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What to Do about Climate Change

by Indur M. Goklany

Executive Summary

The state-of-the-art British-sponsored fast-track assessment of the global impacts of climate change, a major input to the much-heralded *Stern Review on the Economics of Climate Change*, indicates that through the year 2100, the contribution of climate change to human health and environmental threats will generally be overshadowed by factors not related to climate change. Hence, climate change is unlikely to be the world's most important environmental problem of the 21st century.

Analysis using both the Stern Review and the fast-track assessment reveals that notwithstanding climate change, for the foreseeable future, human and environmental well-being will be highest under the "richest-but-warmest" scenario and lower for the poorer (lower-carbon) scenarios. The *developing* world's future well-being should exceed present levels by several-fold under each scenario, even exceeding present well-being in today's *developed* world under all but the poorest scenario. Accordingly, equity-based arguments, which hold that present generations should divert scarce resources from today's urgent problems to solve potential problems of

tomorrow's wealthier generations, are unpersuasive.

Halting climate change would reduce cumulative mortality from various climate-sensitive threats, namely, hunger, malaria, and coastal flooding, by 4–10 percent in 2085, while increasing populations at risk from water stress and possibly worsening matters for biodiversity. But according to cost information from the UN Millennium Program and the IPCC, measures focused specifically on reducing vulnerability to these threats would reduce cumulative mortality from these risks by 50–75 percent at a fraction of the cost of reducing greenhouse gases (GHGs). Simultaneously, such measures would reduce major hurdles to the developing world's sustainable economic development, the lack of which is why it is most vulnerable to climate change.

The world can best combat climate change and advance well-being, particularly of the world's most vulnerable populations, by reducing present-day vulnerabilities to climate-sensitive problems that could be exacerbated by climate change rather than through overly aggressive GHG reductions.

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Climate change exacerbates existing environmental and human health problems, but only to a modest degree relative to other factors.

Introduction

Most future scenarios suggest that the world will get more populated and wealthier during this century. Although this should advance human well-being, it may also increase climate change, which might in turn at least partly offset, if not overwhelm, any advances in well-being that would have occurred absent climate change. The U.N. Intergovernmental Panel on Climate Change reports in its 2001 assessment that modest global warming (1 to 2°C over 1990 levels) could increase global economic product with gains in the higher-latitude, developed countries, more than offsetting losses in developing countries.¹ However, global temperature increases beyond that could reduce global economic product and wreak substantial environmental damage.

Such considerations have led influential politicians such as former British prime minister Tony Blair, former U.S. president Bill Clinton, and former French President Jacques Chirac, to proclaim that climate change is the most important environmental problem facing the globe this century and, unless checked drastically, would before long reduce human and environmental well-being.²

This study examines whether climate change is in fact the world's most pressing environmental and human health problem and considers the merits of mitigation (that is, policies that would restrict emissions or concentrations of greenhouse gases) versus adaptation (policies that would reduce or take advantage of the impact of the climate change caused by greenhouse gas emissions) to address whatever problems are created or exacerbated. In short, careful analysis reveals that through the foreseeable future, climate change exacerbates existing environmental and human health problems, but only to a modest degree relative to contributions from other factors not related to climate change. Hence, the threats posed by climate change are more robustly and cost-effectively addressed, at least in the short- to medium-

term, by policies that address the underlying causes of the environmental and human health problems that are exacerbated by climate change.

The data and projections used in this study come primarily from two reports:

- The “fast-track assessment” (FTA) of the global impacts of climate change, sponsored by the U.K. Department of Environment, Forests and Rural Affairs; and
- The Stern Review on the economics of climate change.

The Fast-Track Assessment

The FTA of the global impacts of climate change was published in a special issue of *Global Environmental Change: Part A* edited by Martin Parry.³ This is supplemented, as necessary, by other DEFRA-sponsored studies. Many, if not most, authors of these papers have served as coordinating lead authors, lead authors, or contributing authors of the IPCC's third and fourth assessment reports. Parry is, moreover, the current chairman of the IPCC's Work Group II, which oversees the impacts, adaptation and vulnerability sections of the assessments.

Like all estimates of the impacts of climate change, the FTA's analyses are plagued with uncertainties resulting from the fact that such estimates are derived using a series of linked models with the uncertain output of each model serving as the input for the next model. To compound matters, each model is necessarily a simplified representation of reality.

The chain of models typically starts with emission models, which are driven by various socioeconomic assumptions about the next 100 years or more in order to generate emission scenarios extending to the latter part of this century. But even users of these emission scenarios acknowledge that 2085 is at the outer limit of the foreseeable future because socioeconomic predictions beyond that point are too speculative.⁴ Even 2085 is likely too great a stretch. For instance, a paper commissioned for the Stern Review noted that “changes in socioeconomic systems cannot

be projected semi-realistically for more than 5–10 years at a time.”⁵

Emission scenarios are used to drive models to estimate future trends in atmospheric greenhouse gas concentrations. Those concentrations are then used to model the amount of heating (or “radiative forcing”) of the climate system which is next fed into coupled atmosphere-ocean general circulation models to estimate spatial and temporal changes in climatic variables, which are in turn used as inputs to simplified and often inadequate biophysical models that project location-specific biophysical changes pertaining to the resources that are affected by climate change (e.g., vegetation and other species, crop, or timber yields).

The finer the spatial scale of the analysis, the greater the uncertainties in climatic variables. But because the resources that are affected by climate change are spatially heterogeneous—as are the socioeconomic conditions that affect those resources and determine whether and how human beings will respond to changes—it is more appropriate to do the biophysical impacts analysis at the local scale than at larger regional or national scales.

Finally, depending on the human or natural system under consideration, the outputs of these biophysical models may have to be fed into additional models to calculate the social, economic, and environmental impacts on those systems, including the calculation of regional and global scale impacts through the use of trade models.

In addition to the cascading uncertainties that propagate from model to model—the cumulative effects of which have yet to be quantified—the results of these impact assessments are subject to potentially large systematic errors which tend to substantially overstate negative impacts while simultaneously understating positive impacts of climate change. Those systematic errors are due to the fact that the assessments generally do not account fully, if at all, for the increases in adaptive capacity resulting from

- increases in wealth postulated under the socioeconomic assumptions used to

- generate emissions scenarios; and
- the creation of new or improved technologies that would come on line over time, because technology accrues over time.⁶

In other words, the impact assessments are inconsistent with the assumptions built into the emissions scenarios used to drive climate change.

Despite these shortcomings, for the purposes of this study I will, for the most part, take the results of the FTA at face value because it has figured prominently in the international debate on global warming and because it allows us to develop estimates of the relative contribution of climate change to various climate-sensitive problems in the future.⁷ Like the FTA, this paper does not consider low-probability but potentially high-consequence outcomes such as a shutdown of the thermohaline circulation or the melting of the Greenland and Antarctic ice sheets. They are deemed unlikely to occur during this century if they occur at all.⁸

Stern Review

The Stern Review on the Economics of Climate Change was commissioned from Nicholas Stern, the erstwhile chief economist of the World Bank, by the then-chancellor of the exchequer, Gordon Brown, on behalf of the British government. It was released on October 30, 2006. The Stern Review estimated that unmitigated climate change will reduce welfare by an amount equivalent to a reduction in consumption per capita of 5–20 percent “now and forever” if one accounts for market and non-market impacts and the risk of catastrophe.⁹ It also suggested that by the year 2200, the 95th percentile of the equivalent per capita GDP losses could rise to 35.2 percent.¹⁰

Several researchers have disputed the Stern Review’s impact estimates and consider them greatly overblown.¹¹ The review’s authors themselves emphasize “strongly” that the numbers should not “be taken too literally.”¹² I will, nevertheless, put aside these concerns and accept the Review’s findings in order to

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Table 1
Characteristics and Assumptions of Various Scenarios

| | Scenario | | | |
|---------------------------------------|------------------|--------------------|---------------------|-----------------|
| | A1FI | A2 | B2 | B1 |
| Population in 2085 (billions) | 7.9 | 14.2 | 10.2 | 7.9 |
| GDP growth factor, 1990–2100 | 525–550 | 243 | 235 | 328 |
| GDP/capita in 2085, Global average | \$52,600 | \$13,000 | \$20,000 | \$36,600 |
| GDP/capita in 2100 | | | | |
| Industrialized countries | \$107,300 | \$46,200 | \$54,400 | \$72,800 |
| Developing countries | \$66,500 | \$11,000 | \$18,000 | \$40,200 |
| Technological change | Rapid | Slow | Medium | Medium |
| Energy use | Very high | High | Medium | Low |
| Energy technologies | fossil intensive | regionally diverse | “dynamics as usual” | high efficiency |
| Land use change | Low–medium | Medium–high | Medium | High |
| CO ₂ concentration in 2085 | 810 | 709 | 561 | 527 |
| Global temp change (°C) in 2085 | 4.0 | 3.3 | 2.4 | 2.1 |
| Sea level rise (cm) | 34 | 28 | 25 | 22 |

Sources: N. W. Arnell, “Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios,” *Global Environmental Change* 14, no. 1 (2004): Tables 1, 6, 7; and R. J. Nicholls, “Coastal Flooding and Wetland Loss in the 21st Century: Changes under the SRES Climate and Socio-Economic Scenarios,” *Global Environmental Change* 14, no. 1 (2004): Tables 2 and 3. GDP and GDP/capita are in 1990 U.S. dollars. Note: Global temperature change is based on the HadCM3 model.

estimate whether unmitigated climate change will lower future well-being to below today’s levels. Specifically, I will assume for the sake of argument that climate change under the warmest scenarios will result in a welfare loss equivalent to 35.2 percent of GDP in 2100.

IPCC Scenarios of the Future

In 2000, the IPCC developed four “families” of greenhouse emissions scenarios to depict what the future might look like given different assumptions about demographic, technological, economic, and social trends during the period 1990–2100. This study is primarily concerned with exploring, in light of the results of the FTA and Stern Review, the implications for human well-being and environmental quality in four scenarios, with each scenario representing one family.

The IPCC scenarios are less predictions than they are inputs for “if-then” calculations. That is, the scenarios (sometimes called “story-lines”) represent plausible futures that serve as grist for the analytic mill. Scenarios are often

preferred to predictions because predictions of the above mentioned socioeconomic trends that determine emissions over the course of the next 100 years are extremely unreliable.

The FTA report employed emission scenarios developed by the IPCC’s *Special Report on Emissions Scenarios* to project future climate change from 1990 (the base year for each scenario) through 2100.¹³ The emissions scenarios assume that no new policies or measures will be implemented to reduce damages from climate change. This assumption virtually guarantees that negative impacts will be overestimated, while positive impacts will be underestimated.

The dominant characteristics of the “story-lines” used in those scenarios are shown in Table 1. Table 1 also provides corresponding estimates for the atmospheric CO₂ concentrations, temperature increases, and sea level rise that result from each scenario through 2085.¹⁴ Those impact calculations are the product of chained computer simulations discussed in the FTA subsection above.

The IPCC scenarios represent plausible futures that serve as grist for the analytic mill.

The columns in this and most subsequent tables are arranged by scenario in the order of decreasing global temperature changes. Using the labels provided by the IPCC, these scenarios from left to right are A1FI (warmest), A2, B2, and B1 (coolest).¹⁵

The FTA used these climate change projections to estimate the global impacts on various climate-sensitive threats which also serve as determinants of human and environmental well-being.¹⁶ With respect to threats affecting human well-being, the FTA analyzed hunger, water stress, coastal flooding, and malaria.¹⁷ With respect to environmental well-being, the FTA projected the net biological productivity of the terrestrial biosphere (as measured by its ability to fix carbon in vegetation, i.e., sequester carbon as biomass) and the global extent of coastal wetlands and croplands.¹⁸

Wealth Creation, Technological Advance, and Climate Change

Although climate change can lead to a deterioration of many human health and environmental metrics, that does not tell us what we really want to know. What we want to know is this: Will human health and environmental quality be better under richer but warmer scenarios than under poorer but cooler scenarios? That's primarily because wealth creation, human capital, and new or improved technologies often reduce the extent of the human health and environmental "bads" associated with climate change more than temperature increases exacerbate them.

The data in Table 1 suggests that, on one hand, the impacts of climate change should decrease as one goes from scenario A1FI on the left to B1 on the right (in accordance with the pattern of declining climate change, *ceteris paribus*). On the other hand, economic and technological development—both critical determinants of adaptive capacity—ought to attenuate the impacts of climate change.¹⁹ Considering future levels of economic and technological development, that attenuation should be greatest for the A1FI scenario, followed by the B1, B2 and A2 scenarios, in that

order. Thus, even though the A1FI scenario has the greatest amount of warming and thus, the largest amount of climate change, it would not necessarily have the worst outcomes. That's because it should also have the highest degree of adaptive capacity.

Economic growth broadly increases human well-being by increasing wealth, technological development, and human capital. These factors enable society to address virtually any kind of adversity, whether it is related to climate or not, while specifically increasing society's capacity to reduce climate change damages through either adaptation or mitigation.²⁰ Many determinants of human well-being—hunger, malnutrition, mortality rates, life expectancy, the level of education, and spending on health care and on research and development—improve along with the level of economic development, as measured by GDP per capita.²¹

Increasing wealth also improves some, though not necessarily all, indicators of environmental well-being. Wealthier nations have higher cereal yield (an important determinant of cropland, which is inversely related to habitat conversion) and greater access to safe water and sanitation. They also have lower birth rates.²² Notably, access to safe water and access to sanitation double as indicators of both human and environmental well-being, as does crop yield, since higher yield not only means more food and lower hunger, it also lowers pressure on habitat.²³

Cross country data also indicate that for a fixed level of economic development, these indicators of human and environmental well-being (e.g., malnutrition, mortality rates, life expectancy, access to safe water, crop yields, and so forth) improve with time (because technology almost inevitably improves with time).²⁴ Similarly one should expect, all else being equal, that society's ability to cope with any adversity, including climate change, should also increase with the passage of time.

Thus, over time, the combination of economic and technological development should increase society's adaptive capacity which, barring inadvertent maladaptation, ought to reduce the future impacts of climate change.²⁵

Economic growth broadly increases human well-being by increasing wealth, technological development, and human capital.

The FTA and Stern Review confirm that richer and warmer worlds will not necessarily have lower levels of human and environmental well-being than poorer but cooler worlds.

This is evidenced, for example, in the remarkable declines—99 percent or greater—during the 20th century in mortality and morbidity rates in the United States for various water-related diseases, e.g., typhoid, paratyphoid, dysentery, malaria and various gastrointestinal diseases.²⁶

This study highlights the tension between the public health and environmental improvements associated with wealth creation and technological advance on one hand and the countervailing negative impacts on the same from increased greenhouse gas emissions on the other hand. By and large, as I will show, the FTA and Stern Review confirm that richer and warmer worlds will not necessarily have lower levels of human and environmental well-being than poorer but cooler worlds.

The Impact of Climate Change—Four Scenarios

In this section I present the FTA’s scenario estimates of the populations at risk in 2085 with and without climate change for four climate-sensitive threats to human well-being—hunger, water stress, coastal flooding, and malaria—and on a number of environmental indicators that are also sensitive to climate.

When comparing the population at risk from these threats *without* climate change with the population at risk from these threats *with* climate change, a couple of issues should be kept in mind.

First, the A1FI and B1 scenarios are assumed by the IPCC to have the same population in 2085. That assumption, however, is dubious. In the real world, lower total fertility rates are generally associated with higher levels of economic development.²⁷ Hence, the A1FI world should have a lower population in 2085 than the B1 world. Accordingly, the populations at risk in the A1FI scenario are probably overestimated relative to the B1 scenario. Likewise, relative to the B1 scenario, greenhouse gas emissions and associated climate changes are probably overestimated in the A1FI scenario because emissions would be lower in a less-populated world. That, too,

leads to higher estimates of the population at risk in the A1FI scenario relative to the B1 scenario.

Second, neither the FTA studies nor the Stern Review deal very satisfactorily with endogenous adaptation. Some FTA studies (e.g., the ones for hunger and coastal flooding) allow for some “spontaneous” adaptive responses because it should be expected that even in the absence of new governmental policies, people would employ existing technologies to protect themselves from economic or bodily harm even in a “business-as-usual” world. Yet the study for water stress doesn’t allow for *any* adaptation. And even where the FTA studies allow for some adaptation, they limit the range of available technological options to currently available technologies.²⁸ But we should expect that the menu of technological options would be much broader, more cost-effective, and more affordable in the future under any scenario because of the following:

- The world will be wealthier under any of the scenarios (see Table 1) and, therefore, better able to develop, afford, and implement new as well as improved technologies;
- Technology will, through the accretion of knowledge, advance, even if society doesn’t get any wealthier; and
- Even in the absence of specific policy changes, new and improved technologies will inevitably be developed to specifically cope with the negative impacts of climate change.

Hence, limiting adaptation between now and 2085 to “current” technologies is tantamount to estimating today’s food production based on the technology of 1920 (or earlier). Any such estimate is bound to underestimate food production and overestimate hunger.²⁹ In our case, doing so overestimates the population at risk in all scenarios, but the overestimates are greatest for the A1FI scenario, followed by B1, B2 and A2, in that order.

Table 2
Population at Risk in 2085 for Hunger

| Units | Population at Risk in the Absence of Climate Change | | Additional Population at Risk Because of Climate Change | | Total Population at Risk | |
|---------------|--|------------------------------------|--|------------------------------------|-----------------------------|------------------------------------|
| | Millions | Percentage of Global Population | Millions | Percentage of Global Population | Millions | Percentage of Global Population |
| Baseline 1990 | 798 to 872 | 15.1 to 16.5 | | | 798 to 872 | 15.1 to 16.5 |
| A1FI 2085 | 105 | 1.3 | 28 | 0.4 | 133 | 1.7 |
| A2 2085 | 767 | 5.4 | -28 to -9 | -0.2 to -0.1 | 739 to 758 | 5.2 to 5.3 |
| B2 2085 | 233 | 2.3 | -11 to 5.0 | -0.1 to 0.05 | 222 to 238 | 2.2 to 2.3 |
| B1 2085 | 90 | 1.1 | 10 | 0.1 | 100 | 1.3 |

Source: M. L. Parry et al., "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2004): 53–67.

Hunger

The FTA's estimates of population at risk for hunger in 2085 both with and without climate change for the various scenarios are shown in Table 2. These estimates, which assume CO₂ fertilization in the event of climate change, show that under every scenario the world will be better off in 2085 with respect to hunger than it was in 1990 despite any increase in population.

There are three conclusions that one can draw from Table 2:

- The cooler scenarios (B2 and B1) do not yield markedly less hunger than the hottest scenario (A1FI). The hottest scenario actually yields less hunger than two of three cooler scenarios. But for the FTA's systematic overestimates of the populations at risk of hunger in the A1FI world relative to the B1 world, the A1FI scenario might have resulted in the lowest overall levels of hunger with or without climate change.
- For some scenarios (A2 and, possibly, B2), climate change might, in fact, reduce the incidence of hunger at least through 2085.
- For each scenario, the additional population at risk from hunger because of climate change alone is smaller than the population at risk from hunger without climate change. Through 2085 at least,

the impact of climate change is secondary to the impact of other factors.

The estimates in Table 2 are based on the assumption that atmospheric CO₂ will improve crop yields. If that does not prove to be the case, then climate change would increase the total population at risk under all scenarios. Even so, the additional population at risk of hunger due to climate change would still be less than the population at risk of hunger without climate change in all but the A1FI scenario.³⁰ But such outcomes are unlikely because the probability that direct CO₂ effects on crop growth are zero or negative is slight, particularly since future societies, especially the A1FI society, should have a greater capacity to adapt.

The Stern Review argues, based on a study by Long et al., that the beneficial effect of carbon fertilization has been overestimated.³¹ Accordingly, it uses the results from FTA's hunger study that assumes "no fertilization." But in fact, Long et al. estimate that the CO₂ fertilization effect could be a third to half as large in areas where insufficient nitrogen is applied or if crops are not well-watered, not zero.³² Even so, a peer-reviewed paper that evaluated the Long et al. study found that their analysis was "incorrect, being based in part on technical inconsistencies and [lacks] statistical significance."³³

Table 3
Population at Risk in 2085 for Water Stress

| Units | Population at Risk in the Absence of Climate Change | | Additional Population at Risk Because of Climate Change | | Total Population at Risk | |
|---------------|--|------------------------------------|--|------------------------------------|-----------------------------|------------------------------------|
| | Millions | Percentage of Global Population | Millions | Percentage of Global Population | Millions | Percentage of Global Population |
| Baseline 1990 | 1,368 | 25.8 | | | 1,368 | 25.8 |
| A1FI 2085 | 2,859 | 36.2 | -1,192 | -15.1 | 1,667 | 21.1 |
| A2 2085 | 8,066 | 56.8 | -2,100 to 0 | -14.8 to 0 | 5,966 to 8,066 | 42.0 to 56.8 |
| B2 2085 | 4,530 | 44.4 | -937 to 104 | -9.2 to 1.0 | 3,593 to 4,634 | 35.2 to 45.4 |
| B1 2085 | 2,859 | 36.2 | -634 | -8.0 | 2,225 | 28.2 |

Source: N. W. Arnell, "Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2004): p. 41, Table 8.

Moreover, the Long et al. study justified its low estimate of the fertilization effect by arguing that nitrogen usage per hectare is lower in the developing world than in the Organization for Economic Cooperation and Development. Although that might be true today, increased use of nitrogen is precisely the kind of adaptation that would become more affordable in the future as countries, even developing countries, become wealthier. Indeed, this is one of the autonomous adaptations allowed under the FTA study.³⁴ In addition, the development of crops that would be drought-resistant and/or utilize nitrogen more efficiently is among the more active areas of crop research.³⁵

While the contribution of climate change to the total population at risk from hunger in 2085 seems large (21 percent), it results from a small (2 percent) warming-related drop in future global food production between 1990 and 2085.³⁶ In other words, unmitigated warming would reduce the annual growth in food productivity from 0.84 percent per year to 0.82 percent per year. This suggests two things. First, a small decline in the rate of productivity growth—perhaps "forced" by the assumption that no new technologies will develop autonomously to adapt to climate change—would lead to disproportionately large effects in terms of the population at risk from hunger.³⁷ Second, a small boost in annual productivity of the food and agricultural

sector could go a long way toward ensuring that hunger does not increase in the future.

Finally, the estimates provided in Table 2 indicate that in order to compare the consequences of various scenarios, it is insufficient to examine only the impacts of climate change. One should also look at the total level of hunger. Otherwise, based merely on an examination of the population at risk from climate change alone, one could conclude, erroneously, that, with respect to hunger, A2 is the best of the four worlds examined. But, based on either the total population at risk or the proportion of the global population at risk, A2 would be the worst of the four scenarios for hunger. This also illustrates that efforts focused on minimizing the consequences of climate change to the exclusion of other societal objectives might actually reduce overall human welfare.

Water Stress

The FTA's estimates of the population at risk for water stress in 2085 with and without climate change are shown for each scenario in Table 3.³⁸ A population is deemed to be at risk if available water supplies fall below 1,000 m³ per capita per year. The populations at risk in Table 3 reflect the fact that, because of climate change, some populations will move in and out of the water stressed category.

Table 3 clearly demonstrates that the

Table 4
Population at Risk in 2085 for Coastal Flooding

| Units | Population at Risk in the Absence of Climate Change | | Additional Population at Risk Because of Climate Change | | Total Population at Risk | |
|---------------|--|------------------------------------|--|------------------------------------|-----------------------------|------------------------------------|
| | Millions | Percentage of Global Population | Millions | Percentage of Global Population | Millions | Percentage of Global Population |
| Baseline 1990 | 10 | 0.2 | | | 10 | 0.2 |
| A1FI 2085 | 1 to 3 | 0 | 10 to 42 | 0.1 to 0.5 | 11 to 45 | 0.1 to 0.6 |
| A2 2085 | 30 to 74 | 0.2 to 0.5 | 50 to 277 | 0.4 to 2.0 | 80 to 351 | 0.6 to 2.5 |
| B2 2085 | 5 to 35 | 0 to 0.3 | 27 to 66 | 0.3 to 0.6 | 32 to 101 | 0.3 to 1.0 |
| B1 2085 | 2 to 5 | 0 to 0.1 | 3 to 34 | 0 to 0.5 | 5 to 39 | 0 to 0.5 |

Source: R. J. Nicholls, "Coastal Flooding and Wetland Loss in the 21st Century: Changes under the SRES Climate and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2004).

warmest (and richest) scenario has the least total water stress.

This is all the more striking given that the calculations informing Table 3 assume zero adaptation despite the ready availability of time-tested adaptive responses on both the supply and demand side (e.g., water storage facilities to augment water supplies during drier periods, or water pricing and other conservation measures).³⁹ Thus it overestimates the populations at risk in all scenarios. These overestimates, however, are greatest for the A1FI (richest) scenario and lowest for the A2 (poorest) scenario. Although the ranking among the scenarios would not change, the differences in the populations at risk between the various scenarios would have been magnified had adaptation been considered.

Coastal Flooding

The FTA's estimates of the population at risk for coastal flooding with and without any climate change between 1990 and 2085 are shown in Table 4. Note that sea level will rise relative to the land not only because of climate change but also because the land may subside for a variety of reasons not related to climate change (e.g., extraction of water, gas, or oil under the coastline). In this table, population at risk is measured by the average number of people who would experience coastal flooding

by a storm surge in 2085 with and without climate change, assuming that populations would be attracted preferentially to the coast and that some adaptations would occur with a 30-year lag time.⁴⁰ The low and high end of the ranges for populations at risk for each entry in Table 4 assume low and high subsidence due to non-climate-change-related human causes, respectively.

The main conclusion one draws from Table 4 is that the warmest and richest scenario (A1FI) produces only slightly larger coastal flooding damages than the coolest scenario (B1). This conclusion is at least partially due to the fact that although the calculations in Table 4 make a creditable effort to incorporate improvements in adaptive capacity due to increasing wealth, some of the underlying assumptions are questionable.

For instance, the scenarios in Table 4 allow societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions, but ignore such changes due to subsequent sea level rise.⁴¹ But one would expect that whenever any measures are implemented, society would consider the latest available data and information on the surge situation at the time the measures are initiated. That is, if the measure is initiated in, say, 2050, the measure's design would at least consider sea level *and* sea level trends as of 2050, rather than merely the 1990 level.

Efforts focused on minimizing the consequences of climate change to the exclusion of other societal objectives might actually reduce overall human welfare.

The calculations also allow for a constant lag time between sea level rise and initiating protection. But one should expect that if sea level continues to rise, the lag between upgrading protection standards and higher GDP per capita will be reduced over time. Moreover, it is conceivable that the richer a society is, the faster the adaptation. In fact, if data confirms that trends in sea level rise are robust, it is possible that protective measures may be taken in advance, i.e., the lag times may even become negative, even in a “business-as-usual” world.

In addition, these calculations do not allow for any deceleration in the preferential migration of the population to coastal areas, which is not unlikely if coastal flooding becomes more frequent and costly. Alternatively, if migration to the coasts continues unabated, a country’s expenditures on coastal protection might increase because its coastal population increases relative to its total population.

Finally, the scenarios used in Table 4 assume that subsidence is more likely under the A1FI world than the B1 and B2 worlds. That assumption contradicts real world experience which indicates that once richer countries are convinced of a problem, whether environment or health related, they generally respond quicker to remedy the problem, spend more, and have greater environmental protection than poorer ones, especially at the high levels of development that, as indicated in Table 1, are projected to exist virtually everywhere later this century under all of the IPCC scenarios.⁴² Hence, one should expect that the richest (A1FI) world would spend more and be better protected from subsidence than would the B1 (and A1 and B2) worlds.

Malaria

The study used in the FTA’s analysis for malaria provides estimates for changes in global population at risk due to climate change, but not for populations at risk in the absence of climate change.⁴³ As we saw in Table 2, the scenario with the highest population at risk due to climate change does not always have the highest total population at

risk, and the latter is a more relevant measure of human well-being. Thus, the published analysis doesn’t allow us to determine whether the contributions to malaria would be dominated by climate change or other factors.⁴⁴ Nor does it tell us whether well-being (as measured by the total population at risk for malaria) would be greater in a richer-but-warmer world compared to poorer-but-cooler worlds.

In order to answer these questions, I will use the results of an earlier version of the FTA of the global impact of climate change.⁴⁵ That earlier analysis used a “business-as-usual” scenario—the so-called IS92a scenario—developed for the 1995 IPCC impact assessment. It neither included any additional greenhouse gas controls nor allowed for any adaptation. Under that scenario, the global population and average GDP per capita in 2085 were projected at 10.7 billion and \$17,700 (in 1990 \$U.S.).⁴⁶ The UK Meteorological Office’s HadCM2 model projected that under this scenario, average global temperature would increase by 3.2°C between 1990 and 2085, which approximates the temperature increase using HadCM3 under the A2 scenario.⁴⁷

That study’s results for malaria are summarized in Table 5. The study indicates that the global population at risk of malaria transmission in the absence of climate change would double from 4,410 million in 1990 to 8,820 million in 2085, while the additional population at risk due to climate change in 2085 would be between 256 million and 323 million. In other words, climate change would contribute only a small portion (no greater than 3.5 percent) of the total population at risk for malaria in 2085.⁴⁸

Note that the current range of malaria is dictated less by climate than by human adaptability. Despite any global warming that might have occurred so far, malaria has been eradicated in richer countries, although it was once prevalent there in earlier centuries, and it sometimes extended into Canada and as far north as the Arctic Circle.⁴⁹ This is because wealthier societies have better nutrition, better general health, and greater access to public health measures and technologies targeted at

Table 5
Population at Risk in 2085 for Malaria (millions)

| | Baseline 1990 | 2085 |
|---|---------------|----------------|
| Population at risk in the absence of climate change | 4,410 | 8,820 |
| Additional population at risk because of climate change | | 256 to 323 |
| Total population at risk | 4,410 | 9,076 to 9,143 |

Source: N. W. Arnell et al., “The Consequences of CO₂ Stabilization for the Impacts of Climate Change,” *Climate Change* 53 (2002): 413–46.

controlling diseases in general and malaria in particular. In other words, today’s wealthier and more technologically advanced societies have greater adaptive capacity, and that is manifested in the current geographic distribution of malaria prevalence around the globe.⁵⁰

The fact that malaria is a significant health risk only in the poorest of countries reaffirms the importance of incorporating adaptive capacity—and changes in future adaptive capacity due to economic growth and technological change—into impact assessments. In fact, analysis suggests that malaria is functionally eliminated in a society whose annual per capita income reaches \$3,100.⁵¹ But as shown in Table 1, even under the poorest (A2) scenario, the average GDP per capita for developing countries is projected to be \$11,000. Hence, few, if any, countries ought to be below the \$3,100 threshold in 2085. Moreover, given the rapid expansion in our knowledge of diseases and development of the institutions devoted to health and medical research, the \$3,100 threshold will almost certainly drop in the next several decades as public health measures and technologies continue to improve and become more cost-effective.

Ecological Changes in 2085–2100

Thus far, we’ve examined the impact of climate change on human well-being. But climate change will also affect global ecology. In particular, climate change will have an impact on the terrestrial biosphere’s ability to remove

carbon from the atmosphere (i.e., “sink” carbon in the biosphere), the expanse of cropland (a crude measure of the amount of habitat converted to agricultural uses, which is perhaps the single largest threat to global terrestrial biodiversity),⁵² and the expanse of coastal wetlands.

Table 6, derived from the FTA, summarizes the impact that warming might have on these ecological indicators in each of the four scenarios discussed thus far.

Under each scenario, net carbon sink capacity is higher in 2100 relative to 1990 because the positive effect of carbon fertilization will not have been offset by the negative effects of higher temperatures during that period. Sink capacities under the warmest scenarios (A1FI and A2) are approximately the same in 2100, and greater than the sink strengths under the cooler scenarios (B1 and B2).

Partly for the same reason and also because of its low population, the amount of cropland is lowest for the A1FI world, followed by the B1 and B2 worlds. (Cropland estimates were not provided for the A2 scenario). Thus, through the foreseeable future, the A1FI scenario would have the least habitat loss and, therefore, pose the smallest risk to terrestrial biodiversity, while the cooler scenarios would have the highest habitat losses.

Regarding the loss of coastal wetlands, estimated losses due to sea level rise for each scenario are substantial. But the contribution of climate change to total losses in 2085 is smaller than losses due to subsidence from other manmade causes.⁵³ Table 6 shows that total

Malaria is functionally eliminated in a society whose annual per capita income reaches \$3,100.

Table 6
Ecological Indicators

| Indicator | Unit of Measurement | Base 1990 | A1FI | A2 | B2 | B1 |
|--|-----------------------|-----------|-------|-------|-------|-------|
| CO ₂ concentration (in 2100) | ppm | 353 | 970 | 856 | 621 | 549 |
| Net carbon sink capacity with climate change (in 2100) | Pg C/yr | 0.7 | 5.8 | 5.9 | 3.1 | 2.4 |
| Area of cropland with climate change (in 2100) | % of global land area | 11.6 | 5.0 | NA | 13.7 | 7.8 |
| Losses of coastal wetlands due to sea level rise alone (1990–2085) | % of current area | | 5–20 | 3–14 | 3–15 | 4–16 |
| Losses of coastal wetlands due to other causes (1990–2085) | % of current area | | 32–62 | 32–62 | 11–32 | 11–32 |
| Combined losses of coastal wetlands (1990–2085) | % of current area | | 35–70 | 35–68 | 14–42 | 14–42 |

Sources: Nigel W. Arnell et al., “The Consequences of CO₂ Stabilization”; Indur M. Goklany and David A. King, “Climate Change and Malaria,” Letter, *Science* 306 (2004); Robert J. Nicholls, “Coastal Flooding and Wetland Loss in the 21st Century: Changes under the SRES Climate and Socio-Economic Scenarios,” *Global Environmental Change* 14, no. 1, (2004): 69–86; and P. E. Levy et al., “Modeling the Impact of Future Changes in Climate, CO₂ Concentration and Land Use on Natural Ecosystems and the Terrestrial Carbon Sink,” *Global Environmental Change* 14, no. 1 (2004): 21–30.

wetland losses are much higher for the A1FI scenario than for the B1 and B2 scenarios, but this is due mainly to the assumption that under A1FI, societies would take fewer or less effective measures to alleviate non-climate-change-related subsidence which, as noted, is suspect.⁵⁴

Is Climate Change the Most Important Environmental Problem for the Foreseeable Future?

A review paper in *Nature* claims that global warming may have been responsible for about 0.17 million deaths worldwide in 2000.⁵⁵ This estimate is based on an analysis which was put out under the auspices of the World Health Organization. However, the authors of that analysis acknowledge that

climate change occurs against a background of substantial natural climate

variability, and its health effects are confounded by simultaneous changes in many other influences on population health. . . . Empirical observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses, would therefore require long time-series (probably several decades) of careful monitoring. *While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future.*⁵⁶

In other words, the 0.17 million estimate should be viewed with skepticism since science was admittedly sacrificed in hot pursuit of a predetermined policy objective. But, absent serendipity, one cannot base sound policy on poor science.

Nevertheless, for the purposes of this paper, I will accept this problematic estimate

One cannot base sound policy on poor science.

at face value. An annual death rate of 0.17 million would constitute 0.28 percent of global mortality.⁵⁷ Data from the WHO, however, indicates that climate change doesn't even make the top 10 global health risk factors related to food, nutrition, and environmental and occupational exposure. Specifically, the WHO attributes

- 1.12 million deaths in 2001 to malaria;
- 3.24 million deaths to malnutrition;⁵⁸
- 1.73 million deaths to unsafe water, inadequate sanitation, and hygiene;
- 1.62 million deaths to indoor air pollution from indoor heating and cooking with wood, coal, and dung;
- 0.8 million deaths to urban air pollution; and
- 0.23 million deaths to lead exposure.⁵⁹

Climate change is clearly not the most important environmental, let alone public health, problem facing the world today.

Is it possible that in the foreseeable future, the impact of climate change on public health could outweigh that of other factors? To shed light on that question, let's translate the populations at risk in Tables 2, 4 and 5 for hunger, coastal flooding, and malaria into "ball park" estimates for mortality assuming (1) that the mortality scales linearly with populations at risk between 1990 and 2085, and (2) that there has been no change in mortality for these threats between 1990 and 2001.⁶⁰

Because Table 5 for malaria only has information regarding the IS92a scenario, additional assumptions are necessary to derive mortality for each of the four standard scenarios. Specifically, with respect to malaria, mortality estimates for each of the four IPCC scenarios are derived by assuming that (1) in the absence of climate change, population at risk scales linearly with the global population in 2085 under each scenario, and (2) the ratio of the additional population at risk due to climate change to the population at risk absent climate change varies with the square of the ratio of the global temperature change.⁶¹

Note that the methodology used to trans-

late populations at risk into mortality probably overestimates the latter because it doesn't allow for increases in adaptive capacity due to both economic development and technological progress (or time). However, this would be consistent with the methodologies used in the impacts assessments in that they don't account for either new technologies for combatting hunger or increasing wealth and new technologies for treating malaria. In any case, both mortality without climate change and the increase in mortality due to climate change alone should be overestimated to the same degree. Because impact analyses generally underestimate changes in adaptive capacity, mortality estimates are probably overestimated for each scenario, with larger overestimates for the wealthier scenarios.

Table 7 shows results for mortality without climate change, the increase in mortality due to climate change alone, and the sum of the two in 2085 for each scenario. In order to keep Table 7 simple, it shows only the mortality using the upper bound estimate for the population at risk under each scenario.

This table shows that *for each scenario*, the contribution of climate change to the total mortality burden from malaria, hunger, and coastal flooding is substantially smaller than that due to other factors. The former varies from 3.6 percent for the B2 scenario to 10.3 percent for the A1FI scenario. Thus, if climate change were halted at its 1990 level, it would reduce the mortality burden in 2085 from these three factors by no more than, for example, 10.3 percent for the warmest but wealthiest A1FI scenario, corresponding to 237,000 deaths out of a possible 2,304,000.

These results, in conjunction with those from Table 3 for populations at risk of water stress and Table 6 for ecological indicators, indicate that the effect of non-climate-change-related factors generally outweighs the effect of climate change with respect to either human or environmental well-being. Climate change is therefore unlikely to be the most important environmental problem confronting human or environmental well-being, at least through the foreseeable future.

Climate change is unlikely to be the most important environmental problem confronting human or environmental well-being.

Well-being in 2100 should, in the aggregate, be highest for the richest-but-warmest scenario and lowest for the poorest scenario.

Table 7
Deaths in 2085 Resulting from Hunger, Malaria, and Coastal Flooding (thousands)

| | 1990 Baseline | A1FI 2085 | A2 2085 | B2 2085 | B1 2085 |
|---|------------------|--------------|------------|------------|------------|
| Mortality in absence of climate change | | | | | |
| Hunger | 3,240 | 407 | 2,976 | 904 | 349 |
| Coastal flooding | 8 | 2 | 59 | 28 | 4 |
| Malaria | 1,120 | 1,657 | 2,977 | 2,143 | 1,657 |
| (Subtotal) | 4,368 | 2,067 | 6,012 | 3,075 | 2,010 |
| Change in mortality due to climate change | | | | | |
| Hunger | 0 | 109 | -35 | 19 | 39 |
| Coastal flooding | 0 | 42 | 222 | 53 | 27 |
| Malaria | 0 | 95 | 96 | 44 | 26 |
| (Subtotal) | 0 | 237 | 282 | 116 | 92 |
| Total mortality | 4,368 | 2,304 | 6,295 | 3,191 | 2,102 |

Sources: Tables 2, 4, and 5.

Are Richer and Warmer Worlds Worse Off Than Poorer but Cooler Worlds?

Climate change will leave future generations poorer than they otherwise would have been absent climate change. But would net welfare necessarily be reduced below today's levels? To answer this question, I rely on the data produced by the Stern Review, which estimated that unmitigated climate change will reduce welfare by an amount equivalent to a reduction in consumption per capita of 5–20 percent “now and forever” if one accounts for market and nonmarket impacts and the risk of catastrophe.⁶² It also suggests that by the year 2200, the 95th percentile of the equivalent per capita GDP losses could rise to 35.2 percent.⁶³

Table 8 uses the Stern Review to estimate net welfare per capita under each of the four scenarios. It provides estimates of welfare losses assuming unmitigated climate change and adjusts the GDP per capita in 2100 downward to account for those losses assuming that they would increase with the square of the average global temperature increase from 1990 to 2085 indicated in Table 1.

Table 8 indicates that, notwithstanding

the Stern Review's gross inflation of the adverse impacts of climate change, welfare should be higher in 2100 than it was in 1990. Remarkably, even after accounting for climate change, welfare in developing countries (on average) should be higher in 2100 than it was for developed countries in 1990 for all but the A2 scenario.

This calls into question arguments that present generations are morally bound to take aggressive actions now to mitigate climate change because future generations' well-being will otherwise be worse. Future generations will not only be better off, they should also have at their disposal better and more effective technologies to address not just climate change but any other sources of adversity.

Most striking, however, is the fact that well-being in 2100 should, in the aggregate, be highest for the richest-but-warmest (A1FI) scenario and lowest for the poorest (A2) scenario. This conclusion was reached despite the previously noted tendency of impact analyses to overestimate net adverse impacts, especially for wealthier societies.

If future well-being is measured by per capita income adjusted for welfare losses due to climate change, the surprising conclusion using the Stern Review's own estimates is that

Table 8
GDP per Capita (in 1990 Dollars) for Developing and Industrialized Countries in 2100

| | 1990 | 2100 | | | |
|---|----------|-----------|----------|----------|----------|
| | Actual | A1FI | A2 | B2 | B1 |
| Temperature increase in 2085 [°C] | — | 4.0 | 3.3 | 2.4 | 2.1 |
| Developing Countries | | | | | |
| GDP per capita, no climate change | \$875 | \$66,500 | \$11,000 | \$18,000 | \$40,200 |
| Maximum cost of climate change* | 0 | \$23,408 | \$2,635 | \$2,281 | \$3,900 |
| Net consumption per capita, with climate change | \$875 | \$43,092 | \$8,365 | \$15,719 | \$36,300 |
| Industrialized Countries | | | | | |
| GDP per capita, no climate change | \$14,500 | \$107,300 | \$46,200 | \$54,400 | \$72,800 |
| Maximum cost of climate change* | 0 | \$37,770 | \$11,069 | \$6,894 | \$7,063 |
| Net consumption per capita, with climate change | \$14,500 | \$69,530 | \$35,131 | \$47,506 | \$65,737 |

* Assuming (a) climate change will reduce welfare by 35.2% for A1FI in 2100 (see text), (b) welfare losses vary with the square of the average global temperature change, and (c) the cost of climate change in 1990 is zero.

Sources: R. Warren et al. "Understanding the Regional Impacts of Climate Change," Tyndall Centre Working Paper no. 90, 2006, prepared for the Stern Review, http://www.tyndall.ac.uk/publications/working_papers/twp90.pdf; N. W. Arnell, "Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change* 14, no.1 (2004): pp. 31–52, World Bank, *World Development Indicators* (2006), and *Stern Review on The Economics of Climate Change*, 2006.

future generations will be better off in the richest but warmest world (A1FI) world. This suggests that, if protecting future well-being is the objective of public policy, governmental intervention to address climate change ought to be aimed at maximizing wealth creation, not minimizing CO₂ emissions.

Costs and Benefits of Mitigation and Adaptation

In the near term, mitigation (that is, measures to reduce anthropogenic greenhouse gas concentrations) will have little or no impact on reducing the impacts of climate

change due to the inertia of the climate system. However, over time, mitigation will have a greater impact.

In Table 9, I show the impact of two mitigation scenarios on human mortality and habitat loss for three of the key scenarios examined thus far.⁶⁴ The two mitigation scenarios represent the two poles at either end of the spectrum in terms of stringency, namely, the Kyoto Protocol at the low end of effectiveness and cost and, at the high end, a scenario that would ensure no climate change beyond 1990 levels. These decreases, derived from Tables 3, 6, and 7, are shown relative to the unmitigated case, that is, no emission controls whatsoever.

If protecting future well-being is the objective of public policy, governmental intervention to address climate change ought to be aimed at maximizing wealth creation, not minimizing CO₂ emissions.

Table 9
Impact of Mitigation Policies, 2085–2100

| | A1FI (richest-but-warmest) | | A2 (poorest) | | B1 (coolest) | |
|--|-------------------------------------|-------------------|----------------|-------------------|-------------------------------------|-------------------|
| | No Climate | | No Climate | | No Climate | |
| | Kyoto Protocol | Change after 1990 | Kyoto Protocol | Change after 1990 | Kyoto Protocol | Change after 1990 |
| Decline in mortality from malaria, hunger and coastal flooding (in thousands)* in 2085 | 21 (1%) | 237 (10%) | 51 (1%) | 282 (4%) | 10 (0%) | 92 (4%) |
| Decline in population at risk from water stress (in millions)* in 2085 | -83 (-5%) | -1,192 (-72%) | 0 | 0 | -44 (-2%) | -234 (-11%) |
| Habitat available for the rest of nature measured by extent of cropland in 2100 | Small decrease in available habitat | Larger decrease | NA | NA | Small decrease in available habitat | Some decrease |

Sources: Tables 3, 6, and 7; and Indur M. Goklany, “A Climate Policy for the Short and Medium Term: Stabilization or Adaptation?” *Energy & Environment* 16 (2005): 667–80. Note: The negative sign in the second-to-last row (for water stress) indicates that mitigation will make matters worse in 2085. The figures in parentheses indicate the percent declines in total mortality from malaria, hunger, and coastal flooding (or populations at risk from water stress) under the control scenarios. NA = not available.

The effects of mitigation could be a mixed bag—declines in mortality from malaria, hunger, and coastal flooding but increases in populations at risk from water stress and decreases in the habitat available for other species.

To construct this table, I optimistically assumed that by 2085 the Protocol would reduce climate change, as represented by the changes in global temperature and sea level, by 7 percent, which would then reduce the impacts of climate change on malaria, hunger, and water stress by a like amount, and the impacts of coastal flooding by 21 percent.⁶⁵ This is based on research published by Thomas Wigley, which estimates that if the Kyoto Protocol were to be fully implemented, it would reduce the amount of warming in the 2080s by no more than 7 percent.⁶⁶ As will become evident, however, the validity of the arguments and conclusions in this paper hold regardless of the assumptions about the effectiveness of the Kyoto Protocol in reducing climate change.

Table 9 demonstrates that, at least through 2085, the effects of mitigation could be a mixed bag—declines in mortality from malaria, hunger, and coastal flooding but increases in populations at risk from water stress and decreases in the habitat available for other

species. This illustrates one of the major shortcomings of mitigation, namely, mitigation is indiscriminate—it reduces all impacts, whether they are positive or negative.

Table 9 also demonstrates that the benefits of the Kyoto Protocol are relatively trivial compared to the magnitudes of the problems that it would address. For example, it would reduce cumulative mortality for malaria, hunger, and coastal flooding by 0–1 percent, compared to 4–10 percent if climate were to be somehow frozen at its 1990 level.

Those relatively trivial benefits, however, would cost significant amounts of money. For instance, if the Kyoto Protocol were fully implemented by all signatories (including the United States and Australia), it would likely cost Annex 1 countries at least \$165 billion per year in 2010, a figure on the lower end of the range of estimates produced by the IPCC’s 2001 report.⁶⁷ The cost of the no-climate-change scenario, assuming it’s even feasible, would be far greater than that, but the

literature doesn't provide any good cost estimates for such a scenario.

Focused Adaptation

As indicated in Table 7, suspending climate at its 1990 level at a cost somewhere above \$165 billion annually would leave 90–96 percent of the mortality problem for the three listed threats unsolved. By contrast, policies focused on solving the whole problem not only would have a larger target of opportunity (namely, 100 percent of the problem) but would likely prove more cost-effective than mitigation. Focusing on the former will necessarily enhance human well-being more than policies that would only mitigate climate change.

Moreover, measures that would reduce vulnerability to the non-climate-change-related portion of the problem would also reduce the component related to climate change.⁶⁸ In particular, policies and measures that would reduce present day vulnerabilities to climate-sensitive problems would also reduce similar problems in the future, whether they are caused by climate change or other factors. For instance, a successful malaria vaccine would help reduce malaria cases regardless of whether the avoided cases would be due to climate change or other factors.

Such an approach—which I will call “focused adaptation”—would, unlike mitigation, bring substantial benefits in the near-to-medium term. That is mainly due to the fact that mitigation will not affect mortality due to the non-climate-change-related component of the threat. As shown in Table 7, mortality from hunger, malaria, and coastal flooding in the absence of climate change ranges from 4.4 million in 1990 to 2.1–6.3 million in 2085 (depending on the scenario). Moreover, due to the inertia of the climate system, mitigation would not reduce the climate change component of the problem significantly until a few decades had elapsed.

Mitigation has the additional problem that it indiscriminately reduces all impacts of climate change whether they are positive or negative. But adaptation can selectively capture

the positive aspects of climate change while reducing its negatives. And while the impacts of global warming are uncertain, there is no doubt that malaria, hunger, water stress, and coastal flooding are real and urgent problems here and now. Thus, focused adaptation is far more likely to deliver benefits than is mitigation, and to deliver those benefits sooner rather than later.

Significantly, work on focused adaptation measures can commence, and in some areas has already begun, without detailed knowledge of the impacts of climate change. Cases in point are the development of malaria vaccines, transferable property rights for water resources, development of early warning systems for climate-sensitive events ranging from storms to potential epidemics of various kinds, and elucidation of mechanisms that confer resistance in crops to drought, water logging, or saline soils. To the extent that such measures do not rely on the location-specific details of impacts analyses, focused adaptation reduces the risk of having wasted resources by pouring them into problems that may or may not occur at specific locations.⁶⁹

Ancillary benefits of adaptation focused on reducing vulnerability to malaria and hunger include better health, increased economic growth, and greater human capital, which should advance human well-being and the capacity to address a much wider variety of problems.⁷⁰ These co-benefits, in fact, are among the goals and purposes of sustainable development as articulated in the Millennium Development Goals.⁷¹ In other words, focused adaptation to reduce the vulnerability to existing climate-sensitive problems would advance sustainable development in addition to explicitly laying the foundations for adapting to future climate change.

Finally, the conclusion that focused adaptation is for the foreseeable future superior in terms of both global benefits and global costs is robust to the choice of discount rates. That is because the benefits of focused adaptation will generally follow relatively soon after its costs are incurred. On the other hand, the cli-

Focused adaptation is far more likely to deliver benefits than is mitigation, and to deliver those benefits sooner rather than later.

An additional \$5 billion annual investment in agricultural R&D should raise productivity sufficiently to more than compensate for the estimated 0.02 percent annual shortfall in productivity caused by climate change.

mate system's inertia ensures that the costs of emission reductions will have to be borne for decades before any benefits accrue.

Examples of what focused adaptation might entail are discussed below.

Malaria

The UN Millennium project reports that the global death toll from malaria could be reduced by 75 percent at a cost of \$3 billion per year.⁷² Adaptations focused on reducing current vulnerabilities to malaria include measures targeted specifically at malaria as well as measures that would generally enhance the capacity to respond to public health problems and deliver public health services more effectively and efficiently. Malaria-specific measures include indoor residual (home) spraying with insecticides, insecticide-treated bed nets, improved case management, more comprehensive antenatal care, and development of safe, effective, and cheap vaccines and therapies.⁷³ Moreover, if these measures are even partly successful, they could further reduce the likelihood of outbreaks because the risk of exposure would be lower.

The posited expenditures may have to be increased by the year 2085 to keep pace with the projected increase in the global population at risk from malaria in the absence of climate change (see Table 7). I will assume—based on the ratio of estimated deaths in 2085 to that in 1990 under the A2 scenario (the worst scenario for malaria) and rounding up to the nearest whole number—that expenditures should be tripled, regardless of the emission scenario, in order to reduce malaria deaths by 75 percent.

Hunger

An additional \$5 billion annual investment in agricultural R&D—approximately 15 percent of global funding of agricultural research and development during the 1990s—should raise productivity sufficiently to more than compensate for the estimated 0.02 percent annual shortfall in productivity caused by climate change.⁷⁴ As Table 2 shows, that should reduce the total population at risk for hunger

in the future significantly more than the largest estimated increase under any scenario for the population at risk for hunger as a consequence of climate change—particularly if the additional investment is targeted toward solving developing countries' current food and agricultural problems that might be exacerbated by warming.

An alternative cost estimate can be derived from the work of the UN Millennium Project, which estimates that somewhere between 5 and 8 percent of the extra funding needed to realize the MDGs would be required to reduce global hunger by 50 percent in 2015.⁷⁵ That works out to less than \$12 billion in 2010 and about \$15 billion in 2015.⁷⁶ For the purpose of this discussion, I will assume \$15 billion per year for the 2010–2015 period.

Current agricultural problems that could be exacerbated by warming and should be the focus of vulnerability-reduction measures include growing crops in poor climatic or soil conditions (e.g., low-soil moisture in some areas, too much water in others, or soils with high salinity, alkalinity, or acidity). Because of warming, such conditions could become more prevalent and agriculture might have to expand into areas with poorer soils, or both. Actions focused on increasing agricultural productivity under current marginal conditions would alleviate hunger in the future whether or not the climate changes.

Similarly, because both CO₂ and temperatures will increase, crop varieties should be developed to take advantage of such conditions.⁷⁷ Progress on these approaches does not depend on improving our skill in forecasting location-specific details of climate change impacts analyses. These focused adaptation measures should be complemented by development of higher-yield, lower-impact crop varieties and improved agronomic practices so that more food is produced per unit acre. That would help reduce hunger while providing numerous ancillary benefits for biodiversity and sustainable development.⁷⁸

Coastal Flooding

According to estimates in the latest IPCC (2007) report, the annual cost of protecting

against a sea level rise of about 0.66 meters in 2100—equivalent to about 0.52 meters in 2085 compared with 0.34 meters under the warmest (A1FI) scenario—would vary from \$2.6 to \$10 billion during the 21st century.⁷⁹ I will assume \$10 billion for the purposes of this paper. Governments could, moreover, discourage maladaptation by refusing to subsidize insurance and/or protective measures that allow individuals to offload private risks to the broader public.

Water Stress

Although, as Table 3 shows, climate change could relieve water stress, there are many measures that would help societies cope with present and future water stress regardless of their cause. Among them are institutional reforms to treat water as an economic commodity by allowing market pricing and transferable property rights to water. Such reforms should stimulate widespread adoption of existing but underused conservation technologies and lead to more private-sector investment in R&D, which would reduce the demand for water by all sectors. For example, new or improved crops and techniques for more efficient use of water in agriculture could enhance agricultural productivity. That would provide numerous ancillary benefits, including reductions in the risk of hunger and pressures on freshwater biodiversity while also enhancing the opportunity for other in-stream uses (e.g., recreation). Notably, diversion of water to agricultural uses might be the largest current threat to freshwater biodiversity.

Improvements in water conservation following such reforms are likely to be most pronounced for the agricultural sector, which is responsible for 85 percent of global water consumption. A reduction of 18 percent in agricultural water consumption would, on average, double the amount of water available for all other uses.⁸⁰

Sustainable Economic Development: A Third Approach

So far I have examined two approaches to address warming through the foreseeable future. The first, mitigation, would reduce

impacts—positive and negative—across the board. That approach entails significant near-term costs, whereas any payoff will be delayed far into the future. The second approach, focused adaptation, would reduce vulnerability to climate-sensitive effects now through 2085 by focusing on individual threats and attacking those threats simultaneously.

However, developing countries are most at risk of climate change not because they will experience greater climate change, but because they lack adaptive capacity to cope with its impacts. Hence, another approach to addressing climate change would be to enhance the adaptive capacity of developing countries by promoting broad development, i.e., economic development and human capital formation, which, of course, is the point of sustainable economic development.⁸¹ Moreover, since the determinants of adaptive and mitigative capacity are largely the same, enhancing the former should also boost the latter.⁸² Perhaps more important, advancing economic development and human capital formation would also advance society's ability to cope with all manner of threats, whether climate related or otherwise.⁸³

One approach to estimating the costs and benefits of sustainable economic development is to examine the literature on the MDGs, which were devised to promote sustainable development in developing countries. The benefits associated with these goals—halving global poverty; halving hunger, halving the lack of access to safe water and sanitation; reducing child and maternal mortality by 66 percent or more; providing universal primary education; and reversing growth in malaria, AIDS/HIV, and other major diseases—would exceed the benefits flowing from the deepest mitigation (see Table 9). Yet, according to the UN Millennium Project, the additional annual cost to the richest countries of attaining the MDGs by 2015 is pegged at about 0.5 percent of their GDP.⁸⁴ That is approximately the same cost as that of the ineffectual, but costly, Kyoto Protocol.

Since focused adaptation would only address the climate-sensitive barriers to sus-

Developing countries are most at risk of climate change not because they will experience greater climate change, but because they lack adaptive capacity to cope with its impacts.

At a cost of less than \$34 billion per year (for 2010–2015), focused adaptation would deliver far greater benefits than would even halting climate change.

tainable economic development (e.g., malaria, hunger, water stress) without necessarily addressing other significant problems (e.g., poverty, access to safe water and sanitation, illiteracy, child and maternal mortality), broad pursuit of sustainable economic development would, not surprisingly, deliver greater benefits but could also cost more than focused adaptation.⁸⁵

Mitigation Versus Adaptation

Table 10 compares for the A1FI (warmest but richest) and the A2 (poorest) emission scenarios, the costs and benefits of two scenarios of mitigation—the Kyoto Protocol and a halt in climate change as of 1990—against two adaptation scenarios, namely, focused adaptation and sustainable economic development. In this table, benefits are provided in terms of

- declines in mortality from hunger, malaria, and coastal flooding,
- changes in net population at risk of water stress,
- progress toward the MDGs, and
- habitat lost to cropland.

This table shows that, at a cost of less than \$34 billion per year (for 2010–2015), focused adaptation would deliver far greater benefits than would even halting climate change. Moreover, it would do so at one fifth the cost of the ineffectual Kyoto Protocol.

Given the sorry track record of external aid over the past few decades—particularly where institutions to bolster economic development, human capital, and technological change are weak and governance is poor—several analysts are skeptical that external aid can ensure sustainable economic development.⁸⁶ As these analysts correctly note, sustainable economic development can rarely, if ever, be imposed or purchased from outside. The necessary institutional changes have to come from within. Nevertheless, according to Table 10, even if the UNMP's target goals are met at only the 20 percent level for whatever reason (e.g., corruption, rosy cost estimates generated by the UN

Millennium Project, overconfidence in chances of success, unforeseen circumstances) the residual benefits would exceed what can be obtained through mitigation, at least through the foreseeable future, and probably at lower cost.

Table 10 doesn't show the differences between the *cumulative* reductions in mortality or population at risk between the present and 2085 due to the two adaptation options relative to the mitigation options. Given that hunger, malaria, and coastal flooding would be responsible for millions of deaths annually between 1990 and 2085, these cumulative reductions ought to be very large indeed,⁸⁷ perhaps in the range of all deaths in wars, genocide, and other atrocities during the 20th century, which one estimate pegs at 231 million people.⁸⁸ Thus, consideration of the cumulative reductions would favor either adaptation approach, because unlike mitigation, adaptation will also reduce present-day climate-sensitive problems in the near-to-medium term, and will start to provide a steady stream of benefits in the very near term. By contrast, because of the inertia of the climate system, the benefits of mitigation will not be significant until decades have elapsed.

Adaptive Management of Climate Change Risks

It has sometimes been argued that it is only fair that present generations expend resources on mitigation now, instead of leaving future generations with a bigger mess and a larger clean-up bill. But as the data presented thus far clearly demonstrates, well-being tomorrow is best enhanced by adaptation, or sustainable development, or both—not by mitigation.

In light of the benefits associated with focused adaptation and sustainable development, the most cost-effective and comprehensive policies to address climate change in the near-to-medium term will eschew direct greenhouse gas emission controls that go beyond “no-regret” policies, that is, policies that would entail no net costs. Instead, poli-

Table 10
Benefits (in 2085) and Costs (~2010-2015) for Mitigation and Adaptation Scenarios

| | AIFI (warmest-but richest) | | | | A2 (poorest) | | | |
|---|----------------------------|------------------------------|--|--|---------------------------|------------------------------|--|--|
| | Mitigation | | Adaptation | | Mitigation | | Adaptation | |
| | Kyoto Protocol after 1990 | No Climate Change after 1990 | Focused Adaptation | Sustainable Economic Development | Kyoto Protocol after 1990 | No Climate Change after 1990 | Focused Adaptation | Sustainable Economic Development |
| Change in mortality from malaria, hunger, and coastal flooding (in thousands)* | -21 | -237 | -1,480 | -1,480 | -51 | -282 | -3,784 | -3,784 |
| Change in mortality relative to baseline (percent) | -1% | -10% | -64% | -64% | -1% | -4% | -60% | -60% |
| Change in net population at risk from water stress (millions) | +83 | +1,192 | Climate change may reduce net population at risk | Climate change may reduce net population at risk | 0 | 0 | Climate change may reduce net population at risk | Climate change may reduce net population at risk |
| Change in population at risk relative to baseline (percent) | +5% | +72% | | | | | | |
| Progress toward Millennium Development Goals | Almost none | Some | Substantial | Should be met | Almost none | Some | Substantial | Should be met |
| <ul style="list-style-type: none"> ● 50% reduction in poverty ● 67-75% reduction in child & maternal mortality rates ● 50% improvement in access rates for safe water and sanitation ● 100% reduction in illiteracy | | | | | | | | |
| Available habitat (as measured by extent of global cropland) | Small decrease | Larger decrease | Some increase | Some increase | NA | NA | NA | NA |
| Annual costs | ~\$165 billion | >> \$165 billion | <\$34 billion | ~\$165 billion | ~\$165 billion | >> \$165 billion | <\$34 billion | ~\$165 billion |

Sources: Tables 3, 6 and 7; and I. M. Goklany, "A Climate Policy for the Short and Medium Term: Stabilization or Adaptation?" *Energy & Environment* 16 (2005): 667-80.

Policymakers should strengthen the institutions necessary to advance economic growth, human capital, and the propensity for technological change.

cymakers should work to enhance adaptation and promote economic development.

First, policymakers should work toward increasing adaptive capacity, particularly in developing countries, by promoting efforts to reduce vulnerability to today's urgent climate-sensitive problems—malaria, hunger, water stress, flooding, and other extreme events—that might be exacerbated by climate change.⁸⁹ The technologies, human capital, and institutions that will need to be strengthened or developed to accomplish this will also be critical in addressing these very problems in the future if and when they are aggravated by climate change. Increasing adaptive capacity might also increase the level at which GHG concentration would need to be stabilized to “prevent dangerous anthropogenic interference with the climate system,” which is the stated “ultimate objective” of the UN Framework Convention on Climate Change.⁹⁰ Alternatively, increasing adaptive capacity could postpone the deadline for stabilization. In either case, it could reduce the costs of meeting the ultimate objective.

Second, policymakers should strengthen or develop the institutions necessary to advance and/or reduce barriers to economic growth, human capital, and the propensity for technological change. Doing so would improve both adaptive and mitigative capacities, as well as the prospects for sustainable development.⁹¹

Third, policymakers should implement no-regret mitigation measures now, while expanding the range and diversity of future no-regret options. The latter could be advanced by research and development to improve existing—and develop new—technologies that would reduce atmospheric greenhouse gas concentrations more cost-effectively than currently possible. Should new information indicate that more aggressive mitigation action is necessary, future emission reductions might then be cheaper, even if they have to be deeper to compensate for a delay in a more aggressive response in the short term.

Fourth, policymakers should allow the market to run its course in implementing no-regret (i.e., no-cost) options. Among other things, that implies reducing subsidies that

directly or indirectly increase energy use, land clearance, coastal development, and other activities that contribute to greater greenhouse gas emissions or climate change damages.

As part of this effort, OECD nations should also reduce, if not eliminate, agricultural subsidies and barriers to trade. Not only are such subsidies and barriers expensive for consumers in OECD nations, they damage the economies and well-being of many developing nations whose economies and employment are dominated by the agricultural sector.⁹²

Ironically, one of the arguments advanced for rapid reductions in greenhouse gases is that it would help developing countries who are considered to be least able to cope with climate change because they currently lack the necessary economic and human capital to implement adaptive technologies. Reducing such subsidies would go some way toward relieving a major reason of concern for climate change.

Fifth, policymakers should develop a more robust understanding of the science, impacts, and policies of climate change in order to develop response strategies that would forestall “dangerous” impacts of climate change (per Article 2 of the UN Framework Convention on Climate Change) while at the same time advancing human well-being.

Sixth, policymakers should monitor the impacts of climate change to give advance warning of “dangerous” impacts and, if necessary, to rearrange priorities should the adverse impacts of warming on human and environmental well-being occur faster, threaten to be more severe, or threaten to be more likely than is currently projected.

Together, these policies constitute an adaptive management approach to addressing climate change that would help solve today's urgent problems while bolstering our ability to address tomorrow's climate change challenge.

Conclusion

Climate change is not now—nor is it likely to be for the foreseeable future—the most

important environmental problem facing the globe, unless present-day problems such as hunger, water-related diseases, lack of access to safe water and sanitation, and indoor air pollution are reduced drastically. Otherwise, with respect to human well-being, it will continue to be outranked by these other problems and, with respect to environmental well-being, by habitat loss and other threats to biodiversity.

Through 2085, human well-being is likely to be highest under the richest-but-warmest (A1FI) scenario and lowest for the poorest (A2) scenario. Matters may be best in the A1FI world for some critical environmental indicators through 2100, but not necessarily for others. Either focused adaptation or broad pursuit of sustainable development would provide far greater benefits than even the deepest mitigation—and at no greater cost than that of the barely effective Kyoto Protocol.

For the foreseeable future, people will be wealthier—and their well-being higher—than is the case for present generations both in the developed and developing worlds and with or without climate change. The well-being of future inhabitants in today's developing world would exceed that of the inhabitants of today's developed world under all but the poorest scenario. Future generations should, moreover, have greater access to human capital and technology to address whatever problems they might face, including climate change. Hence the argument that we should shift resources from dealing with the real and urgent problems confronting present generations to solving potential problems of tomorrow's wealthier and better positioned generations is unpersuasive at best and verging on immoral at worst.

Equally important, resources expended on solving today's climate-sensitive problems and advancing sustainable economic development will build human capital, advance technology, and enhance the adaptive and mitigative capacities of future generations.

If one believes that developed countries have a moral and ethical obligation to deal

with climate change, that obligation cannot, and should not, be met through aggressive emission reductions at this time—"cannot" because the planet is already committed to some climate change—and "should not" because the threats that climate change would exacerbate can be reduced more effectively, not to mention more economically, through focused efforts to reduce vulnerability or through broader efforts to advance economic development. Any such obligation is best discharged through efforts to reduce present-day vulnerabilities to climate-sensitive problems that are urgent and could be exacerbated by climate change.

Notes

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1. Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2001: Impacts, Adaptation, and Vulnerability* (Cambridge, MA: Cambridge University Press, 2001). See also Samuel Hitz and Joel Smith, "Estimating Global Impacts from Climate Change," *Global Environmental Change* 14, no. 1 (2004): 201–218.

2. William J. Clinton, *State of the Union Address* (1999), <http://www.washingtonpost.com/wp-svr/politics/special/states/docs/sou99.html>; and Cordis News, "Reducing Global Warming Is Our Priority, Say Chirac and Blair," November 19, 2004, on file with author.

3. Martin L. Parry (ed.), *Global Environmental Change: Special Issue: An Assessment of the Global Effects of Climate Change under SRES Emissions and Socio-Economic Scenarios* 14, no. 1 (2004): 1–99.

4. See, for example, Nigel W. Arnell et al., "The Consequences of CO₂ Stabilization for the Impacts of Climate Change," *Climate Change* 53 (2002): 413–46.

5. Irene Lorenzoni and W. Neil Adger, "Critique of Treatment of Adaptation Costs in PAGE and FUND Models," in *Spotlighting Impacts Functions in Integrated Assessment*, ed. Rachel Warren et al., Tyndall Centre for Climate Change Research Working Paper no. 91, September 2006, p. 74 (pre-

If one believes in a moral and ethical obligation to deal with climate change, that obligation cannot be met through aggressive emission reductions at this time.

- pared for the *Stern Review on the Economics of Climate Change*.)
6. Indur M. Goklany, "Integrated Strategies to Reduce Vulnerability and Advance Adaptation, Mitigation, and Sustainable Development," *Mitigation and Adaptation Strategies for Global Change*, doi: 10.1007/s11027-007-9098-1 (2007).
 7. The Fast-Track Assessment (FTA) results for the impacts of climate change on food, agriculture, water resources and coastal flooding were a prominent part of a 2005 UK government-sponsored symposium staged as part of the run-up to the 2005 Gleneagles Summit of the G-8. See U.K. Department of Environment, Food and Rural Affairs (DEFRA), *Symposium on Avoiding Dangerous Climate Change* (Exeter, UK, February 1–3, 2005), <http://www.stabilisation2005.com/programme.html>; as well as the more recent *Stern Review on the Economics of Climate Change* (2006). Prior to that, Her Majesty's chief science adviser Sir David King's (2004) claim that "climate change is the most severe problem that we are facing today—more serious even than the threat of terrorism" was based, in part, on older FTA estimates which were published in another special issue of *Global Environmental Change*. See Indur M. Goklany and David A. King, "Climate Change and Malaria," letter to the editor, *Science* 306 (2004): 55–57. The older FTA results were published in Martin L. Parry and Matthew Livermore, eds., "A New Assessment of the Global Effects of Climate Change," *Global Environmental Change* 9, S1–S107 (1999). Results of that FTA were used in the IPCC's 2001 assessment, while the current FTA results have been reported extensively in the latest IPCC assessment. See IPCC, "Summary for Policymakers," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, www.ipcc.ch/SPM13apr07.pdf.
 8. DEFRA, *Scientific and Technical Aspects of Climate Change, Including Impacts and Adaptation and Associated Costs* (September 2004), www.defra.gov.uk/environment/climatechange/pdf/cc-science-0904.pdf; J. M. Gregory et al., "A Model Intercomparison of Changes in the Atlantic Thermohaline Circulation in Response to Increasing Atmospheric CO₂ Concentration," *Geophysical Research Letters* 32: L12703, doi: 10.1029/2005GL023209; and IPCC, *Climate Change Impacts, Vulnerability, and Adaptation*.
 9. Stern Review, p. x.
 10. *Ibid.*, pp. 156, 158.
 11. See Ian Byatt et al., "The Stern Review: A Dual Critique, Part II: Economic Aspects," *World Economics* 7, no. 4 (2006): 199–229; Robert M. Carter et al., "The Stern Review: A Dual Critique, Part I: The Science," *World Economics* 7, no. 4 (2006): 167–98; William Nordhaus, *The Stern Review on the Economics of Climate Change*, 2006, <http://www.nordhaus.econ.yale.edu/SternReviewD2.pdf>; Richard S. J. Tol and Gary Yohe, "A Review of the Stern Review," *World Economics* 7, no. 4 (October–December 2006); and Robert O. Mendelsohn, "A Critique of the Stern Report," *Regulation* 29, no. 4 (2006): 42–46.
 12. Stern Review, p. 2.
 13. IPCC, *Special Report on Emissions Scenarios* (New York, Cambridge University Press, 2000).
 14. Nigel W. Arnell et al., *Global Environmental Change* 14, no. 1 (2004): 3–20.
 15. The "FI" in "A1FI" indicates that this scenario is fossil fuel intensive.
 16. Arnell et al., *Global Environmental Change*.
 17. Martin L. Parry et al., "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2004): 53–67; Nigel W. Arnell, "Climate Change and Global Water Resources: SRES Emissions and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2004): 31–52; Robert J. Nicholls, "Coastal Flooding and Wetland Loss in the 21st Century; Changes under the SRES Climate and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1 (2006): 69–86; and M. van Lieshout et al., "Climate Change and Malaria: Analysis of the SRES Climate and Socio-Economic Scenarios," *Global Environmental Change* 14, no. 1(2004): 87–99.
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 20. Goklany, "Strategies to Enhance Adaptability," Goklany, "Integrated Strategies"; G. Yohe, "Mitigative Capacity"; and B. Smit et al., "Adaptation to Climate Change."

21. Indur M. Goklany, "Affluence, Technology and Well-Being," *Case Western Reserve Law Review* 53 (2002): 369-90.
22. Indur M. Goklany, *The Improving State of the World: Why We're Living Longer, Healthier, More Comfortable Lives on a Cleaner Planet* (Washington: Cato Institute, 2007). One indicator that, so far at least, has not shown an improvement with wealth is total CO₂ emissions. Also, some environmental indicators, e.g., air pollutants such as sulfur dioxide and particulate matter, generally worsen initially as incomes increase before declining at higher income levels. See N. Shafik, "Economic Development and Environmental Quality: An Econometric Analysis," *Oxford Economic Papers* 46 (1994): 757-73; Gene E. Grossman, and Alan B. Krueger, "Economic Growth and the Environment," *Quarterly Journal of Economics* 110, no. 2 (1995): 353-77; and S. Dasgupta et al., "Environment during Growth: Accounting for Governance and Vulnerability," *World Development* 34, (2006): 1597-1611.
23. Indur M. Goklany, "Saving Habitat and Conserving Biodiversity on a Crowded Planet," *BioScience* 48 (1998): 941-53; and Rhys E. Green et al., "Farming and the Fate of Wild Nature," *Science* 307 (2005): 550-55.
24. Goklany, *Improving State*.
25. Goklany, "Integrated Strategies."
26. Goklany, *Improving State*; and US Bureau of the Census, *Historical Statistics of the United States: Colonial Times to 1970* (Washington: Government Printing Office, 1975), p. 77.
27. Goklany, *Improving State*; and World Bank, *World Development Indicators 2002, CD-ROM*.
28. See, for example, Parry et al., "Effects of Climate Change," p. 57. Generally, the adaptation technologies available in these studies are from the early 1990s or earlier vintages. Thus the food and hunger study doesn't include consideration of adaptations that may be possible through genetically modified crops.
29. Since 1920, U.S. wheat and corn yields have tripled and quintupled, respectively, partly, if not largely, due to technological changes. See National Agricultural Statistics Service (NASS), "USDA-NASS Quick Stats," http://www.nass.usda.gov:8080/QuickStats/PullData_US.jsp. Similarly, total cereal yields have multiplied by 2.5 in the developing countries since 1961. See Food and Agriculture Organization of the United Nations (FAO), *The State of Food Insecurity 2004* (Rome: FAO, 2004). Much of these improvements would not be captured using the methodology used in the FTA.
30. Parry et al., "Effects of Climate Change."
31. S. P. Long et al., "Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO₂ Concentrations," *Science* 312 (2006): 1918-21; and Parry et al., "Effects of Climate Change."
32. Long et al., "Food for Thought."
33. Francesco N. Tubiello, et al., "Crop Response to Elevated CO₂ and World Food Supply: A Comment on 'Food for Thought ...' by Long et al.," *Science* 312 (2006)," *European Journal of Agronomy* 26, no. 3 (2006): 215-23. See Carter et al., "The Stern Review: A Dual Critique."
34. Parry et al., "Effects of Climate Change."
35. Goklany, *Improving State*; and A. Ligi and J. Kaskey, "Monsanto, BASF to Spend \$1.5 Billion on Biotech Seeds," Update 6, Bloomberg.com, March 21, 2007.
36. Parry et al., "Effects of Climate Change."
37. Indur M. Goklany, "Relative Contributions of Global Warming to Various Climate Sensitive Risks, and Their Implications for Adaptation and Mitigation," *Energy & Environment* 14, no. 6 (2003): 797-822.
38. Arnell, "Climate Change and Global Water Resources," also uses the "10-year return period minimum annual runoff" as a measure of water availability. Even under this variation, climate change relieves water stress in 2085 (compared to the "no-climate-change" condition). Hence, those results are not shown.
39. Indur M. Goklany, "A Climate Policy for the Short and Medium Term: Stabilization or Adaptation?" *Energy & Environment* 16, no. 3-4 (2005): 667-80.
40. The high coastal population growth scenario assumes that coastal population grows twice as fast as the general population, or, if populations are projected to drop, it drops at half the pace of the general population. See Nicholls, "Coastal Flooding and Wetland Loss," Table 6.
41. *Ibid.*, p. 74.
42. Goklany, *Improving State*.
43. Van Lieshout et al., "Climate Change and Malaria."
44. This author contacted various coauthors of the van Lieshout et al. paper to obtain their results for populations at risk with and without climate change, but to no avail.

45. P. Martens et al., "Climate Change and Future Populations at Risk from Malaria," *Global Environmental Change* 9 (1999): S89-S107, and Arnell, et al., "Consequences of CO₂ Stabilization."
46. Mike Hulme et al., "Climate Change Scenarios for Global Impact Studies," *Global Environmental Change* 9 (1999): S3-S19.
47. Martin L. Parry et al., "Viewpoint. Millions at Risk: Defining Critical Climate Change Threats and Targets," *Global Environmental Change* 11 (2001): 181-83.
48. Goklany, "Climate Policy."
49. See Paul Reiter, "From Shakespeare to Defoe: Malaria in England in the Little Ice Age," *Emerging Infectious Diseases* 6 (2000): 757-73; A. Murray Fallis, "Malaria in the 18th and 19th Centuries in Ontario," *Canadian Bulletin of Medical History* 1, no. 2 (1984): 25-38; and Ken Watson, "History of the Rideau Lockstations: Malaria on the Rideau," <http://www.rideau-info.com/canal/history/locks/malaria.html>.
50. Goklany, *Improving State*.
51. Richard S. J. Tol, and Hadi Dowlatabadi, "Vector Borne Diseases, Development and Climate Change," *Integrated Assessment* 2 (2001): 173-81.
52. Goklany, "Saving Habitat."
53. Nicholls, "Coastal Flooding and Wetland Loss," pp. 69-86.
54. *Ibid.*, p. 76.
55. Jonathan A. Patz et al., "Impact of Regional Climate Change on Human Health," *Nature* 438, no. 7066 (2005): 310-17.
56. Anthony J. McMichael et al., "Global Climate Change," in *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors* (Geneva: World Health Organization [WHO], 2004), p. 1546. Emphasis added.
57. WHO, *World Health Report 2002* (Geneva: WHO, 2002).
58. This estimate excludes an estimated 0.51 million people who died from malaria but whose deaths were attributed to underweight in the report. See *ibid.*
59. See also Goklany, *Improving State*.
60. This assumption is necessary because mortality data for hunger and malaria are not readily available for 1990. According to FAO, *The State of Food Insecurity 2004*, the number of people suffering from chronic undernourishment in the developing countries was virtually unchanged between 1990 and 1992 and between 2000 and 2002 (going from 824 million to 815 million in developing countries between those two periods). According to WHO, *World Health Report 1995* (Geneva: WHO, 1995), malaria killed 2 million in 1993 (compared to 1.12 million in 2001). I will use the 1.12 million figure for 1990. Thus, to the extent the ratio of deaths-to-population at risk may have declined between 1990 and 2001, future deaths due to malaria would be underestimated. Finally, there were 7,100 fatalities due to floods, windstorms and waves/surges in 1990 and an average of 7,500 for 2000-2004 (excluding deaths due to the Christmas tsunami of 2004). Table 7 assumes: (a) an estimate of 8,000 deaths in 1990 due to these extreme weather event categories, and (b) all deaths for these categories are due to coastal flooding. Thus Table 7 underestimates the relative importance of malaria compared to the other threats, while overestimating future deaths due to coastal flooding. Figures regarding flood-related deaths come from *EM-DAT: The OFDA/CRED International Disaster Database*, www.em-dat.net, Université Catholique de Louvain, Brussels, Belgium.
61. Most integrated assessment models—Nordhaus' RICE/DICE, Manne et al.'s MERGE and Tol's FUND—assume that the impacts of climate change are linear or quadratic functions of global temperature increases (ΔT), whereas Hope's PAGE assumes that impact functions (I) take the form of a polynomial such that $I = \text{constant} \times T^n$, where n is an uncertain variable whose minimum, most likely and maximum values are 1, 1.3, and 3 respectively. Thus, for the purpose of this analysis, assuming that impacts depend on the square of temperature change would seem to be conservative. Rachel Warren et al., *Understanding the Regional Impacts of Climate Change*, Tyndall Centre Working Paper no. 90, 2006 (research report prepared for the Stern Review), http://www.tyndall.ac.uk/publications/working_papers/twp90.pdf.
62. Stern Review, Executive Summary, p. x.
63. *Ibid.*, pp. 156 and 158.
64. Qualitatively, results for the fourth scenario are no different from those shown for the three scenarios in Table 9.
65. Goklany, "Climate Policy."
66. T. M. L. Wigley, "The Kyoto Protocol: CO₂, CH₄ and Climate Implications," *Geophysical Research Letters* 25 (1998): 2285-88.
67. IPCC, *Climate Change 2001: Synthesis Report* (New

- York: Cambridge University Press, 2001), estimates that in 2010 the Protocol could cost between 0.1 and 2.0 percent of the GDP of Annex I countries. I will assume that its cost is 0.5 percent of their cumulative GDP, which is at the lower end of this range. This translates to \$165 billion (in 2003 dollars). See Goklany, "Climate Policy."
68. Goklany, "Climate Policy."
69. Goklany, "Strategies to Enhance Adaptability."
70. Indur M. Goklany, "Potential Consequences of Increasing Atmospheric CO₂ Concentration Compared to Other Environmental Problems," *Technology* 7S (2000): 189–213, Goklany, "Integrated Strategies"; and UN Millennium Project (UNMP), *Investing in Development: A Practical Plan to Achieve the Millennium Development Goals* (New York: EarthScan and UNMP, 2005).
71. UNMP, *Investing in Development*.
72. UNMP, *Coming to Grips with Malaria in the New Millennium, Task Force on HIV/AIDS, Malaria, TB, and Access to Essential Medicines*, Working Group on Malaria, 2005.
73. *World Health Report 1999* (Geneva: WHO, 1999), chap. 4; and *ibid.*
74. Goklany, "Climate Policy."
75. Calculated using UNMP, *Halving Hunger: It Can Be Done*, Task Force on Hunger (London: EarthScan and UNMP, 2005), p. 18.
76. UNMP, *Halving Hunger*; and UNMP, *Investing in Development*.
77. Goklany, "Integrated Strategies," and Goklany, *Improving State*.
78. Goklany, "Saving Habitat."
79. See figure 6.10 from IPCC, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter6.pdf>, (attributed to Richard S. J. Tol, "The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of FUND," *Mitigation Strategies for Global Change*, forthcoming; and Virginia Burkett, Testimony before the Commerce on Science and Technology, United States House of Representatives, April 17, 2007, http://democrats.science.house.gov/Media/File/Comm_docs/hearings/2007/full/17apr/burkett_testimony.pdf).
80. Goklany, "Climate Policy."
81. Goklany, "Strategies to Enhance Adaptability," and Goklany, "Integrated Strategies."
82. Goklany, "Integrated Strategies."
83. Goklany, "Potential Consequences."
84. UNMP, *Investing in Development*.
85. In the long run, it could be argued that economic development should pay for itself.
86. William R. Easterly, *The White Man's Burden: Why the West's Efforts to Aid the Rest Have Done So Much Ill and So Little Good* (New York: Penguin Press, 2006).
87. Table 7 suggests that annual aggregate deaths due to malaria, hunger, and flooding could range from 4.4 million in 1990 to between 2 and 6 million in 2085.
88. Milton Leitenberg, "Deaths in Wars and Conflicts in the 20th Century," Cornell University Peace Studies Program, Occasional Paper no. 29, 3rd ed., 2006, http://www.einaudi.cornell.edu/peaceprogram/publications/occasional_papers/Deaths-Wars-Conflicts3rd-ed.pdf.
89. Goklany, "Strategies to Enhance Adaptability," and Goklany, "Climate Policy."
90. Article 2 of the UN Framework Convention on Climate Change (UNFCCC) specifies that its "ultimate objective . . . is to achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." See: United Nations, United Nations Framework Convention on Climate Change, <http://unfccc.int/resource/docs/convkp/conveng.pdf>.
91. Goklany, "Strategies to Enhance Adaptability"; Goklany, "Potential Consequences"; and Goklany, "Integrated Strategies."

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