

IS A RICHER-BUT-WARMER WORLD BETTER THAN POORER-BUT-COOLER WORLDS?

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ABSTRACT

Greater economic growth could lead to greater greenhouse gas emissions, while simultaneously enhancing various aspects of human well-being and the capacity to adapt to climate change. This begs the question as to whether and, if so, for how long would a richer-but-warmer world be better for well-being than poorer-but-cooler worlds. To shed light on this issue, this paper draws upon results of the “Fast Track” assessment (FTA) reported in a special issue of *Global Environmental Change: Part A* 14 (1): 1–99 (2004), which employed the IPCC’s emissions scenarios to project future climate change and its global impacts on various determinants of human and environmental well-being. Results suggest that notwithstanding climate change, through much of this century, human well-being is likely to be highest in the richest-but-warmest (A1FI) world and lower in poorer-but-cooler worlds. With respect to environmental well-being, matters may be best under the A1FI world for some critical environmental indicators through 2085–2100, but not necessarily for others. An alternative analysis using the Stern Review’s worst-case results for potential welfare losses due to climate change indicates that welfare, adjusted for market and non-market impacts of climate change and the risk of catastrophe, should be highest under the A1FI scenario, at least through 2100.

1. INTRODUCTION²

One of the conundrums facing the world, which should be addressed in the course of developing climate change policies, is whether, and, if so, for how long, would a richer-but-warmer world be better for human and environmental well-being than a poorer-but-cooler world. This conundrum arises because, unless climate change is modest (IPCC, 2001a; Hitz and Smith, 2004), greater economic growth could, by increasing greenhouse gas (GHG) emissions, lead to greater damages from climate

¹Views expressed in this paper are the author’s, and not necessarily those of any unit of the U.S. government.

²This paper is a modified version of a paper with the same name presented at the 25th North American Conference of the USAEE/IAEE, Denver, CO, September 18–21, 2005.

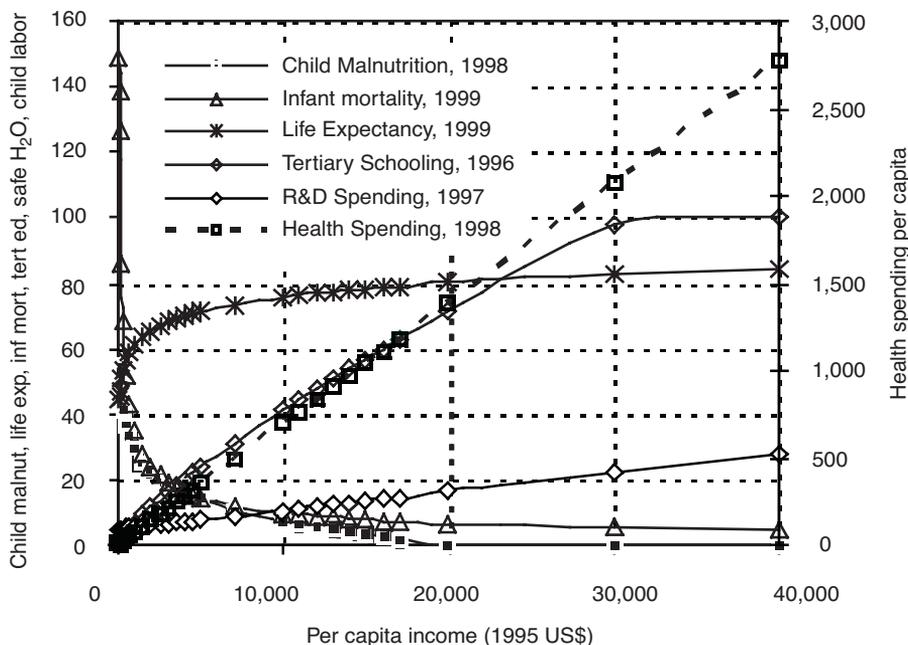


Figure 1: Dependence of various indicators of human well-being on per capita income for the late 1990s. Child malnutrition measured as % of children <5 years with subnormal height, infant mortality is in deaths per 1,000 live births, life expectancy is in years, “tert ed” measures enrollment in tertiary schools (as % of eligible population), R&D spending is in terms of % of GDP, health spending is in 1998 US\$ per capita. Sources: Goklany (2002a, 2007a), based on data from various years of the World Bank’s World Development Indicators.

change. On the other hand, by increasing wealth, technological development and human capital, economic growth would broadly increase human well-being (Goklany, 2002a), and society’s capacity to reduce climate change damages via adaptation or mitigation (Goklany, 1995, 2007a; Yohe, 2001; Smit et al., 2001).

Specifically, 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, a surrogate for both per capita income and wealth (or “affluence”) (see Figure 1; Goklany, 2002a). Improvements in these determinants are associated with increased human capital and should aid technological diffusion.

Increasing wealth would also improve some, though not necessarily all, indicators of environmental well-being, e.g., wealthier nations have higher cereal yield (an important determinant of cropland, which is inversely related to habitat conversion), greater access to safe water and sanitation, and lower birth rates (see Figure 2; Goklany, 2002a, 2007a).³ Notably, access to safe water and access to

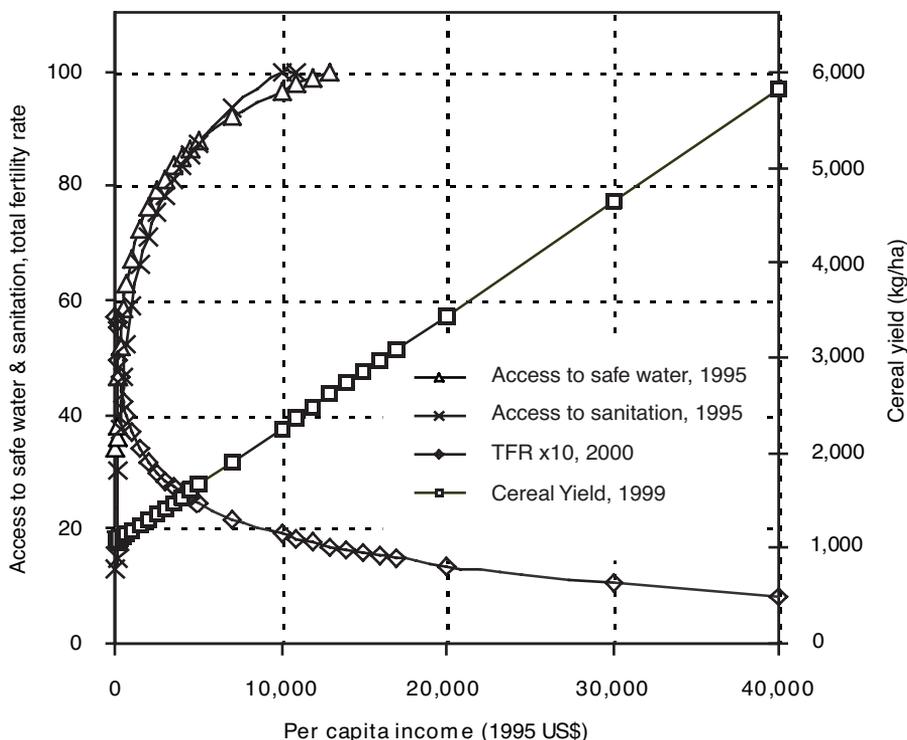


Figure 2: Dependence of various indicators of environmental well-being on the level of economic development (for the late 1990s). Sources: Goklany (2002a, 2007a), based on data from various years of the World Bank’s World Development Indicators and WRI (2000).

sanitation double as indicators of both human and environmental well-being, as does cereal yield since higher yield means more food and lower hunger (in addition to lower pressure on habitat; Goklany, 1998; Green et al., 2005).

Cross country data also indicate that at any given level of economic development, the previously-noted 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, which itself is a surrogate for advances in, and diffusion of, technology (Goklany, 2002a, 2007a). Figure 3 illustrates this time-dependent (or secular) improvement for two of the most important indicators of human well-being, namely, life expectancy and infant mortality. Thus one should expect, *ceteris paribus*, that society’s adaptive capacity should also increase with the passage of time which, barring inadvertent maladaptation, should reduce the future impacts of climate change (Goklany, 2007a).

³One indicator that, so far at least, has not shown an improvement with wealth is 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 Goklany, 2002a, and references therein).

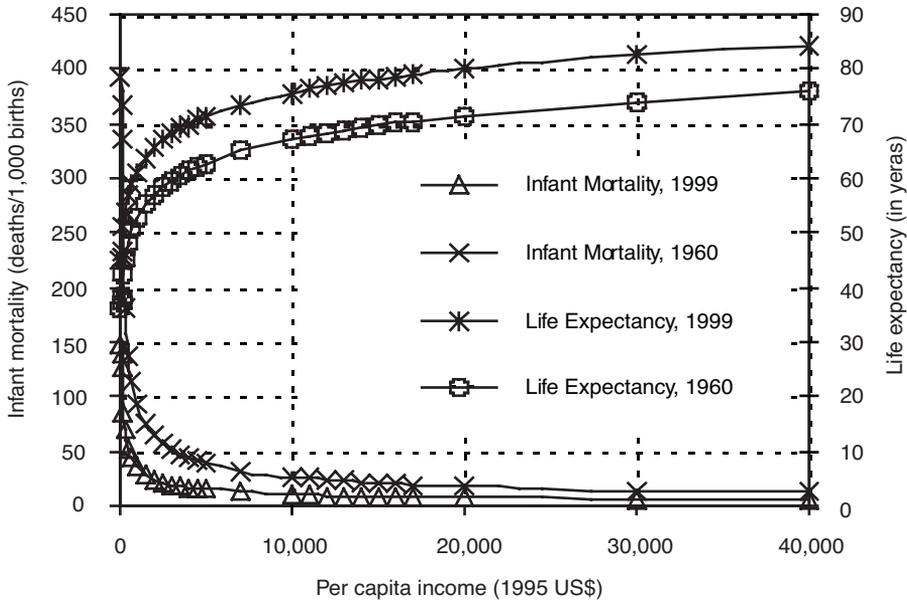


Figure 3: Secular (time-dependent) improvements in life expectancy & infant mortality due to technological change (from 1960 to 1999). Sources: Goklany (2002a, 2007a), based on World Bank (2001).

1.1. Which Emissions Pathways Are To Be Preferred?

Nowadays most assessments of the impacts of climate change use, as a starting point, emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC, 2000). Table 1 summarizes the dominant characteristics of the “storylines” associated with these scenarios (IPCC, 2000) and corresponding estimates in 2085 of atmospheric CO₂ concentrations and climate change used by the “Fast Track” assessment (FTA) of the global impacts of climate change sponsored by the U.K. Department of Environment, Forests and Rural Affairs (DEFRA). In Table 1, climate change is represented by increases in globally averaged temperature (Arnell, 2004; Arnell et al., 2004). The columns in this, and subsequent, tables are arranged from left to right in the order of decreasing CO₂ concentrations (and global temperature changes), that is, A1FI, A2, B2 and B1.⁴

Note that although the IPCC scenarios were intentionally devised as “no policy” scenarios which presumed no pro-active measures to mitigate or adapt to climate change, many analysts, pointing to the differences in emissions between the various scenarios, claim that “we can choose our emissions futures” (Schneider 2007). In a similar vein, Hayhoe et al., (2004) writing in the *Proceedings of the National Academy of Sciences* note

⁴The “FI” in “A1FI” indicates that this scenario is fossil fuel intensive.

Table 1: Characteristics and assumptions for the 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 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

Note: Global temperature change is based on the HadCM3 model. Sources: Arnell et al., (2004), Tables 1, 6, 7; Arnell (2004), Table 1. The baseline (1990) GDPs per capita for developed and developing countries were \$13,700 and \$900, respectively (IPCC, 2000: 301).

that, “The magnitude of future climate change depends substantially on the greenhouse gas emission pathways we choose,” before proceeding to explore the implications of the highest and lowest IPCC emissions pathways and associated impacts in California. Likewise, Gerald Meehl (2007), in recent testimony to the Committee on Science and Technology, United States House of Representatives, notes that “As we approach the middle part of the 21st century and beyond, it makes a difference regarding what emissions scenario we choose to follow now” before elaborating on the differences in projected impacts under the various IPCC scenarios. The implication of these statements is that the A1FI scenario, being the warmest, is something humanity should avoid, if possible. In fact, it could be argued that much of the worldwide activity designed to reduce greenhouse gas emissions is about “how human society might be *steered* towards preferred socio-economic development paths (e.g., building on the logic of the IPCC SRES B1 scenario)” (IPCC 2001c: 3; emphasis added).

Other analysts may, however, argue that it is not for the global community to choose from A1FI, A2, B2, and B1 scenarios, that we do not know which of these scenarios will unfold although it may be argued that some of these scenarios are more likely than others. Theoretically, the differences between the scenarios reflect uncertainties about the future development paths for human society and the economy, rather than conscious choices about which path is preferable or which policies to implement. These analysts would point out that the scope for pro-active human intervention lies within each of the scenarios not by choosing between them. But the reality seems to be that the notion that

well-being would be worse in a richer-but-warmer world is, in fact, prompting governments and other institutions to “steer” the world toward the lower emission scenarios as evidenced, for example, by the recent pronouncements at the G8 Summit (2007) and statements made by President Bush and Secretary General Ban Ki-moon (Knowlton, 2007; United Nations News Centre, 2007).⁵ Accordingly, this paper will investigate whether human and environmental well-being will necessarily be worst under the richest-but-warmest of the four worlds characterized by the IPCC’s scenarios, while recognizing that given the current state of knowledge, definitive answers are unlikely at this time. The answer will also shed light on the propriety of “steering” the world toward the lower emissions scenarios if that would also mean lower economic development. However, the analysis undertaken here doesn’t tell us whether, how much or what mitigation and adaptation activities should be undertaken to maximize welfare. Such an analysis is outside the scope of this paper.

1.2. The Approach Used in this Paper

This paper draws mainly upon peer-reviewed results of the DEFRA-sponsored “Fast Track” assessment (FTA) of the global impacts of climate change reported in a special issue of *Global Environmental Change Part A* (volume 14, issue 1, pp. 1–99, 2004). It then uses, as a check, results from the recent Stern Review of the economics of climate change (Stern Review 2006).

With respect to hazards affecting human well-being, the FTA analyzed hunger (Parry et al., 2004), water stress (Arnell, 2004), coastal flooding (Nicholls 2004), and malaria (van Lieshout et al., 2004). With respect to environmental well-being, the FTA projected net biome productivity (a measure of the strength of the terrestrial biosphere as a carbon sink), and the global extent of coastal wetlands and croplands (Levy et al., 2004). For the most part, global climate change impacts were estimated through 2085 or 2100. 2085 is probably at the outer limit of the foreseeable future since socioeconomic scenarios are not deemed credible beyond that (Arnell et al., 2002).

Like the FTA, this paper does not consider low-probability but potentially high-consequence outcomes such as a shut down of the thermohaline circulation or the melting of the Greenland and Antarctica Ice Sheets. They are deemed unlikely to occur during this century (see, e.g., DEFRA, 2004; IPCC, 2007).

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, since economic development and the rate of technological change are both critical determinants of adaptive capacity (Goklany, 1995, 2007a; Smit et al., 2001; Yohe 2001), these impacts ought to be attenuated through a combination of autonomous and pro-active adaptations. Considering future levels of economic and technological development (see Table 1), this attenuation should be greatest for the A1FI scenario,

⁵This highlights a fundamental problem with static scenarios purporting to follow specific paths over decades (or longer) regardless of whatever problems and hurdles may be encountered in the future. They assume fatalist human beings. Although this might facilitate paper analyses, they do not reflect real world behavior, as recent events abundantly reveal.

followed by the B1, B2 and A2 scenarios, in that order. Thus, it is not obvious that although the A1FI scenario has the highest climate change, it would necessarily have the highest damages from climate change (because A1FI should also have the highest adaptive capacity).

It has been sometimes argued that the extent to which economic growth increases society's (or another entity's) capacity to reduce climate change damages via adaptation or mitigation, this capacity would depend considerably on the distribution of the determinants of human well being (such as economic growth) between and within countries. For example, if economic growth is concentrated on countries that are already wealthy, as sometimes has been claimed to be the case in recent decades, then today's poorer countries' ability to reduce future climate impacts (due to higher adaptive capacity because of economic growth) could be seriously overestimated.

While there is some merit to this argument, it should be noted that in the recent past, economic growth in some of the most populous developing countries (e.g., China and India) has outstripped that in developed countries. As a result, income inequalities have, for the world population as a whole, shrunk around the world (Sala-i-Martin, 2007; Bhalla, 2002), as have inequalities between developing and developed countries since the 1950s *in terms of determinants of human well-being*.⁶ More importantly, according to the IPCC scenarios, between 1990 and 2100 income growth in developing countries relative to developed countries will be greater by a factor of 3.6 to 9.4 (IPCC, 2000: 301). Secondly, an examination of Figures 1 and 2 indicates that the dependence of virtually all determinants of human well-being on income is highly non-linear (generally logarithmic) with their improvements occurring much more rapidly at the lowest levels of income (Goklany, 2007a). Thus even a small improvement in income for poor societies (or the poor within a country) could enhance their adaptive capacity more than a larger increase for richer societies (or the rich). Thirdly, over the long haul (say, 50 to 100 years), secular improvements in technology could dominate over increases in income with respect to enhancing adaptive capacity, particularly at low income levels (see Figure 3). The long term impact of technological change is one reason for 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) (Goklany, 2007b: 153; USBC, 1975: 77).

Therefore, keeping these considerations in mind, the question must be asked: over the foreseeable future, would the benefits of a richer and more technologically advanced world be cancelled out by the costs of a warmer world?

The FTA's results, which this paper uses to help answer this question, are like all other estimates of the impacts of climate change plagued with uncertainties resulting from, among other things, the fact that such estimates are based on a series of linked models with the uncertain output of each model serving as the input for the next model. The first link in the chain of models are emission models which use socioeconomic assumptions extending 100 or more years into the future to generate emission scenarios (see Table 1).

⁶For a more nuanced discussion, see Goklany (2007b: Chapter 3).

This information is then converted into radiative forcing which is fed into coupled atmosphere-ocean general circulation models (AOGCMs) to estimate spatial and temporal changes in climatic variables which are, then, used as inputs to simplified and often inadequate biophysical models that project location-specific biophysical changes (e.g., crop or timber yields). Notably, the uncertainty of estimates of climatic changes increases as the scale at which they have to be specified becomes finer. This is particularly true for precipitation, which is a key determinant of the natural resources (e.g., water and vegetation) that human beings and all other living species depend on either directly or indirectly. Unfortunately, the analyses should be done at relatively fine scales because the distribution and status of these natural resources are spatially heterogeneous (as are the socioeconomic factors that would determine “spontaneous” responses to the impacts of climate change).

Next, 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. A major shortcoming of impacts assessments is that the models used at this step do not fully incorporate changes in adaptive capacity due to higher levels of economic development and technological change (see Table 1; more on this below). In other words, the methodology used to estimate impacts under any scenario is not entirely consistent with the underlying assumptions of the particular scenario.

Despite the resulting cascade of uncertainties associated with the concatenation of models used to make such impacts assessments and the many legitimate criticisms of the IPCC scenarios (Henderson and Castle, 2003, Carter et al., 2006) underlying the FTA analyses, for the purposes of this chapter I will take the results of the FTA at face value because they: (a) have been peer-reviewed, (b) are state-of-the-art, (c) have figured prominently in the international debate over global warming. The FTA's results for the impacts of climate change on food, agriculture, water resources, and coastal flooding were a prominent part of a symposium, *Avoiding Dangerous Climate Change*, sponsored in 2005 by the UK Government as a prelude to the 2005 G-8 Gleneagles Summit (DEFRA, 2005). They were also used heavily in the impacts assessment portion of the recent Stern Review of the Economics of Climate Change, and have been referred to quite frequently within the latest (2007) IPCC report on impacts, adaptation and vulnerability.

Notably, climate change is only one factor impinging on future human and environmental well-being. Consequently, to answer the question posed in the title of this paper, it is insufficient to examine just the incremental problems caused by climate change (denoted by ΔP) for each of the above-noted climate-sensitive hazards and threats to well-being. To these incremental problems we should add the problems that would exist in the absence of climate change (denoted by P_0). Hence, the total problem [P_T] with climate change equals $P_0 + \Delta P$ (Goklany, 2000, 2003).

Accordingly, in this paper, for each category of climate-sensitive hazard or threat, I will rank the four scenarios according to the magnitude of P_T as provided in the FTA analyses before attempting to develop an aggregate ranking for each scenario in order to answer the question whether a richer-but-warmer world is better than poorer-but-cooler worlds. Note, however, that this is not the same as asking whether mitigation

may advance well-being or what is the optimal mix of adaptation and/or mitigation actions for dealing with climate change. Answering these questions requires a different kind of analysis than is undertaken here.

1.3. Nomenclature

In the following, in consonance with the FTA, the magnitude of the problem (P) due to each climate-sensitive hazard affecting human well-being, namely, malaria, hunger, water stress and coastal flooding, will be measured by the global population at risk (PAR) or suffering from the specific climate-sensitive hazard. For these hazards, P and PAR will, henceforth, be used interchangeably, as will ΔP and ΔPAR . With respect to environmental well-being, P will be measured by three indicators: (a) global cropland area (an indicator of habitat loss, the most important threat to global terrestrial biodiversity, see, e.g., Green et al., 2005; Goklany, 1998 and references therein), (b) losses in coastal wetlands, and (c) the negative of net biome productivity (a measure of the terrestrial carbon sink capacity).

2. POPULATION AT RISK FOR VARIOUS CLIMATE-SENSITIVE HAZARDS, WITH AND WITHOUT CLIMATE CHANGE

This section examines the FTA's estimates of populations at risk with and without climate change (i.e., P_0 and ΔPAR) associated with four climate-sensitive hazards to human well-being, namely, hunger, water shortage, coastal flooding and malaria, in 2085 under each of the four scenarios summarized in Table 1.

In our examination of P_0 and ΔPAR under the various scenarios, it should be kept in mind that, firstly, 2085 is, as noted, at the outer limits of the foreseeable future. Secondly, the FTA analyses assumed no new policies and measures to reduce damages from climate change, but it included some, but not all, "spontaneous" adaptations that could be reasonably assumed to occur (IPCC, 2001a). Accordingly, the FTA analyses have a tendency to simultaneously overestimate negative impacts (see below) while underestimating positive outcomes.⁷

This tendency is more pronounced the higher the future adaptive capacity (that is, the higher the level of economic growth and technological change). In other words, the overestimates of net negative impacts are largest for A1FI and least for the A1 scenario.

Thirdly, the A1FI and B1 scenarios have the same populations in 2085 (see Table 1). This, however, is an exogenously-imposed assumption within the scenario story lines. In fact, in the real world, lower total fertility rates are generally associated with higher levels of economic development (see, e.g., IPCC, 2000: 112–113; Goklany 2007a). Arguably, therefore, the A1FI world should have a lower population in 2085 than the B1 world, which suggests that emissions and the amount of climate change indicated in Table 1 under the A1FI scenario is further overestimated, relative to the B1 scenario. Moreover, since a higher population would result in a higher population

⁷This is self-evidently true for impacts directly impinging on human well-being. It's also valid for environmental impacts to the extent these impacts are also affected directly or indirectly by a population's wealth or technological prowess, e.g., habitat loss or species protection.

Table 2: Population at risk (PAR) in 2085 for hunger with and without further climate change

	Units	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	millions	798–872	105	767	233	90
Δ PAR	millions	NA	28	-28 to -9	-11– +5	10
Total PAR	millions	798–872	133	739–758	222–238	100

Note: P_0 = PAR in the absence of climate change; Δ PAR = change in PAR due to climate change; Total PAR = $P_0 + \Delta$ PAR. Source: Parry et al., (2004).

Table 3: Population at risk (PAR) in 2085 for hunger with and without further climate change, as percent of total population

	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	15.1%–6.5%	1.3%	5.4%	2.3%	1.1%
Δ PAR	NA	0.4%	-0.2% to -0.1%	-0.1%–0.5%	0.1%
Total PAR	15.1% – 6.5%	1.7%	5.2%–5.3%	2.2%	1.3%

Note: P_0 = PAR in the absence of climate change; Δ PAR = change in PAR due to climate change; Total PAR = $P_0 + \Delta$ PAR. Source: Parry et al., (2004).

at risk (PAR) for various climate-sensitive hazards, it is conceivable that estimates of both P_0 and Δ PAR for A1FI will have been overestimated relative to the B1 scenario.

Hunger. Tables 2 and 3 show the FTA's estimates of PAR for hunger in 2085 both with and without climate change for the various scenarios. Table 2 gives PAR in absolute numbers, while Table 3 provides it as a proportion of the specific scenario's global population. These estimates, taken from Parry et al., (2004), show that whether or not climate changes beyond 1990 levels, no matter which scenario we choose, through 2085 the future world will be better off with respect to hunger than it was in 1990 both in terms of absolute numbers and as a proportion of total population. Second, in 2085, some of the warmer scenarios might actually result in lower levels of hunger, than some cooler scenarios. Third, hunger in 2085 will be lowest in the B1 scenario, followed by A1FI, B2 and A2 (in that order). Thus, the warmest scenario (A1FI) does not lead to the lowest level of well-being. Note, however, that this is not just the consequence of wealth-related adaptive capacity, but also higher CO₂ levels (and, at least in some areas, greater soil moisture). Finally, for some scenarios (A2 and, possibly, B2), climate change might, in fact, reduce the PAR for hunger at least through 2085.

Notably, Parry et al.,'s analysis allows for some secular (time-dependent) increases in agricultural productivity, increases in crop yield with economic growth due to greater application of fertilizer and irrigation in richer countries, decreases in hunger due to economic growth, and for some adaptive responses at the farm level to deal with climate change. However, as that study itself acknowledged, these adaptive responses are based on currently available technologies, not on technologies that would be available in the

Table 4: Population at risk (PAR) in 2085 for water shortage, with and without further climate change

	Units	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	millions	1,368	2,859	8,066	4,530	2,859
Δ PAR	millions	NA	-1,192	-2,100-0	-937-104	-634
Total PAR	millions	1,368	1,667	5,966-8,066	3,593-4,634	2,225

Note: PAR measured as the number of people inhabiting countries where available water supplies are less than 1,000 m³ per person per year. P_0 = PAR in the absence of climate change; Δ PAR = change in PAR due to climate change; Total PAR = $P_0 + \Delta$ PAR. Source: Arnell (2004, Table 8 on p. 41).

Table 5: Population at risk (PAR) in 2085 for water shortage with and without further climate change, as percent of total population

	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	25.8%	36.2%	56.8%	44.4%	36.2%
Δ PAR	NA	-15.1%	-14.8%-0.0%	-9.2%-1.0%	-8.0%
Total PAR	25.8%	21.1%	42.0%-56.8%	35.2%-45.4%	28.2%

Note: P_0 = PAR in the absence of climate change; Δ PAR = change in PAR due to climate change; Total PAR = $P_0 + \Delta$ PAR.

future or any technologies developed to specifically cope with the negative impacts of climate change (Parry et al., 2004, p. 57). The potential for future technologies to cope with climate change is large, especially if one considers bioengineered crops (Goklany, 2003, 2007b).⁸ Thus the projections of Δ PAR in Tables 2 and 3 are probably overestimates, especially for the A1FI world, which has the highest level of wealth, because yields generally increase with greater wealth (see Figure 2; Goklany, 1998, 2007b). Moreover, as noted previously, the population of the A1FI world might be an overestimate relative to the B1 world. Had these factors been considered, the A1FI scenario might conceivably have resulted in the lowest levels of hunger.

Tables 2 and 3 assume that the direct CO₂ effects on crop yields would be realized. If, however, these direct effects are not realized, then Parry et al.'s analysis indicates that the climate change would exacerbate the total population at risk under all scenarios, including the A2 and B2 scenarios while Δ PAR would still be less than P_0 for all but the A1FI scenario. But such outcomes are unlikely. First, the probability that direct CO₂ effects on crop growth are zero or negative is quite low, if not non-existent (IPCC, 2001b: 254-256). Second, as already noted, the FTA most likely overestimates

⁸It is also unclear how well Parry et al.'s analysis accounts for potential increases in overall productivity of the food and agricultural sector that might occur as technologies that are underutilized today become more affordable and are, therefore, likely to be used more broadly with rising incomes. These include technologies that would, for instance, reduce post-harvest and end-use losses that have been estimated at 47 percent worldwide (Goklany 1998, and references therein).

the declines in agricultural yields and as well as the populations at risk with or without climate change because it does not fully account for technological options that would be available to richer and more technologically advanced societies of the future.

These tables also confirm that in comparing the consequences of various scenarios, it is not sufficient 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 Δ PAR, one could conclude, erroneously, that, with respect to hunger, A2 is the best of the four scenarios. But, in fact, based on total PAR, A2 would be the worst. 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 PARs for water stress in 2085 with and without climate change are shown for each scenario in terms of absolute numbers in Table 4, and in terms of the proportion of global population in Table 5 (Arnell, 2004).⁹ [A population is deemed to be under water stress if its available water supplies fall below 1,000 m³ per capita per year.] Both tables indicate that for each scenario, climate change by itself might, in fact, *reduce* the total PAR for water shortage.

Note that Δ PARs in Tables 4 and 5 account for the fact that because of climate change some populations will move out of the water stressed category, while other populations will move into that category. However, Arnell (2004) and a derivative paper (Arnell 2006) in a book titled, *Avoiding Dangerous Climate Change*, tend to emphasize the *increase* in the population under water stress due to climate change over the decrease in that population. Specifically, after acknowledging that "If the absolute numbers of people living in waterstressed watersheds was taken as the indicator of water resources stress, then climate change would appear to reduce global water resources pressures because more watersheds move out of the stressed class than move into it" he argues that would give a misleading indication of the effect of climate change: "Firstly, the increases in runoff generally occur during high flow seasons, and may not alleviate dry season problems if this extra water is not stored: the extra water may lead to increased flooding, rather than reduced water resources stresses. Secondly, the watersheds that apparently benefit from a reduction in water resources stress are in limited, but populous, parts of the world, and largely confined to east and southern Asia: areas that see an increase in stress are more widely distributed." (Arnell 2004: 50).

While Arnell's second argument is not persuasive if one is interested in estimates of the total global population at risk (as is this study), his first argument only highlights the fact that in contrast to Parry et al.'s study on hunger, his water stress estimates exclude any spontaneous or proactive adaptations that might be undertaken, albeit at some cost, to alleviate future water shortages. Specifically,

⁹Arnell (2004) 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 (compared to the "no climate change" condition). However, his paper does not provide estimates using this measure of the population in 2085 living in countries where water availability would fall below 1,000 m³/capita/year assuming climate change. Hence, those results are not shown in Tables 4 or 5.

Table 6: Population at risk (PAR) in 2085 for coastal flooding with and without further sea level rise (SLR)

	Units	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	millions	10	1–3	30–74	5–35	2–5
Δ PAR	millions	NA	10–42	50–277	27–66	3–34
Total PAR	millions	10	11–45	80–351	32–101	5–39

Note: For coastal flooding, PAR is measured as the average number of people who experience flooding each year by storm surge or “average annual people flooded” (AAPF). The low (high) end numbers are based on an assumption of low (high) subsidence. P_0 = PAR in the absence of SLR; Δ PAR = change in PAR due to SLR; Total PAR = $P_0 + \Delta$ PAR. Source: Nicholls (2004).

Table 7: Population at risk (PAR) in 2085 for coastal flooding with and without further climate change, as percent of total population

	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
P_0	0.2%	0.0%–0.0%	0.2%–0.5%	0.0%–0.3%	0.0%–0.1%
Δ PAR	NA	0.1%–0.5%	0.4%–2.0%	0.3%–0.6%	0.0%–0.5%
Total PAR	0.2%	0.1%–0.6%	0.6%–2.5%	0.3%–1.0%	0.0%–0.5%

Note: P_0 = PAR in the absence of SLR; Δ PAR = change in PAR due to SLR; Total PAR = $P_0 + \Delta$ PAR. Source: Nicholls (2004).

these estimates do not consider either current or future adaptive capacity, as a function of economic progress or secular (i.e., time dependent) technological development. One should expect that at least a portion of the available options for alleviating water stress (and forestalling human and economic losses to floods) would be undertaken even in a business-as-usual world, particularly since such measures are known, have been implemented for centuries, and will only become more affordable as future populations become wealthier per the SRES scenarios (see Table 1), and with secular (i.e., time dependent) advances in technological prowess (Goklany 2007a). Consequently, Arnell’s analysis not only overestimates the populations living in water stressed areas, his rationale for highlighting the increased population at risk of water stress (at the expense of the population with reduced risk) is unpersuasive, at best.

Tables 4 and 5 also show that in the absence of climate change, A1FI and B1 have the smallest PAR in 2085, while A2 generally has the highest. This is true in terms of both absolute numbers and the fraction of total population for the relevant scenario. The reason why in the absence of climate change, the A1FI and B1 scenarios have identical PARs is due to the population assumptions built into the story lines, which seem unrealistic in light of experience.

Third, with climate change, the A1FI world continues to have the lowest PAR but that for B1 falls to second place (both in terms of absolute numbers, and a fraction of the global population).

Fourth, for each scenario, P_0 exceeds ΔPAR in 2085, that is, with respect to water shortage, non-climate change related factors are more important than climate change, at least through the foreseeable future.

As noted, Arnell (2004) did not consider any adaptation, although several supply side and demand side adaptations are currently available that would reduce PAR for water shortage whether or not climate changes (see, e.g., Goklany, 1998, 2000, 2007b). Moreover, one should expect that the wealthier societies of 2085 will be better able to afford and, therefore, would be more likely to employ such adaptation technologies than are today's relatively poorer societies, particularly if, in the meantime, water shortages are heightened, as indicated in Tables 4 and 5. Therefore, had Arnell's (2004) analysis considered adaptations, the PAR estimates would have been reduced for each scenario. These reductions would have been greatest for the A1FI (richest) scenario and lowest for the A2 (poorest) scenario and, although the ranking among the scenarios would not change, the differences in PAR between the various scenarios would have been magnified.

Coastal flooding. Table 6, which is based on Nicholls (2004), provides the Fast Track Assessment's estimates of the PAR for coastal flooding with and without any sea level rise between 1990 and 2085. In this Table, PAR is measured by the average number of people who would experience coastal flooding by storm surge in 2085 with and without climate change, assuming that the 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), and "evolving" protection with a 30-year lag time. The low and high end of the ranges for PAR for each entry in Table 6 assume low and high subsidence due to non-climate change related human causes, respectively.

Table 7 provides the same information as in Table 6, but as a proportion of the global population in 2085 for each scenario.

Nicholls (2004) makes a creditable effort to incorporate improvements in adaptive capacity due to increasing wealth. Nonetheless some of its assumptions are questionable. For instance, Nicholls allows societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions, but they ignore subsequent sea level rise (Nicholls, 2004, p. 74). But one would expect that whenever any measures are implemented, they 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. Nicholls also allows for a constant lag time between initiating protection and sea level rise. 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 the faster this reduction. In fact, if the trend in sea level rise proves to be robust, it is possible that protective measures may be taken in advance, i.e., the lag times may even become negative.

In addition, Nicholls (2004) does not allow for any deceleration in the preferential migration of the population to coastal areas, as might be likely if coastal flooding becomes more frequent and costly. But if the preferential migration continues

unabated, it would not be implausible to expect a country's expenditures on coastal protection to increase as its coastal population also increases relative to its total population. A plausible adjustment would be to increase such expenditures on a per-GDP basis as the fraction of the population in coastal areas rises. Such an outcome would not be inconsistent with democratic governance.

Nicholls (2004, Table 7) also suggests that subsidence is more likely under the A1FI and A2 worlds than the B1 and B2 worlds. Although this assumption conforms with the SRES's narratives regarding the priority given to environmental issues, it contradicts real world experience which indicates that once richer countries are convinced of a problem, whether it is 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 the IPCC's scenarios (see also Goklany, 2002a). Hence, one should expect that the richest (A1FI) world would spend more and be better protected from subsidence, than would the B1 or B2 worlds. If greater concern for the environment, in fact, translates into a higher fraction of GDP spent on the environment then, despite spending a smaller fraction under A1FI, total spending on—and the amount of—coastal protection could be higher under that scenario than, say, the B1/B2 scenarios, given the wide gaps in GDP per capita between these scenarios.

Putting aside these shortcomings, Tables 6 and 7 show that in the absence of climate change, the PAR for coastal flooding in 2085 under the A1FI and B1 worlds would be lower than what it was in 1990, but it would be higher under the A2 world; and it may or may not be higher under the B2 world. With climate change, the PARs would increase under each scenario with A2 having the highest total PAR by far, followed, in decreasing order, by B2, and perhaps A1FI and B1. Notably, the difference in PAR between A1FI and B1 scenarios is not very large, considering the several assumptions, noted above, that tend to downplay the adaptive effects of wealth.

Malaria. Van Lieshout et al., (2004) reported on the FTA's analysis for malaria. However, they only provide numerical estimates for changes in global PAR due to climate change (i.e., Δ PAR) under the various scenarios, but not for PARs in the absence of climate change, or for total PARs with climate change.¹⁰ But, as noted, the scenario with the highest Δ PAR does not always have the highest total PAR, a much more relevant measure of human well-being. Moreover, although van Lieshout et al., (2004) attempt to include adaptive capacity as it was in 1990, they do not adjust for changes in adaptive capacity over time, i.e., with advances in economic and technological development, as ought to occur between 1990 and 2085. Thus, their analysis sheds no light on the issue of whether well-being (as measured by the population at risk for malaria) would be greater in a richer-but-warmer world as compared to a poorer-but-cooler world.

¹⁰This author contacted various co-authors of the van Lieshout et al., paper to obtain their results for PAR with and without climate change, but to no avail.

However, the results of an earlier (pre-SRES) assessment of the global impact of climate change on the PAR for malaria (Martens et al., 1999) that were also sponsored by DEFRA and whose authors included the co-authors of van Lieshout et al., (2004) allows us to get an idea of the relative contribution of climate change to the total population at risk for malaria in 2085. That earlier analysis used a “business-as-usual” scenario that was developed for the 1995 IPCC impact assessment, and did not include any additional greenhouse gas controls. The UK Meteorological Office’s HadCM2 model projected that under that scenario, the globally averaged temperature would increase by 3.2 °C between 1990 and 2085 (Parry et al., 2001), which approximates the temperature increase using HadCM3 under the A2 scenario (see Table 1).

That study’s results for malaria—also reported in Arnell et al., (2002)—indicate that the global population at risk of malaria transmission in the absence of climate change (P_0) would double from 4,410 million in 1990 to 8,820 million in 2085, while Δ PAR in 2085 would be between 256 million and 323 million. In other words, climate change would contribute only a small portion (about 3.2 percent) of the total PAR for malaria in 2085 (Goklany, 2003).

Note that these PARs for malaria transmission are substantially larger than the numbers of people who would actually contract or die from that disease in any given year. By comparison with the P_0 of 4,410 million in 1990, the number of people who actually contracted malaria each year in the 1990s was an order of magnitude lower (300–500 million), while the number who died (about 1 million) was smaller by more than three orders of magnitude (WHO, 1999). One reason for these differences is that the actual prevalence of malaria does not coincide either with its historical or potential range based on the presence of the malaria transmitting vectors and/or the malaria parasite. This, in fact, reaffirms the importance of incorporating adaptive capacity—and changes in adaptive capacity due to economic growth and technological change—into impact assessments.

The current range of malaria is dictated less by climate than by human adaptability, and despite any global warming that might have taken place over the past century (or more), malaria has been virtually eradicated in richer countries although it was once prevalent there (e.g., the U.S. and Italy) (Goklany, 2000, 2007b). This is because, in general, a wealthier society has better nutrition, better general health, and greater access to public health measures and technologies targeted at 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 (Goklany 2007a).

In fact, analysis by Tol and Dowlatabadi (2001) suggests that malaria is functionally eliminated in a society whose annual per capita income reaches \$3,100. But Table 1 indicates that 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, one can be relatively confident that the \$3,100 threshold will almost

Table 8: Ecological indicators under different scenarios, 2085-2100

		Baseline 1990	A1FI	A2	B2	B1
Global temperature increase (ΔT) (in 2085)	$^{\circ}\text{C}$	0	4.0	3.3	2.4	2.1
Global population (in 2085)	billions	5.3	7.9	14.2	10.2	7.9
GDP/capita, global average (in 2085)	\$/cap	3.8	52.6	13.0	20.0	36.6
CO ₂ concentration (in 2100)	ppm	353	970	856	621	549
Net Biome Productivity 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%
<i>Global losses of coastal wetlands in 2085</i>						
Losses due SLR alone	% of current area	NA	5–20%	3–14%	3–15%	4–16%
Losses due to other causes	% of current area	NA	32–62%	32–62%	11–32%	11–32%
Combined losses	% of current area	NA	35–70%	35–68%	14–42%	14–42%

Sources: Arnell et al., (2004); Nicholls (2004); Levy et al., (2004)

certainly drop in the next several decades as public health measures and technologies continue to improve and become more cost-effective.

3. ECOLOGICAL CHANGES IN 2085–2100, WITH AND WITHOUT CLIMATE CHANGE

Table 8, based on Levy et al., (2004) and Nicholls (2004), provides information on the variation in three specific ecological indicators across the different scenarios. One indicator is the net biome productivity (a measure of the terrestrial biosphere's net carbon sink capacity). The second indicator is the area of cropland (a crude measure of the amount of habitat converted to human use). Notably, land conversion to agricultural uses is perhaps the single largest threat to global terrestrial biodiversity (Goklany, 1998). The third indicator is the global loss of coastal wetlands relative to 1990 levels.

The biosphere's sink capacities under the A1FI and A2 scenarios are approximately the same, at least through 2100. Largely because they result in higher CO₂ concentrations, their sink strengths are greater compared to the B1 and B2 scenarios and, at least through 2100, the positive effect of carbon fertilization under the A1FI scenario

Table 9: Ranking of scenarios in order of future well-being per each indicator, 2085–2100

Indicator	Without climate change				With climate change			
	A1FI	A2	B2	B1	A1FI	A2	B2	B1
<i>Indicators of human well-being</i>								
GDP/capita	1	4	3	2	1	4	3	2
Hunger (PAR in 2085)	2	4	3	1	2	4	3	1
Water stress (PAR in 2085)	1.5	4	3	1.5	1	4	3	2
Coastal flooding (PAR in 2085)	1	4	3	2	2	4	3	1
<i>Indicators of environmental quality</i>								
Terrestrial carbon sink strength (in 2100)					1.5	1.5	3	4
Cropland area (in 2100)					1	NA	3	2
Coastal wetland area (in 2085)					3.5	3.5	1.5	1.5

was not projected to be reversed by the negative effects of higher temperatures. 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 2085, the A1FI scenario would have the least habitat loss and, therefore, pose the smallest risk to terrestrial biodiversity from this particular threat, while the B2 scenario would have the highest habitat loss.

With regard to the loss of coastal wetlands, the estimated loss due to sea level rise (SLR) for each scenario is quite substantial but the contribution of climate change to total losses in 2085 are smaller than losses due to subsidence from other man made causes, confirming the results of earlier studies (Nicholls 1999). According to Table 8, wetland losses are much higher for the A1FI and A2 scenarios than for the B1 and B2 scenarios. This is due mainly to the assumption that the first two scenarios would have higher non-climate change related subsidence (Nicholls 2004, p. 76) but, as noted, this assumption is suspect.

4. DISCUSSION: IS A1FI THE WORST SCENARIO FOR HUMAN AND ENVIRONMENTAL WELL-BEING?

Results Based on the Fast Track Assessment

For each indicator for which data were provided in the foregoing, Table 9 ranks the four scenarios according to the level of human or environmental well-being per that indicator for both the climate change and the non-climate change cases. In this ranking scheme, “1” indicates the best level of well-being while “4” indicates the worst. If two scenarios show the same level of well-being then they share the same ranking. For example, in the absence of climate change, scenarios A1FI and B1 are both ranked at the top with respect to water stress in 2085 (because they both have

the same low population in 2085). Accordingly, they split the number one and two rankings, and their joint ranking is indicated as 1.5.

Table 9 assumes that the relative ranking of the scenarios with respect to GDP per capita (a surrogate for per capita wealth or income) will be maintained despite any climate change. This is likely because the differences in GDP per capita from one scenario to the next for either developing or developed countries are quite large (see Table 1) by comparison to the equivalent reduction in consumption due to climate change through 2085–2100 (IPCC, 2001). If there is any change in ranking, examination of Table 9 indicates that the most likely change with respect to GDP/capita would be A1FI and B1 trading places. But considering that the differences in average GDP per capita in 2100 between the A1FI and B1 scenarios range from 47 to 65 percent (for developed and developing countries, respectively; see Table 1), it is unlikely that any drop in equivalent consumption by 2100 due to climate change will close the differences in GDP per capita between the A1FI and B1 scenarios.¹¹

Perhaps serendipitously, the rankings are the same whether one uses absolute numbers or the proportion of global population as the measure of the impact of climate change.

The top part of Table 9 provides rankings for various indicators of human well-being (HWB) in 2085, namely, wealth (for which GDP per capita is a surrogate), hunger, water stress, and coastal flooding. If one considers that: (a) GDP per capita—or perhaps more accurately, the logarithm of GDP per capita (Goklany, 2002a, 2007a; Figures 1–3)—should probably be given greater weight because it is a surrogate for numerous, and more appropriate, HWB indicators (e.g., life expectancy, mortality rates, access to safe water and sanitation, and level of educational attainment), and (b) impacts analyses have a general tendency (discussed previously) to underestimate changes in adaptive capacity as a function of both economic development and technological progress (or time), then Table 9 suggests that HWB in 2085 would, in the aggregate, be highest for the A1FI scenario and lowest for A2. Reinforcing this conclusion is the possibility that compared to the B1 scenario, populations at risk for the A1FI scenario might be overestimated (as might the amount of climate change).

Applying the same logic and considerations, it would seem that HWB should be somewhat better under B1 than B2. These aggregate rankings would stay the same whether or not climate changes, or whether they are based on PAR in terms of absolute numbers or the proportion of global population.

The last three rows of Table 9 rank scenarios based on the three environmental indicators addressed in Section 3 (and Table 8). Based on the strength of the terrestrial carbon sink and cropland area, environmental quality would be superior under the A1FI scenario than under either the B1 or B2 scenarios through 2100, but these rankings would

¹¹For instance, 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 (Stern Review, 2006, Executive Summary, p. x). Although several researchers have disputed the Review’s impacts estimates as overblown (Byatt et al., 2006; Carter et al., 2006; Dasgupta, 2006; Nordhaus, 2006; Tol and Yohe, 2006) and the Review’s authors themselves emphasize “strongly” that the numbers should not “be taken too literally” (Stern Review, FAQ, 2007, p. 2), if one accepts its estimates, then at most consumption would be reduced in 2100 by 20%, which is less than the 47–65% differential between the A1FI and B1 scenarios.

Table 10: GDP per capita (in 1990 U.S. \$, market exchange rates) for developing and industrialized countries in 2100, adjusted for maximum losses due to climate change per the Stern Review (2006).

Year Scenario	1990	2100			
	Actual	A1FI	A2	B2	B1
Temperature increase in 2085 [°C]	-	4.0	3.3	2.4	2.1
<i>Developing countries</i>					
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
<i>Industrialized countries</i>					
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: Warren (2006b), Arnell et al., (2004), World Bank (2006); Stern Review (2006).

apparently be reversed for coastal wetlands, at least through 2085—“apparently,” because, as noted, that could be an artifact of the assumption that subsidence should/would be lower under the B1 and B2 scenarios than the A1FI scenario.

Results Based on the Stern Review’s Analysis. An alternative approach to determining whether the A1FI scenario is necessarily the worst of the four worlds depicted by the IPCC scenarios is to use the results of the Stern Review. 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 (Stern Review, 2006, Executive Summary, p. x). It also suggests that by the year 2200 the 95th percentile of the equivalent per capita GDP losses could rise to 35.2 percent (Stern Review, pp. 156 and 158). Several researchers have disputed the Review’s impacts estimates as overblown (Byatt et al., 2006; Carter et al., 2006; Dasgupta, 2006; Nordhaus, 2006; Tol and Yohe, 2006) and the Review’s authors themselves emphasize “strongly” that the numbers should not “be taken too literally” (Stern Review, FAQ, 2007, p. 2). I will, nevertheless, put aside these concerns and, in this section, be guided by the Review’s results in order to estimate whether unmitigated climate change will lower future well-being to below today’s (1990)

levels. Specifically, I will assume, for the sake of argument that climate change under the warmest scenario (A1FI) would result in a welfare loss equivalent to 35.2 percent in 2100.

Table 10 shows, for each SRES scenario listed in Table 1, the GDP per capita in 1990 (the base year for the SRES scenarios) and 2100 in the absence of any climate change. It also provides estimates of equivalent welfare losses per capita assuming unmitigated climate change, and adjusts the GDP per capita in 2100 downward to account for this loss assuming that the loss would increase with the square of the average global temperature increase from 1990–2085 per Table 1 (see Warren et al., 2006b).¹²

Table 10 indicates that notwithstanding gross inflation of the adverse impacts of climate change, welfare should be higher in 2100 than it was in 1990 under all scenarios. 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 also calls into question arguments that present generations are morally bound to take aggressive actions now to mitigate climate change because future generations will, otherwise, be worse off in the future. Future generations will not only be better off, they should also have at their disposal better and more effective technologies and greater human capital to address not just climate change but any other sources of adversity.

Second, 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 impacts analyses to overestimate net adverse impacts, especially for wealthier societies.

To summarize, over this century the SRES scenario that leads to the greatest risk of climate change is also the one that leads to the greatest gains in human welfare. Notwithstanding climate change, through this century human well-being is likely to be highest in the richest-but-warmest (A1FI) world and lower in poorer-but-cooler worlds. Thus, if humanity could choose between the four scenarios examined here, it should for the next few decades strive to realize the richest-but-warmest (A1FI) world.

5. CONCLUSION

Strictly from the perspective of *human well-being*, the richest-but-warmest world characterized by the A1FI scenario would probably be superior to the poorer-but-cooler worlds at least through 2085, particularly if one considers the numerous ways GDP per capita advances human well-being. Human well-being would likely be the lowest for the poorest (A2) world. With respect to *environmental well-being*, the FTA's results suggest matters may be best in the A1FI world for some critical environmental indicators through 2100, but not necessarily for others. On the other hand, the Stern Review's worst-case results for potential welfare losses due to climate change suggest that, welfare, adjusted

¹²Most 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) while 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 (Warren et al., 2006b).

for market and non-market impacts and the risk of catastrophe due to climate change, will be highest under the A1FI scenario, at least through 2100.

It should however be noted that the results of this paper would not by themselves justify any inference that intervening to mitigate the impacts of climate change, either through limiting emissions and concentrations of greenhouse gases or through adaptation, would reduce welfare by making us poorer. That needs a different type of economic analysis involving, among other things, analysis of the marginal costs and benefits of various interventions and include consideration of co-benefits of adaptation and mitigation and opportunity costs (Goklany, 2007a), which is outside the scope of this paper.

Nevertheless, the above results cast doubt on a key premise implicit in all calls to steer the world toward lower emission pathways and to take actions now that would go beyond “no-regret” policies in order to reduce GHG emissions in the near term, namely, a richer-but-warmer world will, before too long, necessarily be worse for the globe than a poorer-but-cooler world. But the above analysis suggests this is unlikely to occur, at least not before the 2085–2100 period, and that in the short-to-medium term, societies should strive to advance their level of economic development and their ability to develop, implement and acquire new and improved technologies while simultaneously implementing “no-regret” actions to mitigate climate change and reduce vulnerability to current climate-sensitive problems that might be exacerbated by climate change (Goklany, 2005, 2007a).

- Increasing adaptive capacity, particularly of developing countries, by investing in efforts now to reduce vulnerability to today’s urgent climate-sensitive problems—malaria, hunger, water shortage, flooding and other extreme events—that might be exacerbated by climate change (Goklany, 1995, 2003, 2005). 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. This might also increase the level at which GHG concentrations 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.¹³ Alternatively, it could postpone the deadline for stabilization. In either case, it could reduce the costs of meeting the ultimate objective;
- Strengthening or, where needed, developing the institutions necessary to advance and/or reduce barriers to economic growth, human capital and the propensity for technological change. These factors underpin both adaptive and mitigative capacities, as well as sustainable development (Goklany, 1995, 2000, 2007a). This can be achieved, among other things, through efforts to meet the Millennium Development Goals in 2015, which were, in fact, designed to advance sustainable development by alleviating poverty, disease and illiteracy;

¹³Article 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.”

- Expanding the range of no-regret options through R&D to improve existing—and develop new—technologies that would reduce atmospheric greenhouse gas concentrations more cost-effectively than currently possible so that future emission reductions might be cheaper, even if they have to be deeper to compensate for the delay in a more aggressive response in the short term;
- Allowing the market to run its course in implementing no-regret options as their range expands with improvements in cost-effectiveness. Among other things, this implies reducing subsidies that directly or indirectly increase energy use, land clearance, use of fertilizers or other activities that contribute to greater greenhouse gas emissions;
- Developing 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 the UNFCCC’s Article 2) while at the same time advancing human well-being; and
- Monitoring the impacts of climate change to spot “dangerous” impacts before they become imminent.

Such an approach would allow us to solve today’s urgent problems while bolstering our ability to address tomorrow’s climate change challenge.

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