Power Engineering International*, September 19, 2008, <http://pepei.pennnet.com> (accessed on January 12, 2009).

Clean Development Mechanism

Even though it has been plagued with loopholes (see appendix D), the CDM has attracted considerable attention. In 2007 CDM permits accounted for about 94 percent of project-based transactions in value term (table E.1).⁶ Of note is the fast growth of secondary markets for the CDM. Facing procedural delays and the growing risk of regulatory hiccups in the issuance of individual CER permits, CER markets have shifted toward secondary markets that are largely based on a portfolio of guaranteed CER (gCER) contracts. In 2007 the secondary market for gCERs grew by more than 10 times in value terms compared with 2006 (table E.1). The primary buyers of CDM and joint implementation system permits were European firms (and governments), accounting for almost about 90 percent of the overall volume, followed by Japanese firms (11 percent) (World Bank 2008a).

Australia: New South Wales Greenhouse Gas Abatement Scheme

New South Wales launched an emissions trading scheme in 2003 that requires electricity retailers to obtain and submit a certain numbers of emissions reduction credits, so-called New South Wales greenhouse abatement certificates. Each certificate is worth one metric ton of CO₂e. Under the New South Wales scheme, electricity retailers and other participants are required to reduce their annual emissions to 7.27 tons of CO₂e per capita by 2012.⁷

While the New South Wales market increased by 25 percent in traded volume in 2007, its value fell slightly from \$225 million in 2006 to \$224 million in 2007, since the greenhouse abatement certificates price dropped from AU\$10 to AU\$5 in 2007.⁸

United States: Chicago Climate Exchange (CCX)

The Chicago Climate Exchange (CCX), launched in 2003, is the world's first voluntary but legally binding carbon trading system. Under this scheme, members make a voluntary but legally binding commitment to reduce their aggregate greenhouse gas emissions by 6 percent below a

6. The figures include both primary and secondary CDM markets.

7. An initial target was 8.65 tons of CO₂e per capita in 2003, and it was dropped to 7.27 tons of CO₂e per capita in 2007. For more details, see the New South Wales greenhouse gas abatement scheme website at www.greenhousegas.nsw.gov.au (accessed on January 12, 2009).

8. The price collapse resulted mainly from an oversupply of credits. See World Bank (2008a).

baseline period (1998 to 2001) by 2010. Members can sell or bank surplus allowances or they can meet their targets by purchasing CCX carbon financial instrument (CFI) contracts. Each CFI contract represents 100 metric tons of CO₂e. On January 14, 2009, the closing prices for all vantages of CCX CFI contracts were in the vicinity of \$1.90 per metric ton of CO₂e.⁹ CCX transactions have doubled in both volume and value terms in 2007 (table E.1). The CCX has expanded its coverage to other contracts as well. For example, the CCX started listing futures on CER contracts in August 2007; futures on EUA contracts in September 2007; and CER options in December 2007 (World Bank 2008a).

United States: Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative, a program initiated by nine Northeast and mid-Atlantic states, currently has 10 participating states: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. Under the program, these 10 states will stabilize their total CO₂ emissions at a cap of 188.1 million short tons through 2014.¹⁰ Six states—Connecticut, Maine, Maryland, Massachusetts, Rhode Island, and Vermont—took part in the first US auction for CO₂ allowances held on September 25, 2008. This auction offered about 12.5 million CO₂ allowances with a reserve price of \$1.86 per CO₂ allowance (equal to one short ton of CO₂), and all allowances were cleared at a price of \$3.07 per metric ton of CO₂. Any CO₂ allowances purchased at the auction can be used by a regulated facility for compliance in any of the 10 participating states.¹¹

9. For more details, see the CCX website at www.chicagoclimatex.com (accessed on January 12, 2009).

10. See Carbon Market North America Newsletter, *Point Carbon* 3, no. 15, July 30, 2008.

11. For more details, see the Regional Greenhouse Gas Initiative website at www.rggi.org (accessed on January 12, 2009).

