LIMITS TO ECONOMIC GROWTH

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ORIGINALLY WRITTEN AS APPENDIX 4,

CLIMATE CHANGE AND THE FLORIDA KEYS

JULY 21, 2010

SOCIOECONOMIC RESEARCH AND MONITORING PROGRAM

FLORIDA KEYS NATIONAL MARINE SANCTUARY (FKNMS)

NATIONAL ATMOSPHERIC AND OCEANIC ADMINISTRATION (NOAA)

This study was funded by NOAA's Coral Reef Conservation Program

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LIMITS TO ECONOMIC GROWTH

INTRODUCTION

NO MEASURE OF LIMITATIONS TO CONVENTIONAL ECONOMIC GROWTH

The IPCC projections of global GDP and population in the *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) apparently do not consider the possibility that a world with highly elevated temperatures and other consequences of climate change might find it difficult to grow at the rates projected. The scenario builders seem to have assumed that such problems can be solved through technology, which according to the SRES summary for policymakers was defined as "at least as important a driving force as demographic change and economic development."

There is no discussion in the IPCC literature (that we have been able to find) of how seven billion people or more would be able to live comfortably, or at least tolerably, in the global growth scenario A1, in temperatures four or more degrees Celsius above pre-industrial levels (comparable to the warming from the ice age to the 19^{th} century). This might possibly work for the richest nations but it stretches credibility to extend the assumption to all nations – despite the embedded assertion that average incomes in developing and rich nations would converge in the high-growth scenario A1.

NO MEASURE BEYOND THE CONVENTIONAL ECONOMIC STATISTICS EITHER

Another problem is regarded by many as a glaring omission. It is relevant because the underlying implication is that conventional measures of economic growth are too high because they omit reference to the depletion of the natural capital of the planet. Crudely put, our apparently high economic growth rate is sustained because humans have been able to consume in a short time span the accumulated capital made up of non-renewable resources millions of years old.

Despite many years of ongoing research into the matter, only modest progress has been made on developing national accounting statistics that take environmental degradation into account (UNSD 2009). The main reason seems to be the complexity, lack of hard data, and difficulty of obtaining agreement to get a system of standardized accounts going. There have been attempts to build in statistics showing the change in mineral stocks and the like, but putting a value on ecosystems and on a healthy atmosphere has been considered too hard.

As a possible alternative, or supplement to the conventional statistics, the Wentworth Group of Concerned Scientists in Australia has produced a blueprint of a system of standardized environmental accounts (Cosier 2008). The group advocates a regional data collection and reporting framework that measures the health of the following five asset classes as a starting point:

1. Land (native vegetation, native fauna, soils)
2. Water (rivers, wetlands and estuaries)

3. Atmosphere (greenhouse gas emissions which cause climate change)
4. Marine and coastal resources (fish stocks, reefs, beaches)
5. Towns and cities (air quality, waste, water use, consumption).

Any such extension would fall outside a conventional national accounting system, which has indeed been the stumbling block for any real progress on the matter. [1] As far as the Florida Keys project is concerned, we can do little except pointing to the issue, and suggesting that proper accounting for environmental degradation would put a brake on excessive reliance on unbridled economic growth by providing adjustments for matters such as humankind's rapid consumption of resources it took millions of years to accumulate, and the real value of ecosystems and how they interact. Regrettably there is no agreed approach. We are stuck with conventional measures of economic product, as was the IPCC, and can only continue to point to the scientific evidence of degradation and the possible consequences thereof.

Perhaps the most promising development is a major report published in September 2009, which not only seeks ways of going "beyond GDP", as one commentator expressed it (Holderness 2009), but involved two Nobel Prize-winning economists in recommending how. The background is explained in the first paragraph of the 291-page report (Stiglitz, Sen and Fitoussi 2009): French President Sarkozy, "unsatisfied with the present state of statistical information about the economy and the society", asked the economists to create a Commission on the Measurement of Economic Performance and Social Progress (CMEPSP), chaired by Stiglitz, advised by Sen, and coordinated by Fitoussi.

"The Commission's aim has been to identify the limits of GDP as an indicator of economic performance and social progress, including the problems with its measurement; to consider what additional information might be required for the production of more relevant indicators of social progress; to assess the feasibility of alternative measurement tools, and to discuss how to present the statistical information in an appropriate way."

A couple of excerpts from the executive summary set the stage:

"To focus specifically on the enhancement of inanimate objects of convenience (for example in the GNP or GDP which have been the focus of a myriad of economic studies of progress), could be ultimately justified – to the extent it could be – only through what these objects do to the human lives they can directly or indirectly influence. Moreover, it has long been clear that GDP is an inadequate metric to gauge well-being over time particularly in its economic,

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[1] The main developmental work is carried out by the London Group of Environmental Accounting, created in 1993 to allow statisticians to share their experience. The 2008 meeting of the group lists 28 presentations, spread across an array of specific subjects. Most deal with specific technical problems, including two on the value of time passing (discounting) as natural resources are depleted (Comisari 2008, Pedersen 2008). Another contribution deals with the harmonization of IPCC statistics of greenhouse gas emissions and energy statistics (Treanton 2008). But there are no indications of how to measure the value of, say, ecosystem degradation which would be more compatible with Cosier's asset classes – probably because conventional statistical methodology is considered inadequate. (http://unstats.un.org/unsd/envAccounting/londongroup/meeting13.asp?sID=3).

environmental, and social dimensions, some aspects of which are often referred to as sustainability.” (p 8)

”We are also facing a looming environmental crisis, especially associated with global warming. Market prices are distorted by the fact that there is no charge imposed on carbon emissions; and no account is made of the cost of these emissions in standard national income accounts. Clearly, measures of economic performance that reflected these environmental costs might look markedly different from standard measures.” (p 9)

Well-being is a central concept. The authors define it as having the following dimensions, which should ideally be measured simultaneously: 1 Material living standards (income, consumption and wealth); 2 Health; 3 Education; 4 Personal activities including work; 5 Political voice and governance; 6 Social connections and relationships; 7 Environment (present and future conditions); 8 Insecurity, of an economic as well as a physical nature.

In summary, the scope of the study is to cover all socio-economic and environmental aspects. T he following recommendations deal at least in part with environmental concerns:

- *Sustainability assessment requires a well-identified dashboard of indicators. The distinctive feature of the components of this dashboard should be that they are interpretable as variations of some underlying “stocks”. A monetary index of sustainability has its place in such a dashboard but, under the current state of the art, it should remain essentially focused on economic aspects of sustainability.*

  At a minimum, in order to measure sustainability, what we need are indicators that inform us about the change in the quantities of the different factors that matter for future well-being. Put differently, sustainability requires the simultaneous preservation or increase in several “stocks”: quantities and qualities of natural resources, and of human, social and physical capital.

  These assets should ideally be expressed in monetary values, which is difficult because of the absence of many markets on which valuation of assets could be based. Even when there are market values, there is no guarantee that they adequately reflect how the different assets matter for future well-being. This suggests starting with a more modest approach, focusing the monetary aggregation on items for which reasonable valuation techniques exist, such as physical capital, human capital and certain natural resources. In so doing, it should be possible to assess the “economic” component of sustainability, that is, whether or not countries are over-consuming their economic wealth. (p 17)

- *The environmental aspects of sustainability deserve a separate follow-up based on a well-chosen set of physical indicators. In particular there is a need for a clear indicator of our proximity to dangerous levels of environmental damage (such as association with climate change or the depletion of fishing stocks).*

  Placing a monetary value is particularly difficult for irreversible and/or discontinuous alterations to the environment. For that reason there is a need for a clear indicator of increases in atmospheric concentrations of greenhouse gases associated with proximity to dangerous levels of climate change (or levels of emissions that might reasonably be expected to lead to such concentrations in the future). Climate change caused by increases in greenhouse gases is also special in that it constitutes a truly global issue that cannot be measured with regard to national boundaries. Physical indicators of this kind can only be identified with the help of the scientific community. Fortunately, a good deal of work has already been undertaken in this field. (pp 18-19)

The body of the Stiglitz, Sen and Fitoussi report is organized in two sections with three identical chapter headings: 1 GDP-related issues, 2 Quality of life, and 3 Sustainable development and environment. The first section contains "a short narrative of the report contents," the second the substantial arguments that were presented (not reviewed here).

The report concludes on sustainability (p 77): "Assessing sustainability requires many assumptions and normative choices, and it is further complicated by the existence of interactions between the socio-economic and environmental models followed by the different nations. The issue is indeed complex, more complex than the already complicated issue of measuring current well-being or performance. But we shall nevertheless try to articulate a limited set of recommendations, which we shall also try to keep as pragmatic as possible." The headline recommendations follow:

1. Sustainability assessment requires a well-identified sub-dashboard of the global dashboard to be recommended by the Commission.
2. The distinctive feature of all components of this sub-dashboard should be to inform about variations of those "stocks" that underpin human well-being.
3. A monetary index of sustainability has its place in such a dashboard, but under the current state of the art, it should remain essentially focused on economic aspects of sustainability.
4. The environmental aspects of sustainability deserve a separate follow-up based on a well-chosen set of physical indicators.

In conclusion, the report represents very significant progress, reinforced by its eminent authorship, which is expected to bring the matter to the attention of larger numbers of economists, other social scientists, and scientists specializing in ecosystems and climate change. Economics itself is having a serious look at its past performance and is expanding its cooperation with other disciplines, for example through the complexity theory which originated at the Santa Fe Institute in New Mexico (Hoegh-Guldberg 2010c).

But we are not yet there. Meanwhile the old GDP-dominated national accounting approach remains the basic indicator. We can qualify these measures but we cannot yet quantify their shortcomings.

WHAT THE PUBLISHED SCENARIOS DO, AND DON'T

The SRES scenarios project emissions of carbon dioxide and other greenhouse gases. Nowhere are these projections translated into global temperature changes and other characteristics of climate change. To make the connection, future estimates from separate tables showing expected temperature increases and greenhouse gas emissions had to be correlated (Figure 2).

The closest SRES comes to a explicit recognition of the implications of climate change, as distinct from the emissions that cause it, is in Chapter 6 (summary discussion and recommendations): "The first step in the formulation of the scenarios was the review and analysis of the published literature and the development of the database with more than 400 emissions scenarios. One of the recommendations of the writing team is that IPCC or a similar international institution should maintain such a database to ensure continuity of knowledge and scientific progress in any future assessments of GHG scenarios. An equivalent database to document narrative and other qualitative scenarios would also be very useful for future climate-change assessments."

The SRES collection consists of unmitigated scenarios – they envisage worlds that might emerge in the absence of specific corrective action on climate change (the scenarios are not otherwise "policy-free"). Mitigation of climate change will of course happen in the real world; the scenarios themselves are important catalysts in this process. The troubling question is how prompt the action will be.

Table 1: IPCC scenarios: Range of global warming estimates

	Estimated temperature change (°C)			Ratio		CO_2 level in 2100 (ppm)
Scenario	Lowest (L)	Most likely (M)	Highest (H)	(H-M)/(M-L)	In logs	
B1	1.1	1.8	2.9	1.57	0.97	545
A1T	1.7	2.4	3.8	2.00	1.33	578
B2	1.7	2.4	3.8	2.00	1.33	616
A1B	1.7	2.8	4.4	1.45	0.91	710
A2	2.0	3.4	5.4	1.43	0.87	846
A1FI	2.4	4.0	6.4	1.50	0.92	964

Notes:

Estimates are from various sources including many Atmosphere-Ocean General Circulation Models (AOGCMs). They do not include deterioration of climate change prospects after IPCC 2007 was finalized. The estimates are therefore conservative.

Temperature changes are expressed as the increase from 1980-1999 to 2090-99. To express the change relative to the period 1850-1899 add 0.5%.

The CO_2 forcing in 2100 is the average reference case for two models: ISAM and Bern-CC (IPCC 2001 WG1 report, Appendix II: SRES tables).

Source: IPCC 2007 Synthesis Report, Table 3.1.

The projections of temperature change are loaded with uncertainties in the carbon cycle and in the response of the climate to a given increase in atmospheric greenhouse gases. A worst-case scenario may turn out better than the median estimates suggest, and a best-case scenario may result in temperature increases exceeding risky levels. This background paper draws attention to such uncertainties.

Climate change has become a progressively more urgent issue during the past decade, due largely to the impact of positive feedback effects exceeding expectations (such as the melting of sea-ice and the impact on the Greenland ice sheet). Some scientists find it difficult to imagine how we can enter a world where average global temperatures have risen three or four degrees or more and still charge ahead at the predicted rates of growth. NASA's James Hansen warns that unless we limit the atmospheric greenhouse gas content to current levels or even below, we may trigger major events that will make the Earth a very difficult place to live (Hansen et al. 2008). Quoting from the abstract of the paper: "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that."

Using probabilistic analysis, Meinshausen et al. (2009) find that if global greenhouse gas emissions grow to more than 25% above 2000 levels in 2020, the probability of exceeding a $2^{O}C$ rise by 2100 rises to between 53% and 87%. Even halving emissions by 2050 carries a probability of between 12% and 45% of exceeding $2^{O}C$. The authors note that more than 100 countries have adopted a global warming limit of $2^{O}C$ or below, relative to pre-industrial levels, as a guiding principle for mitigating climate change risks, impacts and damages. "Given the substantial recent increase in fossil CO_2 emissions (20% between 2000 and 2006 [as reported by Canadell et al. 2007]), policies to reduce global emissions are needed urgently if the below $2^{O}C$ target is to remain achievable." (Meinshausen et al. 2009, p 1160).

Science journalists Mark Lynas (2008) and Gaia Vince (2009) describe nightmarish "above-4-degree" worlds based on persuasive scientific findings. So does Clive Hamilton (2010) based on a conference of 140 climate scientists and others that he attended (and contributed to) in Oxford in September 2009, named "4 degrees and beyond: Implications of a global change of 4+ degrees for people, ecosystems and the earth system."[2]

Prominent Stanford University environmental scientist Stephen Schneider points to the low but significant probability that the CO_2-equivalent level will reach 1,000 ppm, which adjusted for other greenhouse gases was the level predicted in 2001 in the worst-case IPPC scenario, A1FI (see Table 1). He writes: "An atmosphere in 2100 with 1,000 parts per million of carbon-dioxide equivalent would be catastrophic. To understand the effect of this, we need to peer into what Harvard University economist Marty Weitzman calls the "fat tail" of the probability distribution for climate damage. Although the likelihood is uncertain — and probably low[3] — we should give these events more attention because not doing so could be potentially disastrous." (Schneider 2009)

Weitzman (2009a) has done fundamental research into what has become known as the *fat tail* of the probability distribution – that is, a modification of the kurtosis of the standard bell curve or normal distribution. A high kurtosis means a low, relatively even distribution with more extreme observations (the fat tail), whereas a low kurtosis portrays a chart with skinny tails and a distribution concentrated towards the mean. In another paper (2009b) Weitzman explains:

"The probability of a disastrous collapse of planetary welfare from too much CO_2 is non-negligible, even if this low probability is not objectively knowable." (p 1)

"A key starting point for any CBA of climate change should recognize that future temperatures or damages cannot be known exactly and must be expressed as a probability

[2] A 204-page abstract book of the conference (http://www.eci.ox.ac.uk/4degrees/downloads/abstractbook.pdf) starts with the keynote address by Professor Hans Joachim Schellnhuber of the Potsdam Institute for Climate Impact Research. Hamilton's contribution, with Tim Kasser, was on adaptive coping strategies in a $4^{O}C$ world.

[3] The *Synthesis Report* from the science conference on climate change in Copenhagen in March 2009 takes a stronger view. Its "Key Message 1" is that greenhouse gas emissions and other indicators of climate change are changing near the upper boundary of the IPCC range of projections (Richardson et al. 2009, p 6).

density function (PDF). Yet, most existing IAMs treat central forecasts of temperatures or damages as if they were certain and then do some sensitivity analysis on parameter values. In the rare cases where an IAM formally incorporates uncertainty, it typically uses thin-tailed PDFs including, especially, truncation of PDFs at arbitrary cutoffs. … I will argue that the PDF of distant-future temperature changes is fat tailed. A thin-tailed PDF assigns a relatively much lower probability to rare events in the extreme tails than does a fat-tailed PDF." (p 2)

"Fat-tailed CBA has strong implications that have neither been recognized in the literature nor incorporated into formal CBA modeling of disasters like climate-change catastrophes." (p 3)[4]

Weitzman's analytic focus differs from most other economists' concerns. The economic debate on the IPCC scenarios has been largely along two interrelated lines. One concern is the use of market exchange rates (MER) to compare standards of living from country to country, rather than purchasing power parity (PPP), where the conversion factor shows how much of a country's currency is needed in that country to buy what $1 would buy in the United States. There is generally less difference between apparent living standards using PPP, so in general terms the poorer nations have less catching up to do (though still a lot) in the A1 scenario.

The economists' second concern relates to IPCC's method of building up the global projections from four massive aggregates of national statistics: 'OECD 90' (the members in 1990), REF (Eastern Europe and the former Soviet Union), ASIA (developing Asian countries), and ALM (developing countries in Africa, Latin America, and the Middle East). The criticism has considerable validity, not followed up in this paper. McKibbin et al. (2004) advocate a multi-sector, multi-country, inter-temporal comparison base as a superior solution.

This background paper has a different purpose. Economists have made little or no attempt to quantify the impact of global warming and other aspects of climate change on GDP across the range of the IPCC scenarios. However, Hoegh-Guldberg (2010a) showed three of the most prominent contributors to the economics of climate change and poverty agreeing that a (BAU) scenario would have dismal consequences for the world economy: Stern (2006), Garnaut (2008), and Sachs (2008). According to the IPCC no SRES scenarios should be interpreted as BAU, but many scientists put that label on the global economics-driven fossil-energy intensive A1FI scenario. This is incorrect because the whole idea of scenario *planning* is to establish a framework of alternative equally credible futures, but late 20th century economic policies were admittedly highly growth-driven, increasingly globalized, based on fossil energy, and influenced by powerful lobby groups.

Chapter 2 of the recent book by Nicholas Stern on the economics of climate change (2009) is called *The dangers.* A table on page 26 shows that if the stabilization level is 450 ppm CO_2-e (counting all greenhouse gases and not just CO_2) there is a 78% chance of exceeding 2^{O}C, and 18% chance of exceeding 3^{O}C, after which the percentages reduce drastically (3% chance of exceeding 4^{O}C). But at a stabilization level of 750 ppm CO_2-e the chance of exceeding 2^{O}C is 100%, that of exceeding 3^{O}C 99%, 4^{O}C 82%, 5^{O}C 47%, 6^{O}C 22%, and 7^{O}C 9%. These estimates,

[4] CBA stands for cost-benefit analysis and IAM for integrated assessment model.

incidentally, are in excess of the probabilistic data in this paper, which are from IPCC's Fourth Assessment Report in 2007.

Some of Stern's comments follow: "If we do not act responsibly, it is likely that by the end of this century or sometime in the first half of the next century, we will see temperature increases of 4-5^{O}C or higher relative to 1850. It is very difficult to describe such a world; the science has much less to go on. But it would, in all likelihood, be a radical transformation of the world we know." (pp 30-31)

"Some areas, probably much of Southern Europe, might become deserts. Most of Florida and Bangladesh would eventually be submerged. Of great importance here is that the pace at which temperature changes occur would be extraordinarily rapid in relation to historical and evolutionary time. Increases of the scale of 5^{O}C could happen, indeed are likely to happen, within the space of a century or two if we do not act." (p 31)

"The point is that with temperature changes of this magnitude, the physical geography is rewritten. If the physical geography is rewritten then so too is the human geography of the world. There would be movement of people on an immense scale. The lessons of the last few hundred years surely tell us that the movements of billions of people in a fairly short period of time would plunge the world into massive and extended conflict." (p 31)

Stern is a world leader in climate change economics. Aided by Garnaut's and Sachs's and his own previous assessments of the adverse consequences of BAU, his comments remove some of the unease this writer has felt seeing that most warnings come from the world of science, while his fellow economists apparently steer away from quantifying the possible economic consequences of a 4^{O}, 5^{O} of 6^{O} world in favor of tackling technical matters like MER versus PPP and the extent to which the global economic scenario model should be disaggregated. These matters are of course also very important.

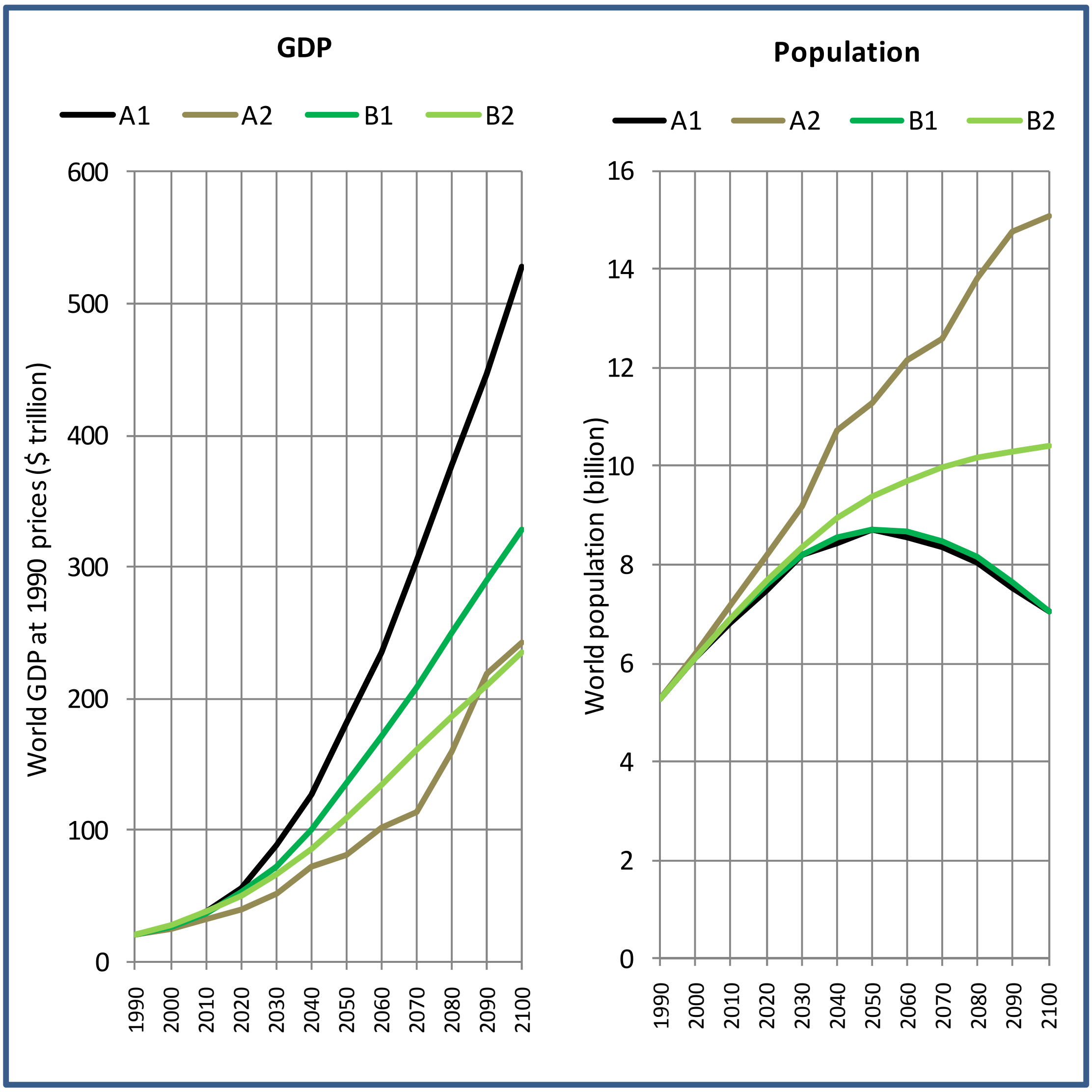
Before presenting the analysis that follows, a disclaimer is needed. To all intents and purposes, this background paper is based on adequate, reasonably readily available data. It could be refined in many ways, given much more time and better and more complete national and regional statistics. Its main focus is on the connection between the quantitative IPCC scenarios and the estimated impact of living in a world where the *average global temperature* has risen by one, two, three, four, five, or six degrees Celsius. What the more extreme increases would mean for particular geographic regions must be, for now, left mainly to the imagination.

THE IPCC SCENARIOS

Table 1 showed the range of temperature estimates associated with each scenario. Three variations of A1 depict worlds of globally interconnected economic growth: fossil-energy dominated (A1FI), balanced use of fossil and renewable energy (A1B), and renewables (probably supplemented by nuclear energy) as the principal energy source (A1T). A2 is also driven by economics but globalization is no longer a strong force. Environmental considerations are more important in the two "B" scenarios, with B1 depicting a globalized world and B2 a regionalized world. [5]

The scenarios were devised between 1997 and 2000 for the SRES report (from data relating to the early 1990s), but most of the information in Table 1 was derived from the Fourth Assessment Report in 2007. In addition to the "most likely" estimates, our analysis uses the extreme high and low observations to indicate the possible ranges under each scenario.

Figure 1: Global IPCC 2001 projections



An attempt was made to estimate the probability distributions between the extremes, but there is insufficient published information. It would be interesting to find out whether one or both of the tails of the distribution are "fat" as suggested by Weitzman. The table shows a longer tail towards the upper boundary, indicated by a ratio between the upper and lower intervals averaging a little below 1.5 for four of the six scenarios. The exceptions are the

[5] The final analysis of scenario stories in Chapter 6 suggests that B2, if written today, would be more favorably judged. The B2 estimates in this paper, however, are based on the original SRES scenario from 2000.

regionalized environmental scenario B2 and A1T, the renewable energy driven growth case. We shall see below that these two scenarios are a little out of line with the remaining four, when compared with cumulative CO_2 emissions to 2100.

Transforming the three estimated temperature changes to logarithms, as shown in the second buff-colored column of Table 1, suggests that the distributions may be closer to log-normal rather than normal: the ratio of the transformed upper to lower intervals is between 0.87 and 0.97 for the four scenarios, compared with a range from 1.43 and 1.57 for the untransformed data. This still doesn't tell us whether the tails are fat – though perhaps the distribution hints that the upper tail may be.

Table 2: Annual rates of change: main 2001 projections (10-year averages)

	Scenario A1			Scenario A2		
	Population	GDP	GDP/head	Population	GDP	GDP/head
1990						
2000	1.52%	2.50%	0.97%	1.57%	2.31%	0.73%
2010	1.07%	3.55%	2.46%	1.54%	2.38%	0.83%
2020	0.97%	4.07%	3.07%	1.33%	2.41%	1.06%
2030	0.88%	4.66%	3.74%	1.12%	2.36%	1.23%
2040	0.31%	3.62%	3.30%	1.57%	3.52%	1.92%
2050	0.31%	3.62%	3.30%	0.53%	1.21%	0.68%
2060	-0.19%	2.63%	2.83%	0.72%	2.25%	1.52%
2070	-0.19%	2.63%	2.83%	0.36%	1.14%	0.77%
2080	-0.42%	2.16%	2.59%	0.94%	3.40%	2.43%
2090	-0.64%	1.70%	2.36%	0.64%	3.20%	2.54%
2100	-0.64%	1.70%	2.36%	0.22%	1.07%	0.85%

	Scenario B1			Scenario B2		
	Population	GDP	GDP/head	Population	GDP	GDP/head
1990						
2000	1.49%	2.48%	0.97%	1.47%	3.08%	1.58%
2010	1.19%	3.38%	2.16%	1.24%	3.15%	1.89%
2020	1.01%	3.48%	2.45%	1.08%	2.76%	1.67%
2030	0.73%	3.35%	2.60%	0.88%	2.67%	1.78%
2040	0.42%	3.26%	2.83%	0.65%	2.62%	1.96%
2050	0.19%	3.02%	2.82%	0.48%	2.50%	2.02%
2060	-0.04%	2.39%	2.43%	0.35%	2.10%	1.74%
2070	-0.22%	1.96%	2.18%	0.26%	1.82%	1.56%
2080	-0.41%	1.82%	2.24%	0.20%	1.44%	1.24%
2090	-0.60%	1.51%	2.13%	0.14%	1.22%	1.07%
2100	-0.83%	1.25%	2.10%	0.10%	1.11%	1.01%

Source: http://sres.ciesin.org/final_data.html (Excel version)

The statistics on CO_2 abundance in Table 1 are from the 2001 Third Assessment Report and would almost certainly be higher if calculated today. The numbers also exclude other greenhouse gases such as methane and nitrous oxide, and soot. The evidence (including Stern's probability table quoted in the introduction) is that prospects have deteriorated further since the temperature ranges were calculated for the Fourth Assessment Report in

2007, and that could have an influence on the policies directed towards non-CO_2 greenhouse gases.

The four scenarios display very different projections of GDP and population (Figure 1). Economic growth unrestrained by warming is highest in A1 (all three variants), second-highest in the globally and environmentally orientated scenario B1, and lowest in the regionally divided A2 and B2 scenarios. The two globally orientated scenarios show similar population patterns over the century, reaching a maximum of about 8.7 billion in 2050 and falling thereafter. The regionalized scenarios show continuous population growth, A2 to over 15 billion by 2100, B2 to over 10 billion. Such increases in the global population would in itself have potential impacts on economic growth, which may not have been taken adequately into account in the SRES projections.

The assumptions behind the four GDP and population projections (Table 2) are also queried. The high-growth A1 scenario shows an acceleration in economic growth to 4.7% pa in the 2020s, and even at the end of the century, when population has been falling for decades, total GDP is assumed to grow by 1.7% pa. The annual average for the period from 1990 to 2100 is 3.0%. GDP per capita is assumed to slow down from 3.8% pa in the 2020s to a still substantial 2.4% between 2080 and 2100.

Scenario A2 shows somewhat erratic growth patterns through the century, which were retained when the revised projections shown in Table 2 were published. The average for the full period is 2.3% pa, second-lowest of the four main scenarios.

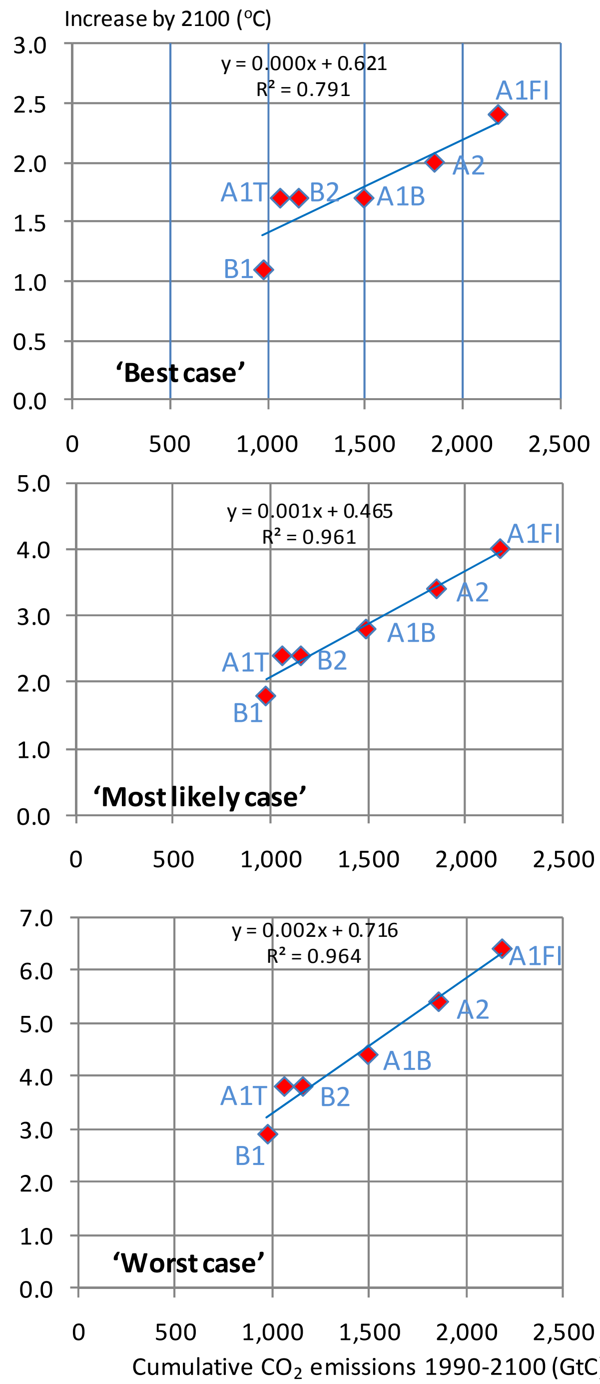
Of the two more environmentally aware scenarios, the globally geared B1 shows GDP growth in excess of 3% pa through the first half of the century, before the rate reduces towards 1.25% in the last decade (average 1990-2100 2.5% pa). Population growth and decline is similar to A1, so GDP per head is more regular, peaking at 2.8% pa in the 2030s and 2040s and maintaining a rate of over 2% in 2090-2100. The regionalized environmentally

Table 3: Cumulative CO2 emissions since 1990 (GtC)

Year	A1FI	A2	A1B	B2	A1T	B1
1990	-	-	-	-	-	-
2000	75	75	75	75	75	75
2010	164	163	170	159	162	162
2020	276	272	287	248	260	261
2030	421	407	423	343	373	370
2040	602	561	572	446	499	484
2050	821	729	731	554	623	599
2060	1,069	912	892	667	741	704
2070	1,334	1,112	1,051	783	848	794
2080	1,614	1,332	1,206	901	937	868
2090	1,899	1,579	1,353	1,026	1,008	928
2100	2,182	1,855	1,492	1,157	1,061	976

Source: http://sres.ciesin.org/final_data.html orientated B2 shows lower growth, the rate decreasing to just over 1% pa by the 2090s. The annual average for the full period is 2.2%, the lowest growth rate among the four scenarios. The growth prospects are consequently much lower in the regionalized scenarios than the globalized ones, and since these scenarios have much higher population growth, the gap in per-capita GDP is even higher.

Figure 2: Cumulative emissions and global temperature rise



Source: See Tables A2.1 and A2.3

SRES SCENARIOS LINK WITH GLOBAL WARMING PROJECTIONS

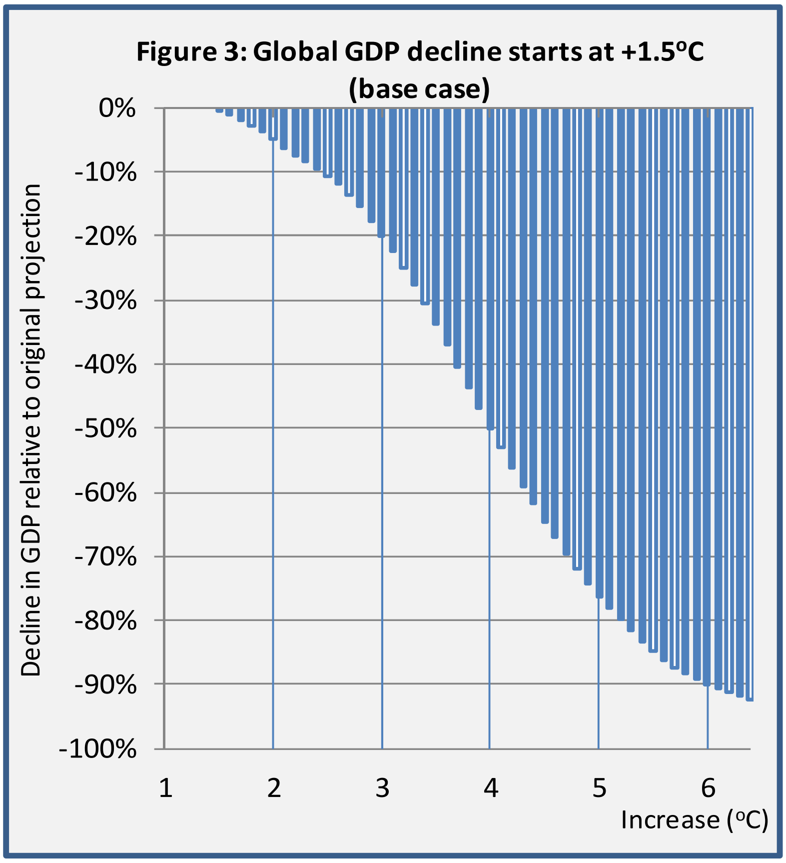
One problem in setting up this research was the lack of a direct link between economic growth and the global average temperature through the 21st century. The final quantitative analysis is shown for all 40 A1, A2, B1 and B2 SRES scenarios (from which IPCC selected the six marker and variant scenarios discussed in this background paper) in the source shown below Table 3.

The quantitative projections contain a great deal of detail in addition to GDP and population, relating to final and primary energy use, cumulative use of coal, oil and gas resources, land use, and standardized anthropogenic emissions. They also, importantly for our purposes, show cumulative CO_2 emissions per decade from 1990 to 2100 (Table 3). These emissions are shown in order of size in 2100, from 2,182 gigatons of carbon for the fossil-intensive A1FI scenario to under 1,000 GtC for B1. The emissions vary enormously between the three A1 scenarios with the renewables-driven variant not much higher than B1.

It remains to test the statistical relationship between cumulative CO_2 emissions and the estimated increase in global average temperature by 2100. This involved setting up a "best", "most likely" and "worst" case for each of the six scenario variants. The best case is the lowest temperature change along the ranges shown in Table 1, the most likely case is as shown in Table 1, and the worst case the highest temperature change along the ranges. The scatter diagrams in Figure 2 show how the level of cumulative CO_2 emissions in 2100 shown in Table 3 correlate with the estimated temperature increase over the century in the three cases. The plots show that there is a clear connection.

In the best case, the unconstrained temperature increase for scenario B1 is 1.1°C, and for three scenarios, A1T, B2, and A1B, all 1.7°C. The highest readings relate to the regionalized economic scenario A2 (+2.0°C), and the fossil-fuel-dominated A1FI (+2.4°C). This does not yield a particularly high correlation between cumulative emissions and the global temperature rise, mainly because of the lack of differentiation between A1T, B2 and A1B. At these relatively small changes, the clearest signs of differentiation are the higher increases in temperature for the regionalized economic growth scenario (A2) and the fossil-fuel global growth scenario (A1FI).

The differentiation becomes clearer in the 'most likely' case, where the only real deviations from the regression line are A1T (a fraction of a degree warmer than might be expected) and B1 (one-fifth of a degree lower). The picture is similar in the extreme upper case, designated "worst". The correlation between the cumulative emissions and the expected global temperature increase between the late 20th century and 2100 is high (R^2 is over .96 for both the most likely and the worst case).



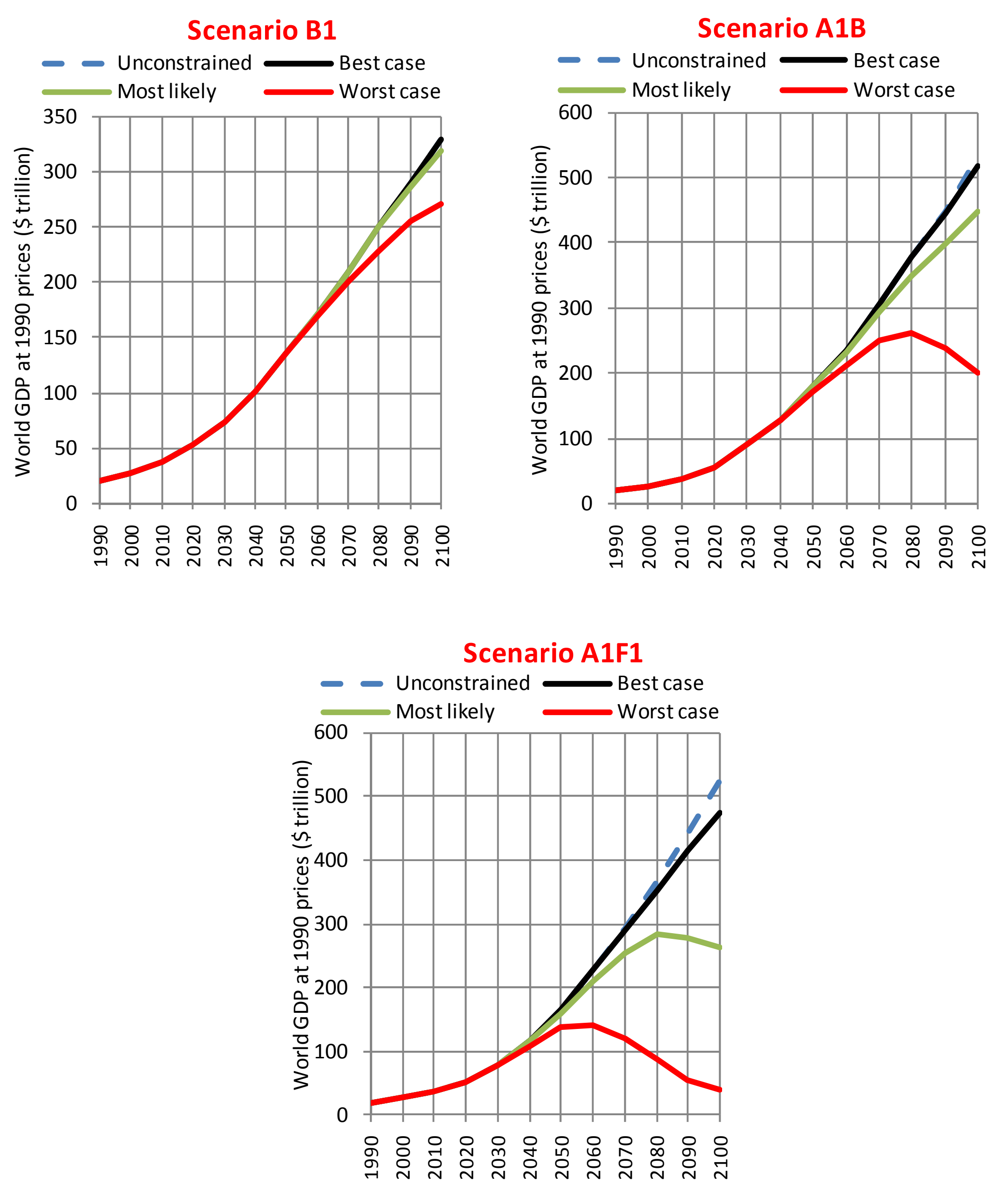
WHAT IS THE IMPACT OF WARMING ON GDP?

These assumptions need careful debate; all we can do in an explorative review is to postulate some impacts (from Figure 3):

An increase of 2°C is now seen by many as a limit beyond which the world should not move. The assumption in Figure 3 is that when 2°C is reached, GDP has lost 5% compared with the original projections. The impact of warming starts to kick in at +1.5°C.

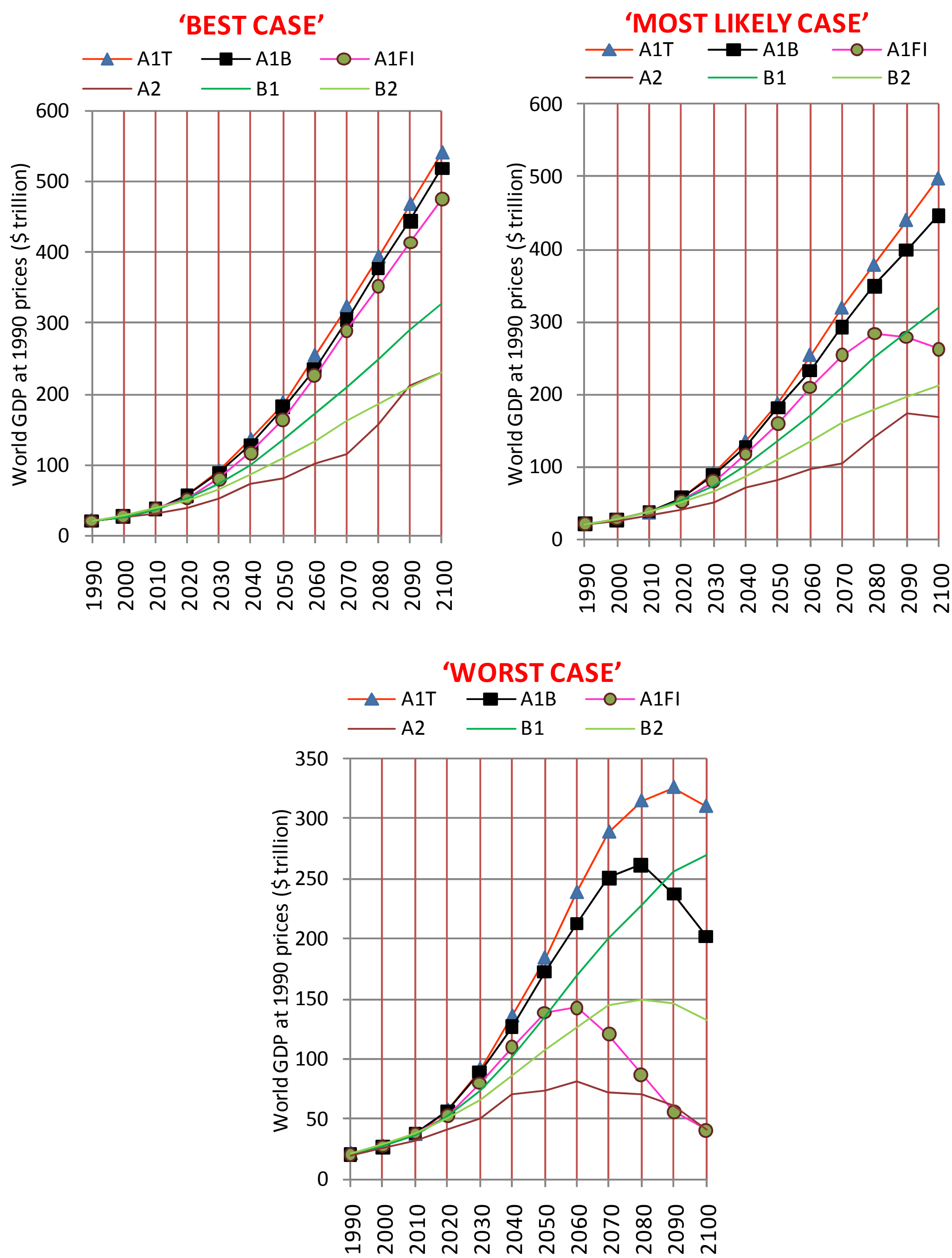
At the other end of the range, from say 5°C up, economies around the world may be largely ruined, according to the scientific opinions collected by Lynas and others, and the qualitative assessment by Stern and others. These levels are not sacrosanct but the judgment is that the reduction could be severe. James Lovelock would endorse that. The final paragraph in *The Revenge of Gaia* (Lovelock 2006) begins: "Meanwhile in the hot arid world survivors gather for the new Arctic centers of civilization; I see them in the desert as the dawn breaks and the sun throws its piercing gaze across the horizon at the camp. … Their camel wakes, blinks and slowly rises on her haunches. The few remaining members of the tribe mount. She belches,

Figure 4: Global GDP, three selected scenarios, base case



and sets off on the long unbearably hot journey to the next oasis." (p 159) Gaia has had her revenge.

Figure 5: All cases: all six scenarios, base case



How the graph develops between these extremes is unknown. It is assumed in the base case represented by Figure 3 that 20% of GDP may have been lost at 3^0C, 50% by 4^0C, a little over 75% by 5^oC, and 90% by 6^oC. Smaller reductions relative to the unconstrained IPCC projections may be possible, but would merely change the scale and timing, not the substance (refer the first variant of the base case below). It may also be argued that the reductions would be less severe at lower temperature changes but would kick in more strongly, say, from +3°C or +4°C – the second variant case shown below. The shape of the curve in Figure 3 and subsequent graphs showing the variants is not sacrosanct, only a first approximation.

As previously noted, all these cases assume that a given scenario is allowed to play out without action to mitigate the events. This is the usual assumption behind the IPCC scenarios developed to date, and therefore also here.

BASE CASE RESULTS

Figure 4 compares three of the scenarios, B1, A1B (the balanced-technology strong global growth scenario), and A1FI, where fossil fuels continue to reign supreme. The three cases compared are the best case (lowest growth in warming under a given CO_2 regime in Table 1), the 'most likely' case; and the worst case, again according to Table 1. The partly or fully hidden "unconstrained" dotted line on the charts is the original SRES projection.

Figure 5 compares all six scenarios (including the three variants of A1). In the best case which may not occur, especially if the tail in the distribution towards higher temperature changes is the longer and fatter one, the three A1 scenarios are way ahead of the others. In the "most likely" case, A1FI turns down from 2080 and is exceeded by the environmentally orientated B1 in the final decade of the century. In the worst case scenario, A1FI collapses after 2050 and all GDP measures start to decline between 2050 and 2090 except B1 that continues to grow and by 2100 is second to only A1T, the renewable technology high-growth orientated scenario. The green B1 line on Figure 5 highlights that this scenario retains its original unconstrained level and growth much better than the other scenarios.

Despite the importance of renewable energy sources in the economics-driven A1T scenario, it too reaches a limit of growth in our base case while the environmentally friendly global B1 scenario doesn't within the time set. All this is based on the probability distributions in Table 1, which were developed by the IPCC. Subsequent evidence suggests that these distributions remain largely current for the best case (B1) but the worst cases – A1FI in particular – are getting worse (Pearce 2009).

These conclusions depend on the assumption on how much global GDP will be affected by particular increases in warming (based on Figure 3). There are plenty of other factors to take into account, including patterns of warming across the planet, how warming interacts with other climate change variables such as sea-level rise, ocean acidification, droughts and floods, regional weather patterns such as monsoons and hurricane activity, and how much adaptation is possible not just for the big end of town but for all people in all countries.

ALTERNATIVE ASSUMPTIONS

The remainder of this background paper presents two alternatives to the base case. The first alternative postpones the onset of reduced economic growth due to climate change from

+1.5°C to +2.5°C (Figure 6). The shape of the curve is otherwise unchanged from the base case in Figure 3.

Figure 6: Global GDP decline begins at +2.5ºC

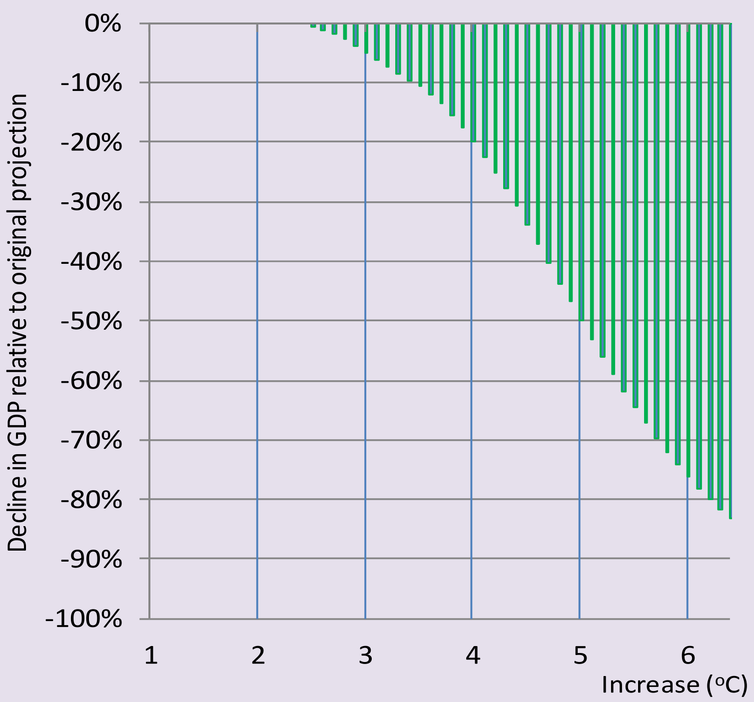
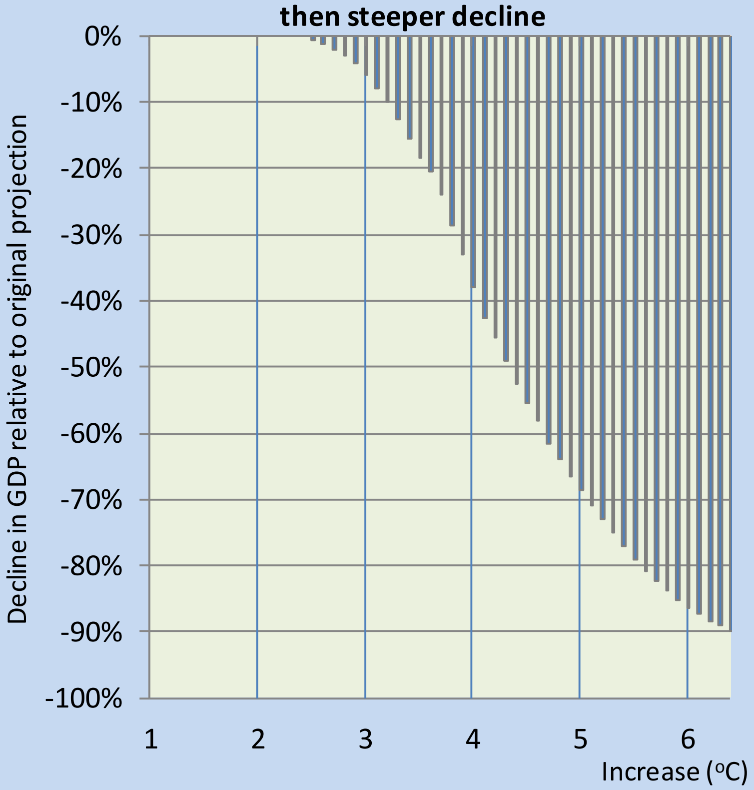


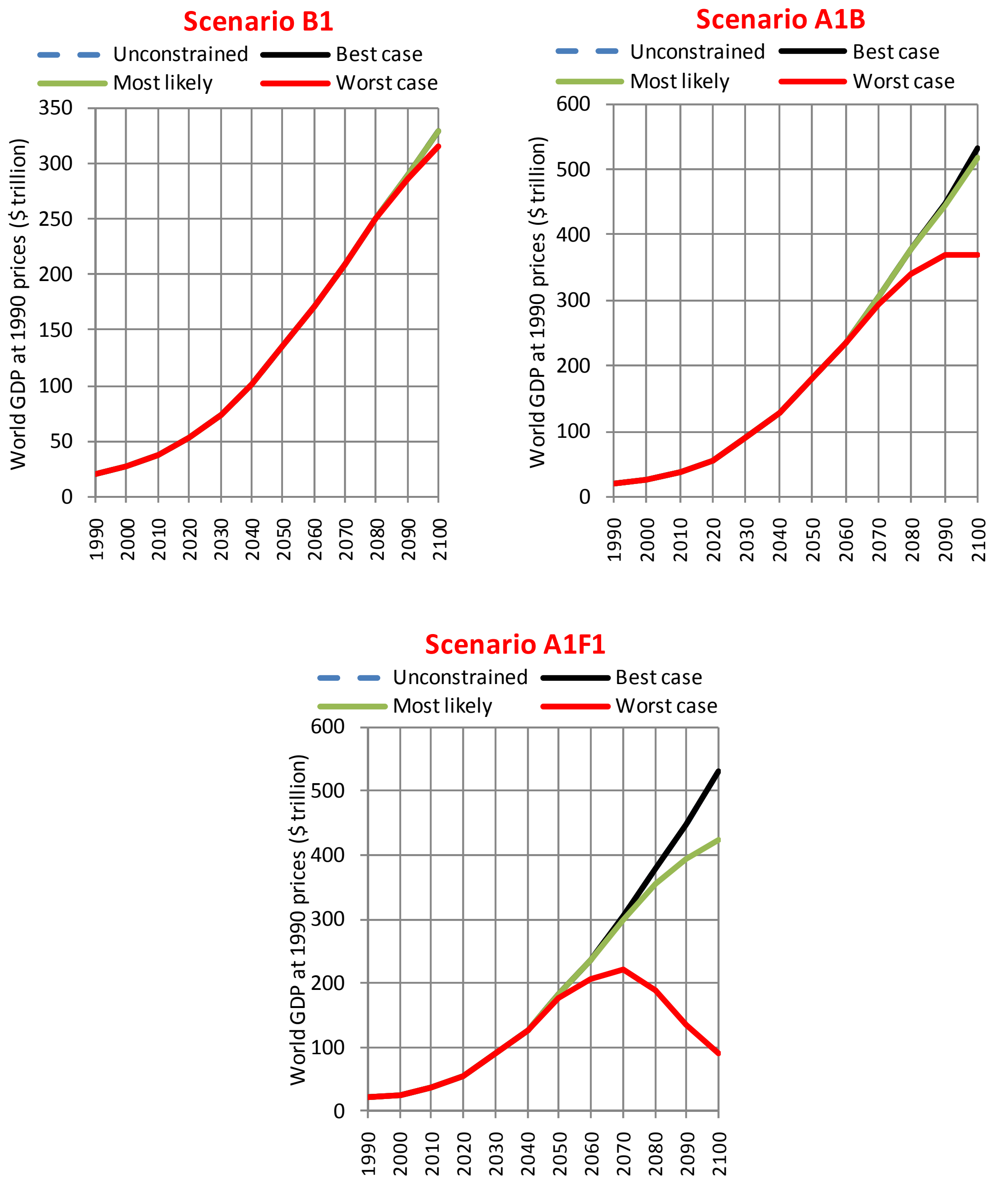
Figure 7: Global GDP decline begins at +2.5ºC, then steeper decline



In the second variant, economic growth is again assumed to be unaffected by global warming and other climate change impacts until the average global warming gets to 2.5°C above preindustrial levels. However, it then plunges more heavily than in the two other cases towards a 90% reduction in global GDP by 2100 (Figure 7).

In the more benign case, the three chosen scenarios are naturally least affected by the economic assumptions (Figure 8). The global environmental B1 scenario is only marginally affected even in the worst case. The global economic middle-of-the-road scenario A1B is also fairly unaffected except in the worst case, where economic growth is curbed in the last decade of the 21st century. The fossil fuel scenario A1FI, however, is reduced by 20% ($100 trillion) by 2100 in the most likely case, and collapses from 2070 in the worst case. And that is the most benign of our three variant cases and possibly too optimistic.

Figure 8: Global GDP when decline starts at 2.5°C

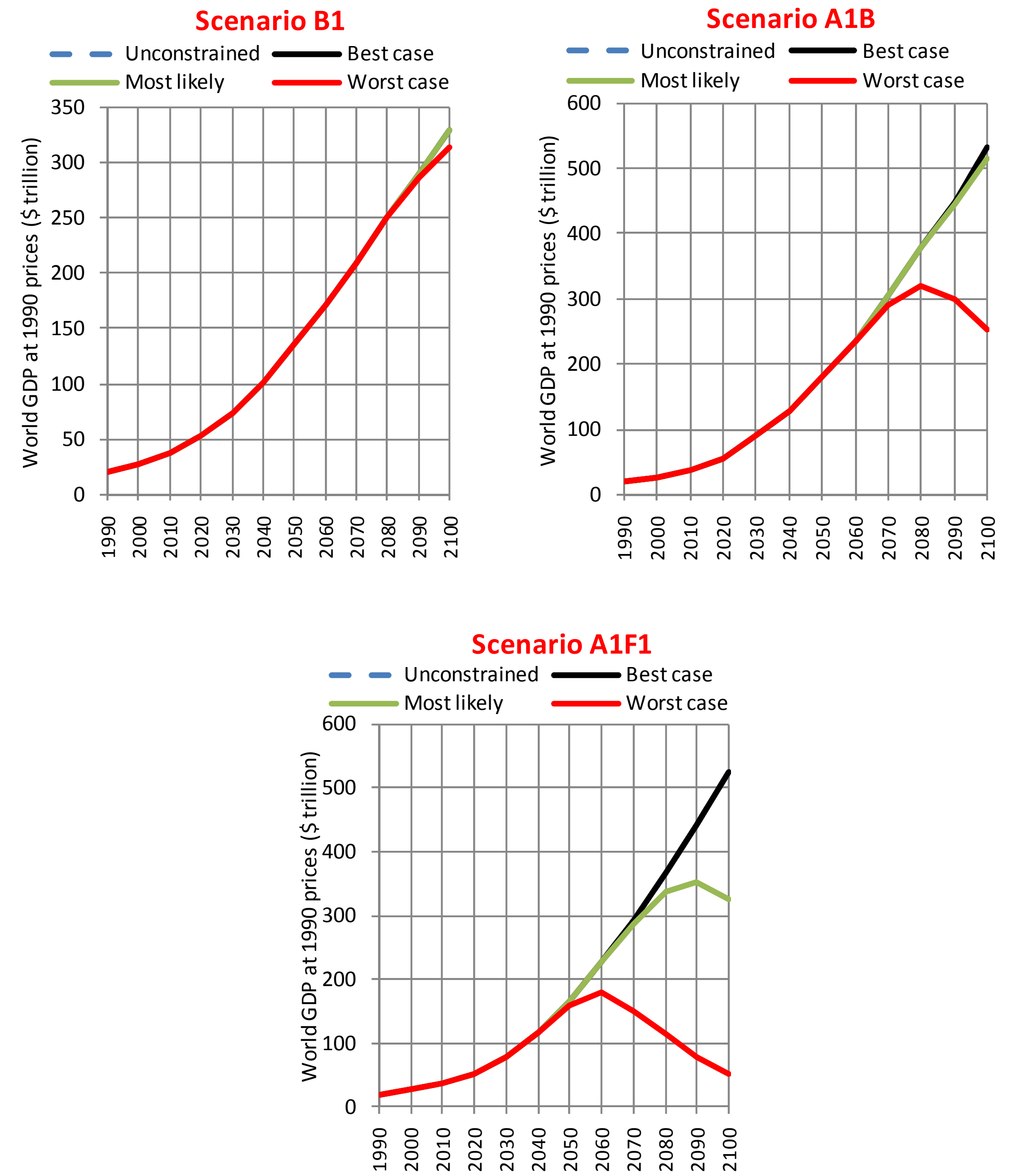


The first result in the third case, where the impact on the global economy starts at +2..5^{O}C but then has greater impact than the first two cases (Figure 9) is that the environmentally benign global scenario B1 is again only marginally affected by the assumptions and only in the worst case. In the two other cases, B1 continues its path towards a global world product of some $330 trillion by the end of the century.

The "balanced" global growth scenario A1B is projected to suffer economic collapse in the late 21st century as the worst case, while it will be largely unscathed in the best and most likely cases (growing towards a world product of more than $500 trillion).

If the world insists on continuing to favor fossil fuels, economies starting to collapse are indicated from about 2090 in the most likely case, and from 2060 in the worst case. Only in the best case would it be favored to show economic growth to the end of the 21st century. This is similar though slightly less severe than the base case presented in Figure 4.

Figure 9: Global GDP when impact first delayed, then steeper



In summary, postponing the impact of rising temperatures until +2.5^{O}C is reached, but then assuming a more precipitate collapse as the Earth moves into climates governed by +4^{O}C or more, initially makes these assumptions look relatively benign but the growth-based economic scenarios begin to take on a nightmare character in the second part of the century. It reinforces the need, already suggested by the base case, to move to an environmentally friendlier world like the one represented by the B1 scenario.

These assumptions can of course be varied in many ways. Have we been too severe in postulating gross world product declines of 90% or more when the global average temperature increases to 6^{O}C or more? One final check was to assume an arithmetically constant decline of 1.875% for each tenth of degree increase from +2.5^{O}C to the maximum +6.4^{O}C, reaching a total 75% decline at that temperature. Concentrating on the worst case only, there is little change to the B1 scenario, while the marker A1B scenario starts to slow down from 2070 ($276 trillion) to reach $307 trillion in 2080, $322 trillion in 2090, and $332 trillion in 2100. This is still higher than the B1 level for that year ($298 trillion), but the margin is clearly reducing between the two.

The fossil-intensive scenario A1FI now peaks in 2070 at $189 trillion, declines marginally to $188 trillion by 2080, after which the decline gathers speed: $168 trillion in 2090 and $131 trillion in 2100. So within a wide range of assumptions about the connection between global warming and the gross world product, the worst case remains that the unmitigated fossil-intensive scenario spells economic collapse towards the end of this century.

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