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Climate Change and India: Implications and Policy Options

> Action on Climate Change must enhance, not diminish the prospects for development. It must not sharpen the division of the world between an affluent North and an impoverished South, and justify this with a green label. What we require is a collaborative spirit which acknowledges the pervasive threat of Climate Change to humanity and seeks to find answers that enhance, not diminish the prospects of development, particularly of developing countries. All members of our common global family should have equal entitlement to the fruits of prosperity.
>
> —Government of India, 2009

Introduction

Despite recent rapid growth, India remains an extremely poor country. Its per capita income in current dollars at $1,016 in 2008 is less than one-third that of China, itself a country with substantial pockets of poverty. Based on the National Sample Survey of 2004–05, 300 million Indians live in abject poverty. In the same vein, going by 2001 Census, nearly 400 million Indians are without an electricity connection. If India is to provide a humane existence to all its citizens, it must sustain its current rapid growth for some decades to come.

Perhaps the greatest challenge to India's ambition to stamp out poverty and give its citizens a decent living standard comes from international pressures to accept targets for mitigation of greenhouse gas (GHG) emissions in the near future, say, beginning 2020. Based on the data for 2006, the latest year for which detailed reliable data are available, China's total carbon emissions from fossil fuels are 4.7 times those of India. Even making the generous assumption that China could cut its current emissions by 25 percent by

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adopting more efficient technologies without sacrificing any income, its total emissions would remain 3.5 times those of India. The inevitable implication is that barring major breakthroughs in green technologies, India cannot reach even the current Chinese total income without a significant increase in its carbon emissions.[1] Any restrictions on carbon dioxide (CO_2) and other GHG emissions beginning in the near future would greatly undermine India's poverty alleviation objective. It is this context that makes India's policy choices with respect to GHG mitigation a far more daunting task than that of the rich countries.

In this paper, I offer a detailed analysis of India's options on GHG emissions in the context of the mitigation efforts being made by various countries individually at the national level and jointly at the international level. At the outset, this analysis must recognize at least four major complications.

First, accepting that global warming is real and that GHG emissions have contributed to it, policy analysis must take into account uncertainty at three different levels:[2] (*i*) precise future response of temperatures and rainfall to GHG emissions; (*ii*) precise quantitative effect of rising temperatures ("global warming") on glacier melting, sea levels, and extreme events such as heat waves, drought, floods, and cyclones; and (*iii*) quantitative response of agricultural productivity, GDP (gross domestic product) growth, health, volume, and pattern of migration and poverty to GHG emissions directly as well as through global warming and the changes in rainfall, glacier melting, sea levels, and extreme events. Each analyst must form some expectation with respect to these relationships before he can make a recommendation with respect to regulatory policy toward GHG emissions, that is, mitigation.

The second complication arises from the fact that the benefits of GHG emissions in the form of extra output and growth accrue to emitting countries while the costs in terms of global warming and more frequent and severe extreme events fall on the entire world. Therefore, on its own, a country will underestimate the cost-benefit ratio associated with emissions and undertake too little mitigation relative to what is globally optimal. Optimal mitigation requires cooperation by all major emitters.

1. I hasten to add that by the time India reaches the current Chinese total income, its population will cross that of the latter. Therefore, achieving the current Chinese total income will still not grant India the current Chinese per capita income.

2. As discussed in the second section, there still remain disagreements within the scientific community regarding whether there exists a warming trend in the temperatures. As such, in principle, we could add yet one more uncertainty to the list of uncertainties in the text: that regarding the existence of a global-warming trend.

Third, given that the GHGs stay in the atmosphere for up to 100 years, whereas the benefits of GHG emissions largely accrue to the generation responsible for them, costs fall disproportionately on the future generations. Because individuals value present consumption more than future consumption, with the present value of a consumption basket declining the farther into the future it becomes available, agreement on a policy that curbs present consumption in favor of larger future consumption is difficult. This problem is exacerbated by the uncertainties associated with the effects of GHG emissions: whereas the output gains from GHG emissions are here and known, the precise form and timing of costs are uncertain.

The final complication arises from the fact that while GHG emissions have been concentrated heavily in the developed countries, according to most analysts their costs will fall disproportionately on the developing countries. Approximately 71 percent of the carbon emissions from 1850 to 2000 were accounted for by the United States, EU, Russia, Japan, and Canada alone. Although China has recently emerged as the largest carbon emitter, according to 2006 emission data, Canada, US, Europe, Eurasia, and Japan together account for more than 50 percent of the current emissions. When it comes to the regions most likely to be subject to the adverse effects, South Asia and Africa end up at the top of most experts' lists. This geographical patter of winners and losers naturally generates tension along the traditional North–South fault line.

Against this background, the present paper asks how India should approach its policies toward adaptation and mitigation, where the former refers to improved capability to protect against and respond to extreme natural events that occur and the latter to efforts aimed at capping the increases in the frequency and severity of the events themselves. For a poor country like India, mitigation imposes two sets of costs by undermining sustained rapid growth. First, it compromises poverty alleviation and the ability to provide basic amenities such as electricity and water to the citizenry. Second, it also undermines the ability to adapt against extreme events that will visit the country even if emissions were eliminated altogether worldwide. Sustained rapid growth gives the citizens access to shelter that better protects them against heat, cold, rain, and floods. It also speeds up transportation and communication thereby enhancing the ability of the citizens to rapidly evacuate in case of natural disasters. Furthermore, sustained rapid growth places more resources into the hands of the government enabling it to move the population from coastal regions or build dikes in response to rising sea levels and to develop water resources to combat droughts. In deciding upon mitigation policy, India must weigh these costs against the expected benefits of capping the escalation in the frequency and severity of extreme events in the light of mitigation efforts by other countries.

I begin in the second section with a broad discussion of some of the uncertainties mentioned earlier. In the third section, I discuss the changes in temperatures and rain patterns in India during the last century, as well as their impact if any on sea levels, glacier melting, and the natural disasters such as drought, and cyclones. The fourth section details the predictions of temperature and rainfall changes in the 21st century India and how they might impact the frequency and severity of drought, floods, and cyclones on the one hand and agriculture, health, migration patterns, and poverty on the other. The fifth section constructs a simple analytic model to derive optimal levels of mitigation worldwide and in individual countries and the associated instruments to implement the solution. In the sixth section, I turn to the distributional issue: who should pay for the costs of mitigation? The seventh section discusses mitigation in practice at both national and international levels. In the last substantive section, the eighth section, I finally come to a frontal discussion of India's options going forward. The ninth section concludes the paper.

The Uncertainties

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2007a), the warming of the climate system in the second half of the 20th century is unequivocal and this change is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Although the available *statistical tests* of a rising trend in temperatures between 1979 and 1993 contradict this proposition, policy-makers around the world now generally accept it.[3] Accepting the existence of

3. Santer et al. (2000) test whether the linear trend in the deep-layer temperature data from 1979 to 1993 is significantly different from zero. They conclude, "Using this [preferred] test, we find that none of the individual 1979–93 trends in deep-layer temperatures is significantly different from zero. This result holds for virtually all datasets and atmospheric regions that we consider. In all datasets, individual (cooling) trends in lower-stratospheric temperatures become significant if volcanic effects are first removed from the time series." There also exist a controversy within the scientific community around differences in warming trends of earth's surface temperatures as recorded by thermometers and the lower troposphere temperatures as monitored by satellites. The trend rate in the former dataset shows greater warming than the latter. While the IPCC (2007a) has argued that the differences can be reconciled around the surface temperature readings, Klotzbach et al. (2009) conclude that the IPCC reported temperature trends carry an upward bias of 30 percent.

global warming and GHG emissions as its principal cause, there still remain significant uncertainties with respect to the precise nature of temperature increases as also what thy imply for rains, floods, droughts, and storms.

At the broadest level, there inevitably remains uncertainty with respect to the magnitude of the change in the mean temperature that would accompany different levels of GHG emissions during the course of the 21st century. Predictions based on the experience to-date are uncertain because the response of temperature changes to GHG emissions, which has itself been highly variable over time, may not repeat itself in the future.[4] Even ignoring this problem, the temperature change is going to vary across regions, over different parts of the year and during different parts of any given day. The annual mean temperature is a highly aggregative measure consistent with a variety of distributions. A given increase in the mean temperature in any given year in any specific location may result from a uniform increase in the temperature at all points in time in the year, increase in the number of hot days, decrease in the number of cold days, increase in the temperature during the summer or during the winter, increase in the maximum or minimum temperature, and so on.[5]

Greater uncertainties are associated with the consequences of global warming for other natural phenomena. Rainfall may increase or decrease on average with differential impact across seasons and across regions. A rise in mean rainfall may represent an increased intensity of rains, increased frequency, expanded rainy season or the emergence of new rainy days outside the rainy season. One further uncertainty relates to the presence of factors other than GHG emissions contributing to warming.[6] If such factors are present and significant, changes in them may reinforce or counteract the effects of GHG emissions.

4. For example, even though GHG emissions have accumulated steadily during the past century, surface air temperatures have risen in two phases: 1910 to 1945 and 1976 to-date. The period from 1945 to 1975 exhibited no trend change in the average annual temperatures around the globe.

5. Surprisingly, in the case of India, we encounter disagreement on even the *actual* change in the average temperature. While the Intergovernmental Panel on Climate Change (IPCC, 2007c) states that the average temperature in India has been increasing at the rate of 0.68°C per century, the World Bank (2009a: 162) states, “There have been no significant increases in temperatures observed over the country.”

6. IPCC leaves the door open to this possibility when it states in its Fourth Assessment, “Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.” [Italics in the original.] In principle, natural phenomena such as El Niño and La Niña can explain some of the short-term shifts in temperatures and extreme weather events.

Scientific evidence on the link between global warming and extreme events such as hurricanes is far less definitive. In Pielke et al. (2005: 1574), an interdisciplinary team of researchers surveyed the peer-reviewed literature on the relationships between global warming and the frequency and severity of hurricanes. They concluded thus,

> To summarize, claims of linkages between global warming and hurricane impacts are premature for three reasons. First, no connection has been established between greenhouse gas emissions and the observed behavior of hurricanes (Houghton et al., 2001; Walsh, 2004). Emanuel (2005) is suggestive of such a connection, but is by no means definitive. Second, the peer-reviewed literature reflects that a scientific consensus exists that any future changes in hurricane intensities will likely be small in the context of observed variability (Knutson and Tuleya, 2004; Henderson-Sellers et al., 1998), while the scientific problem of tropical cyclogenesis is so far from being solved that little can be said about possible changes in frequency. And third, under the assumptions of the IPCC, expected future damages to society of its projected changes in the behavior of hurricanes are dwarfed by the influence of its own projections of growing wealth and population (Pielke et al., 2000). While future research or experience may yet overturn these conclusions, the state of the peer-reviewed knowledge today is such that there are good reasons to expect that any conclusive connection between global warming and hurricanes or their impacts will not be made in the near term.

China's top climatologist has also expressed reservations on the predictions of calamities. In a recent story in the *Guardian*, Jonathan Watt (2009) writes, "A 2°C rise in global temperatures will not necessarily result in the calamity predicted by the IPCC, China's most senior climatologist has told the Guardian." Watt goes on to add, "Despite growing evidence that storms in China are getting fiercer, droughts longer, and typhoons more deadly, Xiao Ziniu, the director general of the Beijing Climate Center, said it was too early to determine the level of risk posed by global warming."

Policy analysis is further complicated by the fact that virtually all predictions of large changes attributable to GHG emissions are back loaded. At least until 2030, no dramatic impacts with or without mitigation are predicted. On the other hand, predictions beyond 2030 remain subject to revision based on what will be observed between now and 2030 in the same way that the current predictions have been greatly influenced by the events of the past 15 years.

The IPCC predictions on changes in temperatures, rainfall, and related natural phenomena are derived using simulation models of the climate system. Few models in economics and meteorology consistently forecast with accuracy even over a short time horizon, let alone 100 years. Fred Pearce (2008) graphically described the uncertainty associated with the forecasts of the climate change models in an article published in the *Guardian*. Pearce, himself no skeptic on global warming, states

> Now, a skeptic might say that if the modelers are only just learning about the importance of natural cycles to climate forecasts, why should we believe their predictions at all? Fair point. In their desire to persuade us about the big picture of global warming, scientists have sometimes got cocky about coloring in the detail.
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> Recently I attended a conference in Reading where some of the world's top experts discussed their failings. How their much-vaunted models of the world's climate system can't reproduce El Niños, or the "blocking highs" that bring heat waves to Europe—or even the ice ages. How their statistical mimics of tropical climate are "laughable," in the words of the official report.
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> This sudden humility was not unconnected with their end-of-conference call for the world to spend a billion dollars on a global centre for climate modeling. A "Manhattan project for the 21st century," as someone put it.
>
> Even so, scientists are concerned that many of their predictions about how climate change will play out in different parts of the world are little better than guesses. But whatever the local wrinkles and whatever natural cycles may intervene, man-made global warming is real, current and matters a great deal.

Suppose we take the IPCC predictions of global warming and the associated natural phenomena at face value. Even then the formulation of well-informed mitigation policy over a time horizon extending all the way to the end of the 21st century requires predictions of innovations of clean technologies and green sources of energy. As the information technology revolution that swept the world in the 1990s and beyond illustrates, such predictions are highly uncertain as well.

This discussion suggests that any analysis of optimal mitigation policies is likely to carry a significant speculative element in it. This is particularly true of *quantitative* estimates of costs and benefits of mitigation. Therefore, references to such estimates must be taken with a heavy dose of skepticism. Indeed, where possible, I will try to rely on qualitative and conceptual analysis turning to numbers only when they are useful for clarifying a point.

Climate Change in India during the Past Century

Let us now turn to a brief consideration of global warming-related developments in India. India is a peninsular country with a coastline of approximately

6,000 kilometers along the mainland and an additional 1,500 kilometers around the islands of Lakshadweep and Andaman and Nicobar. The Tropic of Cancer divides the country into two halves with the northern half being temperate and southern half tropical. Variations in temperatures in the peninsular region are smaller and rains heavier than in the inner continent. In the inner continent, temperatures range from near-freezing levels in the winter to 40°C or more during the summer. The Himalayan states in the northernmost part of the country experience sub-freezing temperatures during the winter with elevated regions in those states receiving sustained snow.

In *India's Initial National Communication to the United Nations Framework Convention on Climate Change*, the Government of India (2004) identifies four seasons during a year: winter from December to February; pre-monsoon season from March to May; southwest or summer monsoon from June to September; and post monsoon from October to November.[7] The precise timing of these seasons exhibits some variation across regions. A major variation relates to the northeast monsoon that occurs in October and November. The states of Tamil Nadu, Karnataka, and Kerala receive most of their rainfall from the northeast monsoon during November and December. The Himalayan states experience two additional seasons: autumn and spring.

The primary points of impact of GHG emissions are air temperature and rainfall.[8] These changes in turn impact the rates at which glaciers melt, sea levels and the occurrences of extreme weather events such as the frequency and intensity of droughts, cyclones, and floods. In the following, I briefly discuss the changes in the temperatures and rainfall, melting of glaciers and sea levels, and the pattern of extreme weather events in the last century.

Temperatures

Three different figures for the increase in the mean temperature in India during the 20th century have been reported. The World Bank (2009a: 162) reports no change, the Government of India (2004: 62) notes a 0.4 percent increase and the IPCC (2007b, Table 10.2: 475) observes a

7. The ancient Hindu calendar divides a year into six seasons with each season lasting approximately two months. The six seasons are: spring (*vasanta* in Sanskrit), summer (*grīsma*), monsoon (*varsā*), early autumn (*śarada*), late autumn (*hemanta*), and winter (*śiśira*).

8. Air temperature, also termed surface temperature in meteorology, refers to the ambient temperature indicated by a thermometer exposed to the air but sheltered from direct solar radiation and kept 1.5 to 2 meters above ground.

0.68 percent increase.[9] Because these sources neither refer to each other nor explain details of methodologies used to compute the temperature change, the sources of the differences cannot be explained.

The Government of India (2004: 62) further notes,

> On a seasonal scale, the warming in the annual mean temperatures is mainly contributed by the post-monsoon and winter seasons. Also, data analyzed in terms of daytime and nighttime temperatures indicate that the warming was predominantly due to an increase in the maximum temperatures, while the minimum temperatures remained practically constant during the past century. The seasonal/annual mean temperatures during 1901–2000 are based on data from 31 stations, while the annual mean maximum and minimum temperature during 1901–90 are based on data from 121 stations. Spatially, a significant warming trend has been observed along the west coast, in central India, the interior peninsula and over north-east India, while a cooling trend has been observed in north-west India and a pocket in southern India.[10]

Figure 1, in Lal (2003: 8), shows that temperatures in India have recently increased in two phases: the first half of the 20th century and the period since the mid-1970s. The average annual temperature during the approximate quarter century between 1950 and 1975 exhibited no trend. As just noted, the warming in India is concentrated in the post-monsoon and winter seasons and in the maximum daytime temperatures rather than nighttime minimum temperatures. In the monsoon season, temperatures exhibit a *declining* trend in northwest India and no trend in the rest of the country. Increases in surface air temperatures relative to climatologically normal temperatures have been observed at most of the locations in India.

Rainfall

With respect to rainfall, the Government of India (2004: 61) notes,

> Although the monsoon rainfall at the all-India level does not show any trend and seems mainly random in nature over a long period of time, the presence of pockets of significant long-term changes in rainfall have been recorded. Areas of increasing trend in the monsoon seasonal rainfall are found along the west coast, north Andhra Pradesh and north-west India (+10 to +12 percent of normal/100 years) and

9. These changes are in contrast to 2–3°C increases in North Asia, the region subject to most global warming within Asia.

10. IPCC evidently relies on Lal (2003: 8) who states that "an analysis of seasonal and annual surface air temperatures, using data from 1880 to 2000 for 25 or more stations, showed a significant annual mean warming of 0.68°C per 100 years."

> those of decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (–6 to –8 percent of normal/100 years).

This assessment is consistent with that in Lal (2003, Figure 2), which reports no change in the trend on either the annual or seasonal basis during 1871–2000 in all-India rainfall.

Glacier Melting

According to NASA, although certain types of glaciers—for example, surge glaciers and tidewater glaciers—have been expanding, the vast majority are shrinking. The Glacier National Park in North America had 147 glaciers 150 years ago. Today, only 37 remain.[11] In India, glaciers in the Himalayas are in decline. According to Naithani et al. (2001), at 30.2 kilometers long and between 0.5 and 2.5 kilometers wide, Gangotri glacier in the Uttarkashi district of Garhwal Himalaya is one of the largest Himalayan glaciers. It has been receding since scientists began to keep its measurement in 1780. Data between 1936 and 1996 show that 1,147 meters of the glacier melted away during the 61 years. This works out to a rate of 19 meters per year. Data for 1975 to 1999 show the glacier has receded 850 meters during these 25 years. At 34 meters per year, the rate at which the glacier is melting has accelerated over that observed in the prior years. The account in Naithani et al. (2001) is at odds with that in the Government of India (2004, Box 3.5: 79), however. The latter notes, "The rate of retreat of the snout of Gangotri glacier demonstrated a sharp rise in the first half of the 20th century. This trend continued up to around the 1970s, and subsequently there has been a gradual decline in its rate of retreat." The fact that Gangotri glacier has been receding since 1780 raises some doubt about the link between GHG emissions and glacier melting. And if the Government of India (2004) accounts on the speed of melting during various periods in the 20th century are correct, GHG emissions and the melting of Gangotri glacier would seems to be unrelated.

Over 1 percent of water in the Ganges and Indus basins is currently due to runoff from wasting of permanent ice from glaciers. This water flow will first rise and then decline as the Glacier becomes smaller and smaller. In assessing the cost of the glacier retreat, we must take into account two benefits as well: it is currently helping ameliorate the rate at which water availability per person is declining due to rising population and as the glacier recedes, land underneath becomes available for use.

11. See http://earthobservatory.nasa.gov/IOTD/view.php?id=4594 (accessed on May 13, 2010).

Sea Level

The average of the sea level along India's coastline is reported to be rising at 1 mm per year on the average. According to the Government of India (2004: ix), at 0.4 to 2.0 mm per year, the rise is the highest along the Gulf of Kutchh in Gujarat and the coast of West Bengal. Along the Karnataka coast, there is a relative decrease in the sea level. Much of the rise in the sea levels has been due warming of seawater that increases its volume rather than the accelerated inflow of water.

Extreme Weather Events

Although numerous accounts of increased risk of extreme weather events can be found, the available historical data on the incidence of extreme weather events—heat waves, droughts, floods, cyclones, and tidal waves—are equivocal.[12] De et al. (2005) compile data spanning over approximately the entire 20th century from various sources. Assuming the data are comparable, the incidence of heat waves declined in Uttar Pradesh, Madhya Pradesh, and Gujarat during 1978–99 relative to 1911–67 but rose in Rajasthan, West Bengal, and Maharashtra between the two time periods. Major cyclones over the North Indian Ocean numbered four in the 1940s, 1960s, and 1990s and three in the 1970s. Frequency of rainfall of 30 inches or more in one day also does not show a clear pattern.

The bottom line with respect to droughts and floods offered by the Government of India (2004: 63) is consistent with these observations:

> Instrumental records over the past 130 years do not indicate any marked long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season. The only slow change discernible is the alternating sequence of multi-decadal periods of more frequent droughts, followed by periods of less frequent droughts. This feature is part of the well-known epochal behavior of the summer monsoon.

Regarding cyclones, the report points to nuances not noticeable in the data in De et al. (2005). It notes (p. 63),

12. For example, Lal (2003: 8) states, "The frequency of extreme weather events in India—for example, heat waves, droughts and floods—has increased over the past two decades." While Lal discusses *examples* of droughts and floods from Orissa, Maharashtra, and other states during the1990s and early 2000s, he does not compile complete comparative data necessary to reach the conclusion just noted. Surprisingly, IPCC (2007b) echoes Lal without additional data.

> In the northern Indian Ocean, about 16 cyclonic disturbances occur each year, of which about six develop into cyclonic storms. The annual number of severe cyclonic storms with hurricane force winds averages to about 1.3 over the period 1891–90. During the recent period 1965–1990, the number was 2.3. No clear variability pattern appears to be associated with the occurrence of tropical cyclones. While the total frequency of cyclonic storms that form over the Bay of Bengal has remained almost constant over the period 1887–1997, an increase in the frequency of severe cyclonic storms appears to have taken place in recent decades (Figure 3.7). Whether this is real, or a product of recently enhanced monitoring technology is, however, not clear.

Predicted Changes

Given the difficulties and uncertainty in accurately measuring even the past *observed* shifts in temperatures and rainfall, it should be no surprise that predicting the future shifts in them is bound to be subject to extremely large errors. The predictions on changes in temperatures, rainfall, and related natural phenomena are derived using simulation models of the climate system. As I noted earlier in the second section, few models of climate change forecast with any degree of accuracy over the long horizon under discussion.

This uncertainty in predictions makes the assessment of vulnerabilities resulting from future climate change-related events extremely difficult. To complicate matters further, significant climate change impacts are predicted to occur well after 2030 and possibly closer to the end of the 21st century. In the interim, new products and production processes that allow drastic cuts in GHG emissions at very low cost and counteract the effects of climate change-related impacts may emerge. The upshot is that predicted changes below must be taken with a grain of salt.

I divide the discussion into impacts on physical and economic phenomena. In the latter case, I also touch on India's prospects for adaptation to GHG-induced changes.

Physical Phenomena

GHG emissions may impact natural phenomena through temperatures and rainfalls; extremes in rainfalls, droughts, floods, and storms; and the rise in sea levels.

Temperatures and Rainfall

In Table 1, I reproduce the predictions of average temperature and rainfall changes during the 21st century in South Asia and North Asia reported in

TABLE 1. Predicted Changes in Temperatures and Precipitation (Baseline: 1961–90)

	Temperature (°C)		*Precipitation (%)*		*Temperature (°C)*		*Precipitation (%)*	
	A1FI	*B1*	*A1FI*	*B1*	*A1FI*	*B1*	*A1FI*	*B1*
Months	*South Asia*				*North Asia*			
2010 to 2039								
DJF	1.17	1.11	–3	4	2.94	2.69	16	14
MAM	1.18	1.07	7	8	1.69	2.02	10	10
JJA	0.54	0.55	5	7	1.69	1.88	4	6
SON	0.78	0.83	1	3	2.24	2.15	7	7
2040 to 2069								
DJF	3.16	1.97	0	0	6.65	4.25	35	22
MAM	2.97	1.81	26	24	4.96	3.54	25	19
JJA	1.71	0.88	13	11	4.2	3.13	9	8
SON	2.41	1.49	8	6	5.3	3.68	14	11
2070 to 2099								
DJF	5.44	2.93	–16	–6	10.45	5.99	59	29
MAM	5.22	2.71	31	20	8.32	4.69	43	25
JJA	3.14	1.56	26	15	6.94	4	15	10
SON	4.19	2.17	26	10	8.29	4.98	25	15

Source: IPCC Fourth Assessment Report, Working Group II, Chapter 10.

Note: Months "DJF" stand for December, January, and February. Other symbols for the months are similarly defined. Scenario A1FI refers to the highest future GHG emission trajectory considered in the simulations by the IPCC Fourth Assessment Report and B1 to the lowest emission trajectory.

IPCC (2007b). The predictions are derived from Atmosphere-Ocean General Circulation Models (AOGCM). The table reports the results of simulations based on two sets of assumptions with respect to GHG emissions: scenario A1FI assumes the highest future emission trajectory and B1 the lowest emission trajectory. Therefore, the two scenarios give the upper and lower limits of predicted changes. The changes are recorded relative to the baseline period of 1961–90.

Two points follow from Table 1. First, the variation in predictions across regions is large. In North Asia, the region with the greatest climate change impact within Asia, the predicted temperature increase in the winter months (December, January, and February) ranges from 6 to 10.5°C during 2070–99 relative to the baseline period 1961–90. That is to say, even if strong measures to contain emissions around the globe are taken, the temperature rise in North Asia would be as much as 6°C during the winter months by the end of the 21st century. The temperature change in South Asia in the winter months during 2070–99 is predicted to be between 3 and 5.5°C in South Asia. The maximum rainfall increase in North Asia is predicted to be in the winter months and in the range of 29–59 percent of the rainfall in the baseline period. In South Asia, the largest rainfall increase during 2070–99 is predicted to be in the summer months of March, April, and May and in the range 20–31 percent of the average rainfall in the baseline period. During the winter months (December, January, and February), rainfall is predicted to fall between 6 and 16 percent. The magnitudes of predicted changes in temperatures are larger during the winter months and become smaller as we move away from those months. The pattern of rainfall predictions across seasons is less clear-cut.

Second, the predicted changes in nearer term are smaller than those in the longer term but still larger than those observed during the last entire century. For example, the temperature increases in South Asia during 2010–39 are predicted to range between 1.1°C and 1.2°C during the winter months and 0.78–0.83°C in the post-monsoon months. Rainfall increase is predicted to range between –3 and 4 percent in the winter months, and 1 and 3 percent in the summer months.

The Government of India (2004) reports the results from a set of General Circulation Models with regional details under the assumption that GHG forcing is increased at the compound rate of 1 percent per year during 1990–2099. Like the IPCC Fourth Assessment, these simulations predict marked increase in temperatures and rainfall by the end of the 21st century. The increase in the average temperature ranges from 3 to 6°C and that in rainfall from 15 to 40 percent over the 1961–90 baseline. The models predict increased precipitation during the monsoon season especially in the northwestern part of the country. State-wise projected increases show wide variation across models, however. The Government of India (2004) cautions that projections based on the models are subject to very substantial uncertainty:

> Regionally, there are large differences among different GCMs [General Circulation Models], especially in precipitation-change patterns over the Indian subcontinent. Most GCM models project enhanced precipitation during the monsoon season, particularly over the northwestern parts of India. However, the magnitudes of projected change differ considerably from one model to the other. Uncertainties exist in the projections of climate models specifically concerning their spatial resolutions. The GCMs are robust in projecting temperature changes rather than rainfall changes.

Extremes in Rainfall, Droughts, and Floods

According to model simulation results reported in the Government of India (2004: 70) the number of rainy days in western and central parts of India would decline by 15 or more and those in the foothill of Himalayas and northeast India would rise by 5 to 10 days in the 2050s.[13] Rainfall intensity is predicted to rise by 1 to 4 millimeters per day except in small areas in northwestern India where it would decline by 1 millimeter per day. The highest one-day rainfall per day over a major part of the country could rise by as much as 8 inches per day while that in some parts of northwestern India could decline by 4 inches per day. With respect to droughts and floods, the report (p. 78) notes, "The preliminary assessment has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India is projected to increase. Further, there is a general reduction in the quantity of the available run-off under the GHG scenario."

Sea Level Rise, Cyclones, and Effects on Coastal Zones

According to the census of 2001, there are 65 coastal districts out of a total of 593 districts countrywide. These districts are spread over nine different states. According to the Government of India (2004), as per the long-term trend, sea level along the Indian coast has been rising 1 inch per 25 years. More recent data suggest a rising trend of 2.5 inches per 25 years. Model simulations suggest that the oceanic region adjoining the Indian subcontinent will warm at its surface by about 1.5–2°C by 2050 and by about 2.5–3.5°C by 2100. This would lead to sea-level rise between 6 and 15 inches by 2050 and 18 and 24 inches by 2100. It is estimated that a 40 inch rise in sea level would displace approximately 7.1 million people in India and cause a loss of approximately 2,224 square miles of land. Climate change may add to risks by increasing the frequency of cyclones though no evidence that this would happen is so far available.[14]

Economic Phenomena

GHG emissions will impact various economic activities directly as well as indirectly through impact on a variety of natural phenomena. Among the aspects likely to be impacted most are water supply, agriculture, migration, and poverty. The effects raise the issue of adaptation on which I touch toward the end of this section.

13. The India Meteorological Department defines a rainy day as a day with a rainfall of 2.5 millimeter or more. The mean annual number of rainy days varies from less than 20 days in northwestern India (west Rajasthan and Kutchh region of Gujarat) to more than 180 days in the northeastern part of the country (Meghalaya). Northeastern India and the southern parts of the west coast are major areas of relatively high mean annual number of rainy days (approximately 140 days).

14. For more details, see Government of India (2004: 108–13).

Water Supply

India has 16 percent of the world's population but only 4 percent of its water. Rising population has been continuously lowering the availability of water per capita. The current availability of utilizable surface and ground water stands at 1,122 billion cubic meters (Government of India, 2004: 72). Given India's population of 1.15 billion, this works out to approximately 1,000 cubic meters per capita. Conventionally, utilizable water below 1,700 cubic meters per capita per year is associated with "stress" in water availability and that below 1,000 cubic meters per capita per year with chronic water "scarcity." The Government of India (2004, Table 3.1) estimates actual total water consumption in 2010 to be 200 billion cubic meters. With the expected population of 1.2 billion in 2010, this works out to approximately 165 cubic meters per capita per year. This consumption is comparable to that in some of the developed countries though considerably below many others.[15] Irrigation accounts for more than 80 percent of water consumption in India.[16]

Looking ahead, per capita water availability is expected to decline due to rising population. According to some estimates, population is expected to stabilize around 1.6 billion in 2050. Assuming no change in water availability, this would place per capita water availability at approximately 700 cubic meters per year. In the light of the current consumption levels, this may seem adequate but such a conclusion is unwarranted. Surface water accounts for only 60 percent of the available supply and 40 percent of it is concentrated in the Ganges–Brahmaputra–Meghna system. This has meant that water usage in the majority of the river basins is already between 50 and 95 percent of the available supply. In addition, variation in the availability across seasons can also add to scarcity in certain parts of the year.

Climate change can impact water availability through several channels. Increased rains by themselves would add to the availability of surface water. More rapid melting of glaciers will also add to the availability of utilizable water initially though this channel will dry up as glaciers disappear. Increased temperatures that lead to increased evaporation and transpiration cause the

15. This availability level is distinct from actual consumption level. Interestingly, the consumption levels vary vastly across countries. Based on 2002 (or latest available) data, annual per capita water consumption in the OECD countries ranged from 130 cubic meters in Denmark to 1,730 cubic meters in the United States. All OECD countries except Portugal, Australia, Canada, and the United States have water consumption below 1,000 cubic meters.

16. In the United States, industrial, agricultural, and domestic consumption account for approximately 65, 27, and 8 percent of the total consumption.

availability of utilizable surface water to shrink. Estimates reported in the Government of India (2004, Table 3.2) show the net effect to be positive for some rivers and negative for others.

Climate change can further impact water availability through its influence on droughts and floods. Water shortages in specific regions can occur if drought conditions become more severe, prolonged, and frequent. According to the Government of India (2004: 78), areas served by river Luni, which occupies about one-fourth of the area of Gujarat and three-fifths of the area of Rajasthan, are likely to experience acute physical water scarcity conditions. Increased frequency and severity of floods can also temporarily create a shortage of utilizable water.

From the policy perspective, climate induced changes require more intense pursuit of measures to conserve and develop water resources that India must undertake even absent climate change. These include more prudent utilization of surface and ground water through proper pricing as well as training, harvesting of rainwater, building of dams, development of distribution networks, and re-forestation to help replenish ground water. The government can also exercise the option to import of food grains to conserve water utilization in agriculture.

Agriculture

From an economic standpoint, climate change is likely to have its most pronounced effects in the area of agriculture. Approximately 70 percent of India's population lives in rural areas and 55–60 percent of its workforce is engaged in agriculture. On the other hand, the share of agriculture (including forestry and fishing) in the GDP has declined from 29.3 percent in 1990–91 to only 17.8 percent in 2007–08. Already, three-fifths of the workforce lives on less than one-fifth of the GDP.

Very low productivity growth in Indian agriculture is a well-recognized problem. Future prospects also look bleak. The sector is likely to face progressive scarcity of water. Ground water level has been progressively declining and the supply of river water may also shrink over time. Progressive division of land holdings over last several generations has led to extremely low size of land holdings: In 2002–03, 70 percent of land holdings were less than 1 ha (2.47 acres) and the average land holding was 1.06 ha. Land leasing laws in various states result in vast volumes of land being left uncultivated in some states while leading to highly inefficient methods of farming in virtually all states.

Against this background, how do we assess the impact of climate change? There are several possible channels. Increased droughts and floods can lead to partial destruction of crops with greater frequency. Compression of the monsoon season and increased intensity of rains may also impact agricultural productivity. Increased sea levels can reduce the availability of arable land. Rising maximum temperatures in drought-prone areas lead to reduced productivity while those in cooler areas raise productivity. Increased carbon dioxide levels in the air lead to increased productivity in many major crops. According to the World Bank (2009a, Box on p. 76), C3 crops, which include rice, wheat, soybeans, fine grains, legumes, and most trees, benefit significantly from such a change while C4 crops, which include maize, millet, sorghum, and sugarcane, benefit less.

A number of studies try to estimate the effects of rising temperatures, increased or reduced rain, increased carbon dioxide levels and other climate related changes on yields in different crops and regions. Table 7.3 in World Bank (2009a) summarizes the results of many studies. The effects vary widely according to crops, specific climate changes assumed and region. For example, Aggarwal and Mall (2002) simulate various IPCC climate change scenarios for parts of northern, eastern, southern, and western India and predict gains in rice yields ranging from 1.3 percent by 2010 to 25.7 percent by 2070. On the other hand, assuming increases of 2°C in maximum and 4°C in minimum temperature, 5 percent reduction in the rainy days, 10 percent reduction in monsoon rains and an increase in carbon dioxide levels to 550 ppm (parts per million) from 430 ppm, World Bank (2006) predicts 9 percent reduction in rice yields and 2, 3, 10, and 3 percent increases in yields of groundnut, jowar, sunflower, and maize, respectively.

There are very serious problems with these studies. First, they use past information to predict future outcomes going almost 100 years into the future. Surely, technology will change during this period. New seeds, products, and cultivation methods would emerge. This means any response coefficients based on the past data are unlikely to correctly predict the outcomes this far into the future. Second, the use of IPCC predictions of average changes in temperatures and rainfall to predict the changes in future outputs is rather heroic. The changes across regions of India and across seasons within the same region greatly differ. In the case of rainfall, it is expected to rise in some regions and seasons and fall in others. Temperature increases would be above average in some regions and seasons and below average in others. Third, related to the previous points, responses to temperatures, rainfall, and carbon dioxide would themselves differ across regions and seasons. Fourth, as far as the overall agricultural output and income are concerned, the impact would be cushioned by substitution out of crops with larger adverse effect into those with smaller adverse or positive effect. Finally, some studies consider the effects of predicted changes in temperatures and rainfall only. But one cannot accurately assess even the direction of the change without taking into account to favorable impact of carbon dioxide emissions on some of the key crops. Given these flaws, most of which are insurmountable, one wonders if the predictions going beyond even 2020 can be taken any more seriously than those by astrologers relating to one's life.

Health

In general, the relationship between climate change and health outcomes is complex. Therefore, as in other areas, we can only speak in terms of possible outcomes. If temperatures rise in warmer parts of the country and on the maximum end of the spectrum, heat waves may become more intense and longer lived. That would result in increased incidence of heat stroke and related diseases. Heatstroke related deaths might rise as well. Warmer climate also makes air pollution more harmful and contributes to airborne diseases with greater potency. Increased dampness and water pollution accompanying floods are likely to increase the risk of spread of diseases such as malaria. Water contamination that may accompany floods and droughts may also lead to increased incidence of intestinal diseases such as diarrhea. On the other hand, warming in colder regions, during winter season and in minimum temperatures may reduce health risks associated with cold waves. Increased rains in currently dry regions may also reduce the risk of heat waves.

To the extent that climate change is expected to be associated with increased health problems, the change represents an intensification of some of the existing public health problems in India. My detailed analysis of the heath sector (Panagariya 2008, Chapter 19) shows that the government is already behind the curve in addressing these problems. The possibilities outlined above call for renewed vigor in implementing major policy reforms in the sector. India needs to accelerate medical education at all levels to ensure access to trained medical personnel. It also needs to improve access to medicines. And, of course, it needs to take a variety of public health measures to combat the spread of infectious diseases by ensuring proper drainage and supply of clean drinking water.

Migration

Intensification of urban–rural and inter-state migration may be another area of impact of climate change. To begin with, given diverse rates of growth across states and between urban and rural areas, migration is likely to accelerate even independently of climate change. Demographic changes are likely to reinforce this phenomenon: whereas all four southern states (Andhra Pradesh, Kerala, Tamil Nadu, and Karnataka) have reached the replacement levels of fertility rates, many of the poorer states in the north such as Bihar, Uttar Pradesh, Madhya Pradesh, and Rajasthan have high population growth rates. This would likely lead to increased migration from the latter set of states to the former.

Climate change can further add to complications in migration patterns. For example, as previously discussed, rising sea levels may displace a part of the population currently living in the coastal zones. More frequent cyclones, droughts, and floods may also lead to increased migration. Finally, it is commonly suggested that climate-related events may lead to massive migration from Bangladesh into India. These sources of migration are bound to interact with other sources and, very importantly, the ongoing process of urbanization. Other than noting these possibilities, it is not clear what precise policy prescriptions can be offered in anticipation of what are at this stage guesses with high degree of uncertainty. While migration may generate some social stress, in so far as it involves the movement of people from low-income to high-income areas and leads to urbanization and modernization, it is to be welcome.

Poverty

Climate change may impact poverty at two levels: it may increase the number of poor by impoverishing those with incomes just above the poverty line and it may be accompanied by the burden of some of the accelerated and more intense extreme events falling disproportionately on the poor.

The proportion of the poor living below the poverty line may rise due to reduced incomes of farmers many of whom may be living just above the poverty line. But it must be acknowledged that this effect may also go the other way if the net effect of climate change is to increase rather than reduce agricultural productivity. An increase in poverty may also result from reduced opportunities for the bottom deciles elsewhere in the economy and reduced revenues available to the government to carry out anti-poverty programs. Whether or not the effect would be large depends how large climate-related changes in temperatures, floods, cyclones, and droughts are and how close the connections between these changes and reduced farm incomes, shrunken opportunities elsewhere in the economy, and decline in government revenues are.

Turning to climate change-related extreme events such as floods, cyclones, and droughts, a prima facie case can be made that they would asymmetrically hurt the poor. The poor are more exposed to floods. Disproportionately large number of them being landless workers or marginal farmers, they also bear the greatest burden of droughts. Natural calamities are also likely to adversely impact indigenous populations that are less able to shelter themselves. Floods and heavy rains are also likely to asymmetrically damage the urban poor who live in dwellings that readily collapse under heavy downpour.

One way to pose the poverty question in the context of climate change is where we expect poverty levels to be in 2030 absent any climate-related effects and where it will be taking the latter into account. We may then ask how the strategy to combat poverty ought to be different. The same may be said of necessary protection against the vagaries of droughts and floods. These are ongoing phenomena that are predicted to become more frequent and more intense. The question then is how best to modify flood and drought relief policies in anticipation of climate-related changes.

Here we must not shy away from raising the issue of priorities: Given that the government has limited resources and, indeed, very limited capacity to deliver services, how much importance should it give to combating the adverse effects of climate change relative to other priorities such as the provision of education and health, helping sustain a high rate of growth, and attending to localized environmental concerns ranging from pollution of river waters to indoor air pollution associated with cooking with solid fuels such as dung, wood, crop waste, or coal.

An argument can be made that rapid growth currently under way will better prepare the population to cope with vagaries of future climate changes. If the current near-double-digit growth were sustained for two to three decades—an entirely feasible proposition—the country would almost entirely be free of extreme poverty. With proper shelters and substantially improved purchasing power, people will themselves be better prepared to adapt to climate change effects in two decades.[17] This line of reasoning argues for minimizing the commitments for mitigation of GHG emissions in the next two to three decades that might compromise growth. This is not a recommendation for irresponsible behavior but simply for negotiating an agreement whereby India's mitigation commitments are back-loaded. I will return to this theme more frontally in the eighth section.

In concluding this section, let me note that my assessment of the prospects for India's ability to adapt to climate-related changes that will occur even

17. My assessment in this regard is consistent with India's National Action Plan on Climate Change released on June 30, 2008. The plan rightly emphasizes the overriding priority of maintaining high economic growth rates to raise living standards and focuses on identifyng "measures that promote our development objectives while also yielding co-benefits for addressing climate change effectively."

after actions for mitigation are taken are less apocalyptical than some others who describe them as potentially "calamitous." For instance, on the authority of Nordhaus and Boyer (2000), Mendelsohn et al. (2006), and IMF (2008), Joshi and Patel (2010: 4) express the urgency for India to negotiate an agreement in these terms:

> India is more vulnerable to climate change than the US, China, Russia and indeed most other parts of the world (apart from Africa). The losses would be particularly severe, possibly calamitous, if contingencies such as drying up of North Indian rivers and disruption of Monsoon rains came to pass. Consequently, India has a strong national interest in helping to secure a climate deal.

While India faces a severe water shortage problem in large part due to poor management even absent any climate change effects, claims of "calamitous" losses *on account of global warming* are difficult to reconcile with the predictions of the impact of GHG emissions on temperatures, rains, evaporation, and transpiration in India discussed earlier. Rains are almost uniformly predicted to rise and the impact of temperature increase on evaporation and transpiration is not expected to be large enough to significantly change the net availability of surface water. For their part, Joshi and Patel or the sources they cite provide no evidence supporting the hypothesis of calamitous losses due to GHG emissions.

Mitigation: Optimality with No International Transfers Permitted

While the uncertainties discussed earlier are naturally important for the choice of action, there is currently general agreement that an effort needs to be made to bring down GHG emissions to help slowdown global warming and the harmful effects accompanying it. Therefore, in this section, I turn to a consideration of the optimal choice of GHG emissions and the instrument to achieve it.

The first point to note is that GHG emissions are accompanied by a global externality: emissions by one firm impact individuals living everywhere on the globe. Therefore, the optimal solution requires action at the global level. If there was a sufficiently powerful and efficient global government, it could implement the optimal solution by maximizing a global social welfare function that takes into account the expected damage from GHG emissions subject to country-wise resource constraints and production technologies allowing for GHG emissions as an input (see later).

Among other things, such a solution would yield optimal country-specific GHG emissions as well as lump-sum distributions of income across individuals (and therefore nations) necessary to achieve individual welfare levels consistent with the maximized value of the social welfare function. Therefore, to achieve the fully optimized solution, efficiency and distribution problems would be simultaneously solved.

In practice, we do not have a global government with a well-defined global social welfare function and the power to redistribute income internationally. Therefore, as a starting though not ending point, we may consider the optimal solution under the assumption that no international transfers are permitted. Such a solution would exploit any benefits available to each country without affecting any international transfers. This solution can only be implemented, however, if all governments cooperate rather than act strategically. In practice this is unlikely to happen since each individual government will find that since the cost of GHG emissions partially spills over to other countries, it can improve upon its fate by choosing to expand its GHG emissions. But if all governments play this game, the result would be a strategic rather than cooperative equilibrium in which each country would be left worse off.[18]

Realistically, given that GHG emissions stay in the atmosphere for up to 100 years and their costs accrue at points in time different from when such emissions add to output (with costs even falling on generations different from those benefiting from it), the problem is properly formulated in a dynamic framework. Such an ambitious exercise being outside the scope of this paper, I take a short cut by defining the period of analysis to be sufficiently long that we may think of the benefits and costs as accruing in the same period. For example, we may think of the entire 21st century as a single period during which extra output from emissions and the damage they incur would both be realized.

A One-Country Model

For simplicity, I begin with a one-country world. The essential features of the problem within this framework can be captured using a one-good model. Therefore, denoting the output of this aggregate good by X, capital by K, labor by L, and GHG emission by Z, technology for the production of

18. For example, if individual country governments choose to independently maximize their welfare taking the emission choices of other governments as given, we would end up in the standard Cournot equilibrium, which is inferior to the cooperative equilibrium to be considered immediately below.

X can be represented by a conventional constant-returns-to-scale production function F(.).

$$X = F(K, L, Z) \tag{1}$$

The social welfare function to be maximized is written

$$W = U(X, Z) \tag{2}$$

U(.) is rising in X and declining in Z and satisfies the usual properties of a utility function.[19] We take K and L as given. Therefore, the optimization problem is to choose Z (and therefore X as well) to maximize utility. Using a subscript to denote a partial derivative, the solution is given by:

$$F_Z(.) = -U_Z(.) / U_X(.) \tag{3}$$

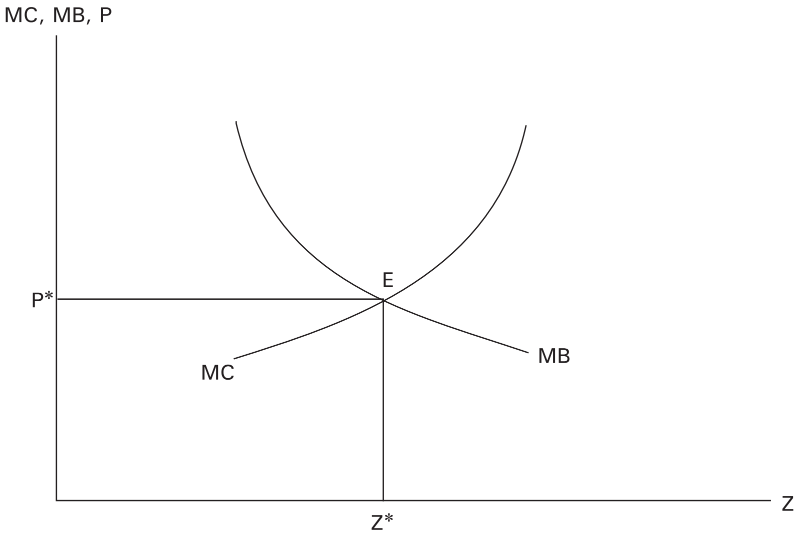
The left-hand side of this equation represents the extra X attributable to the last unit of GHG emission and may be viewed as the marginal benefit of Z. The right-hand side represents the absolute value of social cost imposed by the last unit of GHG emitted, where the cost is measured in terms of units of X. The right-hand side thus represents the marginal social cost of Z.

In Figure 1, I measure Z on the horizontal axis and its marginal benefit, marginal cost and "price," in terms of X, on the vertical axis. Remembering $F_{ZZ} < 0$ by concavity of the production function, the left-hand side of equation (3) can be represented by the downward-sloped marginal benefit curve labeled MB. Likewise, we can represent the right-hand side by the marginal cost curve labeled MC. A sufficient but not necessary condition for MC to be upward sloped is that the marginal utility of X decline with a rise in Z ($U_{XZ} < 0$). In words, the latter condition says that an extra unit of consumption of X gives less pleasure in a more polluted environment. In the rest of the paper, the conditions necessary for the MC curve to be upward sloped have been assumed to be satisfied.

The optimal solution in Figure 1 is given by point E. One way to achieve this solution is to fix the price of Z at P*. This is equivalent to the imposition

19. Under certain assumptions, this social welfare function may be derived from individual utility functions. Under this interpretation, the government must also affect the necessary redistribution of income across individuals in a lump-sum fashion to achieve the maximized value of the social welfare function.

FIGURE 1. Optimal Choice of Emissions



Source: Author.

of a pollution tax at rate P* (measured in terms of X) per unit of pollution. Given P* as the price, firms will use up Z up to the point where the marginal product of Z = P* or F_Z = P*. Recalling that the MB curve represents nothing but F_Z, we immediately obtain Z* as the equilibrium value of Z.

Alternatively, we could fix the quantity of Z at Z*. The instrument to ensure this would be the tradable pollution permit. The government would issue pollution permits for Z* units and auction them competitively. The firms would keep bidding for the permits until the marginal product of Z exceeds the price of the permit. Therefore, if the auction is perfectly competitive, the price of the permit will settle at P*. If the price is any lower, there will be firms with higher marginal product and an excess demand for permits would exist. If it is any higher, some permits will go unsold pushing the auction price down. Therefore, the price (tax) and quantity (pollution permits) solutions are exactly identical.

A Two-Country Model

We may now extend the model depicted in Figure 1 to explicitly allow for a two-country world consisting of a rich northern country and a poor southern country. I use upper-case letters to denote variables associated with the northern country and lower-case letters those associated with the southern country. I also introduce past emissions explicitly denoting the stock of pollutants in the environment from past emissions by ζ_0. The simple model above is now replaced by

$$X = F(K, L, Z), \quad x = f(k, l, z) \tag{4}$$

$$W = U(X, \zeta), \quad w = u(x, \zeta) \tag{5}$$

$$\zeta = \zeta_0 + Z + z \tag{6}$$

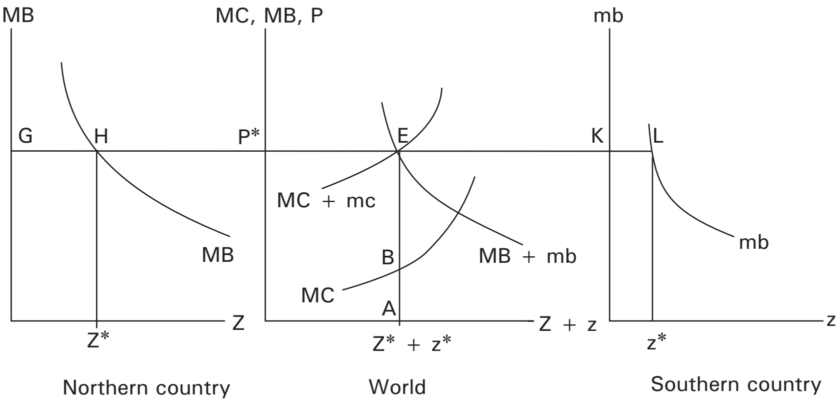
The modification through the introduction of ζ_0 denoting the stock of past emissions in the environment makes explicit the proposition that the social cost of emissions depends on not just current but past emissions as well. The optimal levels of z and Z are now given by

$$(U_\zeta + u_\zeta) / u_x = (U_\zeta + u_\zeta) / U_X = F_Z = f_z \tag{7}$$

This is the usual solution to the public good ("public bad" in the present case) problem: global welfare is maximized by equating the sum of the costs imposed on the two countries by the last unit of emission to the benefit produced by it in either country.

Figure 2 depicts this solution graphically. The marginal products of GHG emissions in the northern and southern countries are depicted by curves labeled MB and mb in the first and last panels, respectively. In the

FIGURE 2. Optimal Emission in a Two-Country Model



Source: Author.

middle panel, MB + mb is derived by horizontally summing the MB and mb curves. Curve labeled MC in the middle panel depicts the marginal cost of worldwide GHG emissions (inclusive of the past emissions) in the northern country. Stacking the marginal cost in the southern country for each value of the worldwide GHG emissions vertically above MC, we obtain MC + mc curve as showing the global marginal costs of worldwide emissions.

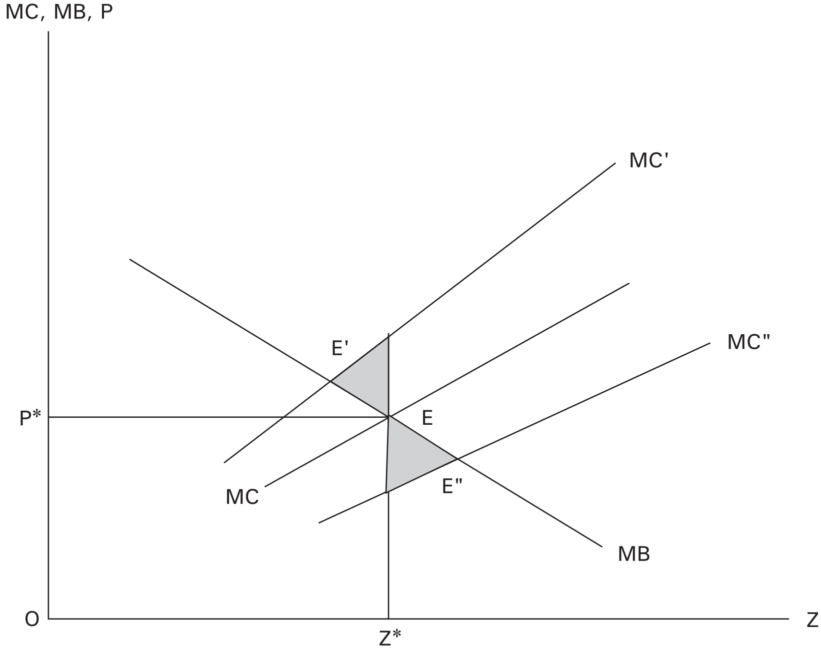
Point E where the global marginal benefit and cost curves intersect yields the optimal level of global GHG emissions, Z* + z*. Setting the price of (tax on) emissions at P*, the northern country firms chooses Z* and the southern country firms z*. Alternatively, if globally tradable permits in the amount Z* + z* are issued and competitively auctioned, permits will be priced at P*, with the northern country firms buying Z* and southern country firms z* worth of permits. The globally efficient solution will be reached.

As drawn, Figure 2 shows that the southern country pollutes much less than the northern country. This feature derives from its smaller economic size mainly captured by smaller resource base and perhaps lower productivity. Given these features, emission levels of the southern country turn out to be small in relation to the northern country. Figure 2 also shows that in equilibrium, the southern country bears the bulk of the cost of emissions: the marginal cost absorbed by the southern country, EB, is significantly bigger than that absorbed by the northern country, AB. As drawn, a comparison of the total costs in the northern country measured by the area under the MC and above the horizontal axis up to emission level Z* + z* and that for the southern country measured by the area below mc curve and above MC curve up to the same emission level shows higher total costs to the latter than the former. This feature is intended to represent the greater vulnerability of the southern countries to climate change that many analysts emphasize, though given the uncertainties previously noted, the truth of this feature is difficult to judge.

Carbon Tax versus Emission Permits

How does the presence of uncertainty with respect to the cost of GHG emissions impact this analysis? Surprisingly, at least under risk-neutral behavior, the equivalence of price and quantity instruments is entirely preserved. The point is readily made using the simpler, one-country model of Figure 1. I reproduce this model in Figure 3 with the modification that the location of the MC curve is known only probabilistically. Specifically, marginal costs may turn out to be high or low each with a probability of 0.5. These are respectively represented by MC′ and MC″ in Figure 3.

FIGURE 3. Uncertainty and the Optimal Instrument



Source: Author.

For simplicity, I make all curves linear. MC represents the expected (or mean) value of the marginal cost for various levels of Z. The objective now is to maximize the expected net benefit from Z. This is achieved at point E with Z = Z*. Given MC shows the mean value of the marginal cost, the shaded triangles are equal in area. If the cost curve ends up being MC′, Z is overshot with a deadweight loss of the upper shaded triangle relative to the ex post optimum E′. If the cost curve turns out to be MC″, Z undershoots with the lower shaded triangle representing unexploited benefits relative to the ex post optimum E″. Any other value of Z will lead to lower expected net benefits.

In view of the fact that the marginal benefits are not uncertain, outcome E can be reached by either setting the price of Z at P* or issuing pollution permits for Z* quantity and auctioning them competitively. In the former case, firms will buy Z until $P^* = F_Z$, which leads to Z* as the solution and P*Z* as revenue. If permits are auctioned competitively, firms are willing to pay a price equal to the marginal benefit, which equals P*. Once again, the same solution is obtained with revenues equaling P*Z*.

This result will not hold in general. A more comprehensive analysis of prices versus quantities as the right policy instrument in the presence of uncertainty can be found in Weitzman (1974). The thrust of Weitzman's analysis is that uncertainty in costs leads to a presumption in favor of quantity as the superior instrument, though this is by no means inevitable.

In practice, the bigger difference between the price (tax) and quantity (permits) instruments is likely to result from the political economy accompanying them. A tax will work more transparently since the revenue collected will be like any other tax revenue and will become a part of general revenues. But a decision to go with permits is likely to allow firms responsible for emissions to lobby for their free distribution. This is amply illustrated by the recent US experience with the "cap and trade" legislation aimed at regulating domestic emissions of US firms. The US Congress opted for permits, which immediately led firms in carbon-intensive sectors to begin lobbying for their free distribution. The outcome has been a decision to distribute 85 percent of the permits freely. To justify this action, the US Congress now plans to hold down the price charged by electricity suppliers, the largest beneficiaries of the give away. This clearly violates the efficiency principle. On the political economy and transparency counts, a tax on GHG emissions is likely to be superior.

From Optimality to Efficiency

Up to this point, the analysis has been overly simple along one dimension but overly complex along another. Taking the former first, I have analyzed the problem of optimal choice within a static framework. As previously noted, there is a time dimension to the problem. We must derive the optimal target levels of emissions based on expected costs and benefits for each period, which may be defined as one year or longer. In general, the optimal tax or number of permits would vary across periods depending on how the expected costs and benefits are phased.

While realism, thus, requires explicit introduction of time into the analysis, it also forces us to take a short cut along the cost dimension. The second, third, and fourth sections of this paper have emphasized the vast uncertainties concerning the timing, object, and value—when, where, and how much—of the costs associated with GHG emissions. Any expectation that such costs can be incorporated into a formal analysis to determine mitigation targets in different years is unrealistic.

The solution to these problems is likely to emerge partly from the scientific evidence and partly from practical (political?) considerations. Scientific evidence, as reported by the IPCC (2007a), gives us guidance on global emission targets for benchmark years. More detailed, annual emission targets must then be devised based on what is practical and politically achievable. Once these targets are set, our analysis in the pervious sections tells us that the least costly way to achieve them is either a globally uniform tax per tone of emissions or globally tradable permits. It must be remembered, however, that this approach does not give us the optimal solution by any means since the emission targets themselves are chosen in an ad hoc manner—all we can claim for a common emission tax or globally tradable permits now is efficiency in achieving the specified targets.

Additional Considerations

Two additional practical considerations in the implementation of an efficient mitigation policy may be noted. First, in a strict sense, efficiency of a uniform emission tax or tradable permits requires participation by all countries. Exclusions would result in the emission in the exempted countries being pushed to the point where it produces less value than the emission tax (or permit price) and, thus, violating the efficiency principle. Yet, few proposals under consideration extend to all countries in the world. Instead, the set of included countries varies from all developed countries that are not transition economies to all developed and major developing countries. Those proposing the latter such as Cooper (2008) defend their position not on efficiency grounds but the assertion that the grant of exemption to major developing countries such as China and India would lead to leakages: dirty industries and firms would simply relocate themselves from regulated to unregulated countries. But the argument has two serious limitations: (*i*) the vast majority of emissions in the rich countries take place in non-traded sectors that cannot migrate, and (*ii*) environmental regulation being only one of the many factors determining the location of industries, leakages are capped even in traded goods sectors. With respect to the latter point, the Environmental Protection Agency of the United States estimates that the US emissions leakage rates under Lieberman-Warner legislation would be approximately 11 percent in 2030 and 8 percent in 2050.[20]

The second implementation issue relating to the efficient solution is the need for monitoring and therefore, a monitoring agency. Again, Cooper (2008) argues that this is not a problem since the International Monetary Fund (IMF)

20. EPA Analysis of the Lieberman-Warner Climate Security Act of 2008. *S. 2191 in 110th Congress*, March 14, 2008.

is well equipped to fulfill this function. But if one simultaneously insists on requiring the developing countries such as China and India to participate in mitigation, acceptability of the IMF to them is far from obvious in view of their near lack of voice in the institution's governance. It is unlikely that these countries will accept surveillance by an institution heavily dominated by many tiny European countries that would themselves make limited contribution to the alleviation of global warming.

A Serious Limitation of the Efficient Solution

An extremely important limitation of the globally uniform emission tax or its equivalent, the globally tradable permits system, as the efficient solution is the presence of prior direct or indirect taxes (or subsidies) at different rates on carbon use in almost all countries. For example, if the United States has a 10 percent sales tax on gasoline and India 20 percent, adding a uniform carbon tax to these will not equalize the marginal social benefit from mitigation between the two countries, a necessary condition of efficiency. If a uniform carbon tax is to be truly efficient, it should replace all other direct and indirect carbon taxes and be set at a level that delivers the targeted global emission absent all other direct and indirect taxes on emission.

A related point is that an initially efficient carbon tax or tradable permits system can be readily subverted by countervailing actions. For instance, if tradable permits are given out free of charge to firms in certain sectors, the firms in those sectors will have an incentive to expand output beyond the (efficient) level obtained when they are required to buy such permits because higher output allows them to obtain more free permits that command a positive price in the marketplace. The result would be a movement away from the efficient solution.

Mitigation: The Distributional Issue

So far, I have entirely sidestepped the contentious distributional implications of mitigation. A uniform carbon tax or globally tradable permit system may yield an efficient solution but absent income transfers across countries is also accompanied by a specific distribution of burden that may be politically or ethically unacceptable. That these considerations directly or indirectly influence even the most ardent advocates of the "efficiency only" view is illustrated by the fact that no one to-date has suggested subjecting the countries in Africa to carbon tax or emission permits.[21] Indeed, most principles of moral philosophy would give some consideration to protecting the interests of those living in abject poverty.

Conceptually, we identify two sources of distributive inequity associated with the use of the common environmental resource: that arising out of free use of the environment in the past and that associated with its use in the future. Bhagwati (2006) refers to the former as "stock" problem since it refers to the cost of the existing stock of emission and to the latter as "flow" problem since it relates to future flows of emissions. Consider each of these problems in turn.

The "Stock" Problem

Carbon emissions stay in the environment for approximately 100 years. Therefore, the damage to the environment is due as much to the past emissions as from the future ones. Bhagwati (2006) argues that if future emitters are to be held responsible for their acts, so must be past emitters. While countries such as China and India are becoming substantial contributors (with India still very far behind China) to the flow problem, they have contributed very little to the stock problem.

According to the Pew Center on Global Climate Change, the United States contributed 30 percent of the cumulative CO_2 emissions between 1850 and 2000; EU-25 together 27 percent (Germany 7 percent, UK 6 percent, France 3 percent, and each of Poland and Italy 2 percent); Russia 8 percent; China 7 percent; Japan 4 percent; and Ukraine, Canada, and India 2 percent each.[22] In other words, approximately 71 percent of the emissions from 1850 to 2000 were accounted for by the United States, EU, Russia, Japan, and Canada alone. As Table 3 shows, with 4.4 percent of the global CO_2 emissions in 2006, the latest year for which data exist, India is now the fifth largest contributor to the flow problem with China (20.6 percent), United States (20.2 percent), EU (14.8 percent), and Russia (5.8 percent) accounting for the top four emitters. Quite apart from the fact that the gap between the current top three emitters and India is very large, the latter's contribution to the stock problem at 2 percent is tiny. Under any reasonable equity principle,

21. Small economic size of these countries is not sufficient to explain the omission. Some African countries are comparable in economic size to some of the tiny but richer countries that the authors propose to cover under the carbon tax.

22. These data are taken from website http://www.pewclimate.org/facts-and-figures/international/cumulative (accessed on May 13, 2010).

TABLE 3. CO_2 Emissions from the Consumption and Flaring of Fossil Fuels, 2006

Serial number	*Country*	*Total emissions (Million metric tons of CO_2)*	*Percent of world*	*Per capita emissions (Tons/capita)*
1	China	6,017.69	20.6	4.58
2	United States	5,902.75	20.2	19.78
3	European Union	4,331.97	14.84	7.99
4	Russia	1,704.36	5.8	12
5	India	1,293.17	4.4	1.16
6	Japan	1,246.76	4.3	9.78
7	Germany	857.6	2.9	10.4
8	Canada	614.33	2.1	18.81
9	United Kingdom	585.71	2.0	9.66
10	South Korea	514.53	1.8	10.53
11	Iran	471.48	1.6	7.25
12	Italy	468.19	1.6	8.05
13	South Africa	443.58	1.5	10.04
14	Mexico	435.6	1.5	4.05
15	Saudi Arabia	424.08	1.5	15.7
16	France	417.75	1.4	6.6
17	Australia	417.06	1.4	20.58
18	Brazil	377.24	1.3	2.01
19	Spain	372.61	1.3	9.22
20	Ukraine	328.72	1.1	7.05
21	Poland	303.42	1.0	7.87
22	World	29,195.42	100	4.48

Source: Energy Information Agency, United States Department of Energy.

it cannot be expected to become a part of an agreement that addresses only the flow problem.

Coming from the opposite viewpoint and drawing on the work of Mueller et al. (2007), Cooper (2008) categorically rejects the case for compensation by rich countries for the past emissions. His principal argument is that past emitters did not know the harmful consequences of their actions at the time they undertook those actions. Moreover, present generations cannot be held responsible for the actions of their forefathers.[23]

Bhagwati counters, however, that compensation by a future generation for a harmful act that its ancestors committed without knowing the associated harmful effects is not unusual. Americans who practiced slavery in the

23. Drawing on the literature on distributive justice, Beckerman and Pasek (1995) have challenged the role for equity in determining the allocation of costs of future mitigation and questioned the validity of compensation for the damage resulting from past emissions.

19th century acted according to the prevailing social norms; they did not know their actions would cause harm to the future generations of African Americans. Yet, once it came to be recognized that those acts had inflicted harm, the affirmative action program was put in place.

There is also an important precedent from within the environmental area in the United States for compensation against past damage. The United States Comprehensive Environmental Response, Compensation and Liability Act of 1980, commonly called the Superfund, allows the Environmental Protection Agency (EPA) to compel parties responsible for dumping toxic waste in the 1970s in rivers, canals, and other sites to perform clean-ups or reimburse the government for clean-ups. The US law also permits individuals adversely impacted by toxic waste sites to sue the offending companies for damages.

If it is agreed that polluter pay principle must be applied to past emissions, how is it to be implemented? Bhagwati (2006) suggests creating a substantial global warming superfund to which developed countries contribute for no less than 25 years. Unlike in the case of the Superfund, there is no toxic waste to be cleaned up in this case. Therefore, the funds could be made available to the developing countries such as India and China to promote clean technologies including wind and solar energy. Given that developed country companies are likely to develop a significant part of these technologies, the fund would also benefit them.

Flow Emissions

The equity issue arises not just with respect to the past stock of damages but the future-flow emissions as well. Given their high levels of current emissions, rich countries will remain substantial emitters in the years to come. Their large demand for emissions would result in relatively high carbon prices in any mitigation scheme. In turn, that would have an adverse effect on growth and development prospects of the developing countries. Adding to this factor are the predictions that developing countries will be damaged disproportionately by emissions already in place.

The obvious instrument for redistribution in the context of future mitigation is the revenue collected through the emission tax or that associated with emission permits. If the mitigation instrument is emission tax, the revenue raised from it could be redistributed in favor of the developing countries. And if emission permits are used, they could be allocated disproportionately to the latter allowing them to raise revenue by selling the bulk of them in the marketplace for cash.

Recognizing this equivalence between the tax and permit systems, I cast the remainder of the discussion in this section in terms of the latter. We can describe some illustrative redistribution schemes in terms of the initial allocation of permits. Assuming a known global cap on emissions, some possibilities are:

- Each country is given permits in proportion to the emissions in an initial base year. This scheme would give the developed countries, which account for the bulk of the current emissions, the lion's share of the revenues and is unlikely to be acceptable to the developing countries, especially absent any compensation for the past emissions.
- Each country is allocated permits equal to its actual emissions in the globally efficient equilibrium. Under an emission tax, this would allow each country the revenue it collects from its firms. Under the permit system, a global body would auction permits to firms around the world, collect the revenue, and then return it to the countries in proportion to permit purchases by firms within their respective jurisdictions. This scheme, favored by Cooper (2008), involves no redistribution of revenues at all.
- Permits are distributed in proportion to each country's population. This scheme awards equal permits per capita across the globe. This is justified on the ground that environment is a common resource with each individual having an equal claim to it. This is the allocation favored by India in its representations but the developed countries oppose it. It may be noted that if the objective is full equity, this allocation still falls short of full egalitarian distribution for two reasons: the stock problem still remains, since the rights to past emissions were not equally distributed and the damage from emissions will still be unevenly distributed across individuals and countries.
- A related scheme would be to distribute permits in inverse proportion to each country's per capita income.[24] Given, the bulk of the population is concentrated in the low-income countries, this criterion would closely track the previous one with the qualification that within developing countries, it would result in smaller allocations for China and within developed countries, for the United States. This scheme would also lack support in the developed countries.

24. Letting y_i denote per capita income of country i, the share of country r according to this criterion would be $(1/y_r)/\sum_i(1/y_i)$.

- Developing countries below a specified per capita income are not subjected to mitigation commitments. They join the mitigation effort as they cross the threshold level of per capita income with liberal allocations of permits in the initial years that eventually decline to their actual emission levels. This alternative allows the poor countries full flexibility to pursue their development goals until they reach a minimum per capita income.

Flow Emissions: Numerical Applications

Many authors have simulated the implications of different allocation schemes for the costs and benefits to various countries. In this section, I discuss the results of one of these studies—Jacoby et al. (2008)—which, in my view, provides a nice illustration of how the developed and developing country interests clash under distribution of revenues associated with emissions (that is, allocation of permits). The basic strategy of the simulations is straightforward. Rather than explicitly model the costs of emission represented by the marginal cost curves in Figures 1–3 and optimally determine the level of emissions, they fix the global emission target exogenously. Permits for the targeted level are then allocated among countries according to a pre-specified scheme. Because permits are tradable, actual emissions at the national level are determined endogenously. Free tradability of permits establishes a single price of emission per unit and thus equalizes the marginal benefits of emissions across countries along the lines of Figure 2 and ensures efficiency in limiting emission to a pre-specified level. Any output losses relative to the scenario in which no restrictions on emissions are imposed, commonly called business-as-usual (BAU), determines the economic cost of mitigation. Permit trading generates financial flows from countries that are initially allocated fewer permits than their firms use to those that have more of them than their use. The scenarios are mainly distinguished according to the rules governing the allocation of emission permits across countries.

In the simple model I considered above and illustrated in Figures 1–3, I packed all production activity into a single aggregate good. The simulations in Jacoby et al. (2008) replace this aggregate good by a full-blown multi-good, multi-factor, and multi-country general-equilibrium model with all major GHG emissions endogenously chosen and free international trade in goods permitted. The model has seven developed and eight developing countries and the rest of the world as an aggregate. Emissions caps are applied to all GHG emission and are defined relative to 2000 emission levels. All simulations bring the global emissions down by 50 percent relative to their

2000 levels in 2050, linearly falling beginning in 2015. The authors consider seven different scenarios of which four suffice to bring out the source of conflict between developed and developing countries:

1. Allocations fall linearly such that developed countries receive permits equaling 30 percent and developing countries 70 percent of their respective 2000 emissions in 2050. Together, these terminal-year allocations yield an exactly 50 percent reduction in 2050 over 2000 emissions.
2. Allocations follow 2000 population shares. That is to say, permits are allocated equally on a per capita basis according to 2000 populations of countries.
3. Allocations are based on inverse share of per capita GDP in year 2000.
4. Developing countries are fully compensated for the costs of mitigation with developed country allocations of the remaining permits determined according to their year 2000 emissions.

Table 2 reports the allocations of emission permits, the welfare changes, and financial flows implied by the purchase or sale of permits in years 2020 and 2050 for the United States and India. Because the results for other countries are not central to the present paper, I suppress them. In the first case, the allocation of permits is 80 percent of 2000 emission levels for the United States and 98 percent for India as shown in the top rows. By 2050,

TABLE 2. Simulated Implications of Alternative Permit Allocation Schemes

	Declining proportion of 2000 emissions		*Equal per capita allocations*		*Allocations in inverse proportion of per capita GDP*		*Full compensation to developing countries*	
	2020	*2050*	*2020*	*2050*	*2020*	*2050*	*2020*	*2050*
Allocations as % of 2000 emissions								
USA	80	30	20.5	11.4	1.7	0.9	49.3	–8.3
India	98	70	265.4	147.1	405.2	224.6	127.6	93.3
Welfare (% change from reference level)								
USA	–0.1	2.6	–2.8	–5.5	–3.7	–7.2	–1.3	–7.4
India	–4.9	–11.4	20.9	21	39	48.9	0	0
Net financial transfers (2000 US$ billion)								
USA	–30.3	–179.6	–368.7	–668.8	–483.5	–1024	–196.7	–1239.4
India	10.1	14.7	232.7	513.9	439.7	1056.3	51.8	176.4

Source: Constructed from simulation results in Jacoby et al. (2008).

these fall to 30 and 70 percent, respectively. On the surface, this may seem like a good deal for India but the catch is that India's emissions in 2000 are very low, relative to where they would be in 2050 absent mitigation. Therefore, India suffers income losses on account of mitigation. This is reflected in the welfare cost shown in the middle rows: by 2050, India suffers a welfare loss of 11.4 percent relative to the level it would achieve absent mitigation. This occurs due to the rather high price of permits with India choosing to sell a part of its allocation to the rest of the world. This last fact can be gleaned from the last set of numbers that show a positive financial flow into India. In comparison, the United States does well in this scenario: in 2050, it experiences a welfare gain of 2.6 percent despite having to buy permits worth $179.6 billion.

As expected, the scenarios 2 and 3 turn out to be good for India as expected. In these cases, India ends up receiving permits several times its emissions in 2000. For instance, under the equal per capita distribution rule, it receives 2.7 times and 1.5 times its 2000 emissions in 2020 and 2050, respectively. This naturally proves a good deal for India: its welfare gain over the business as usual scenario turns out to be 21 percent higher in both 2020 and 2050. The United States takes a major hit: its welfare falls 5.5 percent in 2050. The contrast is even starker in the third case when allocations are done according to inverse per capita income.

In the last case, permit allocations are determined by fixing the welfare of the developing countries at business as usual welfare level. Therefore, by definition, the welfare of India is unchanged throughout relative to the business as usual equilibrium. What is interesting, however, is that by 2050, the United States not only receives zero permit allocation but also must effectively purchase permits worth 8.3 percent of its 2000 emissions in the market and give them away to the developing countries. The result is a whopping 7.4 percent decline in its welfare.

Joshi and Patel (2009) favor this last scenario and present it as their preferred proposal; indeed, they even christened it as the "Joshi–Patel" proposal. While attractive, two limitations of the program not recognized by Joshi and Patel must be noted. First, the scenario does not account for the damage resulting from past emissions in terms of increased frequency and severity of extreme events. The manner in which Jacoby et al. (2008) set up the model, the damage inflicted by emissions is entirely outside the analysis. Mitigation would help arrest the damage but would not make it go away. Second, per capita incomes excluding the transfers in this scenario are below those achieved under business as usual scenario. This implies that unless the transfers to the developing countries are maintained beyond 2050 and, indeed, in perpetuity—an extremely unlikely scenario—they would end up worse off as soon as the compensating transfers end.

Despite these weaknesses, the last three of the numerical examples of Jacoby et al. just presented illustrate why the negotiations for mitigation are so complex and difficult. The uncertainties associated with the implications of global warming for individual countries in the absence of any action, different levels of development and growth trajectories, and different perceptions of equity held by different nations greatly add to this complexity. Unsurprisingly, substantive action so far has been difficult, as we will see below from a brief discussion of the efforts to-date.

Policy Action: The Current State of the Play

Given the free-rider problem externalities generated and the uncertainties associated with the costs and benefits of mitigation, it should be no surprise that action on the latter has been difficult. Efforts have been made at both national and international levels but with extremely limited success. Internationally, the United Nations Framework Convention on Climate Change (UNFCCC) provides the overarching institutional framework, though efforts have also been made at forums other than the UNFCCC. At the national level, countries have taken various steps to promote clean technologies and develop green sources of energy. Recently, the United States House of Representatives also passed a “cap and trade” legislation, known as the Waxman–Markey Bill after its sponsors Representatives Henry Waxman and Edward Markey, though it must also be approved by the Senate to become law.

Action at the International Level

The United Nations Conference on Trade and Environment (UNCED) held in Rio de Janeiro in June 1992 and popularly called the Earth Summit produced the international treaty UNFCCC. The aim of the treaty is to stabilize GHG concentrations to avoid “dangerous anthropogenic interference” with the climate system. In its original form, the treaty contains no enforceable limits on GHG emissions but provides for updates called “protocols” setting such limits. The Kyoto Protocol (see later) is such an update.

The UNFCCC entered into force on March 21, 1994 and has been signed by as many as 192 countries to-date. The members are divided into three categories: Annex I countries, Annex II countries, and Non-Annex or developing countries. Annex I countries consist of all industrialized countries. Annex II countries are a subset of Annex I countries and include all OECD countries in that annex that were not "transition economies" in 1992.

Annex I countries are expected to reduce their GHG emissions to levels to be negotiated within the UNFCCC framework. They may do this by allocating the agreed upon emission targets among the major operators within their borders. The operators must then buy offsets to exceed their limits. Under UNFCCC, developing countries are not expected to limit their GHG emissions unless Annex II developed countries supply enough funding and technology. The signatories have agreed under "common but differentiated responsibilities" that the largest share of historical and current GHG emissions originated in the developed countries; per capita emissions in the developing countries are still low; and the share of developing countries in the global GHG emissions will grow to meet social and development needs.

The signatories to the UNFCCC have been meeting once a year in the Conference of the Parties (COP) beginning 1995. To-date, fifteen COPs have taken place and the sixteenth is scheduled to take place in Copenhagen from December 7 to December 18, 2009. Two of the most visible COP meetings were those in Kyoto in 1997 and Bali in 2007.

The Kyoto conference set out to establish a legally binding international agreement on GHG emissions. The result was the Kyoto Protocol, under which developed (Annex I) countries agreed to bring down GHG emissions 5.2 percent below their 1990 levels with varying limits across countries. For example, the EU15 committed to lowering its emissions by 8 percent of the 1990 levels (with varying targets for different EU members), the United States by 7 percent (though it eventually chose not to ratify the protocol), Japan by 6 percent, and Russia by 0 percent. The protocol permitted Australia and Iceland, both Annex I countries, to increase their GHG emissions by 8 and 10 percent of 1990 levels, respectively.

The Kyoto Protocol required that it could only come into force after 55 or more countries covering 55 percent of the 1990 emissions ratified it. Accordingly, it came into force on February 16, 2005. As of January 2009, 183 countries had ratified the protocol. Neither the Clinton nor Bush administration sent the protocol for ratification to the Congress. George W. Bush explicitly rejected it in 2001.

The signatory countries are to undertake emission reductions between 2008 and 2012. The protocol provides three mechanisms to facilitate implementation: (*i*) Emission trading, (*ii*) Clean development mechanism (CDM), and (*iii*) Joint implementation (JI). Under emission trading, countries that manage to lower their emissions below the assigned target can sell their leftover rights (permits) to other countries that fail to lower theirs down to the assigned target. Under CDM, countries subject to reductions can meet their targets partially by undertaking emission-reduction projects in developing countries. The project earns the country a saleable certified emission reduction (CER) credit, each equivalent to one tonne of CO_2. Under JI, a country with an emission reduction commitment under the Kyoto Protocol (Annex B party) can earn emission reduction units (ERU) from an emission-reduction project in another Annex I party, each equivalent to one tonne of CO_2. The ERU can be counted toward meeting its Kyoto target.

The current status of intentions of countries on the implementation of targeted emission reductions is variable. Canada has stated that it will not be able to meet its obligations. Within the EU, Greece was excluded from the Kyoto Protocol on April 22, 2008 due to an unfulfilled commitment to create adequate mechanisms of monitoring and reporting emissions but the country was reinstated seven months later. Bigger European countries such as France and Germany will meet their targets. The EU15 achieved a reduction of 2.7 percent and EU27 of 7.7 percent by 2006. The Economist Intelligence Unit (EIU) (2009) estimates that if the EU15 implement all planned measures, they will reduce emissions by 11 percent by 2010.

After generally sluggish progress for nearly a decade, the thirteenth UNFCCC COP held in Bali in December 2007 tried to bring the negotiating process back on track. After spending an extra day over what had been planned, it concluded with the "Bali Action Plan," which together with a number of important decisions, formed the Bali roadmap. The Bali roadmap sets out the timing, main elements of and steps in the negotiations leading to a successor climate regime to the Kyoto Protocol. An ad hoc working group was appointed at Bali to complete the work by the fifteenth COP to be held in Copenhagen. The group was entrusted with the responsibility to discuss "mitigation commitments or actions" by all developed countries and "mitigation actions" by developing countries. The negotiations at Copenhagen are to be held on the four building blocks of the UNFCCC process: mitigation, adaptation, technology, and financing.

The success of Bali COP was limited, however. Specifically, it failed to produce an agreement on the future level of ambition on mitigation and ended up vaguely calling for "deep cuts in global emissions." Greater success in setting up the ambition level with respect to mitigation was achieved in the parallel but separate negotiations under the Kyoto Protocol mainly because the United States was not a party to them. The EU, which has been a strong supporter of mitigation, largely drove the process in these negotiations. The parties under the Kyoto Protocol noted in their final statement the need for emissions to peak within 10–15 years and for emissions to be brought well below half of the 2000 level. They also recognized that Annex I parties needed to reduce their emissions in the range of 25–40 percent to reach the lowest stabilization scenarios assessed by the IPCC in its Fourth Assessment Report.

Three additional processes outside the UNFCCC have been at work to promote action on climate change: Gleneagles Dialogue kicked off by the 2005 G8 plus five meeting; Asia Pacific Partnership (AP6) consisting of Australia, China, India, Japan, South Korea, and the United States; and the United States Major Economies Meeting (MEM). Of these, the first one has had the most substantive impact on progress.[25] The 2005 G8 meeting brought five major developing countries—Brazil, China, India, Mexico, and South Africa—to participate and issued the Gleneagles Communiqué and Plan of Action on Climate Change, Clean Energy and Sustainable Development. It initiated the Gleneagles Dialog that came to consist of 20 countries. This dialog concluded at the 2008 G8 Summit in Toyako, Japan, with the G8 leaders expressing strong need to consider and adopt a global Long-Term Goal of a reduction in emissions of at least 50 percent by 2050 in their final statement.[26] The G8 leaders also signaled their intention to agree to a global international climate change framework when the fifteenth UNFCCC COP meets in Copenhagen in 2009.

Under President Bush, the United States had been opposed to participation in an international treaty for mitigation such as the Kyoto Protocol. The US position under President Obama has undergone a drastic change. He has already created the position of a "global warming czar" under the title "White House coordinator of energy and climate policy" and appointed the former EPA Administrator Carol Browner to the task. But the conversion of the US President to the cause is only the necessary step toward a comprehensive agreement. The United States Congress remains steadfastly opposed to an agreement that does not require China and India to undertake binding mitigation commitments. For their part, China and India have stated in no uncertain terms that consistent with the UNFCCC,

25. For details on the other two processes, see European Parliament (2008). This publication offers an excellent overview of the Bali conference.

26. I am unable to ascertain whether this 50 percent reduction is relative to emission levels prevailing in 1990, 2000, or another year.

as developing countries, they have no intention of compromising their development and poverty alleviation programs by undertaking emission reduction obligations. Therefore, the negotiations at Copenhagen promise to be highly contentious.

Action at the National Level

There are several programs under way at the national level in many countries to address global warming. The EU 20:20:20 initiative whereby it plans to reduce GHG emissions by 20 percent, increase the share of renewable energy by 20 percent and curb energy consumption by 20 percent by 2020 is one such program. The United States and China have similarly introduced a number of programs aimed at curbing energy consumption. India has also announced its National Action Plan on Climate Change (Government of India, 2008). Within this plan, India is to launch eight separate missions. According to an August 24, 2009 Government of India press release, the second of these missions, National Mission on Enhanced Energy Efficiency, has just been approved. Announcing the approval, the Prime Minister stated, "This Mission will enable about Rs 75,000 crores [approximately $15 billion] worth of transactions in energy efficiency. In doing so, it will, by 2015, help save about 5% of our annual energy consumption, and nearly 100 million tons of carbon dioxide every year."[27]

While the reader can find summaries of the initiatives taken at the national level by a number of countries in the EIU (2009), it is important to briefly discuss here the implications of the Waxman-Markey "cap and trade" legislation, which has yet to pass the Senate, for India. This legislation proposes to cut the CO_2 emissions to 97 percent of 2005 levels by 2012, 80 percent by 2020, 58 percent by 2030, and 17 percent by 2050. Firms would be required to hold pollution permits for their CO_2 emissions. The current proposal is to distribute 85 percent of the permits for allowable emissions to the firms free of charge and auction 15 percent of them competitively. Once in private hands, permits will be freely tradable in the market. The proportion of freely distributed permits would decline over time dropping to nil in 2030.

A threat facing India and other countries lacking similar cap and trade or equivalent programs is that the United States may subject its goods entering

27. The quotation can be found at http://pib.nic.in/release/release.asp?relid=52092&kwd (accessed on September 9, 2009).

into the United States to similar requirements. Importers of a product from India may be required to buy pollution permits to cover its carbon content or pay a tax equal to the allowance price. The issue then would be whether the World Trade Organization (WTO) dispute settlement body would uphold such a measure under its rules.

In a carefully argued paper, Bordoff (2008) takes the view that though we will know the truth of WTO compatibility of such a measure only when it is challenged in the dispute settlement body and the latter gives its ruling, the case for an affirmative ruling is rather weak. Rather than reproduce various legal arguments made by Bordoff in detail, it suffices to report his broad points here. The United States will have to justify the imposition of a domestic environmental regulation or tax on imports under either the "national treatment" provision of Article III of the General Agreement on Tariffs and Trade (GATT) or the environmental exception allowed under Article XX of the latter. There are problems with justifications under both provisions.

GATT Article III requires that once a product has crossed the border, it be accorded the same national treatment as domestically produced "like" products. In defining like products, the process and production method (PPM) cannot be considered as product characteristics.[28] This would rule out distinguishing imported products from domestically produced ones based on GHG content. An additional problem will arise with respect to the Most Favored Nation (MFN) treatment required under Article I of GATT. So far as many European countries do have cap and trade programs in place, imports from them will have to be exempted from any GHG related charges. This would introduce discrimination based on the origin of imports. A final complication would be that under the current proposals, the United States proposes to hand out 85 percent of the permits free of charge, which is likely to be interpreted as subsidy under the WTO rules.[29]

In all likelihood, the United States will have to justify any effective carbon taxes on imports under the environmental exception permitted in Article XX of the GATT. Under Article XX, discrimination is permitted but the United States will need to persuasively argue that the measure is

28. Some analysts argue that the recent EU Asbestos case opens the door to the inclusion of the PPM as characteristics defining the product. But this is misleading since the ruling in this case explicitly relies on physical differentiation between products made from asbestos laden fibers and others.

29. Bordoff (2008) provides a systematic analysis of the circumstances under which the WTO may or may not rule the subsidy as actionable.

required to reduce the overall leakage. This is a tough sell, given leakage is itself a small proportion of the emissions, and subjecting imports to permit requirements would do little to plug that leakage.[30] Based on the Appellate Body report in the shrimp-turtle case, Bordoff (2008) further argues that the WTO may also consider the differences in the conditions of the United States and developing countries in reaching a decision. To quote him,

> Fourth, the US program must take into consideration "different conditions which may occur" in different countries. Failure to do so may constitute "arbitrary discrimination," according to the Appellate Body. In that regard, the WTO might consider the relevance of developed countries' greater historical responsibility for cumulative carbon emissions and higher current emissions per capita. In that case, there is a possibility the WTO would find that even a border adjustment [through the requirement of permit purchase] applied equally to domestic and imported goods is noncompliant.

In taking action against India, politically, the United States also runs a different risk. Other developed countries, notably in Europe, have emission reduction programs that possibly go farther than the United States program under Waxman-Markey legislation. Therefore, any action by the United States will make it vulnerable to similar actions by other developed countries with tougher mitigation programs.

In sum, while India cannot rule out the possibility that the WTO might approve of the United States effort to "level the playing field" through an effective pollution tax equivalent to that borne by the US firms under the proposed cap and trade system, it is by no means a foregone conclusion.

India's Options

We are now in a position to consider the key question of this paper: What should India do going forward? I divide the answer into three parts: what is in India's best interest, what it can do to contribute to mitigation without compromising its own national interest, and how it should respond to pressures, originating principally in the United States, for undertaking internationally sanctioned mitigation obligations beginning in the near future, say 2020.

30. It is easy to envision countries reshuffling their trade to avoid the charge associated with the permits. For example, the US might import more from Europe, which will not be subject to buying the US permits, and less from India and other developing countries, which will export more to Europe.

India's Interests

Many analysts based predominantly though not exclusively in the West argue that India is so vulnerable to the harmful effects of climate change that it should actively seek a post-Kyoto climate change treaty at the Copenhagen conference in December 2009. They argue that the acceptance of internationally mandated restrictions on GHG emissions by India in the near future, say beginning in 2020, is in its own national interest.

I disagree with this proposition. The foremost objective India must pursue in the forthcoming decades is to provide its citizens with a humane existence with adequate access to basic amenities such as shelter, water, and electricity. Given that 300 million Indians still live in abject poverty and 400 million are without access to electricity, achieving this objective requires sustained rapid growth complemented by well-crafted social programs for some decades to come. The question then is whether such growth is feasible while implementing mitigation targets beginning in the near future, say, 2020.

As I stated in the introduction to this paper, even if India were to aspire to the *current* Chinese living standards, its carbon emissions will have to rise to at least three-and-a-half times their current levels. Achieving the standards currently enjoyed by South Korea and Singapore would mean far greater expansion of the emissions. Based on 2006 data, the latest available, India ranks 137th in terms of per capita carbon emissions. China, South Korea, and Singapore respectively emit as much as 4, 9, and 27 times the emissions by India on per capita basis. Even the world average is 3.8 times that of Indian per capita carbon emissions. Barring the appearance of dramatically cleaner technologies and green sources of energy within a short period of time, acceptance of even modest mitigation commitments beginning in 2020 would condemn a significant number of Indians to an inhuman existence in perpetuity.

A key argument mitigation advocates offer is that by refusing to accept mitigation obligations as a part of a Copenhagen treaty, India makes matters worse for itself by making future catastrophes more likely. They say that being among the most vulnerable to catastrophic events such as cyclones and floods in its coastal regions, India stands to gain the most from joining the mitigation effort. There are at least four objections to this argument.

First, as discussed in greater detail in the second section, while the facts of global warming and GHG emissions as its cause are widely accepted, scientific evidence linking GHG emissions to increased frequency or intensification of catastrophic events such as floods, hurricanes, and cyclones is lacking. To remind, reporting on a careful survey of peer-reviewed literature on the relationships between global warming and the frequency and severity of hurricanes in the *Bulletin of American Meteorological Society of America*, Pielke et al. (2005) concluded that "claims of linkages between global warming and hurricane impacts are premature." They went on to add, "the peer-reviewed literature reflects that a scientific consensus exists that any future changes in hurricane intensities will likely be small in the context of observed variability." Evidence linking global warming and glacier melting is similarly weak: the Gangotri glacier has been receding since scientists began to keep its measurement in 1780.

Second, assuming a connection between GHG emissions and increased severity and frequency of rains, floods, heat waves, and even cyclones and hurricanes exists, mitigation by India in the next two or three decades is neither necessary nor sufficient to arrest global warming and its consequences. The richer world consisting of the US, Europe, Japan, Canada, and Eurasia account for slightly more than 50 percent of the current carbon emissions. Adding China brings the proportion over 70 percent. In contrast, India accounts for only 4.4 percent of global carbon emissions.

If the big and largely rich emitters of today were to take mitigation in the immediate future seriously, they could achieve emission cuts commensurate with the IPCC recommendations without denying the poor in India (and Africa) the prospects of a humane existence. With abject poverty eliminated and electricity and water provided to all, India could join the mitigation effort two to three decades from now. At that point, it would ease the future burden of the countries taking on mitigation obligations in the early decades. The argument that mitigation is not feasible without participation by India, thus, appears to be a political one. Perhaps itself less than fully convinced of the extreme long-run effects of GHG emissions but politically cornered, the United States Congress has taken the expedient if not altogether cynical position that it will not accept internationally mandated emission obligations unless India accepts them beginning in 2020 as well. The Waxman-Markey legislation, which proposes action through purely domestic mechanisms, likewise, faces uphill battle in the Senate.

Third, the stock of carbon in the atmosphere in the next two to three decades would continue to be dominated by the emissions accumulated over the past century. Therefore, in so far as the impact of human activity on global warming, rains, floods, sea levels, and hurricanes in the next two to three decades is concerned, the die is already cast. If India accepts mitigation commitments early on, it will remain woefully inadequately prepared to face the vagaries of nature that would visit it even absent any additional GHG emissions. But if it manages to postpone the commitments for two to three decades and stay course on growth and poverty alleviation, it would be able to provide significantly improved protection against the adverse natural events in the future.

With higher incomes, India will be better able to adapt itself to GHG emission related changes in the climate in the next two to three decades that future mitigation cannot prevent. With better shelters, individuals will be better able to protect themselves against heat, rains, floods, and even cyclones. With access to world-class vehicles on land, sea, and air, good highways, ports and airports, and the state of the art means of communication, they would be better prepared to react to emergencies arising out of natural calamities. At higher incomes, the citizens will also be better able to access modern medicines and healthcare. In a similar vein, the government will have more resources to assist citizens against emergencies arising out of various natural disasters. It will be in a much stronger position to move people away from coastal areas and build dikes as water levels rise. It will also have more resources to alleviate water shortages that threaten India in the forthcoming decades even if mitigation proceeds according to the IPCC recommendations.

Finally, GHG induced effects on extreme events are only one of the many challenges India faces in its quest for the provision of humane existence for all. Nutrition, health, education, urban infrastructure, and local pollution problems are among some of the most pressing problems with which India must grapple. Accepting mitigation obligations in the near future to avert possible rise in the frequency and severity of extreme natural events must be weighed against a compromise along all these pressing problems in the near future.

India has grown a little above 6 percent in per capita terms during the last 6 years. If this average growth rate can be sustained, its per capita income of $1,016 in 2008 (in 2008 dollars) would rise to $3,260 in 2028 and to $5,835 in 2038. At these per capita income levels, India would have essentially conquered abject poverty and would be in a position to fully join the mitigation effort.

Voluntary Mitigation

While internationally mandated mitigation commitments beginning in the near future would compromise its national interest, India can still contribute to mitigation efforts by adopting "green" measures that are consistent with its growth and poverty alleviation objectives. For example, the adoption of certain "green" technologies such as replacing "green" bulbs for the conventional ones cannot only lower carbon emissions but is also less costly in the long run. Likewise, fighting urban pollution that causes lung diseases, replacing dirty sources of energy such as wood by clean sources such as gas in domestic cooking, pricing of electricity to reflect scarcity and reforestation can promote domestic developmental objectives while helping mitigation. India should also welcome the adoption and development of clean technologies when developed countries are willing to provide them free of charge under programs such as the clean development mechanism of the Kyoto Protocol.

Acceleration of policy reform in the electricity sector is of particular importance. Giving free electricity to farmers leads to its economically wasteful use and also contributes to global warming. Large distribution losses due to poor management have the same implications. When struggling to bring electricity to all households, India can ill afford its wasteful disposal.

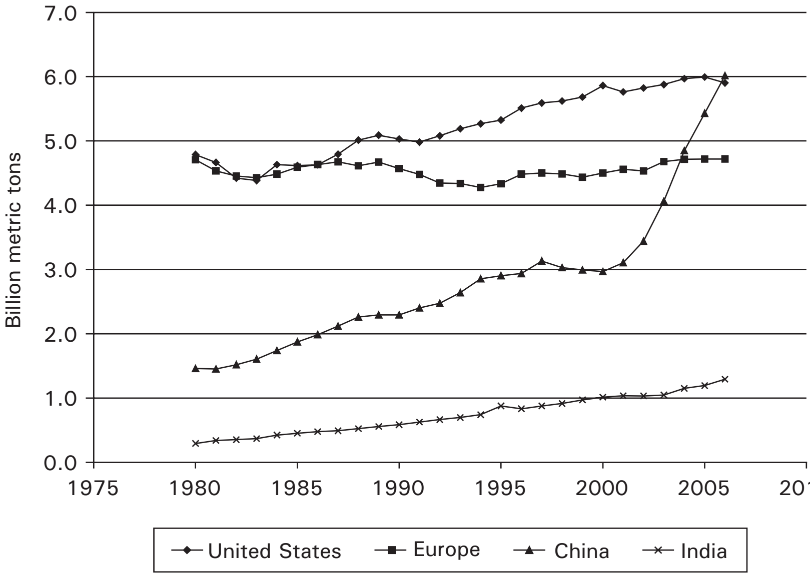
Questioning the Legitimacy of the US Pressure

The United States has been pressuring India to accept internationally mandated mitigation commitments in the near future as a part of a post-Kyoto climate change treaty to be negotiated in Copenhagen. Such pressure would be understandable had the United States been a shining example of mitigation. But this is not the case. The price of gasoline in the United States is among the lowest in the world. The country has also taken few tough steps to curb the inefficiencies in the use of electricity, lighting, heating, and cooling in its building sector. It even refused to ratify the Kyoto Protocol that it had signed and subsequently went on to significantly expand its carbon emissions.

Belatedly, the United States House of Representatives did pass the Waxman-Markey bill providing for a "cap and trade" system aimed at cutting emissions. But this bill too back loads mitigation. It replaces the base year for mitigation targets from 1990 in the Kyoto Protocol to 2005. Given the emission level in the latter year was much higher, the target of 17 percent reduction by 2020 in the Waxman-Markey bill turns out to be 6.4 percent above the target the United States had accepted for the year 2012 in the Kyoto Protocol. Alternatively, the Waxman-Markey target is only 3 percent below the 1990 emission. The bill also gives away 85 percent of the permits free of charge to politically influential and major emitter industries. Finally, the bill, as passed by the House, subjects countries without a similar "cap and trade" system to trade sanctions. Even so, it faces an uphill battle in the Senate.

In comparison, India scarcely qualifies as a big-league emitter. As previously noted, on a per capita basis, it ranks 137th in carbon emissions. While Western analysts routinely club India with China to give credibility to the claim that it is a gigantic emitter, few of them are perhaps aware that India accounts for less than 5 percent of the world's emissions compared with 21 percent of China. The country is, thus, not in the same league as China, United States, and the Europe Union even in terms of absolute emissions. Figure 4 graphically conveys this message. Super-high growth in China has led it to more than double its carbon emissions in less than a decade. But India's emissions have grown only at a modest rate and remain far below those of the United States, Europe, and China despite its second largest population in the world.

FIGURE 4. Total CO_2 Emissions from the Consumption and Flaring of Fossil Fuels, 1980–2006



Source: Based on data from Energy Information Agency, United States Department of Energy.

In view of these facts, the assumption of the high moral ground by the United States and exhortations that India, which bears little responsibility for the existing global warming, join active mitigation even at the cost of condemning a significant part of its citizenry to perpetual poverty borders on hypocrisy.

Exploring the Ways Forward

Before exploring possible avenues to progress, let me express serious reservations about the tactics employed recently by the Western press and politicians to threaten developing countries into accepting mitigation obligations.

The French President Nicolas Sarkozy recently stated, "We need to impose a carbon tax at [Europe's] borders. I will lead that battle."[31] Soon after, the United States climate negotiator Todd Stern joined Sarkozy in the intimidation game. According to a report entitled "China and India Warned to Co-operate Over CO_2 Emissions" in the *Financial Times* (September 16, 2009, p. 4),[32] Stern "warned countries such as China and India that they run greater risk of protectionist measures in the US Congress if they do not cooperate on the international steps to hold down carbon emissions." The Waxman-Markey legislation, still awaiting passage in the Senate, proposes to translate the threat into reality.

Of course, the legality of these tariffs under the WTO agreements has been questioned. Even then, countries such as China and India are large enough to credibly retaliate against such tariffs using WTO-legal instruments. Moreover, they can ill-afford to capitulate to the threat for the simple reason that the injury the carbon tariffs would inflict on them is minuscule in relation to the cost of accepting mitigation obligations.

Consider India. In view of the growth rate of 8.5 percent per year during the last 6 years, it is reasonable to assume that absent mitigation commitments the country can grow at the annual rate of 8 percent until 2030. A further reasonable assumption is that the acceptance of substantive mitigation obligations relative to business-as-usual emissions beginning with, say, 2020 will cut the growth rate of the country by at least 1 percentage point.

At 8 percent rate of growth, India's GDP would rise from $1.2 trillion in 2008 to $3.0 trillion in 2020. From then on, mitigation would take effect. At a 1 percentage point cut in the growth rate, the lost GDP would be a modest $30 billion in 2021. But this figure will rise sharply each successive year, reaching $575 billion in 2030. At a discount rate of 3 percent per year, the stream of losses during the 10-year period would sum to $2.1 trillion in net present value terms in 2020. Add to this the fact that the loss of $575 billion

31. This quotation is taken from the *Financial Times* (September 10, 2009) story titled "Sarkozy Calls for Carbon Tax on Imports." Available online at http://www.ft.com/cms/s/0/a5fb6084-9e32-11de-b0aa-00144feabdc0.html (accessed on May 13, 2010).

32. Available online at http://www.ft.com/cms/s/0/9f0bc6c2-a258-11de-9caa-00144feabdc0.html (accessed on May 13, 2010).

or more would accrue in perpetuity after 2030. The choice between this loss and the cost imposed by carbon tariffs is a no-brainer.

Yet another common threat routinely issued to impress upon China and India, the urgency of acceptance of mitigation obligations is that their refusal to do so will result in a failure to forge a post-Kyoto mitigation agreement at Copenhagen. In turn, the failure will lead to sinking of Shanghai, Mumbai, and Calcutta into the ocean by the end of the 21st century. Once again, such threats are not compelling. Having access to the same research as developed countries, one knows that Miami, New York, London, and Amsterdam face the same risk of ending up under water as Shanghai, Mumbai, and Calcutta by the end of the 21st century. A failure to reach an equitable agreement at Copenhagen is therefore at least as damaging to the United States and some European countries including France as to India and China.

Indeed, it may be argued that relative to their rich counterparts, poor countries may find it perfectly rational to trade a slightly higher risk of rising water level around their coastal cities for faster growth. That choice allows these countries to better prepare against not just the vagaries of global warming but other natural disasters such as earthquakes and ongoing hardships as well.

In arriving at a menu of constructive efforts for progress at Copenhagen, the United States and EU should confront two facts. First, recognizing the likelihood that they will remain among the largest emitters despite significant mitigation they might undertake in the coming decades, they need to convince the developing countries of their sincerity and seriousness in addressing global warming. This will require making significant financial commitments as well as undertaking substantial mitigation obligations. Second, the leaders of developed countries need to promote an environment of cooperation and harmony eschewing threats that are not credible and also certain to lead to acrimony. In particular, they must acknowledge that any acceptance of mitigation obligation by developing countries amounts to sacrifice and is their contribution to safeguarding the future of the planet. Most developing countries understand that sooner or later they have to be a part of the solution to the global warming problem and that this will require sacrifice on their part.

Against this background, efforts at tackling global warming at the international level may proceed along three fronts. First, an agreement may be reached toward giving developing countries credit for voluntary measures that contribute to reduction in GHG emissions. Indeed, for the vast numbers of poor developing countries, these voluntary measures should suffice with mandatory mitigation targets left for negotiation on unspecified future dates.

One important measure in this category could be re-forestation and reduced deforestation. For some developing countries, most prominently China and India, re-forestation is a part of their current development agenda. The adoption of green technologies such as replacement of the conventional bulbs by "green" bulbs is another such example. Yet another example is the effort to curb urban pollution that causes lung diseases as well as the replacement of kerosene and wood as cooking fuels by gas to combat domestic pollution. All these measures are in the interest of the developing countries purely from a national viewpoint but also contribute to combating global warming.

Second, an agreement may be reached to vigorously promote technological solutions at the international level. Schelling (2007) offers a rich discussion of technologies that are unlikely to be developed by private entrepreneurs and ideally require multi-government cooperation. One such example relates to technologies that would allow CO_2 generated in power plants to be captured, transported, and injected into an appropriate underground location. Research and development required for these technologies including sites suitable for permanent storage are unlikely to be undertaken by the private sector. The same holds for research in the area of geo-engineering aimed at finding novel ways to reflect away sunlight thereby counteracting the global warming caused by GHG emissions.

To promote this form of research and development, a substantial fund could be created through contributions by developed countries. The rationale for such contributions can be easily found: it can be seen as a tort payment for the past damage along the Superfund idea of Bhagwati (2006). The United States has long accepted the tort principle for past damage to the environment in the context of domestic pollution. Politically, such a fund may find support in the developed countries on the ground that, by and large, their own researchers and firms, who are currently ahead of the environmental-research curve, will be the principal beneficiaries of the expenditures from it, regardless of the precise modalities chosen to spend the moneys.

Finally, on the core issue of mitigation, there is need for a more relaxed attitude in general and toward developing countries with substantial pockets of poverty in particular. Given the vast amount of uncertainty on how much global warming will result from a given volume of GHG emissions and how global warming will impact the frequency and severity of natural disasters, it is a bit far-fetched to suggest that any specific mitigation target such as the IPCC-recommended 50 percent reduction in the 1990 levels of emission by 2050 is "optimal" in any meaningful sense. Schelling (2007: 4) makes this point forcefully:

> Deciding now, through some multinational diplomatic process, what the ultimate ceiling on greenhouse gas concentrations must be to prevent, in the immortal words of the Framework Agreement, "dangerous anthropogenic interference with the climate system," as a basis for allotting quotas to participating nations, is in contradiction to the acknowledged uncertainty about the "climate sensitivity" parameter, with its factor of three in the range of uncertainty.

Rather than pretend to work toward a grand optimal target far into a future year such as 2050, it surely makes more sense for Annex I countries to agree on targets going no farther than 2020. They, along with other UNFCCC signatories, can then return some time in the late 2010s to evaluate the further scientific evidence that would become available in the interim and decide upon the next step.

If developed countries are keen on bringing the developing countries on board to undertake mitigation obligations, it is important that they themselves agree to sufficiently ambitious targets within the context of the current knowledge on global warming. As noted earlier, at present, there remains suspicion on the part of the developing countries that developed countries themselves are avoiding taking on to their share of responsibility. They are acutely aware that many developed countries have not implemented the Kyoto targets to which they had agreed and have instead added to rather than subtracted from their 1990 emission levels. They also note with dismay that the United States is now proposing a shift in the base year from 1990 to 2005, which sets back the process.[33]

Apart from the provision for giving them credit for voluntary measures such as re-forestation and reduction of deforestation, which will encourage them to take more of such actions, a key concession the developed countries

33. For example, Jairam Ramesh, the Environment Minister of India, recently stated that India and China would "respond very positively" if rich nations such as the US agreed to a goal of cutting emissions 40 percent from 1990 levels by 2020. "That's a game changer," Ramesh said. "It would be very difficult for me, as an Indian minister, not to respond if developed countries accept this proposal. The fat would be in the fire, our bluff would be called." On the one hand, this statement may be dismissed as political rhetoric but on the other hand, a relatively ambitious target that challenges Ramesh is not out of reach. In a January 2009 communication to the European Parliament, the European Commission (2009: 2) has stated, "The EU is willing to go further [than its current commitment] and sign up to a 30% reduction target [relative to 1990 emission levels] in the context of a sufficiently ambitious and comprehensive international agreement that provides for comparable reductions by other developed countries, and appropriate actions by developing countries." If developed countries were to agree on 30 percent reduction in emissions relative to 1990 levels, a lack of response by India would bring Ramesh's credibility in question.

will need to give to bring the developing countries on board on mitigation is an agreement to set emission norms according to criteria that address the equity issue. Two such criteria would rely on the GDP and population. If GDP alone is taken as the basis, the cap for the developing countries will be set in terms of emission per-unit of GDP. If population is chosen as the basis, it will be set in terms of emissions per capita. A combination will effectively bring per capita GDP as a basis. A GDP-based norm gives the developing countries flexibility in maintaining high growth since it allows absolute emissions to rise with the GDP. The same can be said of per capita emissions cap though it will not lead to mitigation until the cap becomes binding.

In short, we now have constructive ideas on the table that can define the contours of an eventual agreement. Copenhagen provides an opportunity that should not be buried in the acrimony of threats from the leaders of the developed countries. Instead, it must be utilized to set us on the path to an equitable and efficient agreement aimed at coping expeditiously with the existential challenge of climate change.

Concluding Remarks

In this paper, I began by noting that that estimates of how much climate change has impacted India in the last century and predictions of how much it will impact the country in the current century are subject to vast amounts of errors. This uncertainly calls for sufficient preparation for adaptation to possible extreme weather change effects. This makes sustaining high rates of growth and poverty alleviation even more urgent.

Using a simple model, I have shown that the efficient solution to mitigation can be achieved through either a carbon tax or internationally tradable emission permits. A key point is that efficiency requires setting a single mitigation target at the global level or a single carbon tax worldwide with individual country-level mitigations endogenously determined. In contrast to this efficiency principle, international negotiations have sought to set mitigation targets by countries.

A key factor undermining the efficiency of a global mitigation target achieved through a uniform carbon tax or globally tradable permits, quite important in practice, is the presence of differential direct or indirect taxes on carbon in the initial equilibrium. For example, countries have different sales or value added taxes on gasoline in the initial equilibrium. The superimposition of a uniform carbon tax on these taxes to achieve a given level of mitigation will fail to minimize the social cost of mitigation.

In practice, efforts toward mitigation are greatly hampered by their asymmetric distributional implications. I discuss these implications at length, dividing them into stock and flow counterparts, following Bhagwati (2006). I argue that at least in principle there is a strong case for the developed countries, which bear the bulk of the responsibility for the past emissions, to compensate the developing countries. Regarding the flow problem, I argue that there is an important equity issue here as well. Developed countries and China are responsible for the bulk of the current emissions. Even if these countries were to undertake significant mitigation obligations, they will remain the largest emitters. Most developing countries are small emitters on a per capita basis. Any agreement that attempts to extend mitigation obligations to these countries will have to address the equity issue.

I have provided a detailed discussion in the paper of the current state of play of mitigation policy at both national and international levels. At the international level, the negotiations for mitigation commitments at the fifteenth UNFCCC COP at Copenhagen are likely to be contentious as the developed countries try to get reluctant India and China to accept binding commitments. At the national level, the United States is poised to introducing a cap and trade program, which may pose some challenge to imports from countries such as India that do not have similar programs. If the United States eventually decides to subject the imports from the countries without cap and trade programs to its domestic permit requirements, a battle at the WTO on the legality of such extension is almost guaranteed. And if the WTO rules in favor of the US measure, countries such as China and India will have no option but to retaliate in a WTO consistent fashion.

Finally, the Copenhagen conference could try to make progress through cooperation in the promotion of research and development that satisfies the property of global public good and setting up mitigation agenda in the near term. Regarding the former, the paper suggests setting up a substantial fund financed by contributions from the developed countries. Regarding the latter, I argue that if developed countries are serious about the necessity of developing countries undertaking mitigation targets beginning some time in the near future, they need to lead by example. To be credible to the developing countries, they themselves need to first accept substantial mitigation obligations by 2020 relative to their 1990 levels. In addition, they will need to address the equity issue by agreeing to set the mitigation targets of the developing countries in either per capita or per-unit GDP terms. In the near term, except in the case of China, they may also have to settle for good-faith voluntary efforts by the developing countries.

Comments and Discussion

Vijay Joshi: Arvind Panagariya has written an excellent paper (hereafter the Paper) on the climate change problem in relation to India. In what follows, I shall focus not on its virtues but on what I consider to be its main shortcomings. Some of the points made below are also discussed explicitly or implicitly in my joint papers with Urjit Patel (Joshi and Patel, 2009, 2010).

The earlier sections of the paper discuss the scientific projections of the impact of climate change on the world and on India in particular. The tone of these sections is skeptical; the uncertainties in climate projections receive a great deal of emphasis. In my opinion, the paper significantly underplays the dangers of climate change. But I shall not discuss this aspect of the paper because I lack the expertise to do so competently. I will only point out that in the last couple of years since the publication of the 4th Intergovernmental Panel on Climate Change (IPCC) Report (IPCC, 2007c), scientists have become even more pessimistic about the impact of climate change than they used to be.

Collective Action

The paper is rather cavalier about the importance of India's contribution to the global mitigation effort. Indeed it goes so far as to imply that it would not much matter if India stood aside from the global mitigation effort until 2040, since the country accounts for only 4 percent of global emissions. There are two things wrong with this. First, to assess India's importance we must consider not its share in emissions now but its share in emissions in a future BAU scenario. This would be significantly higher than 4 percent. Second, even with a 4 percent share, India's total emissions are the fifth highest in the world. There are about 200 countries; if every country, from 5 to 200, took the paper's line, the global mitigation effort would fail. (The same stricture applies to the claim, sometimes heard, that the climate change problem can be solved by the advanced countries [ACs], without help from the developing countries [DCs]. The fact is that DCs are expected to account for two-thirds of incremental emissions from now until the end of the century on a BAU basis.) I do not think the paper shows proper appreciation of the fact that climate change is a collective action problem and that the DCs must share in combating it. Of course, this does not imply that they should pay for the cost of their mitigation policies. Who should mitigate is a different question from who should bear the cost of mitigation.

Carbon Tax versus Cap-and-Trade

The paper's discussion of the choice between a carbon tax and cap-and-trade is not entirely satisfactory. On certain simple assumptions, the two are equally efficient but there is an important political-economy consideration that tells in favor of the latter, when equity is brought into the picture. In a cap-and-trade system, carbon trading would ensure that *any* initial allocation of permits to countries would lead to an efficient solution. This extra degree of freedom means that the allocation can be chosen to deliver equity and/or to offer inducements for compliance and participation. The implied financial transfers would take place automatically as part and parcel of the working of the market in carbon permits. With a carbon tax, a uniform international tax would have to be agreed—difficult enough but only half the battle. Equity could only be achieved by explicit, visible, budgetary transfers, which may be impossible politically to deliver. The only feasible way of combining efficiency and equity may be to distribute carbon permits from the start on an equitable basis. In the rest of my comment, I shall assume that the instrument of mitigation is cap-and-trade. But that is not essential to my argument.

Equity and "Historic Responsibility"

Fair burden-sharing is obviously critical to DCs', and in particular India's, willingness to be part of a climate deal. The paper distinguishes two separate equity considerations that need to be addressed. The first concerns the ACs' historic responsibility for the accumulated stock of carbon. The ACs have used up a large part of the safe carbon-absorbing capacity of the atmosphere and should therefore compensate the DCs for this expropriation. This is a persuasive claim but it runs up against some powerful moral intuitions. The ACs did not expropriate knowingly. They acted in the belief, universally held until quite recently, that the atmosphere was an infinite resource. Moreover, the expropriators are mostly dead and gone. Their descendants, even if they could be identified, cannot be held responsible for actions they did not themselves commit. These points do not entirely overturn "historic responsibility" since ACs benefit hugely from their past carbon-intensive industrialization. Even so, the extenuating factors mentioned earlier surely count to reduce the fair liability of the ACs. The paper does not say how the fair liability of the ACs should be assessed. It does appear to commend, however, the suggestion that a global fund should be set up by the ACs to compensate the DCs for the "stock aspect" of the climate problem. But the need for this is not at all clear. The equity issue could be handled by structuring the distribution of permits to regulate the permissible flow of future emissions. If it were agreed that the ACs must pay for the damage caused by the stock of carbon, DCs could be given more permits annually to allow for that.

Equity, Permit Distribution, and Negotiation

The second equity consideration concerns the distribution of the burden of reducing the future flow of global emissions. If the reduction is to be achieved by a global cap on tradable permits, the critical issue is how to allocate them. On this matter, the paper largely follows Jacoby et al. (2008) in comparing different options. It should be noted that the latter paper is almost wholly a simulation exercise and does not discuss the ethical or political-economy aspects of different allocation criteria, nor does it propose any particular criterion. The paper rightly rejects on equity grounds the criterion currently in play in international negotiations, namely, a phased reduction of AC and DC emissions to 70 and 30 percent respectively of their 2000 levels by 2050. The other alternatives discussed are to distribute permits to countries on the basis of (*a*) population, (*b*) per capita income, and (*c*) zero welfare cost of mitigation for DCs, until a target date. The paper does not advocate any of these criteria or indeed any well-defined criterion. It argues instead that, given its development compulsions, India (and presumably many other DCs) should refuse to take on any quantitative targets until 2040. In my judgment, this would be a mistake. India should adopt a bolder strategy that is consonant with its status as a responsible future global power. It should offer to join a mitigation treaty on fair terms, such as criterion (*c*) above, viz. the "zero welfare cost" criterion.

Ideal fairness is a highly contentious concept and philosophers have argued about it for centuries. Progress in climate change negotiations will require the adoption of a non-ideal but acceptable notion of fairness that can bridge differences in entrenched positions. The population and per capita income criteria fall in the "ideal" category. The rationale of the former is rights-based: each human being has an equal right to use the remaining global carbon space. The rationale of the latter is egalitarian: permits should be given to the very poor because they are very poor. Either way, the above principles imply that most of the permits should be given to DCs. This is because they contain most of the world's people as well as most of the world's poor. The trouble is that such a radical extension of human rights or of egalitarian values would be internationally unacceptable. There is no agreement that natural resources should be equally shared. Why should the atmosphere be any different? Nor is there any enthusiasm for stringent international egalitarian obligations: foreign aid has consistently failed to reach even half the UN target of seven-tenths of 1 percent of ACs' gross national product.

The way forward is to focus on a principle that is widely accepted as a minimal requirement of fairness. The principle is simply, "Do no harm." In the climate change context, this plausibly translates into criterion (*c*) above: DCs should be enabled to reduce their welfare cost of mitigation to zero until they have eliminated abject poverty. In practical terms this would mean allocating enough tradable carbon permits to DCs to allow them to maintain the growth of their living standards along the BAU path, say for the next two decades. (Two decades is an average that may be suitable for India. The time-horizon would be shorter for China, longer for Africa.) After that time, DCs' permit allocations would be progressively reduced. Climate models, of which Jacoby et al. (2008) is an example, are capable of calculating the requisite time path of permit allocations.

This no-harm approach to burden-sharing would have many desirable features. It takes some account of "historic responsibility." This because the damage inflicted by the accumulated stock of carbon consists mainly of raising the cost of future mitigation for all countries. In the no-harm scheme, however, DCs' mitigation costs would be covered for an agreed period. The scheme also takes some account of rights-based and egalitarian arguments by skewing the allocation of permits toward the DCs, which would result in a significant financial transfer to them, unlike an allocation of permits based on current emissions, which would strongly favor the ACs. But the transfer to the DCs would not go beyond offsetting the welfare cost of their mitigation policies for a defined length of time. This would be more acceptable to the governments and citizens of the ACs than distributing permits on a population or per capita income basis, which would result in much larger financial transfers to DCs, several times larger than foreign aid flows today.

The paper takes the view that India should not accept any quantitative targets for three decades. Why not, if India can negotiate compensation for the welfare loss from undertaking mitigation policies? The paper provides no satisfactory answer to this question. A fair treaty would give India enough permits to follow a BAU welfare path for a couple of decades. There would be other advantages in joining a carbon treaty besides a significant inward financial transfer. It would give India some share in controlling the progress of the global climate negotiations. It would also forestall the risks of having trade restrictions imposed against the country as a treaty non-participant. In addition, as a first-mover among DCs, India may be able to negotiate other things it wants as the price of joining a treaty, for example a seat on the UN Security Council. (Note that the Western countries agreed to facilitate Russia's accession to the WTO in return for its joining the Kyoto treaty.)

In sum, the Panagariya paper is a highly sophisticated defense of the Government of India's current stand in climate change negotiations. My view, in contrast, is that India should regard a climate change treaty with quantitative targets as a diplomatic challenge of getting the right terms, not as a bugbear to be feared and shunned.

Devesh Kapur: Thank you. Following up from Vijay who has pretty much said what I wanted to say. But anyway, I would go at it. I shall first briefly summarize my take on what I thought the paper says. It basically says that there are climate changes, not much of a problem for India. Insofar as it is a problem, the cause is the industrialized countries. Therefore, India should not do anything in the near future, at least anything that might restrict its growth path. The author firmly believes that if climate change has any impact and adaptations are required, growth is the best way to adapt. Any additional cost for adaptation, when it is additional to growth, should be paid by financial and technology transfers from industrialized countries. As is usual, there is a very clear argument that there is no justification. One thing that is unusual from other things that I have read by him is that it actually very very strongly supports the GOI's policy. Usually Arvind disagrees with the GOI but in this paper, in summary he is more catalytic. That shows how open-minded you are.

The first point I think he is skeptical about is scientific evidence. I would not go into that as Jessica will be taking on that, but at least my reading would be rather different. I think one thing that is fair, is not explicit, and I think it is around in Delhi policy circles more generally, is that these scientific studies are a bit of scare tactic. The scare tactic, the scare mongering look that India will be the worst affected, etc. etc., is basically to stampede us into agreement that is not really in our long-term interest. This is a bit of thing that these things have somewhat overblown. So, I think the paper says, and think by and large we all agree, that there is considerable uncertainty with the scientific evidence. But I think it is also true that each successive report by the various scientific publications on this is that the trend has been almost pretty unequivocal, each successive year the report has become more and more pessimistic about the way the things are going. I think on that you can be reasonably sure that if you look at all the reports from 1990 scientific evidence, almost everything, from the glacial melt to sea temperatures, all of these seem to show on that. I think we have now resided about the uncertainty about its specific impacts on India per se as opposed to climate change as a global phenomenon.

Well, I think as Vijay said, if there is this large uncertainty—especially I think if at least some of these studies seem to suggest very strongly that there could be non-linearity so that these changes could accelerate if not done now—I think that is what the Urjit Patel and Vijay Joshi paper had that it could have very very strong implications for India if that happens. So, if that happens, then the precautionary principle would ask what the insurance premium that the industrial society pays is. That insurance premium can either come through being part of a global effort, which is mitigation, to some extent, and that is a cost, but that cost is like an insurance premium. Or it could be that you say, look, we are not going to be part of anything international and we will pay the cost through greater expenditure, efforts, and adaptation. Either way there will be a cost that is, in a sense, the insurance premium that you are paying. The question is, how should we think through an appropriate insurance premium given this considerable uncertainty?

Then we step back a little bit about and think about environmental policy in India per se. At least my reading is that much of what happens to the environment by way of policy is out of compulsion, not out of conviction. And the compulsions have largely come from activists, from co-tooling. The Ministry of Environment felt very lucky that the Supreme Court passed an order that every project above Rs 50 crore needs a clearance from the Ministry of Environment, and my understanding is that it became a tremendous source for rent seeking in the Ministry, which is why one particular party that some of you might know, insisted that it always keeps that Ministry which was dead for the better part of the last decade. So, if you see the most recent statement in the Budget Speech, in which the new Minister of Environment states, and I quote: “We have already started implementing the National Action Plan on Climate Change which has eight major Missions and 24 critical initiatives.” This is the sort of thing. The National Action Plan on Climate Change was done a month before the Indian Prime Minister is going to attend the Copenhagen Summit. He had to show something, so, we came up with the Plan which was formed by a few people with very very little widespread consultation, and that was the plan. The basic thing is that we are doing everything and more, by and large, if you read that. When I read this, I called some friend in the Ministry of Finance. I just asked that in the budget how much money had been allocated to eight major Missions and 24 critical initiatives. Well, it so happens that they could not find. Of these Missions, five—Solar, Water, Energy Efficiency, Sustainable Agriculture, and Sustainable Habitat—will apparently be launched at the end of the year. So, forget money; they have not officially. But we are saying that we are doing all this. The budgetary allocation is the only one that I have been able to find and I would be corrected, it is for something called the National…. And Lake Conservation Plan for which Rs 562 crore has been allocated. So, that is the one you put your money into. This is one thing.

What surprised me about the paper is and you said it really thumbs up, with India’s position more as a center of entitlement. It is not really about a bargaining approach to international agreement. What are the second best options given that especially when you begin to see what the other side’s constraints are and what the other side implies to do? We all began with Kyoto and I think one thing which I see Kyoto to quote is the lovely title of the paper. If someone sees the CPR on India’s foreign policy, it was called “Aim low and hit lower.” I do not have to get into Indian foreign policy but Kyoto I think was a very classical example of that. It aimed low, it hit lower and now we also realize the problem is much much bigger than what are we going to do about this. I think there is one very significant difference between the climate for international agreements which have occurred in the past, frankly 50 years, and what is going to happen in the next few decades and I think that for the first time it sensed that the West is no longer hegemonic. I think we really underestimate how that is going to change the entire bargaining climate. Prior to this, whether you liked it or not, a few dominant powers got together for hegemonic stability or whatever you want to call it, and they basically came up with an agreement which served their interests and, by and large, the other countries were made to sign it. So, this was the story. That is not going to happen. When that is going to change, you might believe that the agreements will be fairer, but the agreements will be much more difficult to reach. I think the atmosphere in which the West, whether out of things about guilt and responsibility or foreign policy objectives, you name it, all these complex reasons that drive motivations behind agreement, that is going to be much much less. For instance, if you think of a thing optimally the carbon tax, the idea that the US is going to have a tax, of which the money will be transferred to China, which I think is as unlikely as my becoming the Prime Minister of India. I mean, it is simply not on the cards. I think that is the sort of difference that we are going to see that there are many things that could have taken place when Asia was a rising power. And we cannot have it both ways that we want to be treated as equals but then we immediately take precaution on our commitment and say, Oh, we are really very very small players. So, when we want to be big players in the Security Council, we want to see the IMF and all of that, rightfully so I think, then we have this problem that when it comes to other things, we say we are really very very tiny and pitiful and things like that. Obviously, every side that is going to have its negotiating position, puts its best. So, as a negotiating position, this is fine, but I am just reading the lead down the line that international agreements are going to be much much more difficult to reach on these things.

Then, the questions that India faces are basically three—(*a*) Do you have an agreement where you are prepared to sit it out? (*b*) Do you have an agreement where you pay some price instead of mitigation? or (*c*) Are you prepared to seek no agreement at all? These are the three likely scenarios. I think it would be nice to hear from Arvind and perhaps in this paper about what he thinks would be the different costs and benefits. I mean, how should one think through this? I am not sure myself about which of these three scenarios in likelihood and the different implications for India. I think my sense of belief is that an agreement which at all binds India to any binding commitment is the worst scenario for India and it is better for India to set it out. But I would like to hear even more on that in the paper.

These are few of the points. One is on the adaptation side. I think he has a very firm belief that growth is the best form of adaptation and I think there are very good reasons, good historical reasons, and so on and so forth. But I wonder if we really do want to make the same mistakes as the West made or, for instance, something that China, I believe, is making now in this part of the globe, and whether you would not want to think of qualifying that how—after all, there are different growth strategies, not all growth strategies have same implications—and what are the different forms you see that this might indeed be an opportunity? For instance, we had lamented a lot that India had not done much in manufacturing compared to China, it should have done more. But may that now be a strength because generally services are less polluting as compared to manufacturing. Could that actually be a strength and should that be a more feasible viable growth path, given what we now know about climate change? The second is, I am a bit more hesitant than what the paper says about these very critical links between rapid growth and lower environmental cost. I think the state in India which has had the most rapid growth has been Gujarat and what I have gathered now is that the environmental cost in Gujarat has been really quite high. That has not to do with climate change; it is much more local environmental cost, especially from the chemical industry. But all I am saying is that there are probably more qualifiers. Perhaps one should add that there is nothing automatic. At least I do not see that automatic as perhaps you see.

I will end with the following thoughts. One is that I think that the harder questions India will face are not just external but also internal. There is going to be a range of very tough institutional changes that India will have to think through because the distributional conflicts of this are not just international but are also intra-national. Some work which we have seen shows that inter-state variation in carbon emissions or GHG emissions is actually as large as the difference in emissions between India and the US. So, inequalities within India on this are also extremely high. That is not part of your external bargaining policy, but it is something that I think we cannot avoid that these will have to be part of internal bargaining. If you take institutions, like for watering. If we are going to have, and I think lightly, water shortages and distributional conflicts around waters, you can see what followed from the Cauvery River dispute. That is an example. These are going to multiply manifold. And to add to that, much of India's water comes from China or at least the head waters are from China for our major rivers, and I think there are already several reports that what happens if China faces these problems and diverts these waters northwards? What exactly is India going to do then? If you think of that, frankly it is not clear what India can do. These are some of the issues. I think there is a very recent nice paper by Nirvikar Singh which looks at that and the possible options. But I think these are the possible institutional changes that India will have to think of.

Finally, which I will just end with, I think it is very clear that these debates and thinking on climate change are just actually beginning and given the fact that they are going to involve and have effect on so many people in virtually every just society, I think it is urgent for India to really begin to involve much more wider sectors of society in these debates because that is really going to impact us. Thank you.

Jessica Wallack: The paper's main argument is that India could and should delay commitments to emissions reduction in order to maintain its growth rate and improve its future mitigation and adaptation ability. This conclusion is partly based on a model of trade-offs between growth and emissions cuts over time, although the author acknowledges that it is difficult to derive optimal target levels of emissions based on expected costs and benefits in each period given the uncertainties surrounding the trajectory of emissions and effect of emissions on global and regional climate. The second section, through the fourth, outlines these uncertainties in detail.

My comments raise questions about the treatment of uncertainty about the costs and benefits of emissions reduction now versus later. I argue that Panagariya under-represents the potential costs of climate change and omits key findings regarding the possibility of sudden, irreversible, disruptive environmental change. What we know about the probability distribution of uncertainty about climate change suggests we may be better off thinking about mitigation as insurance rather than consumption-smoothing. The paper also overstates (or too confidently assumes) the benefits of growth for poverty reduction and mitigation/adaptation capacity and ignores the possibility that retrofitting infrastructure and industry may be more expensive than advance planning that would be provoked by commitments now.

The additional evidence I present does not necessarily reverse Panagariya's main conclusion that India should not agree to binding commitments to limit emissions, but it does strengthen the global case for action and make it more difficult to maintain that India should not participate in some way.

The final section of my comments questions Panagariya's choice of title and argues that it should be more circumspect: this paper is about India's options for addressing carbon dioxide emissions (CO_2) and (implicitly) other greenhouse gases, not about India's policy options for addressing climate change. It overlooks emerging evidence about the role of air pollution, particularly ozone and its precursors, black carbon, and sulphates in regional and global climate change. India has distinct interests and policy options for addressing these contributors to climate change. This discussion is probably beyond the scope of this already long and comprehensive paper, but it is a significant omission in paper titled "Climate Change and India: Implications and Policy Options."

I leave discussions of the efficiency of various instruments for mitigating carbon as well as the overview of the international state of play to the other discussants.

Climate Change and its Consequences may be Worse than Portrayed

Panagariya is correct to emphasize the significant uncertainties about the costs of climate change. Climate sensitivity (the relationship between emissions and temperature changes) is the most important source of uncertainty in predicting climate change, but even if this is removed, there is still a 3C range of uncertainty about temperatures at the end of the century under business as usual scenarios due to uncertainty about demographics and social change (von Below and Persson, 2008). Hof et al.'s (2008) analysis of the importance of uncertainties about costs of climate change and costs of abatement finds that a wide range of emissions pathways can be justified by cost-benefit analysis using reasonable parameters. Choices about abatement costs, damage costs, and discount rates—as much value choices as scientific choices given the uncertainty about predicting future trajectories—drive the results.

Panagariya's portrayal of the uncertainties is misleading, however, in that it overemphasizes the reasons for skepticism and neglects to mention several aspects of the nature of uncertainty that are relevant for incorporating the uncertainty into optimal policy design.

The evidence for an upward trend in temperatures is not as weak as he portrays it to be. The only paper on trends cited, Santer et al. (2000), analyzes just 17 years of data. Their primary purpose is to comment on the validity of statistical methods used to estimate trends and adjust for temporal autocorrelation of the data. The authors explicitly state that they do not consider underlying causes of the trends or whether trends are stochastic or deterministic due to the short time series and lack of understanding about how climate forcing may affect natural variability in temperature among other reasons. Both of these factors would work against finding a statistically significant trend even if climate change models were correct. Also, it is important to remember that a finding of lack of statistical significance simply means that the confidence interval includes zero as well as the model-predicted trend assuming anthropogenic warming effects.

Panagariya also neglects to mention the generally accepted scientific argument that observed temperature changes are muted because some types of air pollution have "masked" about a quarter of the warming and oceans' thermal inertia has slowed the manifestation of another quarter of the warming that current levels of CO_2 have already committed us to. Current levels of CO_2 suggest that we should have seen about 2.4°C of warming with a 90 percent confidence interval of 1.4°C to 4.3°C given various assumptions about climate sensitivity.[1] Evidence of relatively greater warming in areas that have reduced emissions of the "masking" air pollution is consistent with this argument (Philipona et al., 2009).

The connection between emissions and temperature change is not as tenuous as Panagariya implies. The Intergovernmental Panel on Climate Change's (2007c) verdict on the evidence is not as wavering as implied by footnote six's statement that the panel "leaves the door open" to doubt about whether GHGs cause warming by stating that anthropogenic greenhouse gas emissions are only "very likely" to be linked to observed temperature increase. The statement "very likely" has a defined meaning of over 90 percent probability and the fact that it is italicized in the original is not for emphasis on the uncertainty, it is for emphasis on the fact that this is a defined term. The fact that a large group of scientists from around the world, interacting and writing a report at least in tacit recognition of policy-makers' preferences, can agree that anthropogenic causation of temperature change is at least 90 percent likely is striking. The door is open to doubt, but it is not open very wide.

Finally, Panagariya downplays the potential impact of climate change on weather and associated economic outcomes. The section on temperature change makes the point that there does not seem to be an overall trend and that temperatures in some areas in some seasons are actually declining. Italics emphasize the word declining, in apparent counterpoint to perceptions of global warming as the problem. However, this point is irrelevant for estimating the impact of regional changes in temperature and its variability on crop yields. Any temperature change, increase or decrease, can be disruptive for crops, and an increase in variability particularly problematic.[2] And the data are not good enough to say anything in particular—reassuring or not—about the extent of change or its impact on farmers. The fact that the government's report is on mean temperature changes is based on 31 stations and that for minimum/maximum from 121 stations in a country of 3,287,590 square kilometers is one indication of the problem.

1. Ramanathan and Feng (2008) use Intergovernmental Panel on Climate Change (IPCC) estimates of greenhouse forcing and climate sensitivity to calculate committed warming of 2.4°C with a 90 percent confidence interval of 1.4°C to 4.3°C.

2. The impact of temperature changes on farm incomes also depends on farmers' ability to adapt by changing crop varieties or farming practices. Adaption ability appears to be low for small farmers, given limited plot size for experimentation, access to agricultural extension information, seeds and inputs, and market infrastructure.

Similarly, the section on rainfall mentions some regional changes in rainfall, but concludes by citing evidence that there has been “no change in the trend on either the annual or seasonal basis” over the past century and a half. The all-India findings, however, are not as relevant as the changes in the location of rainfall, which, again, is not adequately measured.

On glaciers, the author’s conclusion that while glaciers may be melting, the decline is unrelated to climate change is similarly unfounded. Glacier monitoring in India is notoriously incomplete and time series data are rarely comparable enough to justify calculations or comparisons of the rate of change. Measuring the snout of the glacier as discussed here is misleading because glaciers that are actually losing mass can appear to grow if they are slipping due to water melting at the base.[3] There are only two glaciers where mass balance—a better measure of glacial health—has been tracked for more than a few years.[4]

Panagariya’s discussion of the impacts of climate change also neglects to mention that the worldwide evidence seems to look worse as uncertainties are resolved and we understand the risks in more detail.[5] The past decade of scientific evidence on links between temperature changes and “reasons for concern” such as risks to threatened and unique systems, risk of extreme weather events, and risk of large-scale discontinuities suggests greater environmental change at lower temperatures than had previously been estimated in the 2001 IPCC Assessment (Smith et al., 2009). The widely cited Stern report, which advocated early action on emissions cuts to avoid substantially greater costs of adjusting to climate change later, is now considered too conservative by the main author.[6]

More importantly, Panagariya overlooks two commonly accepted findings that are relevant for incorporating uncertainty into policy analysis:

3. The comparability of long historical time series on the snout of the glacier is also questionable. While satellite imagery can pinpoint the snout accurately and comparably over time for the past 40 years, previous measurements could be misleading if collected at different times in the seasonal ebb and flow and geo-location was also less precise.

4. Personal communication with Michele Koppes, Assistant Professor, University of British Columbia.

5. Uncertainty (knowledge of the possibility of various outcomes without a sense of these outcomes’ relative probabilities) becomes risks as we are better able to assign a probability distribution to the possible outcomes.

6. Nicholas Stern’s 2008 statement to a Reuters interviewer, “Emissions are growing much faster than we’d thought, the absorptive capacity of the planet is less than we’d thought, the risks of greenhouse gases are potentially bigger than more cautious estimates, and the speed of climate change seems to be faster,” was widely quoted in the blogosphere. Hepburn and Stern (2008) reiterate the point.

the significant probability of outcomes that are worse that the mid-range scenarios and the finding that environmental change is non-linear and potentially irreversible on human time scales.

Climate sensitivity, the most significant source of uncertainty in calculations of the effects of emissions, has a "fat tailed" distribution (Roe and Baker, 2007). The probability that outcomes on the higher range of climate sensitivity (which imply higher temperatures for a given concentration of CO_2) does not decline to zero in the limit. This means that cost-benefit analyses that approximate risk using the normal distribution (for which the probability of extreme outcomes does go to zero in the limit) or otherwise truncates the distribution of extreme outcomes, understates risk. Weitzman (2009) highlights the difference that such a "fat tail" can make for analysis of climate policy: it points to mitigation now being the optimal solution.[7] He argues in a related paper (Weitzman, 2007) that under these circumstances we should think of the question of mitigation as "how much insurance to buy," rather than as a question of consumption smoothing.

The fact that environmental change may also be sudden and irreversible reinforces the importance of thinking about mitigation policy as insurance rather than consumption smoothing. Lenton et al. (2008) identify a series of "tipping points," or environmental thresholds that trigger a rapid transition to a new state. If the Arctic Sea ice melted, for example, the darker ocean surface that would be exposed would accelerate warming by absorbing more radiation. The Western Antarctic Ice Sheet's melting (and contribution to sea level rise) would accelerate if ocean water undercut its foundation on the bedrock. Similarly, freshwater from melting ice entering the North Atlantic could halt the North Atlantic Deep Water formation and cause significant regional cooling in Europe and elsewhere. The IPCC (2007c) report discusses the risks of these events and finds them to be generally relatively low-probability, but Lenton et al.'s (2008) paper includes additional evidence that reinforces that these are real possibilities. Their conclusion is that "society may be lulled into a false sense of security by smooth projections of climate change" (Lenton et al., 2008: 1792). Many of these changes will be irreversible on a human time scale (Solomon et al., 2009).

Finally, CO_2 remains in the atmosphere for centuries to millennia, leaving a long lag between emissions and the outcomes that they in some sense

7. In more exact terms: it "makes the expected present discounted disutility [due to climate change] very large."

pre-determine. Although some decision-theoretic approaches suggest delaying action in order to resolve uncertainty or better learn about the appropriate actions to tackle a challenge, the net benefits of waiting to learn depend on how quickly the problem grows in the meantime (Summers and Zeckhauser, 2008). We may only learn about these irreversible climate changes too late to make midcourse corrections.

Emissions Do Not Automatically Buy Growth, Development, or Adaptation Capacity

Panagariya's discussion of uncertainties related to the costs of emissions is extensive and detailed. His discussion of the benefits of emissions, however, is cursory. There is substantial variation in how much growth emissions buy as well as how much poverty reduction and adaptation or mitigation capacity results from growth. The paper does not discuss uncertainty about how much return on emissions India will be able to achieve, although there is reason to doubt that it will achieve the maximum development returns without policy and institutional reform. These priorities—the actions India needs to take to have its emission be justified ex post by actual development returns rather than ex ante by potential returns—are not discussed.

Output per kilogram of CO_2 emissions (reported as CO_2 emissions per dollar of GDP) is a crude measure of the "return" on emissions, but it is widely available. These figures highlight the fact that the relationship between emissions and output, and presumably then emissions and growth, varies widely across countries and over time from 0.12 or 0.13 to 6 kg per dollar of GDP.[8] Figure 1 shows the emissions per unit of output for selected countries. Note that China, the example Panagariya uses to show that additional emissions will be required to achieve improved living standards, has dramatically decreased its emissions per unit of output over the 1980s.

The extent of poverty reduction and mitigation or adaptation capacity per unit of growth also varies. Ferreira and Ravallion's (2008) review of the global evidence on growth, poverty, and inequality finds that while poverty tends to be lower in countries with higher per capita income, there is "considerable heterogeneity" around this relationship. The effect of poverty

8. Based on figures from the World Bank (2009b).

reduction on growth is similarly varied: the 95 percent confidence interval of the effect of growth on poverty implies that a 2 percent increase in growth could bring anything from a 1 percent to a 7 percent reduction in poverty. Brazil, for example, achieved more rapid poverty reduction than did India with less growth (Ravallion, 2009).

The elasticity of adaptation and mitigation capacity to growth is harder to judge, but performance on infrastructure provision is a plausible proxy. Panagariya's argument is that the additional growth enabled by CO_2 emissions will improve access to shelter, transport, communications, and water management infrastructure among other support for adaptation to and mitigation of some of the effects of climate change. Here too, income does not assure performance. Figures 2a and 2b plot road density against size of the economy for two measures of the size of the economy. There is a wide variation in outcomes; India performs relatively well in terms of current US$, but not as well considering purchasing power parity. Figures 3a and 3b focus on paved roads only—the kind less likely to wash out during rains and floods. India's achievements are relatively poor for both measures of the size of the economy. Scatter plots for other infrastructure such as water and sanitation show similar "clouds" suggesting a loose relationship between income and infrastructure provision.

There is undoubtedly a relationship between emissions, growth, and development that increases peoples' and states' ability to adjust to environmental change. My point is that the development returns on emissions have varied in the past and are thus not guaranteed in the future without a concerted effort to build state capacity to deliver infrastructure, services, and emergency response.

"Climate Change Policy" Requires Attention to More than Just CO_2

Panagariya's paper focuses on greenhouse gases, and in particular on CO_2. While CO_2 is an important contributor to climate change, it is only responsible for about half of global warming.

The significant contribution of air pollution, specifically black carbon, tropospheric ozone and some of its precursors, and sulphates, to regional and global climate change is increasingly well documented. Black carbon, the dark part of soot produced by diesel engines, power plants, and household and small industry burning of solid fuels and biofuels (wood, coal, cow dung, crop waste), is estimated to have about 55 percent of the warming impact of CO_2.[9] Ozone, which forms from a combination of components found in transport emissions and emissions from biomass burning, has long been a known contributor to global warming with about 20 percent of the impact of CO_2.[10] Ozone precursors oxides of nitrogen (NO_x) and sulphates affect climate change in a more complex way as they interact with better-recognized greenhouse gases to affect their warming effect. These two pollutants can increase the potency of methane, a gas widely seen as second to CO_2 in impact, by 30 percent.[11]

Air pollution also contributes to some of the most devastating regional environmental changes. Black carbon depositions on the Himalayan glaciers are accelerating their melting, while black carbon carried to the Arctic is one of the leading causes of accelerating melting of the ice caps there (Flanner et al. 2007, 2008). The so-called "Atmospheric Brown Cloud," a transcontinental plume of air pollution affecting much of the earth, has been linked to changes in rainfall and monsoon patterns in India as well as dimming of the sunlight that affects crop productivity.[12]

Panagariya mentions the development reasons to limit black carbon, but the regional benefits of regional reducing air pollution are worth reiterating in more detail. Indoor air pollution—in large part black carbon—is second only to unclean water as an environmental cause of illness and premature death, while ozone affects asthma, allergies, and cardiac illness.

The benefits of additional CO_2 for crops (which Panagariya mentions) are likely to be more than offset by the effects of ozone, which interferes with photosynthesis and damages plant cells, on crop yields. Present day global relative yield losses due to ozone are estimated to range between 7 percent and 12 percent for wheat, between 6 percent and 16 percent for soybean, between 3 percent and 4 percent for rice, and between 3 percent and 5 percent for maize. The cumulative economic effect is estimated to be US$14–26 billion annually at 2000 prices—far greater than estimates of the impact of climate change on agriculture. These estimates are likely to be conservative, as they use European crop-response functions without accounting for the

9. As measured by comparing radiative forcing (RF). Ozone estimate is as given by IPCC (2007c), black carbon from Ramanathan and Carmichael (2008).

10. Based on the radiative forcing measures provided in IPCC (2007c).

11. Drew T. Shindell, Greg Faluvegi, Dorothy M. Koch, Gavin A. Schmidt, Nadine Unger, and Susanne E. Bauer. 2009. "Improved Attribution of Climate Forcing to Emissions." *Science* 326: 716–18.

12. UNEP (2008) summarizes the evidence. Ramanathan and Feng (2008) provide an overview of air pollution–climate links including the evolution of the science.

water scarcity or other plant stressors. The global situation is expected to deteriorate mainly for wheat (additional 2–6 percent loss globally) and rice (additional 1–2 percent loss globally). India, under a business as usual scenario, would account for half of this additional yield loss over the next two decades (Van Dingenen et al., 2009).

It is not enough to simply mention air pollution as a development policy aimed at public health. The climate co-benefits of addressing these development challenges supports the argument for increasing state capacity and allocating public resources to tighten regulation on air quality as well as provide enabling infrastructure to make cleaner, more efficient technologies available for more of India. Acknowledging and discussing the climate benefits of improving air quality also helps complete a full cost-benefit analysis. Cleaning up urban air pollution in order to reduce ozone might not pass a cost-benefit analysis focused only on public health benefits. Doing so in order to protect crop yields implies redistribution between rural and urban constituents. Adding in the overall climate benefits of air pollution control could tip the balance.

Air pollution control, particularly ozone and black carbon, is also emerging as a topic in international discussions of mitigation. Existent international efforts to reduce air pollution have mostly been regional emissions commitments (such as the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution Agreement) or based on voluntary collaboration across international networks (such as the Clean Air Initiative for Asia's Cities). How, if at all, air pollution should be integrated with ongoing climate change discussions is one question to be included in any comprehensive overview of the "state of play" that affects India's interests?[13]

Conclusion

All this said, Panagariya's basic point that India and the developing world can ill afford a tax on development is true. Whether early mitigation of emissions or uncontrolled climate change will be a bigger tax on development given

13. I argue elsewhere (Wallack and Ramanathan, 2009) that air pollution should be addressed through regional agreements, since these can be crafted to cover an area large enough to internalize at least a large portion of the international externalities while also preserving the flexibility of small groups and underpinning of stronger regional diplomatic ties that are necessary to address a complex policy challenge guided by science that is still evolving.

the varied opportunity cost of forgone emissions and the worrying risks of costly environmental change is another question and the debate should not obscure the underlying common goal.

General Discussion

The paper and formal discussant comments generated a lively discussion of the implications of climate change and India's role in the international policy negotiations.

Ester Duflo pointed out that there were several historical studies looking at the effects of temperature change in agriculture and health in India; and in contrast to the United States and Europe, the implications were quite uniformly negative. She thought that the paper disregarded too much of the evidence suggesting that higher temperatures could impose substantial costs on India.

Abhijit Banerjee expressed skepticism that India would be able to manage a cap and trade system. He argued that the Indian government does not have a track record in executing past programs that would make its commitment to a complex international agreement credible.

Surjit Bhalla argued that it was a mistake to put India and China together in any discussion because they were really quite far apart, both in their level of economic development, and the magnitude of their emissions. Additionally, reference to India as a poor country is not relevant to the time period under discussion that stretches out to 2040. He thought that India should participate in the international discussion on the basis of where it would be in 2040—not in terms of its present economic position.

Robert Lawrence also emphasized the advantages of early and active participation in the international negotiations. The costs of mitigation would be far lower if India acted before its capital stock had been put in place. This could be a major advantage compared to many of the advanced economies who would be faced with large obsolete capital stocks. He thought that India could influence the negotiations to a much greater extent by participating from the beginning rather than staying on the outside. He agreed with Vijay Joshi that a cap-and-trade system was much different from a tax because it had greater flexibility in dealing with the distributional issues.

Madhav Raghavan thought that an international agreement would be very difficult to negotiate, and that greater attention should be given to policies that India could enact unilaterally (for example, clean technology developments) and to policies aimed at adapting to the climate change.

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