



WORKING PAPER NO.64

Climate Change, Mitigation, and Developing Country Growth

Michael Spence



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Dutch Ministry
of Foreign Affairs

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About the Series

The Commission on Growth and Development led by Nobel Laureate Mike Spence was established in April 2006 as a response to two insights. First, poverty cannot be reduced in isolation from economic growth—an observation that has been overlooked in the thinking and strategies of many practitioners. Second, there is growing awareness that knowledge about economic growth is much less definitive than commonly thought. Consequently, the Commission’s mandate is to “take stock of the state of theoretical and empirical knowledge on economic growth with a view to drawing implications for policy for the current and next generation of policy makers.”

To help explore the state of knowledge, the Commission invited leading academics and policy makers from developing and industrialized countries to explore and discuss economic issues it thought relevant for growth and development, including controversial ideas. Thematic papers assessed knowledge and highlighted ongoing debates in areas such as monetary and fiscal policies, climate change, and equity and growth. Additionally, 25 country case studies were commissioned to explore the dynamics of growth and change in the context of specific countries.

Working papers in this series were presented and reviewed at Commission workshops, which were held in 2007–08 in Washington, D.C., New York City, and New Haven, Connecticut. Each paper benefited from comments by workshop participants, including academics, policy makers, development practitioners, representatives of bilateral and multilateral institutions, and Commission members.

The working papers, and all thematic papers and case studies written as contributions to the work of the Commission, were made possible by support from the Australian Agency for International Development (AusAID), the Dutch Ministry of Foreign Affairs, the Swedish International Development Cooperation Agency (SIDA), the U.K. Department of International Development (DFID), the William and Flora Hewlett Foundation, and the World Bank Group.

The working paper series was produced under the general guidance of Mike Spence and Danny Leipziger, Chair and Vice Chair of the Commission, and the Commission’s Secretariat, which is based in the Poverty Reduction and Economic Management Network of the World Bank. Papers in this series represent the independent view of the authors.

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Abstract

This paper deals with global mitigation strategy. More specifically the main purpose is to address the question of whether growth in the developing world is consistent with long-run climate change objectives. The answer I believe is yes. The first part of this paper lays out time paths for emissions for countries in various categories. These paths are consistent with countries' growth objectives, incomes, and capacity to absorb mitigation costs. The intent is to show that while global emissions are likely to remain flat or even to rise as a result of the combined effect of mitigation undertaken by advanced countries and growth in the developing world, eventually reasonably safe global per capita levels can be reached on a 50-year time horizon. The second part of this paper discusses countries' roles in relation to different categories and mechanisms that would support the achievement of safe emissions paths. These mechanisms create incentives and deal with the absorption of costs. In particular, the paper argues that a carbon credit trading system in the advanced countries, combined with an effective cross-border mechanism and a "graduation" criterion for developing countries to join the advanced group, will create strong incentives, achieve a fair pattern of cost absorption, and support the dynamics described in part one. One point emerges clearly: the cross-border mechanism (or international offsets) is essential in dealing with both the efficiency and the cost absorption/equity challenges of a global mitigation strategy.

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Climate Change, Mitigation, and Developing Country Growth

*Michael Spence*¹

Introduction

Global warming is arguably the leading challenge to our capacity for global governance today. After many years of careful work and persuasion by dedicated scientists and environmentalists, a growing majority of people worldwide believe that there are significant risks of climate change that need to be addressed. It is widely understood that human activity is contributing on an accelerating basis to an increase in the stock of greenhouse gases in the atmosphere. That growing contribution increases the risk of adverse effects of climate change. The stocks of CO₂ in the atmosphere are increasing, but there remains considerable uncertainty about the magnitude of the impact on temperatures and climate. The range of estimates remains wide.²

In the past two years, we have entered a new phase. The focus is shifting from convincing the majority of people that there are significant tail risks in staying on our present course, to a process of developing and agreeing on a global strategy for reducing greenhouse gas emissions, principally carbon. It is a major challenge in part because a combination of scientific, technological, and economic inputs are required to devise a long-term strategy that may succeed and that accords with the values, needs, expectations, and goals of a wide variety of people and countries.

A crucial part of any global strategy is the role of developing countries, particularly the rapidly growing ones: the BRICS,³ others in the G20, and some other large and systemically important countries. The high-growth developing countries now include more than half the world's population. If they succeed in continuing (post-crisis) their pattern of sustained growth as seems likely, then by mid-century or shortly thereafter, they will be approaching advanced country levels of income with associated patterns of consumption, energy use, and carbon emissions. What those patterns will be and how we get to them is the central issue before us. If the patterns are like the present ones, the climate change battle will have been lost.

¹ Michael Spence is the Chairman of an independent Commission on Growth and Development and a 2001 Nobel Laureate in Economics.

² Reference to the IPCC report and the Human Development Report 2007/2008 (UNDP).

³ The BRICS are Brazil, Russia, India and China.

By mid-century the fraction of the world's population with advanced-country income levels (that is, US\$20,000 or above in 2009 dollars) will go from the present level of 16 percent to about 66 percent. The G20 accounts for 90 percent of global GDP and about two thirds of the world's population. The implication is clear. The lion's share of the economic and technological aspects of the mitigation challenge falls within the purview of the G20 and a few other potentially high-growth and populous countries like Egypt, Nigeria, and Mexico. That does not mean that the other countries can be ignored, because they will also grow. In addition, reforestation and afforestation will require the engagement of a much larger group of countries on terms that are understandable and fair. The United Nations Framework Convention on Climate Change (UNFCCC) will continue to be the center of the process for developing international strategies and agreements. But in the next few decades it is the augmented G20 and its ability or inability to reach agreements on mitigation strategy that will largely determine the results.

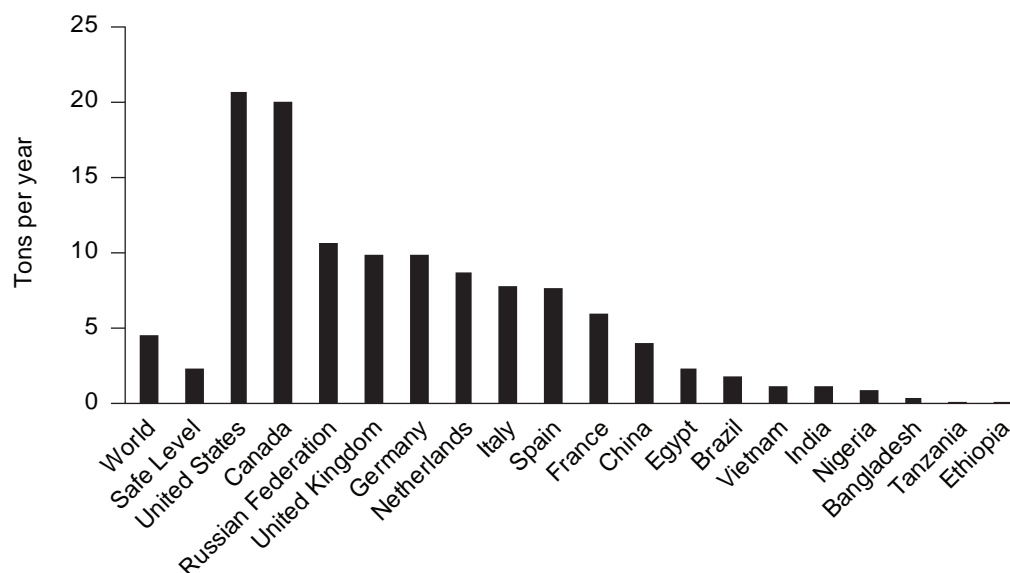
Formulating a global dynamic mitigation strategy turns out to be a very hard problem for several reasons. It has to accommodate the growth of the developing countries in order to be acceptable to them and their citizens. It requires dealing with long time horizons and sequential decision making under very great uncertainty (about technology, costs, and options) with substantial learning along the way. To be successful and broadly acceptable, it needs to meet the dual criteria of efficiency (accomplishing the mitigation at least cost or something approximating least cost) and fairness. This will require separating the location of the mitigation activities from the absorption of cost to some extent.

We cannot predict the evolving global pattern of efficient mitigation because we do not yet have the processes that will determine it, like a global carbon credit trading system (CCTS). However, we do know that as developing countries grow and become richer, they will be needed as participants in any efficient global mitigation program. Without mitigation in developing countries, the current global average per capita emissions of 4.8 tons of CO₂ per year will grow by a factor of almost two to 8.7 tons per person in 50 years—and that figure assumes developing countries will reach current advanced-country levels (excepting North American) of per capita emissions in the range 10 to 11 tons. The current Intergovernmental Panel on Climate Change (IPCC) estimate of a reasonably safe level of CO₂ emissions is 2.3 tons per person globally or roughly half the current per capita average.⁴ On the present course, without a significant mitigation effort, by mid-century we would be at around four times the safe level.

The United States and Canada are at about 20 tons per person at present. The data for various countries are shown in Figure 1.

⁴ With a global population of about 6.4 billion people, this translates to total CO₂ emissions of about 14.7 billion tons per year, or 14.7 gigatons. A per capita figure of 8.7 tons translates into total global emissions of 55.6 gigatons.

Figure 1. CO₂ Emissions per Capita



Source: IPCC and Human Development Report 2007/2008 (UNDP).

Other advanced countries are in the range of 12 to 6 tons per person. France at 6 tons per person is a reflection of the extensive use of nuclear power for electricity generation. The global average and the safe level are shown on the left in Figure 1. The developing countries are generally below 2.3 tons per person and substantially so, except for China.

Progress to date on formulating a framework that is broadly acceptable has been limited. The major developing countries until recently were being pressed to commit to long-term carbon emissions targets and they have been resisting for understandable and legitimate reasons. Trying to get commitments to long-term target emissions from developed and developing countries is unwise and unlikely to result in an agreement. Given the uncertainty about the costs of mitigation and their evolution over time, long-term targets pose significant risks to growth for developing countries. If pursued, this approach probably will produce a standoff, followed by growing controversy and attempts to increase pressure, which could spill over into other aspects of international relations like trade and capital flows. The negative consequences could be far reaching and long term.⁵

There are more constructive ways to approach the problem—approaches that over time are more likely to result in an agreed-upon global strategy. Such and approaches would also take into account developing countries' aspirations our currently limited knowledge of mitigation costs, the pattern of efficient

⁵ As an example, the Waxman-Markey energy and climate change legislation that passed in the U.S. House of Representatives has provisions for import tariffs based on carbon emissions in other countries. To be fair it also has favorable features such as offsets, including international (or cross-border) offsets that address both efficiency and fairness or burden-sharing issues.

distribution of mitigation efforts across countries, and the evolution of options and costs of mitigation over time as new technology is developed.

Terminology

A brief discussion about terminology as it has emerged in the global warming discussion of the past years may be useful. This terminology will be familiar to many. Responding to potential and actual climate change involves what are called mitigation and adaptation.

“Mitigation” refers to actions that result in the reduction of net greenhouse gas emissions. They include increasing energy efficiency, reducing energy consumption (through public transportation, the design of cities and buildings, and so forth), reducing emissions from known sources, and increasing the rate at which carbon is removed from the atmosphere; examples of the latter would be reforestation and afforestation. Mitigation could also include activities that increase the reflectivity of the outer atmosphere so that less heat-generating radiation enters the atmosphere.

“Adaptation” refers to actions that people, countries, and societies take to adjust to climate change that has occurred. They include shifting crops, irrigation, levies, moving away from low-lying coastal areas in the case of sea-level shifts, air conditioning, and adjustments in medical care in response to change in diseases caused by climate change. As a first approximation, mitigation is undertaken to reduce the chances that significant adaptation and its associated costs will be required. Mitigation and adaptation are linked because the options and costs for adaptation partially determine the payoffs to buying insurance in the form of mitigation against significant climate shifts.

This paper is about mitigation. By focusing on mitigation, the intent is not to suggest that adaptation is secondary in importance. Indeed, in some scenarios where mitigation fails or is too late, adaptation may become the dominant issue, and its distributional aspects are of great human and moral importance.

I use the terms “advanced countries” and “developing countries.” These correspond to Annex 1 and non-Annex 1 countries in the language of much of the climate change negotiation process. Cross-border mitigation efforts are mitigation activities undertaken in one country and financed and paid for by an external entity (such as a government, a public utility, or an oil company) that has a mitigation obligation or target. These efforts are referred to collectively in the Kyoto Protocol as the Clean Development Mechanism or CDM. In discussions and legislation they are referred to as international offsets. Domestic offsets are similar but apply to two entities within the same country. Both kinds of offsets occur automatically in a global carbon trading system.

I refer in the second part of the paper to various versions of a CCTS. The more common term is “cap and trade.” I have avoided using the more common

term because “cap” suggests that the participants (including countries) accept caps (which decline over time) and then trade to achieve efficient mitigation and to allow for preferences to enter the picture. For developing countries a literal cap at anything like current per capita levels or aggregate levels would ensure that their growth objectives and aspirations could not be met. The term “cap” implies something that developing countries are not and should not be willing to concede.

Time Horizons, Stocks, and Flows

Time horizons are important. Warming is caused by the stock of carbon dioxide and other greenhouse gases in the atmosphere. We do not know how much warming will be caused by various levels of greenhouse gases in the atmosphere. The estimated ranges are still wide, even after a quarter century of scientific effort, because of the complexity of the relevant dynamic systems. Acting now to reduce the net inflows of CO₂ and other greenhouse gases and hence the rate of increase of the stock can be thought of as buying what in finance is called tail insurance, that is, some degree of protection against the most adverse outcomes in the distribution of possible outcomes. From an intertemporal decision making point of view, an important aspect of the structure of the problem is to recognize that as stocks rise, we will learn more about the distribution of possible outcomes. Sensible global strategies will include adjusting mitigation efforts in response to the new information.

Emissions and natural processes that take down carbon are the flows. Mitigation attempts to reduce the flows and thus reduce the rate of increase of the stock with the ultimate goal of stabilizing (or bringing down) the stock to what are believed to be safe levels. As of 2007, the IPCC, the authoritative body that pools scientific information and expertise, has set a safe level target of 2.3 tons of CO₂ per person per year to prevent stocks from becoming high enough to make major climate shifts likely. IPCC also has suggested a time horizon of 50 to 75 years to achieve this level.

On our current trajectory, unsafe stocks of CO₂ in the atmosphere will be reached on the same time horizon of 50–75 years. Advanced countries have been the most significant sources of carbon emissions until relatively recently. Developing countries are growing at high rates and thereby contributing an increasing fraction of the total emissions. This pattern will continue. China and India, accounting for 40 percent of the world’s population, were growing at 9 to 10 percent a year before the crisis and are likely to resume high growth in the post-crisis period, meaning that their economies will be doubling in size every seven to eight years. Other countries are growing at relatively high rates too. Energy consumption and therefore carbon emissions rise with per capita income. Thus, even though many advanced and developing countries are taking

aggressive actions to increase energy efficiency and adopt clean energy technologies, with existing technology, incentives, regulations, and commitments, total carbon emissions are set to rise rapidly in the coming decades. Successful mitigation at the global level faces stiff headwinds. In the long run, success will require major technological advances that are broadly adopted. But in the next 15 years, the challenge is to jump start the mitigation and learning process, and to create a global system that tends toward efficiency and that creates powerful incentives for technology that increases energy efficiency and reduces CO₂.

The central problem in formulating a global strategy for mitigation is whether this growth can be made consistent with the achievement of safe global carbon emission levels. It may seem to be a problem without a solution. Just waiting for the high-growth developing countries to become much closer in income to advanced countries, completely exempt from a global emission reduction program, is not part of a solution.⁶ But severe restrictions on the growth of their per capita carbon emissions (which are already very low by advanced-country standards) in the short run while per capita incomes are still relatively low will likely impose high costs in the form of reduced growth and poverty alleviation in the coming decades. This is the central problem that needs to be addressed.

Fairness and Per Capita Emissions

A successful framework for a multinational mitigation strategy has to deal with fairness or equity as well as efficiency. The argument that the advanced countries, which are collectively responsible for most of the current stock, should take responsibility for the problem won't work in its simple form, for the reasons cited early. Advanced countries cannot reach the global goals by themselves, unless the developing countries stop growing.

How does one think about fairness? Setting aside the developing countries for the moment, it should be widely accepted that advanced countries (whoever they are at a particular time) should eventually have roughly equal per capita entitlement to carbon emissions, which means that their overall entitlement would be proportional to the population. It may take some time to get there, given starkly differing starting points (see Figure 1), but it is hard to think of a principle that treats advanced countries and citizens asymmetrically in a major way that would be accepted. There will be adjustments for climate or geography but, as a first approximation, equal per capita entitlements seems the right

⁶ There is relatively little disagreement about this. Advanced and developing countries understand that keeping costs down by making the global pattern of mitigation efficient requires mitigation in both developing and advanced countries. The issue is the time path of the absorption of the costs.

baseline.⁷ One implication of this is that developing countries, as they become advanced over the coming decades as a result of growth, will be subject to the same entitlements or quotas as other advanced countries. That means that their long-term growth strategies and trajectories will converge to advanced country per capita carbon emissions level. The latter are a moving target as the advanced countries achieve reduced carbon emissions over time.

A second implication for purposes of setting fair standards is that we cannot fairly treat countries asymmetrically based on just population size. It is true that China and India are key players due in part to their high growth and in part to the fact that combined they represent almost 40 percent of the world's population. But size should not be a handicap. If China and India were four or five countries, each about the size of Indonesia, with high growth but still relatively poor, it is unlikely that all twelve countries would be experiencing intense pressure to commit to targets or some self-generated alternative. Framing size this way clarifies the importance of thinking about the issues in per capita terms.

It is essential that asymmetries based on income and stages of development are addressed by solutions to the global climate change problem. Developing countries have different growth paths and levels of CO₂ emissions. They will need to focus on energy efficient and clean technologies even as their growth raises energy consumption and elevates carbon emissions. It will be a major challenge for the developing countries to reach CO₂ emissions of 3 tons per capita in 50 years. The chances that India, which is at 1.3 tons per person now, will end up well below the advanced country figure when it has grown to

⁷ The challenge is to find an objective formula to make the adjustments. There is a line between legitimately higher costs and choices, and there is a difference between an objective adjustment and an excuse. There is a serious measurement here and therefore an incentive problem because the results we see are the combined effect of "objective differences" and choices. The latter would include the price of fuel, the use of nuclear energy, the layout of cities, the availability of mass transit, incentives for energy efficient buildings, and much more. To make the proper adjustments, what you ideally need to know is how much extra carbon would be emitted by a European country that happened to have the climate, size, and population density of Canada. That is, you need to subtract out the effect of high-energy, high-carbon choices. Quantitatively this is hard to do. But it is important to emphasize that while Canada is cold and large and not densely populated, the population is not scattered evenly through the country. Rather, it is largely arrayed along the U.S. border and largely in cities like all other advanced countries. While some of the energy consumption comes from size, density, and temperature, much more comes from relatively cheap oil and a set of choices, public and private, that creates a high-consumption energy environment. The effect of conflating these two components of the observed differences in energy consumption and emissions depends on the mitigation system. A mitigation system using tradable carbon credits just gives extra credits to some countries, which has the effect of transferring costs away from them. The global pattern of mitigation will not be affected. I will show later in the paper that targets and international offsets produce the same result. With targets only, since the total has to add up to the global total, the reduced required mitigation in one country has to be transferred to other countries in the form of increased mitigation requirements. In all cases it is a zero sum game. Fairness requires that the adjustments be based on real differences without the effect of differential choices (current and historical) included.

advanced country status are negligible. Any solution will need to generate new, more efficient, and cleaner technology and that will have to be imported to the developing countries. Finally, some form of burden sharing is likely to be important. I argue in the next sections that the most plausible path to a relatively satisfactory global outcome on a 50-year time horizon will require all of the above: an increase in emissions from developing countries, muted by their own (already well under way) planning and policy efforts toward energy efficiency and low-carbon energy sources augmented by imported technology, cross-border incentives, and activities, burden sharing, and eventually accommodative allocations in a CCTS.⁸

Fairness for advanced countries of approximately equal status is relatively straightforward. Harder is making precise the meaning and implications of fairness in the context of a dynamic path that achieves global carbon emission goals, a path along which developing countries of necessity will grow and contribute to aggregate carbon reduction goals.

Rather than tackle this difficult issue directly, it may be more helpful to lay out possibly feasible dynamic paths that accomplish the goals and then to consider issues of implementation.

How Do We Get to Safe Levels over Time?

In thinking about viable time paths that eventually solve the problem of getting to safe global targets, it is important to note that the time horizons are long, and the uncertainty is great. As discussed above, the group we think of as the advanced countries will change dramatically in size and composition. Over the next 50 years, the higher growth developing countries will be at or approaching advanced status, and we will learn a lot about the options and costs of mitigation. Furthermore, essential new technologies will alter those options and costs over time.

A set of “common but differentiated responsibilities,” established in the UNFCCC and Kyoto protocols, affirm that solutions with any chance of being acceptable will involve asymmetric roles for advanced and developing countries in various categories. For the higher growth developing countries this will mean

⁸ In advanced countries, energy efficiency at the macro level can be furthered by energy efficiency and what is sometimes called reduced energy policies at a more micro level. The incentives provided by appropriate pricing and taxation are extremely important in this regard. The same is true of developing countries, where a high-priority first step is the removal of widespread energy subsidies. The latter are not useful components of growth and development strategies for reasons outlined in *The Growth Report* (Commission on Growth and Development, May 2008). I have however hesitated to use the term ‘reduced energy’ in relation to the developing countries because interpreted at the macro level, it could be misunderstood as suggesting that there are known high growth paths that can be accomplished while reducing energy consumption. There are no examples of that and with existing technology it is unlikely to be possible.

that the roles in the climate change effort will evolve continuously and eventually become coincident with the other advanced countries, a group they will be joining. More generally, the notion of asymmetric and evolving roles needs to be part of the frame of reference for the international negotiations.

In this section, my goal is to project in general terms how significant long-run reductions in CO₂ emissions can occur in the context of significant growth in developing countries. For this purpose, I have divided the advanced countries into two groups: (i) the United States, Canada, and Australia, and (ii) the rest. This division reflects the significantly different current per capita CO₂ emission levels in the two groups.

I have also divided the developing countries into a high- and a lower-growth group. The lower-growth group is significant in terms of population (though smaller than the high-growth group), but relatively poorer and low in the emissions spectrum, and with much lower growth rates and a much smaller share in global GDP. It will not for the most part have the dominant effect in the next several decades. The high-growth group with more than half the world's population is the center of the action.

Figure 2. Per Capita Emissions, 2009

	Population (millions)	2009 per capita emissions (tons)
United States, Canada, and Australia	330	20
Other advanced	670	11
High-growth developing	3,356	4.2
Lower-growth developing	2,178	1

Source: Population data from United Nations Department of Economic and Social Affairs; emissions per capita from IPCC and Human Development Report 2007/2008 (UNDP).

The time horizon is 50 years to 2059. I assume that the high-growth developing countries will grow at high rates, on the order of 6 percent a year. However, the growth of CO₂ emissions absent mitigation efforts will be lower because energy and carbon intensity both decline as incomes rise (see Appendix A for some data). I assume conservatively that the over the 50 years, the high-growth developing countries will experience CO₂ growth of just under 2 percent per year, which would bring them to the advanced country level of the second group of advanced countries, namely 11 tons per person in 50 years. This assumes no mitigation. The poorer developing countries experience growth in CO₂ emissions of 2 percent (in part because that is where most of the population growth will occur) but from a low base.

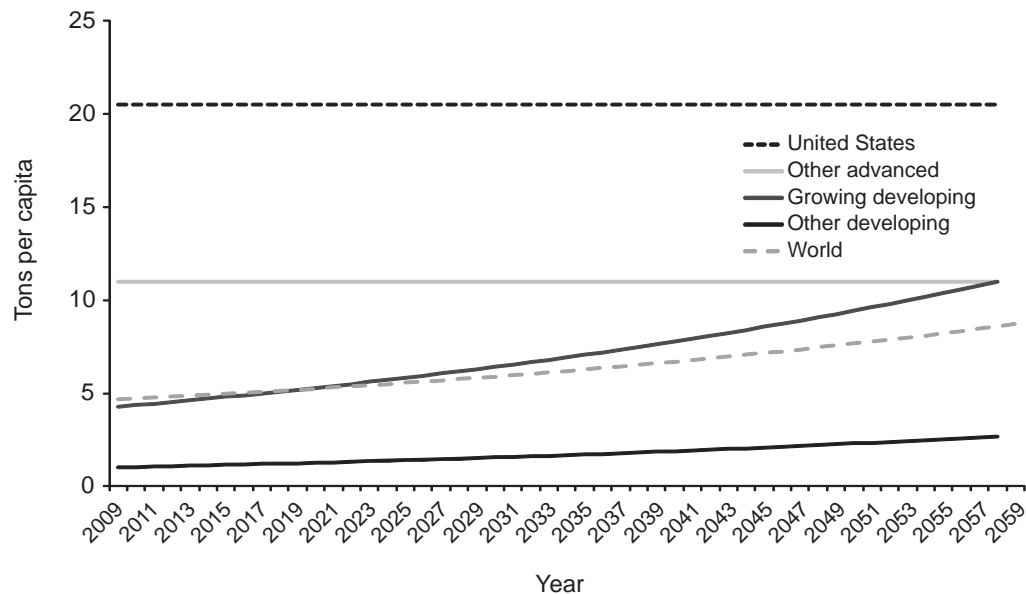
The target in this exercise is to get to roughly three tons a person globally in 50 years. That is not at the current estimated safe level but it is getting close. The main actors are the two categories of advanced countries and the high-growth developing ones. To reach the three-ton target, the high-carbon emitters (the first group of advanced countries) need to reduce per capita CO₂ emissions by just

under 4 percent per year. This may seem a huge challenge, but is more manageable than it appears. Much of it in the early stages can be achieved with large increases in energy efficiency.⁹ The other advanced countries would need to reduce CO₂ emissions at the rate of 2.6 percent a year. One could do this analysis with a somewhat longer time horizon. Specific rates would change but the patterns we will see would not. This analysis presumes that if the two categories of advanced countries are not able or willing to get to about 3 tons per person on a 50-year time horizon, the developing countries cannot get there either, unless their growth slows dramatically.

The projections below are just arithmetic with some assumptions about the rate at which developing countries converge to the advanced country levels, income, and technologies. I emphasize that this is not meant to be an argument that any category of country should set or agree to 50-year targets. Given the structure of the problem—that is, sequential decision making with uncertainty about all the relevant parameters (including costs, the efficient pattern of mitigation, and technology)—it is much wiser to put in place incentives and regulations that will achieve measurable progress and generate a lot of useful information on the way. I return to this later under the heading of implementation.

Assuming no effective mitigation efforts in either the advanced or developing countries, the pattern of global per capita CO₂ emissions is shown in Figure 3. The global average rises to 8.71 tons per person from a starting point of

Figure 3. Per Capita Emissions with No Mitigation Effort



Source: Data provided to author by officials at ENI, the Italian energy company.

⁹ It has been estimated, for example, that if the composition of the European auto fleet were transferred to the United States, the reduction in oil consumption would be around 4–5 million barrels a day, on a base of 21 million barrels a day.

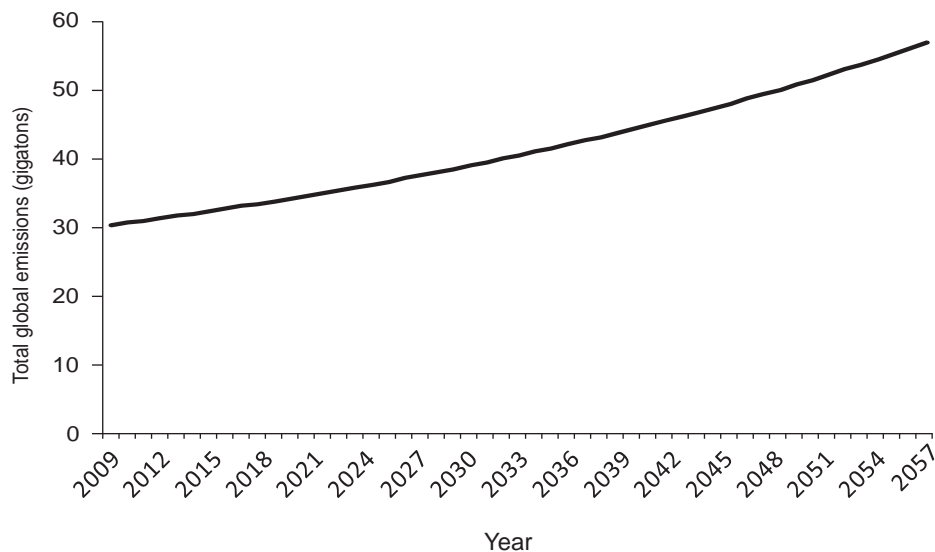
4.65, due mainly to the growing developing countries, with a contribution from the lower-growth group. I have held the advanced countries constant in this hypothetical scenario.

Under this scenario, total global emissions will rise as shown in Figure 4. This path would constitute an extraordinarily high risk and is very unlikely to be followed unless the process for working out an evolving intertemporal mitigation program fails completely. Even then, the drive for increased energy efficiency and lower carbon technologies, well underway in many countries, advanced and developing, is likely to continue and accelerate. While not the course we are on, it may serve as an added concrete incentive to move aggressively and quickly.

Mitigation Scenarios

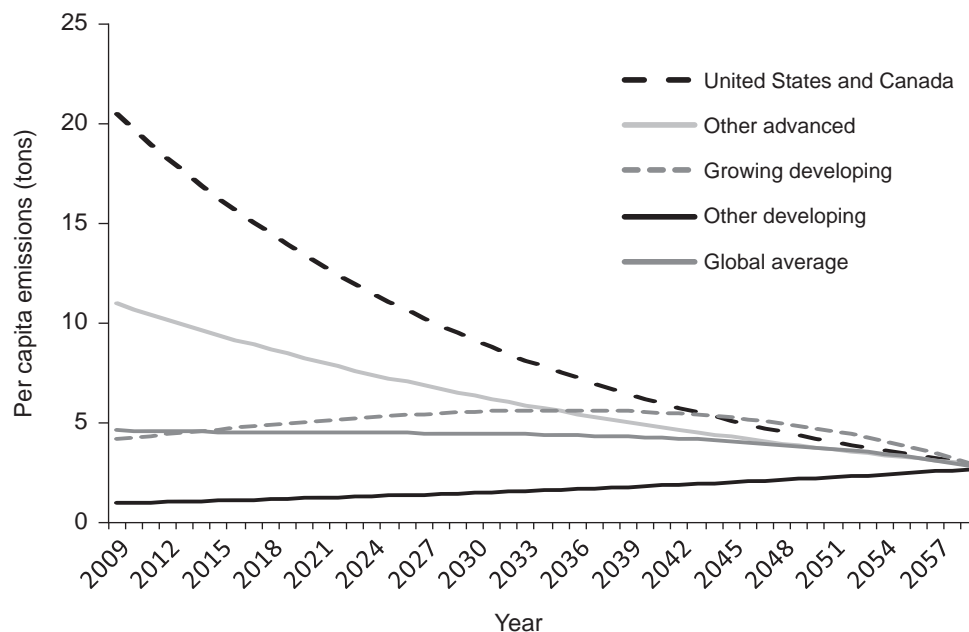
We turn now to mitigation scenarios. The pattern will look something like that depicted below in Figure 5. The ingredients are fairly clear. The advanced countries decline as described earlier at different but substantial rates. There may be periods of rapid declines in CO₂ emissions followed by leveling off, but on average, the basic pattern is right. These declines are important quantitatively in themselves, but they are also critical in providing the technology, policy, and learning base that will influence the high-growth developing country trajectory. Their emissions will rise for an extended period because of high growth. The challenge is not to prevent that from happening but over time to slow emissions growth and eventually turn it around as the countries become richer. This dampening over time of high-growth emissions is crucial and probably doable.

Figure 4. Total Global Emissions (Gigatons)



Source: Author's calculations.

Figure 5. Per Capita Emissions on Path to Safe Target



Source: Author's calculations.

Emissions reduction will occur as a result of a number of forces. One is the use of the successor to the Kyoto Clean Development Mechanism that will be produced as part of the current round of negotiations. A second is a focus on increasing energy efficiency in the developing world in anticipation of rising energy costs. This is clearly in individual countries' self interest and is well underway in many countries. Part of the energy efficiency program will involve the systematic removal of widespread energy subsidies. These are increasingly costly and bad growth policies at the individual country level, as discussed in *The Growth Report* of the Commission on Growth and Development.¹⁰ In some countries like China, India, and Brazil, aggressive plans to deal with energy efficiency, local environmental issues, and carbon emissions are under way.¹¹

A third and very important process is the transfer of technology in the area of energy efficiency, clean energy, and carbon capture from advanced to developing countries. This will require commitment and cooperation between advanced and developing countries. Without it, the process of damping down the energy consumption and rising carbon emissions resulting from growth will prove ineffective.

¹⁰ The implicit expenditures crowd out crucial public sector investment and badly bias the evolution of the economy and its capital stock toward high-energy configurations. The subsidies are in the process of being dismantled.

¹¹ A useful description in some detail of the emerging China programs can be found in an article in the *McKinsey Quarterly*, May 2009, "China's Green Opportunity," by Martin Joerss, Jonathan R. Woetzel, and Haimeng Zhang. India has implemented a switch to compressed natural gas in high-emissions, three-wheeled vehicles in major cities. Brazil has made major progress in transitioning to an ethanol-based transportation system. There are many other examples.

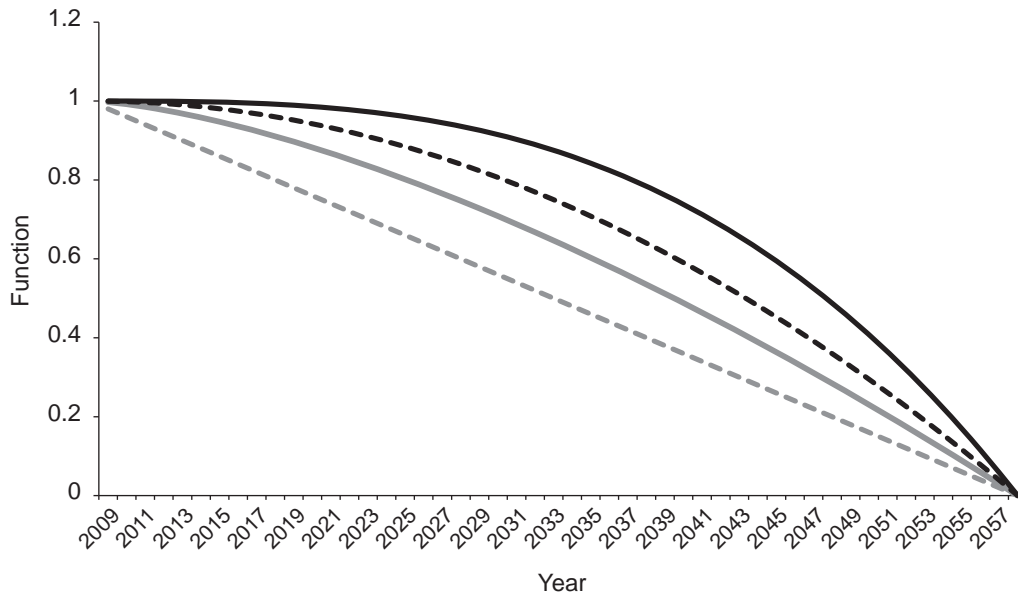
The pattern of per capita carbon emissions in Figure 5 requires a little explanation. Clearly it differs from the path shown earlier with no mitigation, the more so as time goes on. This projection is the result of introducing a function that causes the growing developing countries to converge toward the advanced countries but with a lag or partial convergence in the near term.

Specifically, if $D(t)$ is the per capital emissions in the high-growth developing countries without mitigation, and $E(t)$ is the “European” emissions, (both in year t) then it is assumed that the mitigated emissions in the developing countries are $M(t)$ as follows:

$$M(t) = D(t) \times \left\{ \frac{E(t)}{E(0)} \times [1 - T(t)] + T(t) \right\},$$

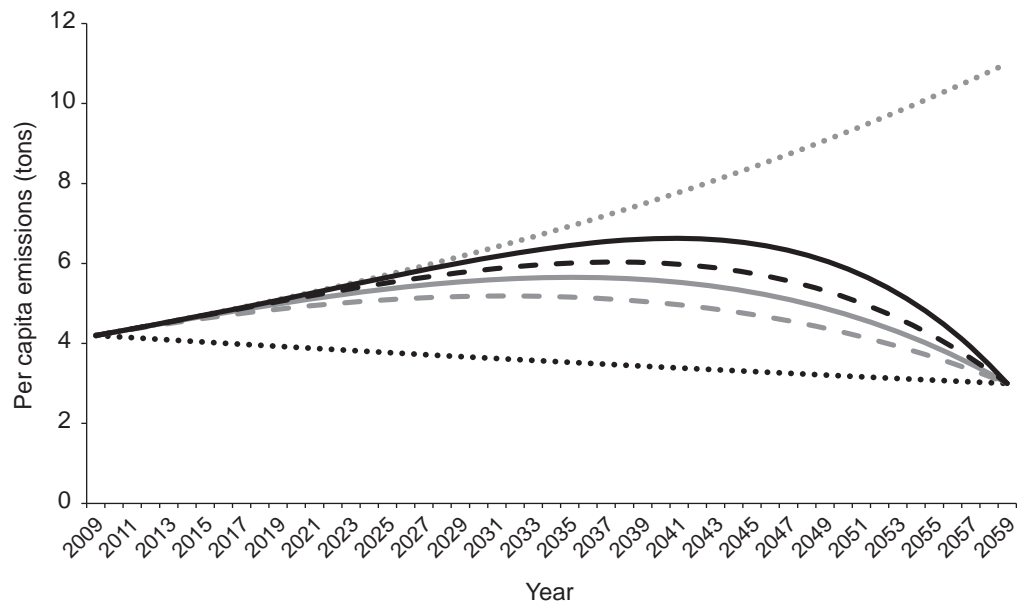
where $T(t)$ is between one and zero, is one at $t = 2009$ and declines to 0 at $t = 2059$. Recall that $D(t)$ converges to $E(0)$ at the end of the period; that is, without mitigation, the developing countries hit the current emissions levels for the second advanced country group when they arrived at advanced country incomes. Thus, with lagged mitigation, the convergence is to $E(2059)$ at the end of the period, when $T(2059) = 0$. In this equation, the speed of transfer of technology is captured by $T(t)$. $T(t)$ is generally concave, the more so the greater the delay in the transfer of advanced country technology to the developed country. In Figure 6, several examples of the delayed convergence function $T(t)$ are shown. The function I have used in the mitigation time paths above corresponds to the version of the transfer convergence function represented by the solid gray line.

Figure 6. Transfer Lags for Advanced Country Technology: Various Versions of the Function $T(t)$



Source: Author's calculations.

Figure 7. High-Growth Developing Country Emissions with Various Transfer Lags



Source: Author's calculations.

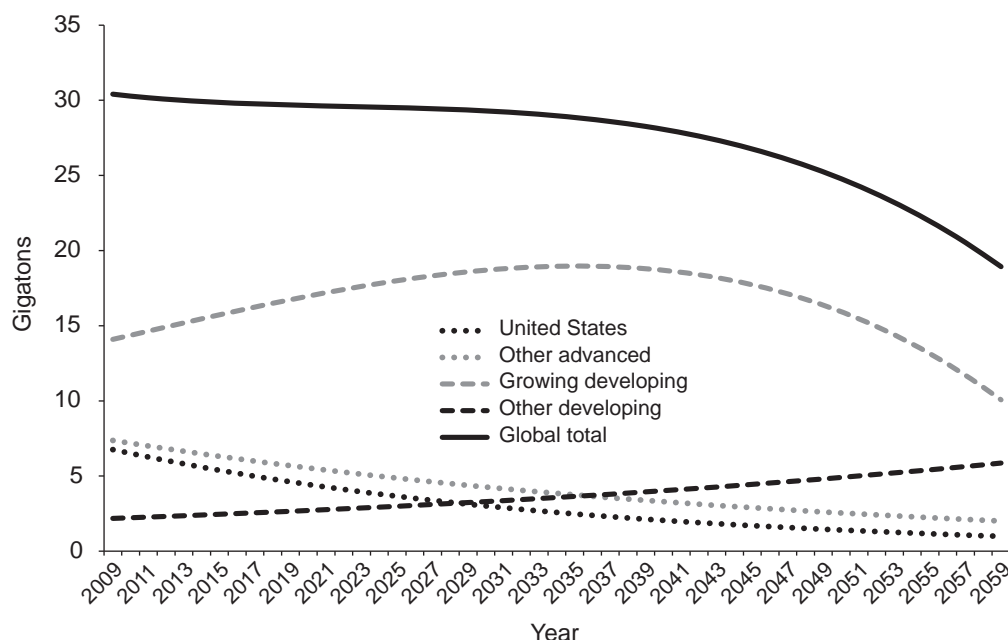
If, for example, one switches to the function represented by the solid black line, the delays are longer and this would cause the high-growth developing countries' emissions to rise more and for longer than those depicted in Figure 5.

The per capita emissions in the high-growth developing world are shown in Figure 7. The top line (dotted gray) represents the emissions with no mitigation. The bottom line (dotted black) represents the emissions following the rate of decline of the non-North American advanced countries. The remaining lines are the per capita emissions corresponding to the transfer functions in Figure 6 with the colors and patterns matching.

What underlies the depicted time paths is rather important: it is the length of time and degree of divergence from advanced country standards that characterizes the growth path of the high-growth developing countries. How this works out in practice will be influenced by international agreements and incentives (in particular, issues related to who pays for what at varying points on the journey) but also importantly by domestic policy choices in developing countries as they approach and converge with international advanced country status and targets.

The aggregate CO₂ emissions that go with the mitigation paths described above (using the version of the transfer lag for high-growth developing countries represented by the solid gray line) are shown in Figure 8.

Figure 8. CO₂ Output in Gigatons with Effective Mitigation



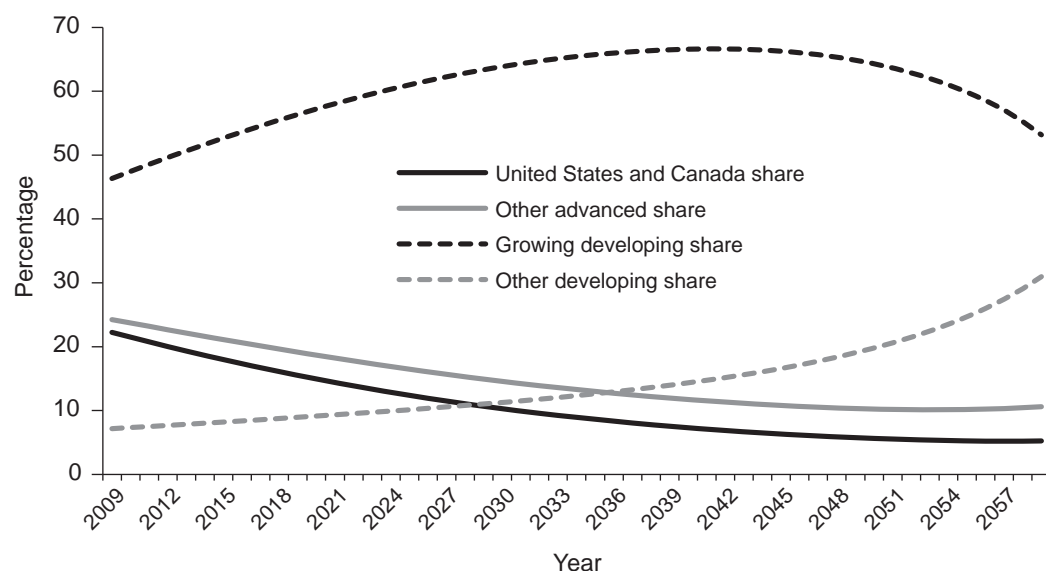
Source: Author's calculations.

Here one can see clearly the rise and subsequent fall of total emissions for the rapid-growth developing countries. As a result, global emissions decline slowly for about 25 of the 50 years and then the decline accelerates. With longer transfer lags, global emissions fall and then rise and then fall again (see Appendix B for an illustration).

Any broadly acceptable mitigation plan will likely have these general characteristics, though the details and timing will vary. We do not and probably cannot know how the race between developing country growth on the one hand and mitigation technology and its adoption on the other will play out. However, it seems unlikely that the high growth and elevated energy use in the high-growth developing world will be overridden in the short run even by large reductions in CO₂ per unit of energy used. And it is certain that in that group of countries, energy consumption will rise in total and per capita.

Given the gradual reduction in total global emissions in the early decades, we might conclude that the assumed initial aggressive efforts in the advanced countries, complemented by significant domestic efforts in developing countries, are insufficient or ineffective in addressing the problem. That assumption would be a big mistake. Advanced country progress, combined with developing country commitment to participate in the cross-border programs (and eventually in a global carbon trading system, discussed below under implementation) and evident willingness to adopt energy saving and clean technologies will form the basis for achieving the long-range targets.

Figure 9. Shares of Total CO₂ Output



Source: Author's calculations.

The shares of total CO₂ emissions are shown in Figure 9. The shares of rapidly growing countries are already substantial; they rise for a couple of decades and then fall again. At that point, the rest of the developing world is becoming more significant, at least in the model, and its emissions will have to be addressed. But for most of the next 50 years, the mitigation dynamics will be determined by the advanced countries and the rapidly growing developing ones.

Implementation: Costs, Efficiency, Technology, Uncertainty, and Burden Sharing

The preceding sections describe in general terms what needs to happen over time in order to approach safe levels after 50 years while there is high growth in the developing world. The obvious next question is what steps are needed in various countries and at the international level to embark on this path. In order to do that, we need to focus on the costs of mitigation and their distribution across countries and over time.

From our present vantage point the costs are not known. Essential components of effective mitigation strategies are (1) a process of discovering the costs over time, (2) an incentive structure that leads to mitigation occurring in locations (sources of emissions by type of source and geographic locations) where the cost is minimized, and (3) incentives for households, companies, entrepreneurs, and governments to develop new behaviors and technologies that will have the effect of reducing the costs of mitigation over time. At present we have some knowledge of parts of the three components above, but nothing like a comprehensive picture. In particular, we do not have global system that is

capable of “solving” these three problems or generating useful information like the evolution of the marginal cost of mitigation. A significant part of the mitigation challenge is to create this global system.

The rest of the paper briefly describes a global carbon credit trading system (CCTS) and discusses what it can and cannot do. To anticipate, the main problem with a fully global CCTS is the allocation of credits, in particular to developing countries. With too few credits they will be forced to absorb the costs of mitigation or of purchasing credits to accommodate the growth. Either way there is a risk to growth. If the allocation of credits is large, then while the incentives to mitigate remain (because it is profitable), there could be large transfers to developing countries that are essentially unrelated to mitigation and would not be acceptable to advanced countries.

I will then argue that there are two alternatives, both of which rely heavily on cross-border mechanisms that result in quite efficient mitigation globally, create significant incentives for developing countries to take actions that increase energy efficiency, and reduce the trajectory of carbon emissions consistent with maintaining growth. In other words, we don’t really need the full global CCTS. In these two alternatives, developing countries do not have formal mitigation requirements. But they do have incentives and commitments—in other words, the substance of common commitment but differentiated responsibilities. The incentives I will describe shortly. The commitment required is basically to the cross-border mechanism, to the monitoring system that is required to support it, and to the transfer of technology. Here I will describe these alternatives and then spell them out in detail in an appendix with a formal model.

A System Based on Carbon Credits

A global CCTS has, in principal, the capacity to solve a challenging problem. If one stipulates (1) that mitigation in developing countries is needed to achieve global objectives because of their presumed and likely growth and (2) that mitigation costs will be absorbed by the countries in which the effort is undertaken, then one has a problem in which mitigation is in direct conflict with developing country growth. The solution in principal is to disconnect the location of mitigation from the cost absorption as happens in the cross-border mechanisms, though the latter are often “sold” as increasing the potential efficiency of mitigation. A global CCTS does both things. The distributional issues are in principle handled by the initial allocation of credits to countries.

The Elements of a Global Mitigation System Based on Carbon Credits

The first component is a global agreement on a time path for global carbon emissions, independent of where the mitigation occurs. It might look like the start of the path for global emissions in Figure 8, but with periodic revisions with

as new information about costs, technology, and impacts on growth is acquired. The price of a carbon credit in this system is the marginal cost of reducing CO₂ emissions.

The second component is a system in which the global targets are achieved as efficiently as possible, meaning in the least total cost manner. That system has two pieces. One is an annual allocation of carbon credits to countries based on a transparent formula, where the sum of the carbon credits adds up to the global target for emissions in that year. These credits are traded and there is a global market price for them. They are time dated and should be thought of as CO₂ emissions rights for a period of time. At the highest level, after trading, countries (including CO₂ emission sources within countries) have to hold credits equal to the aggregate emissions for that period.

The second piece is a system within each country that is designed to cause carbon emissions to hit the national holdings of carbon credits after purchases and sales. There will be variation across countries in these subnational systems including use of carbon taxes, quantity restrictions, and other mechanisms for matching output with the national holding of credits. Allowing this kind of flexibility at the national level is likely to be important for political and administrative reasons.

Futures and derivative markets will develop to provide risk reduction opportunities for various entities in the system and to provide future price signals that will increase the visibility and clarity of the benefits of investment in carbon-reducing technologies.

The combination of these two pieces causes the whole global system to be efficient. The price of the credits is the marginal cost of mitigation. Carbon mitigation will occur in places where it has the least cost at the margin. Furthermore, the incentives are appropriate, because the global price of carbon and futures prices will incentivize investment in carbon-reduction or energy-saving technology by providing appropriate price signals. Countries with opportunities to reduce net emissions by reforestation, afforestation, or other means will do so (assuming the unit costs are below the carbon price) because such investments will lower emissions and either increase the carbon credits that can be sold or reduce the carbon credits that need to be purchased.

It is important to note the following:

- The location of the emissions reductions is not known in advance and, absent a complete understanding of the global cost function, cannot be known in advance. It is part of the purpose of the system to “discover” the location.
- The amounts of mitigation by location are not affected by the initial country allocation of credits. The location is determined entirely by efficiency or cost minimization criteria. What the allocation of credits does is determine who pays for how much of the mitigation.

- The allocation of enough credits to developing countries to avoid reducing their growth by imposing heavy costs will not result in the absence of mitigation in developing countries. Credits are not targets. Countries with significant mitigation opportunities such as reforestation have an incentive to pursue those opportunities. Relatively low-cost mitigation produces “profits” in the form of extra sellable credits or credits that do not have to be purchased.
- Per capita carbon emissions across countries will not necessarily converge. Preferences play a role here. It is at least logically possible that driving distances, the construction of cities, physical distances, the availability of public transportation, climate, and a host of other factors interacting with incomes and wealth could produce different choices and different results. In the global CCTS, these diverse choices are not and probably should not be precluded, but they are in a sense paid for.

The third and final component of a global strategy is a formula or mechanism that dynamically allocates carbon credits to countries. The sum of the credits across countries is the global target for that time period. Therefore, time-dated global targets are inputs to the formula.

How the credits are allocated determines the absorption of mitigation costs across countries and therefore has embedded in it what has come to be called “burden sharing.” This then is the crucial step and also the heart of the problem.

The argument of the developing countries is that to allow their growth to continue, there needs to be an allocation that does not impose large costs or reduce growth. The problem is that we don’t know what those allocations should be. In order to calculate the allocation that would leave a particular country with net costs of zero, one needs to know the growth path of emissions (net of mitigation), the costs of mitigation, and the price of carbon. None of these are known in advance, but all three are required to set the allocations so as to leave them whole ex post. (Details are provided in Appendix A.)

It might be tempting to allocate based on population on the theory that entitlements eventually need to be done on a per capita basis. This may work for the advanced countries, after allowing for a transition period for the high emitters to catch up and some properly calculated adjustments (discussed earlier).¹² But for developing countries this would result in such a large overallocation relative to current emission levels, and hence would cause potentially huge income transfers to the poorer countries whose precise magnitude would be discovered ex post. This is very unlikely to be acceptable to the advanced countries.

I believe that the search for a formula for carbon credit allocations in the context of a fully global CCTS, one that keeps the risks to developing country

¹² It would be easier to deal with the advanced country allocations on a per capita basis if over time their per capita emissions had converged to something like the European levels.

growth low without the possibility of large transfers (unrelated to mitigation), is unlikely to be successful. In principle it is possible. In practice we don't have the information to implement it.

Fortunately, it is not necessary. The solution is remarkably simple in a way: leave the developing countries out of the CCTS until their growth brings them into the advanced country category. Instead, reengage them with a different mechanism, the CDM or a cross-border mechanism, combined with technology transfer.

In the next section I will argue that something very similar to the mitigation paths described earlier (in the section on time paths) can be achieved with a CCTS in the advanced countries combined with an effective cross-border mechanism. Then, in the following section, I will argue that while an advanced country CCTS has a lot of merit in establishing a global price for carbon, the mitigation paths that lead to safe levels can be initiated and sustained for several years without the CCTS. This is accomplished with advanced country targets for CO₂ mitigation in combination again with an effective cross-border mechanism. I call these two systems the Advanced Country CCTS and the Advanced Country Target System. With a cross-border mechanism, both systems produce strong incentives to move to an efficient pattern of mitigation globally. Both require a "graduation" criterion that determines when developing countries move to advanced country status, at which point they become subject to the mitigation system then in place for advanced countries. The graduation criterion is important for two reasons. First, it should create incentives for developing countries to adopt policies that prepare it to cross over to advanced country status without a significant disruption. Second, it defines precisely the parameters that cause the "differentiated responsibilities" to converge to those of advanced countries. It is therefore the operational implementation of fairness and accommodating growth.

The Advanced Country CCTS with a Cross-Border Mechanism

Here I describe this system in general terms and refer to Appendix A for a full layout of the model and the derivation of its properties. Countries are divided into advanced and developing. There is a full CCTS for the advanced countries, with one modification. Advanced countries get credit for mitigation undertaken and paid for in developing countries. Specifically, for each period, each advanced country has to hold credits equal to its own CO₂ emissions minus the total mitigation undertaken by that country in developing countries. To meet this requirement, the advanced country can reduce its own emissions, engage in mitigation in a developing country, or buy carbon credits. At the margin these have to be equally attractive, which means that the marginal costs of advanced

and developing country mitigation have to be equal and equal to the market price of carbon. This is the condition for globally efficient mitigation.

What will actually happen in this structure is that there will be an entrepreneurial search for low-cost mitigation opportunities in developing countries. The incentive is clear and powerful. It is to reduce the cost of mitigation for advanced countries and entities within them that have either targets or incentives to do so. Those who find the low-cost infra-marginal mitigation opportunities—ones that turn out to have unit costs below the price of carbon—will make money. They could be sources with targets but also intermediaries whose main business is to bring information and expertise to the global market for mitigation opportunities.

Turn now to the developing countries. They do not have explicit credits or targets in this system until they graduate to advanced country status. They do have a time path for emissions over which they exercise some control; call it $a_i(t)$ for country i in period t .¹³ Generally for growing developing countries this function will be rising because of growth. But the rate will be affected by energy pricing and efficiency and many other policy choices.¹⁴ This path is before any cross-border mitigation activity. The net emissions in any time period are the gross emissions, $a_i(t)$, minus aggregate effect of the total cross-border mitigation past and present.¹⁵

The Graduation Criteria

A critical determinant of the dynamic performance of the system is criteria that determine when a developing country shifts to advanced country status and is subject to the prevailing regime for advanced countries. There are choices to be made and they will have important effects on incentives. The goal is to allow developing countries to grow rapidly but with as low a carbon footprint as possible. One could use a per capita income criterion or gross or net emissions. These choices are being discussed and debated.

Per capita income by itself is probably not a good criterion. It would allow for growth, but only intersects carbon at the time of graduation, which in many cases is a long way off. Income per capita could be used as a secondary test with emissions gross of cross-border effects as the primary. However, it seems clear

¹³ This is the country-specific analog of $D(t)$ in the earlier section on the dynamics of global emissions. It is the “no mitigation” path.

¹⁴ The configuration of cities, the mass transportation system, and the design of buildings would be among them.

¹⁵ If mitigation were simply a recurring expense, then the present mitigation activities would be sufficient. More realistically however, some cross-border mitigation will involve capital investment. The impact will extend out in time. The accounting system that underpins the cross-border mechanism has to be able to keep track of the intertemporal effects. This accounting represents a significant piece of enabling global infrastructure, one that is required for all systems including the CCTS.

that if any country got to advanced country emission levels with a relatively low level of per capita income, something else would have gone very wrong.

For concreteness, I would propose that the transition occurs when gross (of cross-border mitigation) per capita CO₂ emissions hit the average per capita emissions of advanced countries at that time. If the global economy follows paths like those depicted earlier, then that per capita figure will be declining. I suggest this graduation criterion because it creates a powerful and constructive incentive for developing countries to pursue policies that reduce the growth rate of CO₂ emissions without impairing overall growth. Properly pricing energy would be an example of a pro-growth policy that reduces the growth rate of CO₂ emissions. An aggressive program of importing energy-efficient and clean technologies would be an especially important additional activity.¹⁶ While we know that rapidly growing developing countries will increase CO₂ emissions, they can make choices that affect the rate of growth, and the system as proposed creates an incentive to delay the graduation date with positive effects on emissions.

There is an argument to be made for using net (of cross-border efforts) per capita mitigation levels as the basis for a graduation criterion. The argument is that doing this would make the developing countries incentivized partners in promoting cross-border opportunities and in being part of the search process. Arguably it would also maintain the incentive to take actions consistent with growth that keep gross emissions down.

To be fair, with either gross or net emissions, adjustments for natural endowments will have to be made. Some countries have more hydroelectric resources or natural gas while others are more heavily endowed with coal. These adjustments are important and are also going to have to be worked out for advanced countries. It seems sensible to use the adjustment formula for advanced countries to make the appropriate adjustments in the graduation criteria for developing countries.¹⁷

What happens after graduation? A country at that point becomes a party to whatever negotiated international agreements are in effect for advanced countries. It could be target rates of reduction of per capita CO₂ emissions. It could be the CCTS for advanced countries with credit allocations based on population with possible adjustments for size, climate, and a range of

¹⁶ Technology development and transfer is by general agreement crucial. Developing country activity in this area should be supported by international agencies with an explicit technology transfer mission as part of their mandate.

¹⁷ There is an argument that smaller developing countries may be at a disadvantage in having fewer options with respect to low carbon growth because issues with respect to scale, fixed costs, and the like. This may be true and it is important from a fairness standpoint. But from a practical point of view, for most the graduation is a long way off and the CO₂ output doesn't have a major impact. Rather than hold up the process of reaching an agreement, it would seem sensible to exempt the small countries for now and defer this issue with a promise to return to it with more information later.

differentiating factors that may be deemed appropriate as a result of international negotiations.

Is there anything else required of developing countries to enable this system to work? The main additional requirement is participation in and support for the cross-border mechanism and support for the global monitoring and accounting system that is needed to keep track of mitigation and credit it to the right source.

There is a final point concerning cross-border mitigation that should be noted. The search for mitigation opportunities in developing countries will cause the mitigation in developing countries in a particular time period to expand until the marginal costs are equal to the advanced country marginal costs and the carbon price. That will determine the total mitigation in the developing countries. It will not determine who does it or specifically how those mitigation efforts are spread across advanced countries. Formally, in the model, these are indeterminate. In actuality, they will result from the search for low-cost mitigation opportunities in developing countries and are part of the entrepreneurial dynamics of the system.

To summarize briefly, the advanced country CCTS with an effective cross-border mechanism will tend toward a globally efficient pattern of mitigation. It does not impose onerous costs on developing countries but does create (or can be constructed to create) strong incentives for reducing carbon in ways that are consistent with growth. Developing countries graduate late in the growth cycle and then participate in the latter stages of the mitigation effort as an advanced country. Collectively, advanced countries have an incentive to reduce emissions as rapidly as possible as that will cause the developing countries to engage earlier so that the global mitigation effort will eventually produce the required results. Special provisions are needed for high-emission tradable goods and services industries.

Advanced Country Targets and the Cross-Border Mechanism

It turns out that the advanced country CCTS component is not needed to achieve global efficiency. The cross-border mechanism by itself will do it. Before explaining why, note that some version of the CCTS for advanced countries is highly desirable because it creates a price for carbon. Futures and derivatives markets will develop around the carbon market. These prices will provide a huge amount of information about present and expected future mitigation costs and create incentives and risk management structures and tools for investment in new technology. I would not want the analysis of this section to be interpreted as an argument that a well-constructed CCTS is superfluous. But with a cross-border mechanism and the required accounting and tracking system, one can move toward globally efficient mitigation efforts.

The argument is reasonably straightforward but a bit surprising (at least to me) and is laid out more formally Appendix A. The assumptions are the same as in the Advanced Country CCTS, except that the CCTS is replaced by time-dated targets that advanced countries adopt as a result of an international negotiation. There is a cross-border mechanism and the developing countries engage in the same way with the same incentives and with a graduation criterion. The only difference is that for each advanced country, instead of needing carbon credits equal to its emissions net of its cross-border activities, that country must have emissions net of its cross-border mitigation total equal to its target for that time period.

In this system, advanced countries will mitigate domestically or in developing countries according to where the marginal costs are lower. This will cause the marginal costs in advanced and developing countries to converge. If that were not the case, then some advanced country could shift their domestic mitigation activity to a developing country or vice versa, or from one developing country to another, and lower mitigation costs. The combined effect is to bring the marginal costs of mitigation in advanced and developing countries into line. Since that is the condition of efficiency or cost minimization in global mitigation efforts, the result is efficient mitigation.

The search for the cost-reducing, cross-border mitigation activities would be more complex because of the absence of a global carbon price signal. That could impair the efficiency of the dynamic part of the process and delay the convergence of marginal costs of mitigation across countries. In addition, the absorptive capacity of developing countries with respect to cross-border mitigation investments is not unlimited. It will vary across countries and likely expand over time. One cannot therefore expect instantaneous results, notwithstanding the formal properties of the system. But as a direction of movement, it has attractive efficiency properties while accommodating developing country growth.

Energy-Intensive Tradables and Mobile Industries

There is a concern about the mobility of tradable industries. A global strategy that allows for developing country growth embodies asymmetries in the roles and incentives for different groups of countries. As a result it runs the risk of distorting certain kinds of incentives. Of these risks, a potentially serious one is the migration of high-energy, high-carbon industries that produce tradables to developing countries. Off-shoring of these industries will produce local but not global mitigation and could occur with advanced country targets and an advanced country carbon credit system.¹⁸

¹⁸ The added incentive to move high-energy industries to developing countries would not exist in a full global CCTS that included the developing countries. The reason is that moving production to

It is not clear how great the risk is. Countervailing forces include transport costs, local environmental regulation, and the anticipation of graduation later. Nevertheless attention to the potential problem is warranted. To eliminate the distorted incentives, a global agreement to tax the carbon output of these industries *regardless* of their location would help neutralize adverse incentives. The tax should be based on carbon output and the rate should be at the global carbon price, or an estimate of it before the global carbon price is established via the trading of carbon credits. In addition to un-biasing the location decisions, such a tax would also get built into the output price and avoid excess demand based on under-pricing the negative climate change externality.

It is worth noting that from the mitigation point of view, this is not a crucial issue. If these industries are low-cost mitigation opportunities, mitigation will occur regardless of where they are and conversely under a cross-border mechanism.¹⁹

Asynchronous Mitigation Progress and Competitive Problems

A significant potential stumbling block in international negotiations on mitigation commitments, goals, and timing concerns the potential consequences of mitigation costs on relative international competitive positions. The goal is to achieve a cooperative outcome and avoid some of the negative features of a non-cooperative Nash equilibrium. The perceived problem is that it is not always rational for any single player (in this case a country or region) to adopt the cooperative strategy first. Whether or not this is in fact the case depends on the payoffs and the incentive structure of the game. A non-cooperative equilibrium is clearly the right description of the prisoner's dilemma structure, but not of other structures. It is easy to make assumptions about the incentives that may or may not correspond with reality. One must distinguish between plausible-sounding advocacy and analysis.

In the area of energy efficiency, there are clear differences across countries, developing and advanced. These include large differences across developed countries, which tend to compete with each other in the same classes of goods and services. There is relatively little evidence that the high-efficiency countries have suffered a competitive disadvantage in international markets, although the counterfactual is difficult to calculate. High efficiency is achieved with elevated taxes and prices, direct regulation, consumer values, or a combination of all

India in a full global CCTS would cause India's mitigation costs to rise—they would have to hold more carbon credits. With proper incentives transmitted to the industry, those costs would be imposed on the industry and be reflected in the pricing.

¹⁹ Without the cross-border mechanism this would not be true, and removal of mitigation incentives would also be an issue.

three. It certainly imposes costs, but there are compensating factors. In the case of taxes, the revenues can be used to reduce other taxes so as to create compensating incentives (as in the case of lowering corporate profits taxes) or to invest in productivity-enhancing public goods. For the developing countries, following the Commission on Growth and Development, we have argued forcefully that the net effect of highly subsidized energy on growth is highly negative.

For the advanced countries, there is a good argument for attempting to move forward in a coordinated fashion so as to avoid potential local competitive disadvantage. As Paul Krugman's work has shown, advanced countries tend to compete and trade in common classes of goods and services. Avoiding the reality or the appearance of competitive disadvantage by moving forward in a coordinated way makes sense. Analysts and participants will debate whether and in what areas there are advantages or disadvantages for first movers. The truth is likely to be a combination of the two.

The developing countries as we have argued are a different matter. First they are not a homogenous group in terms of income levels, productivity, and technology. Within subgroups that do tend to compete with each other for global markets in various classes of goods and services, similar arguments to those above for advanced countries should apply. That is, coordinated forward movement is preferable to single countries stepping out into the lead except in cases where the individual and collective incentives are aligned and it is the individual country's interest to move.

But to revert to the main theme of the paper, successful global mitigation that accommodates developing country growth will have to have embedded asymmetries during the long transitions to advanced country status. Energy efficiency convergence will come first but with a lag because of the highly subsidized starting point in many developing countries. Carbon abatement technology will be developed in advanced countries and transferred to developing economies. Clean technologies will experience cost declines driven by the learning curve as the accumulated volumes increase. These declines will help accelerate the transfers.

These asymmetries already exist in the form of differing levels of productivity, incomes, human capital, infrastructure, and capability. The preexisting differences are large, with the result that the global economy has segments and elements of specialization. To a large extent, developing countries compete in the global economy in an evolving but different set of global market segments from advanced countries. The asymmetries required to sustain an inclusive global program to bring carbon emissions down are probably not large relative to the existing differences and should not on the merits present insurmountable obstacles or derail the process.

There are, however, risks to the process of formulating an international framework for moving forward. The competitive disadvantage arguments will

be used and possibly misused to argue for very broad symmetries in targets, commitments, and performance measures. In an extreme form, this approach could substantially diminish the likelihood of an agreed-on direction supported by advanced and developing countries.

Where Does This Leave Us?

The central fact in assessing the dimensions of the climate change challenge is the growth of a significant portion of the developing world. On a 50-year time horizon, the number of people living in advanced countries will quadruple from 16 to about 64 percent of the world's population. The approach I have tried to take is to ask whether there is a path that does not truncate that growth but allows the achievement of global targets on a time horizon of 50 years or a little more. As suggested by the analysis, I believe that there may be several such paths, the features of which are captured in the earlier graphs. Developing countries will grow in terms of income and their emissions will grow per capital and in total, while advanced country emissions will decline. Developing countries will take steps consistent with that growth to moderate the increase in energy consumption and carbon emissions, and graduate to advanced country status in the latter years. At roughly that point their total and per capita emissions will turn over and decline.²⁰ Global emissions will remain relatively flat for an extended period because of the combined effect of advanced country mitigation and developing country growth. That is still major progress, even though it might not look like it, as it lays the basis for rapid reductions later on.

The opportunities for carbon mitigation in the first 25 years are easier to discern than those in the latter years. An honest assessment I think would be that from the present vantage point, we simply do not know for the latter years whether technology will be sufficient to meet the final targets without major changes in global growth, and other things that affect the quality of life. That is a bridge to be crossed when we get there or at least get closer. In the meantime, there is much constructive activity to undertake that promises to reduce carbon emissions and hence the associated risks.

Turning to the question of how we get there, I have tried to suggest that there are mechanisms that have useful incentive, efficiency, and fairness characteristics that support the movement along the paths analyzed earlier. Specifically, the global CCTS has many attractive properties and puts a price on carbon, but presents a major challenge in allocating carbon credits. It can be modified to include only the advanced countries and combined with a cross-border mechanism and a graduation criterion to achieve (or come close to)

²⁰ When this turnover occurs depends on a host of factors including new low-carbon technology, the rate of transfer of the technology, the incentives created by the graduation criterion, levels of cross-border mitigation, and so on.

efficient global mitigation and still accommodate the developing country growth. It requires commitments from all parties, but they are asymmetric for a period of time and converge later as incomes converge. Furthermore, while there are major benefits to the modified advanced country CCTS, movement toward efficient mitigation is achievable with a system that involves advanced country individual mitigation targets (presumably ones that are negotiated in constructing an international agreement) combined with the cross-border mechanism with appropriate accounting and credit. In the short run this is likely to be the best option, with the advanced country CCTS set as an important medium-term goal.

With either the advanced country CCTS or the advanced country targets, both with cross-border activity and crediting provisions, additional action is required in the area of high-emission tradable goods sectors.

Technology development and rapid technology transfer continue to be extremely important and the mechanisms discussed create incentives for both. These incentives probably need to be supplemented with publicly funded or subsidized research and development to accelerate the process and to partially overcome the early stage risks. Such programs would be complementary to the mechanisms discussed above.

One other slightly counterintuitive point is that in the advanced country CCTS and the advanced country target paths, both with the cross-border mechanism, the developing countries do not have targets and the system does not need them. The system does have incentives for developing countries to pay attention to the rate of increase of gross CO₂ emissions as part of the strategies and policies for growth. At graduation the incentives turn into requirements in the form of targets or credits, depending on what advanced country system is in place at the time.

In the near term, the following steps taken by the advanced countries would represent a material advance in meeting the challenge of the risk of climate change:

- The advanced countries set realistic but aggressive goals and incentives for energy efficiency and CO₂ reduction with a time horizon of 10 to 15 years. These policies and commitments will and should vary by country, reflecting differing initial conditions. The most obvious distinction is the large difference in energy efficiency and per capita carbon emissions between North America and the rest of the advanced countries, the EU, and Japan.
- I suggest the high per capita emissions countries (the United States, Canada, and Australia) set 15-year targets with an average annual rate of reduction of around 4 percent a year. That would bring the per capita emissions down to levels similar to the remaining advanced countries now. In the case of the United States, per capita emissions would decline to about 11 tons per person over 15 years.

- Energy efficiency and reduced energy usage are likely to be quantitatively important in the early years in reducing carbon. As I noted earlier, at the macro level they have the same effect. At the micro level, they are different; driving a fuel efficient car versus not driving a car at all is reduced energy at the micro level and shows up as a component of energy efficiency at the macro level. Planning for energy efficiency and security have the advantage of being meritorious in their own right, from a national and a global perspective, quite apart from the positive impact on CO₂ emissions.
- In North America, the adoption of policies that raise fossil fuel prices at a measured pace in advance of a future energy “price” shock would create a large incentive for all sectors to increase energy efficiency with the side effect of reducing carbon. A proactive policy of setting this chain of events in motion now with a steady preplanned increase in prices (and taxes) would also remove some of the substantial costs that are experienced when there are sudden large upward movements in energy prices. Taxes on oil consumption should be set so as to reduce consumer price volatility and consideration should be given to doing this in a way that puts a floor under prices so as to reduce the risk of “alternative” investments. Raising the prices will provide substantial incentives for innovation in energy efficiency. Additional incentives with respect to the development of clean energy technologies are needed and are justified and important because of the externalities inherent in the environment and climate change area.
- The advanced countries undertake to invest in research in technologies closely linked to clean energy and reduced carbon emissions. That investment should probably also subsidize private sector R&D investment in these types of technologies, in part to compensate for the risk and in part to correct for the externalities. The latter will become less important once there is a global price of carbon that gets embedded in cost structure and hence in other prices over time.
- Support the creation of an effective cross-border mechanism for accounting, monitoring, and crediting carbon emissions. This applies to the developing countries too.
- Set in motion a process of creating a CCTS for advanced countries or some other mechanism that creates a global price of carbon and allows for the development of associated financial markets in futures and derivatives.

The Evolving Role of Developing Countries

The developing countries have accepted that they have an important role to play in energy efficiency and climate change. Many have already undertaken actions that are consistent with national and global interests. The issue to be resolved is the nature of the role, and how it evolves with domestic growth on the one hand and international progress on the other.

Consistent with the analysis of paths and mechanisms for achieving them, the following seem to be the key steps for developing country participation in the global effort:

- Participate and support the creation of a global monitoring system and the creation of a workable cross-border mechanism.
- Energy efficiency is a pro-growth component of an overall growth strategy, especially in a post-crisis environment of rising energy prices. Here the national and global interests are aligned. As part of a focus on energy efficiency, removal of energy subsidies is an important step. The subsidies are costly and the costs are rising again and are likely to continue to do so in the future. Placing the opposite bet would not be wise policy. More importantly, expenditures on subsidies would better be deployed to increasing public sector investments in education and infrastructure (often deficient in the developing economy context) that increase the return to private sector investment, incremental productive employment, and growth.²¹
- The developing countries will graduate to advanced country status and acquire symmetric obligations with the existing advanced countries. Working out a fair graduation criterion that creates appropriate incentives is a key negotiating task shared by advanced and developing countries.
- Anticipating graduation to advanced country status, aggressively importing energy and green technologies, and creating incentives for their deployment will promote growth and yield long-run benefits.

Conclusions

We are approaching a significant international meeting in Copenhagen, preparations for which may have been slightly derailed by the financial and economic crisis. But we have the crisis to thank for the emergence of the G20 as an important international group to discuss multinational frameworks, strategies, and principles. As a group it is small enough to be effective and large

²¹ For a further discussion, see part IV of *The Growth Report*.

enough in size and scope to represent the interests of the advanced and an important subset of developing countries. If the members of the G20 cannot agree on a framework that works for advanced and large high-growth developing countries, then a more comprehensive global agreement seems pretty remote.

The UNFCCC will retain the official and dominant role in formally negotiating international agreements and protocols. Furthermore, as a fully representative body, it will continue to have a special responsibility for representing the interests of the numerous smaller, poorer, and as yet relatively lower-growth countries. Other international institutions (including perhaps new ones) will be needed to provide expertise, support, and implementation capability, under the framework of the overall agreement.

What Is Needed from the Copenhagen Meeting?

The most basic output that is required is a shared understanding of feasible paths that achieve the long-term CO₂ global emission targets. Advanced countries will not absorb the full burden for the entire period, but they will take the lead and the largest share of the burden in the beginning. Developing countries will not make commitments that are high risk with respect to growth and development, but they have crucial roles in making the global systems work. The asymmetries in history, initial conditions, and growth rates have to be built into the dynamics and the mechanisms that support developing countries; this is not an easy challenge, but not impossible either.

Finally, the two agendas of (1) energy availability, security, and cost, and (2) climate change need to be merged in international discussions and negotiations. They are clearly very closely related though not completely coincident. Having them on parallel tracks risks contradictory and ineffective strategizing. But more importantly, we need to merge the scientific, technological, economic, and policy inputs, all of which are required to address both challenges. Merging these agendas and ensuring that the full required range of expert inputs is included should be a top post-crisis priority.

The ultimate question is whether a concerted effort along the lines described in this paper will ensure that global and developing country growth can continue for another half century without excessive risks of climate change. The honest answer is that we don't know and won't know for some time.

In the end it is possible that we will face very difficult choices between growth and the environment. If that happens the environment will be damaged but ultimately it will win at the expense of growth. But we are not there yet. It is a bridge we should try to cross if and when we come to it. Avoiding these stark choices later will depend on human ingenuity, technology, values, incentives, and our collective capacity to avoid non-cooperative outcomes.

Appendix A: Carbon Credit Trading Globally and for Advanced Countries, and Advanced Country Targets with Cross-Border Mitigation and Credit

In this appendix we set out the models for the global CCTS, the advanced country CCTS with cross-border mitigation and credit, and the system in which advanced countries have targets and the cross-border system is working. Everything is time dated including the cost functions. I will therefore leave out the time variable. We use the following notation.

$$\begin{aligned} M &= \text{the total global carbon credits} \\ m_i &= \text{the allocation of credits to country } i \\ e_i &= \text{the emissions of country } i \\ c_i(e_i) &= \text{the cost function for emissions for country } i \\ x_i &= \text{purchases of credits by country } i \\ p &= \text{the price of carbon} \end{aligned}$$

Here x_i can be negative (there are sales), the sum of purchases is zero, and for each country emissions have to equal the initial allocation of credits plus purchases:

$$\begin{aligned} \sum_i x_i &= 0 \\ x_i &= e_i - m_i \end{aligned}$$

This means that

$$\sum_i e_i = \sum_i m_i = M$$

Given the price of carbon, p , which is determined in equilibrium, countries act so as to minimize the sum of the cost of mitigation and purchases of credits

$$c_i(e_i) + p(e_i - m_i)$$

The first order condition for each country is

$$c'_i(e_i) + p = 0$$

The price p , which is the marginal cost of mitigation globally, is determined by the requirement that the sum of the emissions cannot exceed M .

This then is the full global credit system. The emissions levels depend only on p and therefore M , the global target, and specifically not on the initial country credits. The initial country credits determine the pattern of cost sharing and nothing else. There are no country targets.

If a developing country, say country j , wanted to be made whole so that the net cost was zero, one would have to set

$$m_j = \frac{c_j(e_j)}{p} + e_j$$

Obviously this cannot be done for every country (developing and advanced) unless all the actual mitigation costs are zero. The problem in trying to approximate this condition for developing countries or poorer ones is that we do not know the functions $c(e)$ in advance and hence do not know the efficient mitigation levels or the marginal cost, p . In other words we don't know any of the magnitudes in this equation. This makes it extremely difficult to have a sensible debate about formulae that will avoid either high costs on particular countries or potentially large "windfall profits," which would result if m_j is much larger than the right-hand side of the above equation.

In what follows we explore two systems in which the advanced countries take the initial lead role in mitigation and hence the cost absorption, but there is a cross-border mechanism in place so that mitigation occurs in developing countries as well.

The Advanced Country CCTS with Cross-Border Mitigation

The advanced countries are in a set designated by A , and the developing countries are the set D . Advanced countries have the same variables, credit allocations, domestic emissions levels, and purchases. The developing countries have emissions levels a_i with no mitigation. In terms of the dynamics, the a_i are time paths associated with their growth. Here I have just suppressed all the time arguments. Even the cost functions are time dependent because of growth, new technology, and other factors.

We need an additional set of variables to capture the cross-border activity.

$$n_{ij} = \textit{the mitigation conducted by advanced country } i \textit{ in developing country } j$$

$$N_j = \sum_{i \in A} n_{ij} = \textit{the total mitigation in developing country } j$$

For developing country j emissions are

$$e_j = a_j - N_j$$

Advanced countries have to hold credits to cover their own emissions minus credits for emissions in developing countries. Thus the purchases are

$$x_i = e_i - \sum_{j \in D} n_{ij} - m_i$$

Here we have to be a little careful about costs for the cross-border activities. The actual costs will depend on which advanced countries find infra-marginal and hence lower-cost mitigation projects first. Nevertheless, at the margin, domestic mitigation will stop when

$$c'_i(e_i) + p = 0$$

For cross-border activity in developing country j , the benefit of an additional unit of mitigation is p , because of the credit and the reduced purchases. The cost is

$$-c'_j(a_j - N_j)$$

Thus when all the potential cross-border mitigation that reduces advanced country costs has been undertaken,

$$c'_j(a_j - N_j) + p = 0$$

The combination of these conditions means that the mitigation is efficiently distributed globally. The advanced countries pay for the mitigation. Carbon is priced. The absorption of costs within the advanced countries is determined by the initial allocation of credits. If E is the total advanced country emissions, N is total mitigation in all developing countries, and M is the total carbon credits, then because net purchases have to sum to zero, it follows that

$$E = M + N$$

That is to say, advanced country emissions net of their own mitigation equal the carbon credits plus the credit they received in aggregate for mitigation in developing countries. If there were not cross-border mitigation, and if the starting point were total emissions of E_0 , then total mitigation in advanced countries would have been $E_0 - M$. With cross-border mitigation added as an option, the sum of the mitigation in advanced and developing countries is $E_0 - M$, and is less costly. That is if $S = E_0 - E$, the actual mitigation in advanced countries, then with cross-border options

$$S + N = E_0 - M$$

As before, the pattern of mitigation adding up to the total required by the credits does not depend on the allocation of the credits.

In this model, the values of e_i and N_j are determined. The values n_{ij} are not completely determined. They are positive or zero and add up to N_j . There is in any given period an entrepreneurial opportunity to find the low-cost cross-border mitigation projects. Those with costs per unit below the carbon price will profit. Because entities including countries can sell credits, the incentives to find these opportunities are strong. In this system, it is logically possible (though very unlikely) that all the mitigation would be done in developing countries. That would occur if the marginal costs there are lower than in the advanced countries. It is also likely that an industry would develop in finding cost-effective projects in mitigating carbon emissions and selling them to entities that need the credits.

There is a potential constraint. It is possible that prior and only partially reversible mitigation could cause the marginal costs in some country to get stuck above the carbon price. In this system, no mitigation will occur there. Formally, the condition would be the marginal cost is equal to or greater than p and if greater than then e_i is the emissions at the start of the period (that is, no mitigation in that country).

Advanced Country Targets with Cross-Border Mitigation and Credit

I conclude by considering what would happen if the advanced country CCTS is replaced by country-specific advanced country targets. In the advanced country CCTS, the main requirement for advanced countries is that holdings of credits (the initial allocation plus purchases) equal domestic emissions minus credits for cross-border efforts.

$$x_i = e_i - \sum_{j \in D} n_{ij} - m_i$$

This requirement is replaced with a country specific target, call it T_i . The requirement then becomes

$$T_i = e_i - \sum_{j \in D} n_{ij}$$

This system is more cumbersome in part because the carbon price signal is missing, so the comparative search for low-cost mitigation options is more complex and difficult. Nevertheless, there is a strong tendency to move toward the efficient pattern of mitigation with total mitigation equal to that implied by the advanced country targets.

First, there cannot be a difference in the marginal costs of mitigation in developing countries for which some mitigation is occurring. Otherwise the activity would move. Second, for advanced countries that do some of the

mitigation in developing countries, the marginal cost of mitigation domestically has to equal the marginal cost in developing countries that have inbound cross-border mitigation. Together this means that in most of the system, the marginal costs are all equal.

There is an exception. If an advanced country does all its mitigation domestically, then its marginal cost will diverge. This will occur if the country is a very low-cost mitigation environment and its target does not put it in the high-cost category at the margin. In addition, some developing countries conceivably could be high-cost environments and be out of the system of cross-border mitigation altogether. With these two exceptions, the rest of the system satisfies the conditions for efficient global mitigation.

The conclusion is that a system with sensible advanced country targets and the cross-border mechanism would be major progress. It is somewhat less flexible than the advanced country CCTS and lacks the carbon price and attendant financial market products and prices, which is a nontrivial reduction in the information available and hence the efficiency of the process.

My conclusion is that in the short run, advanced country targets with the cross-border mechanism would move us in the right direction. The addition of an advanced country CCTS and related infrastructure would be an additional major step forward and should be a priority.

In terms of international agreements, we need to let the developing countries run with growth with a clear and agreed-on graduation requirement and a concrete commitment to making the cross-border mechanism work.

Appendix B: Oil Consumption, Population, and Income Levels

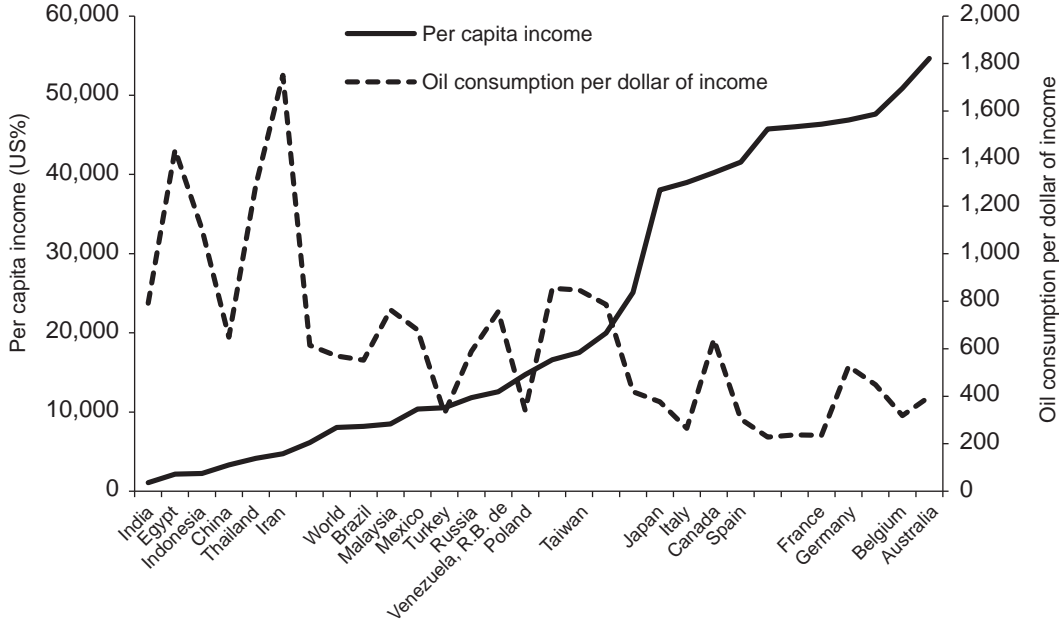
These are the oil consumption figures for the largest consuming countries (with consumption levels above 500,000 barrels a day). Singapore is excluded as its consumption is grossly inflated by oil supplied to ships in the port.

Table B.1. Oil Consumption Figures

Country	Oil	Population	Per capita Income	Oil consumption per capita per year (barrels)	Oil per dollar of income
World	85,220,000	6,783,421,727	8,051	4.59	0.000570
United States	20,680,000	306,553,000	46,859	24.62	0.000525
European Union	14,380,000	498,926,165	25,100	10.52	0.000419
China	7,880,000	1,338,156,900	3,315	2.15	0.000648
Japan	5,007,000	127,630,000	38,055	14.32	0.000376
India	2,722,000	1,164,070,000	1,078	0.85	0.000792
Russia	2,699,000	141,825,000	11,807	6.95	0.000588
Germany	2,456,000	82,062,200	46,352	10.92	0.000236
Brazil	2,372,000	191,380,664	8,197	4.52	0.000552
Canada	2,371,000	33,670,000	40,222	25.70	0.000639
Mexico	2,119,000	109,610,000	10,395	7.06	0.000679
Korea, Rep. of	2,080,000	48,333,000	19,983	15.71	0.000786
France	1,950,000	65,073,482	46,016	10.94	0.000238
United Kingdom	1,763,000	61,612,300	45,731	10.44	0.000228
Italy	1,702,000	60,090,400	38,996	10.34	0.000265
Spain	1,611,000	46,661,950	41,565	12.60	0.000303
Iran	1,600,000	70,495,782	4,732	8.28	0.001751
Indonesia	1,564,000	230,330,000	2,246	2.48	0.001103
Saudi Arabia	1,000,000	25,721,000	16,617	14.19	0.000854
Netherlands	984,200	16,515,285	54,640	21.75	0.000398
Australia	966,200	21,777,000	50,887	16.19	0.000318
Taiwan	935,600	23,027,672	17,521	14.83	0.000846
Thailand	928,600	63,389,730	4,155	5.35	0.001287
Venezuela, R.B. de	738,300	28,347,000	12,561	9.51	0.000757
Turkey	676,600	71,517,100	10,540	3.45	0.000328
Egypt	652,700	76,704,587	2,161	3.11	0.001437
Belgium	628,500	10,741,000	47,617	21.36	0.000449
Poland	524,000	38,130,300	14,737	5.02	0.000340
South Africa	504,900	48,697,000	6,158	3.78	0.000615
Malaysia	501,100	28,200,000	8,495	6.49	0.000763
<i>Total without double counts</i>	<i>72,378,000</i>				
<i>Percentage of World Consumption</i>	<i>85%</i>				

Source: World Fact Book, <https://www.cia.gov/library/publications/the-world-factbook/>.

Figure B.1. Oil Consumption Figures

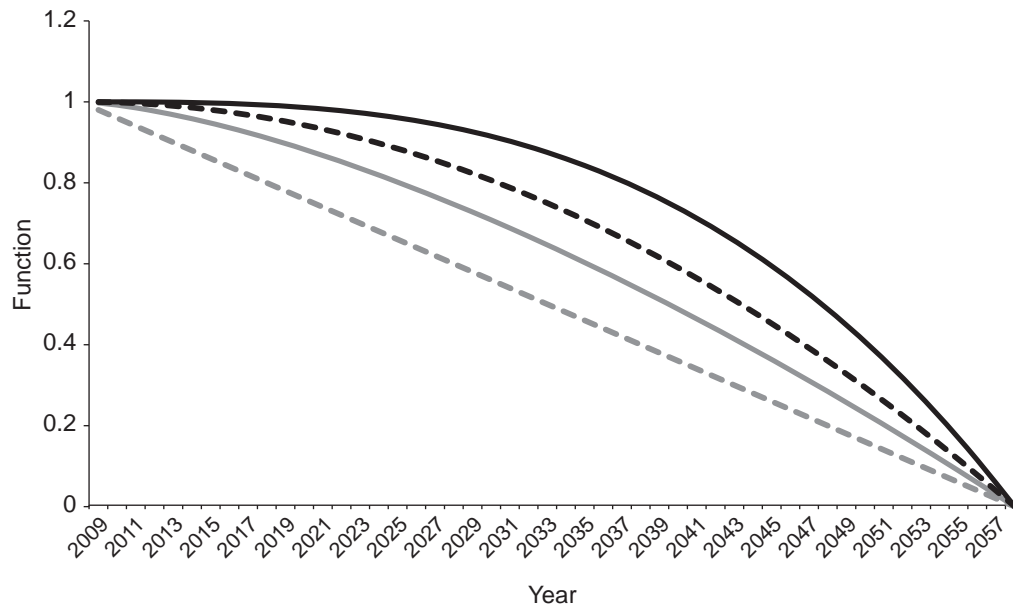


Source: World Fact Book, <https://www.cia.gov/library/publications/the-world-factbook/>.

Appendix C: Global Emissions with a Longer Developing Country Lag

In the paper, the graphs for per capita and total emissions were based on a moderate transfer lag corresponding to the solid gray line in Figure C.1. Here we show the same data if the transfer lag is larger and longer, corresponding to the dashed gray line. The per capita emissions in the rapid-growth developing world rise to about 7 tons per person (as compared with six tons earlier).

Figure C.1. Transfer Lags for Advanced Country Technology: Various Versions of the Function $T(t)$

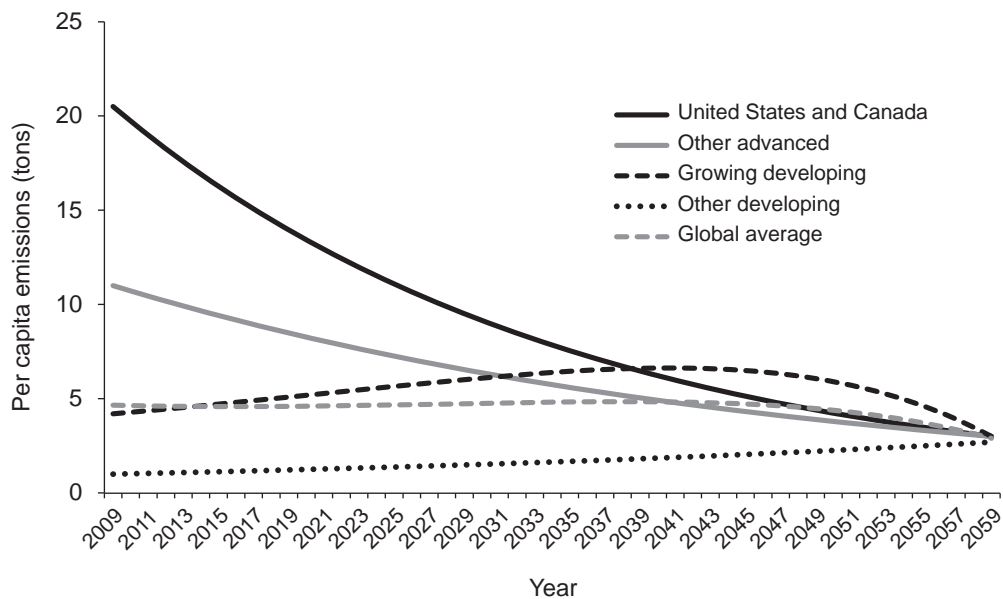


Source: Author's calculations.

The global total emissions and its components are shown in Figure C.2 for the case of the increased transfer lag.

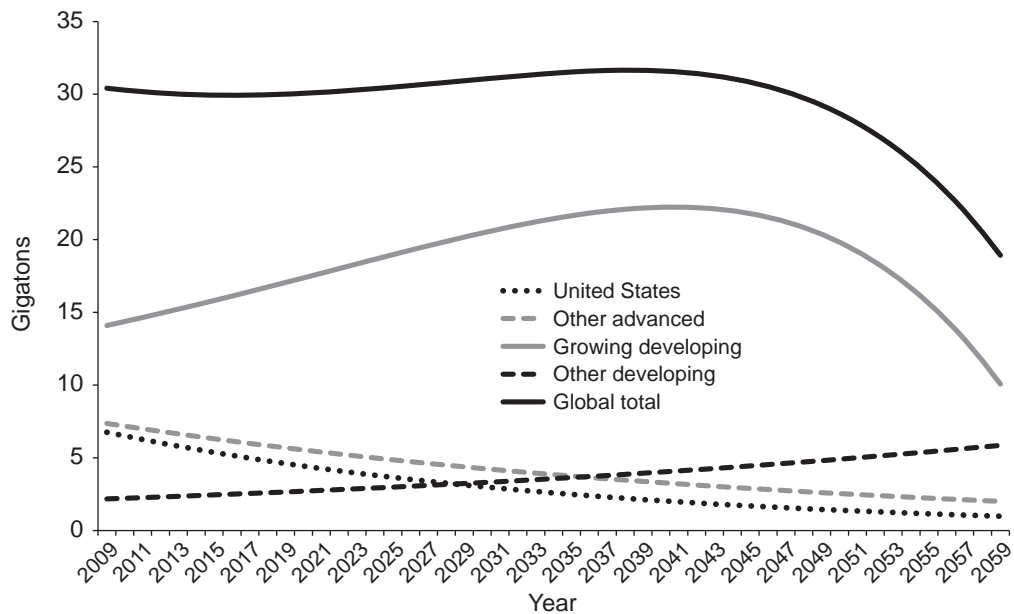
For developing countries the pattern is similar, but the maximum total emissions is higher, the reduction in global carbon output is somewhat delayed, and the growth of the developing countries causes maximum emissions to rise from 10 to 30 years out (Figure C.3).

Figure C.2. Per Capita Emissions on Path to Safe Target



Source: Author's calculations.

Figure C.3. CO₂ Output in Gigatons with Effective Mitigation



Source: Author's calculations.

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This paper deals with global mitigation strategy. In the first part, it lays out time paths for emissions for countries in various categories. These paths are consistent with their growth objectives, incomes, and capacity to absorb mitigation costs. The intent is to show that while global emissions are likely to remain flat or even rise as a result of the combined effect of mitigation undertaken by advanced countries and growth in the developing world, eventually reasonably safe global per capita levels can be reached on a 50-year time horizon. The second part of the paper discusses roles and mechanisms that would support the achievement of these paths. These mechanisms create incentives and deal with the absorption of costs. In particular, the paper suggests that a carbon credit trading system in the advanced countries, combined with an effective cross border mechanism and a “graduation” criterion for developing countries to join the advanced group, will create strong incentives, achieve a fair pattern of cost absorption, and support the dynamics described in part one.

Michael Spence, 2001 Nobel Laureate, Professor Emeritus, Stanford University, Chair of the Commission on Growth and Development

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