

Global Warming: What Sort of Mess Have We Made?

by David K. Levine¹

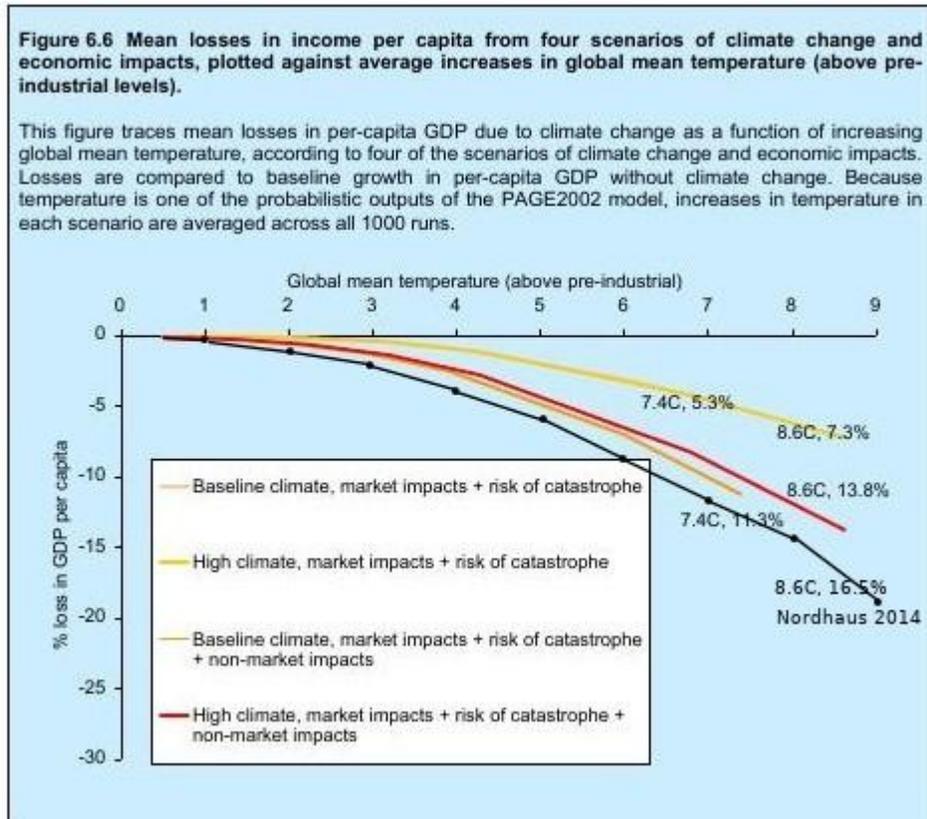
10/21/19

“Our leadership has failed us. Young people must hold older generations accountable for the mess they have created. We need to get angry and transform that anger into action.” Greta Thunberg

I have frequently heard from young people the sentiment articulated by Greta Thunberg: older generations have created a mess due to global warming that is inherited by young people. Based on the best available science this essay articulates our current forecasts of what that mess is. It is based on the view that science is what we have. This cuts both ways: if you want to argue that there is a scientific consensus about global warming and that anyone who disagrees is a “denier” then if you deny the scientific consensus about the economic costs of warming you are equally a “denier.” I’m writing this for those of us who aren’t deniers.

¹ For John who asked all the right questions. I am grateful to Andrea Ichino, Andrea Mattozzi, Salvatore Modica, Catharina Tilmans and my graduate reading group for listening and discussing the issues here. I would also like to express my appreciation to Giorgio Gilestro who despite our many disagreements has been very kind in directing me away from the mishmash of information and misinformation on the internet to the relevant scientific literature.

I'm going to start with a graph that surprised me. It is from the *Stern Review*.²



This graph is not entirely self-explanatory, so let me indicate what is in it. On the horizontal axis is the increase in global mean temperature. On the vertical axis is the economic cost. I am going to start with the red line because it includes a wide range of costs and risks including the risk of catastrophe and non-market impacts as well as market impacts. It is measured as percent of GDP. When it says 8.6C 13.8% it means that if the climate warms 8.6C this would result in world income 13.8% lower than if the climate did not warm.

I have also superimposed on the graph a black line which represents the best current estimates used by Nordhaus.³ Nordhaus is anethema to environmentalists. This reaction to his receipt of the Nobel Prize in economics is indicative:

Nordhaus may have been early to this area of research, but he now looks out of step with its latest developments.

It is a lost opportunity for this prestigious award, which might instead have gone to Nicholas Stern, an economist who has called climate change ‘the greatest market failure the world has ever seen’, and promoted immediate and forceful action to tackle the issue.⁴

² Stern, Nicholas Herbert [2007]: *The economics of climate change: the Stern review*. Cambridge University press.

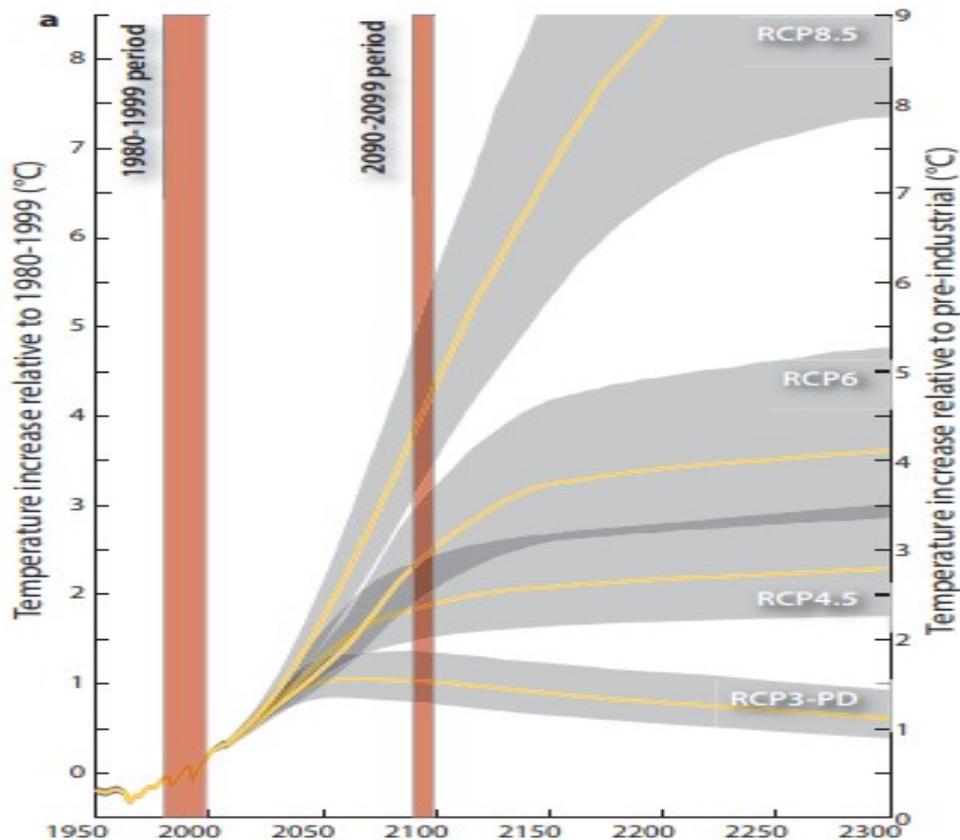
³ I took this from p. 514, equation (6) of Hassler, J., Krusell, P., and Nycander, J. [2016]: “Climate policy,” *Economic Policy* 31: 503-558.

⁴ Holmey, Oliver [2018]: “CSR: Sending out the wrong message on climate change,” *Euromoney* October 16.

Hence I start with the graph from Stern. The *Stern Review* is frequently quoted by environmentalists. Greenpeace,⁵ for example, refers favorably to the study from which I took this graph. However, as the most recent Nordhaus estimates indicate greater environmental damage than Stern, I will use that more pessimistic assessment in my calculations, that is, 8.6C and 16.5%. I am going subsequently to explain where that graph came from and discuss whether it makes sense, but for the moment I am simply going to observe it is the best currently available science.

I want to begin by putting the number 16.5% in perspective. During the Great Depression world income dropped by about 15%. Rhetoric such as “the planet is on fire” or “existential catastrophe” seem excessive for an event the likes of which my parents have seen in their time. On the other hand, those who lived through the depression would not wish it on their children.

Next, how likely is an increase of 8.6C, or better, when is it likely to be relevant? Below I reproduce the best available estimates of global temperature increase from the IPCC.⁶



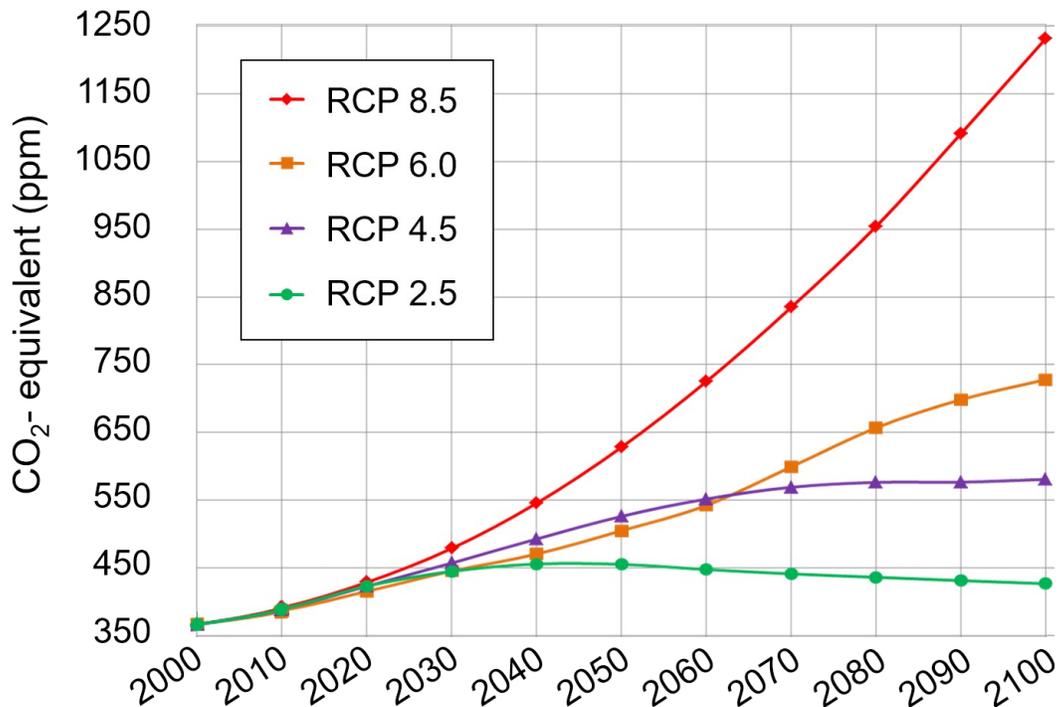
5 <https://secured-static.greenpeace.org/usa/Global/usa/report/2009/8/america-s-share-of-the-climate.pdf>

6 *IPCC Climate Change 2013: The Physical Science Basis*, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Again the graph is not entirely self explanatory. The horizontal axis is the year. The IPCC does not consider its estimates beyond 2100 terribly useful, but does report them up until 2300: the second vertical brown segment marks the end of the estimates that the IPCC ordinarily considers in its assessments. The right vertical axis is the degree of warming in centigrade above the pre-industrial period: it corresponds to the horizontal axis in the previous graph. What is perhaps less clear are the grey regions with yellow lines marked RCP8.5, RCP6, RCP4.5 and RCP3-PD. These represent different emissions scenarios. The yellow line marks the best estimate and the surrounding gray area the range of uncertainty about the forecast. To make sense of this we have to know what the scenarios are. A good description can be found in Wikipedia⁷ and I reproduce their graph below.

IPCC AR5 Greenhouse Gas Concentration Pathways

Representative Concentration Pathways (RCPs) from the fifth Assessment Report by the International Panel on Climate Change



Again, let me first explain the graph. The colored lines correspond to the different RCP scenarios – the same as in the previous graph, except that the most favorable scenario here is RCP2.5 while in the previous graph it is RCP3-PD. On the horizontal axis again is the year. On the vertical axis are the hypothesized atmospheric levels of carbon dioxide. Hence, for example, the purple line RCP4.5 assumes that CO₂ levels will continue to gradually rise until about 2050 then level off. I want to focus on the red line which is the IPCC’s “worst case scenario.” It assumes we will do nothing, just go on

⁷ https://en.wikipedia.org/wiki/Representative_Concentration_Pathway

growing, burning more coal, and emitting correspondingly more carbon dioxide. It is probably unrealistically pessimistic, but that is in the nature of worst cases.

For worst case we need to refer back to the IPCC graph and look at the yellow line marked RCP8.5. It reaches about 4C a hundred years from now and continues to increase to 8.6C in about two hundred years. This is the first point: there is quite a difference between a Great Depression now and one in two hundred years. Never-the-less we probably do not wish a Great Depression on our great-grandchildren. The crucial point, however, is that this analysis is incomplete – it fails to consider what else will happen to income over the next 100-200 years. There are two extreme possibilities with a range in between. One is that economic growth will stop. In this case our grandchildren will be no richer or poorer than us, and we certainly wouldn't wish a Great Depression on them. But if growth stops CO2 emissions will be less: we will be in a scenario like RCP4.5 not RCP8.5. That means two hundred years from now the estimated increase in temperature will be more like 3C than 8.6C. Looking back at the Stern graph, we see that 3C means a reduction in global income⁸ of about 2%. To put that number in perspective, world per capita income dropped about 3% in the Great Recession of 2008. And while I wouldn't wish that on my great-grandchildren either it is not a number to lose sleep over.

How much growth there will be over the next two hundred years is not a question we can answer. Economic growth is driven by technological progress and by poor countries catching up to rich countries. The former is uncertain because we cannot know what technological breakthroughs will or will not happen in the future, the latter because many institutional barriers must be overcome for poor countries to grow and we cannot know how much success or failure there will be. That is, continued economic growth may be a fable and it may not be. It is useful none-the-less to look at the high growth scenario as that is what the RCP8.5 forecast is based on, and also represents our best guess about the future. From 1968 to 2018 world per capita income has grown from \$4937 to \$10881 – that is, it has more or less doubled in fifty years. If we were to continue growing at that rate for the next two hundred years we would double four more times, so income would grow by a factor of sixteen. That does not account for global warming. When we adjust for the 16.5% loss due to global warming, we find that income in two hundred years will be “only” thirteen times greater than today.

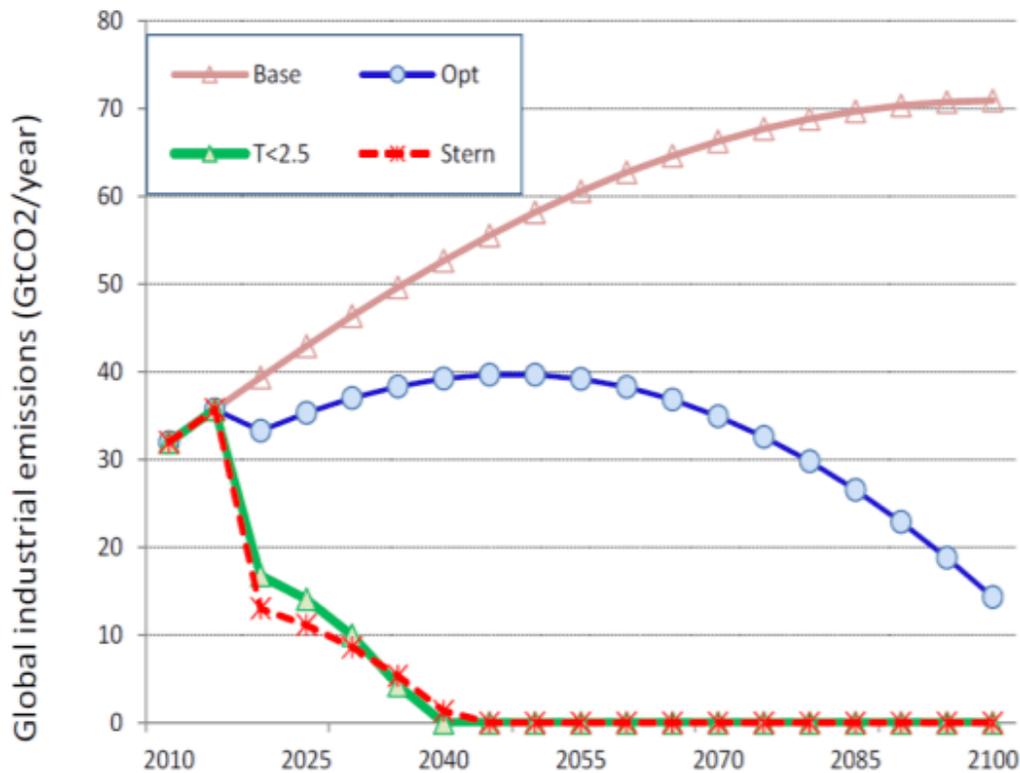
I don't think many economists believe we will go on growing at the same rate for the next two hundred years – and certainly economists that estimate the impact of climate change do not generally assume that. However, per capita income in the USA is \$54,542 so about five times the world average. Is it unimaginable that the rest of the world might over the next two centuries catch up to the USA and share our standard of living? I hope they do catch up – and there are plenty of people in the USA who aspire to higher income than \$54,542. If the world economy were only to double in the next two hundred years then we would be in a warming scenario more like RCP6 than RCP8.5 so would face 4C warming and around a 4% cost to GDP. Hence in two hundred years time our descendants would be “only” 92% better off than we are.

8 I have taken all per capita real GDP estimates from the World Bank <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD> using the series “GDP per capita (constant 2010 US\$)”

The bottom line is: the best science indicates that if we do nothing the effect of global warming on our children will be modest and despite global warming our descendants will likely be considerably better off than we are. Moreover, the growth effect is so much stronger than the damage effect that this conclusion is robust to substantial errors in either the rate of warming or the level of economic damages.

The Stern Review

Although our best available science indicates that the positive effects of growth dominate the negative effects of climate warming this should not be a call to inaction: the effects of warming are serious and they represent costs imposed on people who are not responsible for them. Below I reproduce another graph, this one from Nordhaus.⁹



Here again the horizontal axis is time, this time only going 80 years into the future and on the vertical axis are CO₂ emissions. Note that this differs from the previous graph: the previous graph represents carbon dioxide in the atmosphere, while this one is about emissions. Even when emissions cease carbon dioxide remains in the atmosphere for some time so while the green curve represents the same scenario in both graphs, the previous graph shows how even after emissions cease, carbon dioxide levels remain high.

⁹ Nordhaus, W. D. [2007]: "A review of the Stern review on the economics of climate change," *Journal of economic literature*, 45: 686-702

The base curve corresponds to “do nothing.” Nordhaus, however, does not recommend this, he recommends following the blue line. As you can see it calls for gradually bringing carbon emissions under control over the next eighty years. By contrast the red line is the recommendation of the Stern report. It calls for a crash program to bring carbon emissions to zero by 2040.¹⁰

You will wonder why based on the Stern numbers I draw a relatively optimistic picture of the consequences of doing nothing and based on those same numbers Nordhaus recommends only moderate measures to reduce carbon emission, while Stern himself call for a crash program. This is well explained by a number of reviews in the *Journal of Economic Literature* including that of Nordhaus. While all the reviews say pretty much the same thing, I will base my discussion on that of Marty Weitzman¹¹ who unlike Nordhaus is well-regarded by environmentalists.¹²

Stern argues that as an ethical matter future generations are worth as much as current generations. That sounds reasonable enough, but non-economists are not generally aware of all the implications of that statement, so I will lead you through Marty’s calculations so you can see for yourself what it means. In the calculations I did above I only looked 200 years into the future. But the consequences of global warming will last a very long time, so the 16.5% damage from global warming will continue even after 200 years. To make things simple, I will suppose that there is no damage from global warming for the first 200 years, then 16.5% per year afterwards. What does Stern recommend? He calculates that to prevent that a 16.5% loss to GDP starting 200 years from now we should be willing to give up an amount equal to 80% of that loss, that is, 13.2% of our current GDP starting now and forever. In other words, Stern’s ethics demand that we suffer great depression starting immediately to prevent a slightly larger great depression starting 200 years from now. Moreover, only 18% of the cost of that future great depression we are sacrificing to prevent will occur in the next 400 years, and 55% of the cost lies more than 800 years in the future. Forever is a long time.

When Stern talks about putting equal weight on future generations I think most people think about their children, their grandchildren and perhaps even their children’s grandchildren. I am not so sure they think about their descendants who will only be born 800 or more years from now. Nor when young people speak of the burden we are placing on them do I think they mean their own descendants centuries from now.

The View of Climate Scientists

Some climate scientists are worried about changes of 4C which according to our best science would have a relatively small impact. For example, a respected climate scientist Will Steffen¹³ has said in reference to 4C of warming:

10 The green line which is pretty much the same as the red line is what we need to do if we want to contain temperature change to within 2.5C. The IPCC takes this as our goal, but it is difficult to debate their conclusion as they provide no clear rationale as to why this should be our goal.

11 Weitzman, M. L. [2007]: “A review of the Stern Review on the economics of climate change,” *Journal of economic literature* 45: 703-724. My discussion is based his Stern formula in which the present value of a fraction of GDP t years from now is given by $\exp(-0.001t)$. Taking $t=200$ yields a value of about 0.8 from which my calculations can easily be checked.

12 For example, Greenpeace, see <https://www.greenpeace.org/international/story/21423/failed-economics/>.

The problem there is that, in my view, it is impossible to survive that sort of change. That's beyond human physiology to deal with that sort of change...Our cities are designed for [the pre-industrial temperature level]. And remember, a lot of our infrastructure is designed for a hundred years...[we will reach 5-6C in] 85 years. A human lifetime....that's a collapse scenario. Physiologically we can't survive that. So the real challenge is: we've got to make sure we hit that 2C.

The IPCC as represented by the green line in the last graph apparently concurs at least to the extent that their recommendation for action is based on holding warming to within 2.5C. How can there be such a big gap between the views of these distinguished scientists and the experts who made the damage assessments?

The short answer is: we should listen to experts in their area of expertise. Climate scientists are good at analyzing climate models, at forecasting for a given path of carbon emission what the likely effects will be on temperature, sea level rise, the incidence of storms and so forth. They are not at all expert at assessing the impact of all this on human beings. The story of the economist Julian Simon is a cautionary one for both climate scientists and economists. In an earlier era where there was concern about running out of natural resources Simon strongly that we have nothing to worry about. His views about the adaptability of human systems to change and the consequences for natural resources – something he was an expert in – have stood the test of time relatively well. Simon also had strong views about things he was ill-equipped to analyze – global warming in particular – and there his views have not stood the test of time.

Just as I believe that climate scientists are much better able to answer questions such as “how much warming will a certain amount carbon emissions cause over the next fifty years” than economists – or anyone else – so I believe that economists are much better able to answer questions that fall within the realm that we study such as “what will be the human consequences of 2-4C of global warming” than climate scientists – or anyone else. Just as Simon was wrong about global warming but right about the economic consequences of population growth, so I believe that climate scientists are right about climate change but wrong about the economic consequences.

Frog Theory

A great deal of work by non-economists subscribes to what I would call the “frog theory” of human behavior. The frog theory says that if you put a frog in a pan of water and gradually raise the temperature they will not notice the gradual rise and eventually boil to death. Here is an example:

In principle humans can devise protections against the unprecedented heat such as much wider adoption of air conditioning, so one cannot be certain that $T_{W(\max)} = 35C$ would be uninhabitable. But the power requirements of air conditioning would soar; it would surely remain unaffordable for billions in the third world and for protection of most livestock; it would not help the biosphere or protect outside workers; it would regularly imprison people in their

13 Lecture given in Canberra, May 2016, video with subtitles on twitter
<https://mobile.twitter.com/Jumpsteady/status/1179420109800169474>

homes; and power failures would become life-threatening. Thus it seems improbable that such protections would be satisfying, affordable, and effective for most of humanity.

We conclude that a global-mean warming of roughly 7 °C would create small zones where metabolic heat dissipation would for the first time become impossible, calling into question their suitability for human habitation. A warming of 11–12 °C would expand these zones to encompass most of today's human population.¹⁴

Here are two experts on human physiology opining on the power requirements and cost of air conditioning! Based on this and their apparent assessment that we will sit around like frogs waiting to be boiled they anticipate a great catastrophe. This is simply not a substitute for a careful assessment. Cost assessments are what economists do. We investigate how much air conditioning is needed, how much power is required, whether people might be better off moving to another location, and if so, how much it will cost.

Three other points will jump out at most economists. First: the definition of uninhabitable. This is “cannot survive outdoors in ordinary clothes for more than a few hours.” By this definition much of today's population already lives in zones unsuitable for human habitation: I doubt anyone is foolish enough to go outside for several hours in mid-winter in street clothes in, say, Minneapolis. Just as in cold climates there is heating for indoors and coats for outdoors, so in addition to air conditioning for indoors there are, for example, cooling vests that provide thermal protection outdoors in hot humid climates. An economist will further point out that as temperature rises demand for these vests will rise, and vest manufacturers will have a strong incentive to lower their cost and improve their design.

Second: the importance of integrated assessment. In the more popular literature¹⁵ we read how warming will increase the use of air-conditioning and we will need more power for that. What is often not mentioned is that it will also reduce the use of heating. Neither fact is useful in itself – only an integrated assessment can tell us which effect will be more important and so what the overall cost or damage is.

Third: the frog theory. If large areas become uninhabitable then people will move. Economists know this and have estimates of that cost as well. On this topic: it turns out that the frog theory does not even apply to frogs – once the temperature becomes warm enough they jump out of the pot. Although following Noel Coward, perhaps we should call it the Englishman theory:

In tropical climes there are certain times of day
When all the citizens retire
To tear their clothes off and perspire...
But mad dogs and Englishmen
Go out in the midday sun.

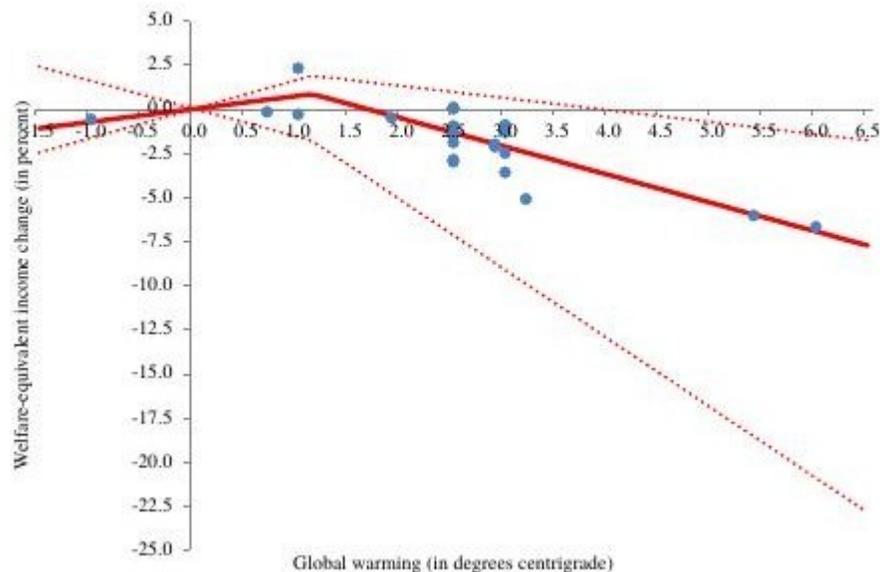
14 Sherwood, S.C. and M. Huber [2010]: “An adaptability limit to climate change due to heat stress,” *Proceedings of the National Academy of Sciences* 107: 9552–9555.

15 For example: <https://www.theguardian.com/environment/2019/aug/29/the-air-conditioning-trap-how-cold-air-is-heating-the-world>.

The issue of heat versus cold is an important one. Increased temperature when it is hot is bad, but increased temperature when it is cold is good. This means that there are beneficial effects of warming as well as detrimental effects so that an integrated assessment must account for both. Here is something that surprised me and no doubt would surprise the authors of the *PNAS* article cited above: in Mexico(!) “89 per cent of weather-related deaths are induced by cold (<10C) or mildly cold (10–20C) days and only 1 per cent by outstandingly hot days (>32C).”¹⁶

How Are the Damages Estimated?

There is absolutely no sense in you or me or anyone else trying to determine the human effects of climate change by saying things like “the power requirements of air conditioning would soar.” What is required is a systematic analysis of all the effects, positive and negative, of heat, of sea level rise, of disease, of the impact on agriculture and labor productivity and on and on. It is that type of integrated assessment that the very first graph I reproduced from the *Stern Review* is based on. I hope it is clear that everything substantive I have reported is based on the accuracy of that graph. It is the best we have, but that neither makes it right nor correct, and given its importance we should ask where it came from. Below I reproduce a much more recent and detailed version of the first graph¹⁷



The axes are the same as the initial figure: global temperature increases along the horizontal axis and damage as a percent of GDP along the vertical axis. The blue dots correspond to all the published

16 From a summary of the article Cohen, F. and A. Dechezleprêtre [2019]: “Mortality, temperature and public health provision: evidence from Mexico,” LSE Grantham Institute.

17 From Tol, R. S. J. [2018]: “The Economic Impacts of Climate Change,” *Review of Environmental Economics and Policy* 12: 4-25.

integrated assessments known to the author. As you can see there are quite a few of them in the 2.5-3C range clustered around 2%, consistent generally with the earlier Stern graph. There are some much more recent studies that goes as high as 5.5-6C with higher estimate of about 5% also consistent with the earlier Stern graph, although those estimates were not available at the time that graph was compiled. The dotted lines are important as they were not in the earlier graph: they are similar to the gray area in the IPCC temperature estimates – they represent the range of uncertainty.

The first observation is that there is a lot of uncertainty. The cost of 2.5-3C could plausibly range as high as 10%. While that would be, to say the least, unfortunate, the current IPCC estimates put that fifty years away in the worst case, and as income is currently doubling every fifty years the growth effect still dominates the global warming effect. Out at 6C the cost could plausibly range as high as 20%, but again even in the unlikely event that took place over fifty years it would still be dominated by the growth effect.

The second observation is really a question: given that careful studies trying to estimate costs from all the data about humidity, temperature, human physiology, cost of air conditioning and on and on as well as survey data about how people feel only go up to 6C where on earth do the estimates for up to 11.5C come from? The answer is extrapolation – a curve is fitted to the estimates from studies from 0-6C and that is extended up to 11.5C. It is not extrapolated linearly as you can see from the original graph, but it rests on the assumption that the amount of curvature in the range 0-6C will remain the same for much higher temperatures.

Large Warming and Migration

How seriously should we take the damage estimates for relatively large warming of 8-12C? Marty Weitzman¹⁸ has argued we should not. It is true that no matter how bad things are at one location – flooding, heat, extreme climate events – as long as there are other locations not subject to these problems – and climate change will worsen circumstances in some locations while improving them in others – it is always possible to move. While economists have good estimates of migration costs, at some stage the scale of migration will involve a large fraction of humanity: we visualize hordes of starving refugees drowning as they make their way in rickety boats across the sea to escape cities that have become burning hot, I imagine...well you've probably seen dystopic science fiction movies too.

At some scale social and economic systems will no longer be able to cope with masses of immigrants and we will face a human catastrophe – the “collapse scenario.” Weitzman, for example, takes the loss at 12C to be 99%, that is, virtually all of GDP. By contrast the Nordhaus function that is widely used and is the black line I superimposed on the Stern graph says at 12C the loss is on the order of 30%. The difference between 30% and 99% loss of income is enormous – it would take a lot of growth indeed to overcome a 99% loss. As there is no hard data what should we believe? Is it true that the level of migration 150 years from now in worst case scenarios will dwarf the range of migration with which we are familiar and threaten the collapse of society?

18 Weitzman, Martin L. [2012]: “GHG targets as insurance against catastrophic climate damages,” *Journal of Public Economic Theory*: 221-244.

The answer is no. Temperature change is gradual. Looking at the IPCC graph we see that even at the extreme upper end of RCP8.5 it will take 150 years to move into the 8-12C range. This means there will be a steady flow of people seeking better living circumstances along with surges of refugees escaping from extreme climate events and flooding. If moving into the 8-12C range means that half the population will relocate that corresponds to 0.33% per year. This is not an unfamiliar level: it is similar in magnitude to the migration from rural to urban areas that took place in the 20th century. That migration, like climate induced migration, took place unevenly and in ebbs and surges, with both steady flows of people seeking better economic circumstances and surges of people escaping crop and price failures. It is true that the climate migration is likely to be from one urban area to another, but the social and economic costs of relocation – the disruption of life, the cost of transportation, the cost of building infrastructure, of the houses, workplaces, factories, offices, roads, sanitation, schools, hospitals, and on and on – are the same regardless of where the immigrants came from. I should emphasize as well while most rural to urban migration took place over modest distances some took place between continents – from Europe and Asia to the Americas – and with modern technology transportation is not a significant bottleneck: every year commercial airlines carry about four billion people – about half the population of the earth.

Here a brief history of rural to urban migration in the second half of the 20th century.¹⁹ In 1950 world rural population was about 1785 million and urban population about 751 million. In 2000 the rural population grew to about 3277 million and the urban population to about 2868 million. This means that while world population grew about 1.8% per year rural population only grew at 1.2% per year. It has long been known that birth rates in rural areas are higher than in urban areas,²⁰ so at least 0.36% of world population migrated from rural to urban areas each year.²¹ This is similar to levels for extreme climate scenarios and did not create economic hardship – during the same period per capita income doubled.

To understand the issues that arise with migration more concretely, consider the situation in Manila a place where climate change is likely to have a major impact. Manila is part of the Philippines a country that has many smaller cities and towns in the highlands. As Manila warms and the sea level rises these cooler locations will become more attractive. There is nothing amazing about a small town growing to the size of Manila over a period of many decades. For example the city of Sao Paulo in Brazil²² grew from a population of about 65,000 in 1890 to 6 million in 1970 and has nearly doubled in size since then. Moreover, many of the immigrants who drove this growth were not Brazilian, but from Italy and Japan. While the rapid growth of Sao Paulo has created social problems the city is a thriving one.

19 The figures are from the UN Department of Economic and Social Affairs Population division and are available online at <https://www.un.org/en/development/desa/population/theme/urbanization/index.asp>.

20 See, for example, Simon Kuznets, Simon [1974]: “Rural-Urban Differences in Fertility: An International Comparison,” *Proceedings of the American Philosophical Society* 118: 1-29.

21 That is, as rural population as a fraction of the world population was about 0.6, the 0.6% of rural population corresponds to about 0.36% of world population.

22 This is documented in the wonderful Museum of Immigration of the State of Sao Paulo. A good summary can be found in Wikipedia: https://en.wikipedia.org/wiki/São_Paulo

In Bangladesh, another place where climate change is likely to have a major impact, the situation is more complicated. There are also cooler highlands nearby, the less densely populated Eastern Himalayas. I am not referring here to the jagged peaks, but rather the area south of the tall ranges, an area of rolling hills – the “hill stations” where the British Raj fled the hot Indian summers. The problem is that the entire country of Bangladesh is hot and humid and the adjoining cool region belongs to India and to Myanmar.

While immigrants are rarely welcome²³ and escaping refugees even less so national boundaries are particularly important. It is not likely that, for example, India and Myanmar will welcome Bangladeshis seeking a cooler environment. Here as part of the costs of global warming we must figure the political conflict, even warfare, that may result. As existing research has reached mixed conclusions about whether climate change increases or decreases conflict in the broad sense,²⁴ these costs are not currently included in economists damage estimates. However, more detailed assessments – for example, combining information about probable paths of migration and data about the impact of migration on conflict – should be possible.

This political dimension of migration is an important one: some institutions cope better than others and some countries and regions are more welcoming to immigrants than others. We see today throughout the world a rising tide of nationalism and xenophobia. Combined with immigration driven by climate change this combination has the potential to be explosive. Still, we should not be misled by the attitude of rich countries towards immigrants: while there was enormous political turmoil in the EU over a million or so Syrian refugees the country of Jordan with a population of less than ten million has absorbed at least that many over a few short years – over 10% of the population of Jordan are recent arrivals.²⁵

It is also important to ask questions about trade-offs: Will richer immigrants be more welcome than poorer ones? Will countries with growing incomes be more hospitable to immigrants than stagnant ones? Is effort better invested in fighting climate change or in fighting xenophobia and promoting growth?

The bottom line is that huge damages at 12C are not plausible. In particular the estimates of economists have meaning because the scale of events caused by global warming are not beyond the bounds of our experience. Even the most catastrophic climate events have human consequences well within the realm of what we know.

23 To take but one of many examples, consider the treatment of Irish arriving in the USA – a country noted for its acceptance of immigrants – in the 19th Century: http://www.elegantbrain.com/edu4/classes/readings/depository/race/irish_immig_cartoon.pdf.

24 Buhaug, H., Nordkvelle, J., Bernauer, T., Böhmelt, T., Brzoska, M., Busby, J.W., Ciccone, A., Fjelde, H., Gartzke, E., Gleditsch, N.P. and Goldstone, J.A. [2014]: “One effect to rule them all? A comment on climate and conflict,” *Climatic Change* 127: 391-397.

25 See the Bloomberg article “U.S. and Jordan in a Dispute Over Syrian Refugees,” Bloomberg, October 6, 2015 and the UNHCR Jordan Fact Sheets at <https://reliefweb.int>.

Tipping

One criticism that has been raised against economic damage assessments is that they do not take account of the possibility of tipping: of the possibility that warming will trigger a series of irreversible events. The reason they do not is because the best science from the IPCC on which economists base their estimates do not. Never-the-less we can ask: what is the science of tipping and what must be done to account for it?

In my reading I have been able to identify three types of tipping. One involves runaway glacier melt, one involves a runaway greenhouse effect, and the third is called the hothouse earth hypothesis.

The first possibility is of runaway glacier melt in Antarctica or Greenland leading to a much faster rise of sea level than anticipated in IPCC estimates. The most recent IPCC estimates²⁶ do discuss tipping and consider it now more likely – but while this means that economic estimates based on earlier forecasts are too low, the increased estimates are still well within the ranges considered by economists so when these newer estimates are adopted the increase in damages will be moderate. The key point is that the gap between the beneficial effects of growth and the harmful effects of climate change are so great that modest changes in damage estimates make little difference – which is why Weitzman had to make extreme and unreasonable estimates to argue for crash measures to prevent climate change.

The second tipping scenario is what is called the runaway greenhouse. Here a vicious cycle is triggered in which heating releases more greenhouse gasses leading to more heating until the atmosphere of the earth is like Venus at 95% CO₂ and the temperature rises into the hundreds of degrees. This would certainly put an end to human life and probably all life on earth. The runaway greenhouse has been studied by astrobiologists who have posed roughly the following question: if we were to dig up all the coal on earth and light it off in a giant bonfire would that be enough to trigger a runaway greenhouse?²⁷ As the Earth is quite different from Venus, not least in that we receive a lot less solar radiation, the answer appears to be: probably not, but we can't quite be sure. Fortunately there is agreement that no level of CO₂ that we are likely to emit in practice is nearly enough to trigger a runaway greenhouse.

The hothouse earth is based on the theory that in the past climate has been unstable, switching between hotter and cooler periods. The idea is that there are indeed tipping points where CO₂ increases become self-sustaining. Unlike the runaway greenhouse there are also countervailing forces so that while temperature inevitably must increase it does so only to a limited extent. The key questions are: how quickly and to what extent? Here I rely on a recent paper in the *Proceedings of the National Academy of Sciences*²⁸ and particularly the Appendix which contains the more detailed estimates. The period of time over which this change might take place is unclear: historically these transitions took

26 https://report.ipcc.ch/srocc/pdf/SROCC_SPM_Approved.pdf

27 A recent paper including a summary of the debate can be found here: Ramirez, R. M., Kopparapu, R. K., Lindner, V., and Kasting, J. F. [2014]: “Can increased atmospheric CO₂ levels trigger a runaway greenhouse?” *Astrobiology* 14: 714-731.

28 Steffen, W., Rockström, J., Richardson, K., Lenton, T.M., Folke, C., Liverman, D., Summerhayes, C.P., Barnosky, A.D., Cornell, S.E., Crucifix, M. and Donges, J.F. [2018]: “Trajectories of the Earth System in the Anthropocene,” *Proceedings of the National Academy of Sciences*, 115: 8252-8259.

thousands of years, but the triggering rate of climate change was much less then, so perhaps such a transition would be now be much faster and fall within the 100-200 year period we are assessing.

What is the likely extent of the increase in temperature in the hothouse earth scenario? Table S1 in the Appendix indicates that tipping into the hothouse earth scenario would lead to an temperature increase over the pre-industrial level of about 4.5C. The key point is that this is well within the range for which we have accurate damage estimates, and these estimates on the high end are less than 15%. That is not a number to be toyed with, but again, is dominated by the effects of the economic growth that might trigger the hothouse earth.

What does this all mean for economic damage assessments? Many account for some probability of a catastrophe. The problem is that reducing an unknown but small chance of catastrophe by an unknown amount is a difficult guide to policy. Never-the-less it should be clear that it strengthens the case for sensible action as opposed to no action. If, however, it is the basis for arguing for immediate and costly action proponents should be clear that this is their reasoning.

The Reality of non-Eternal Growth

Economics is not about money, nor is economic growth. Economic growth is about people: it is about people having greater access to resources. In rich nations increased income may mean a second bathroom, a nicer car, a better college for the kids, the opportunity to eat out more frequently or at a better restaurant, and better security against job loss, poor health, old age, or divorce. You may or may not regard these things as frivolous. What seems certain is that few who live in rich nations have much of a concept of what it means to live in a poor nation. In poor countries increased income means having an indoor toilet, a mosquito net, clean water, access to vaccines and decent medical care, a living place secure against weather, air-conditioning, a car, and a chance to work in a comfortable office rather than doing back-breaking labor under the sun. These things are not frivolous at all.

A richer person is also much better able to cope with changes in the environment whether that is due to climate change or anything else. For example, bad weather causes people to die, but less so for richer people who have heating, cooling, stronger and better protected buildings, and who can remain indoors when the weather is bad.²⁹ Climate change makes malaria more dangerous, but less so for richer people who have medicines and mosquito nets.³⁰ Richer countries have the resources to build early warning systems, shelters, and dykes to protect against cyclones and flooding.

Economic growth leads to global warming. Greater access to economic resources requires energy – a lot of it – and for a poor country to grow that energy needs to be cheap. We need look no further than China to see how this works. In the last twenty-five years per capita income in China has increased by a factor of five. A country that had per capita income in 1998 similar to that of Bangladesh today now has per capita income similar to that of the European Union nation of Bulgaria. During that

29 Cohen, F. and A. Dechezleprêtre [2019]: “Mortality, temperature and public health provision: evidence from Mexico,” LSE Grantham Institute.

30 Tol, R. S., and Dowlatabadi, H. [2001]: “Vector-borne diseases, development & climate change,” *Integrated Assessment*, 2: 173-181.

same period energy consumption about tripled.³¹ That energy is very dirty: China generates about five times as much carbon per unit of income as the United States – the only countries worse than that are Kazakhstan, Ukraine, Mongolia and Uzbekistan.³² The reason is simple: roughly 60% of China's power comes from coal³³ the worst fuel for carbon emissions.³⁴ China grew by increasing its energy consumption and it did that by building many cheap but dirty coal fired electrical generating plants.

This is the basic conundrum of climate change. Do you doubt that China with its power plants, air-conditioned cities, huge dams, subways, high speed trains, modern highways, air conditioned cars, and massive construction capability is vastly better equipped to confront climate change than Bangladesh? Yet the path to those riches lies through increased global warming. This forces us to ask whether it is better for a country like Bangladesh to accept increased warming and become rich or stay poor in an effort to fight global warming? Or more accurately it is for Bangladeshis to ask that question: why should we – who got rich creating the problem – have any voice in the matter?

Property Rights: Bolsonaro versus Macron

There is a strong anti-climate change anti-growth movement in the rich countries of the world. However that may be, carbon output in rich countries is declining and will surely decline further. This is less likely to be the case in poor countries striving to be rich. These countries have the most to gain from growth and the most to lose from global warming. It may be, as some people apparently believe, that green energy is actually cheaper than fossil fuels. In that case we have little to worry about: nobody rich or poor, Chinese, Bangladeshi, or Bulgarian is going to spend extra money for power merely to ruin the planet.

If the poor countries grow as China did by greatly increasing carbon emissions the rich countries face a choice. We can respect their decision, we can attempt to coerce them into reducing carbon emissions, or we can try to bribe them into reducing carbon emission. The recent controversy between the President of Brazil, Bolsonaro and the President of France, Macron, highlights this issue.

In the summer of 2019 many fires broke out in the Amazon rain forest threatening to destroy a valuable natural resource and contributing to further global warming. Norway had been paying Brazil not to burn the forest and quite rightly decided to withhold these payments since they burned the forests anyway. This is the bribery scenario. By contrast France a country with four times the per capita income of Brazil threatened to veto a trade agreement (including with several other nations besides Brazil!) if the fires weren't stopped. Is this, then, our notion of ethics? Threaten much poorer nations with economic sanctions if they do not stop damaging our environment? After we made a mess of theirs? On behalf of people who may or may not live eight hundred years in the future and because of events that the best scientific evidence suggests are highly unlikely?

31 World Bank

32 https://en.wikipedia.org/wiki/List_of_countries_by_ratio_of_GDP_to_carbon_dioxide_emissions

33 <https://www.chinadialogue.net/article/show/single/en/11107-China-s-coal-consumption-on-the-rise>

34 Hassler, John, Per Krusell, and Jonas Nycander [2016]: "Climate policy," *Economic Policy* 31: 503-558.

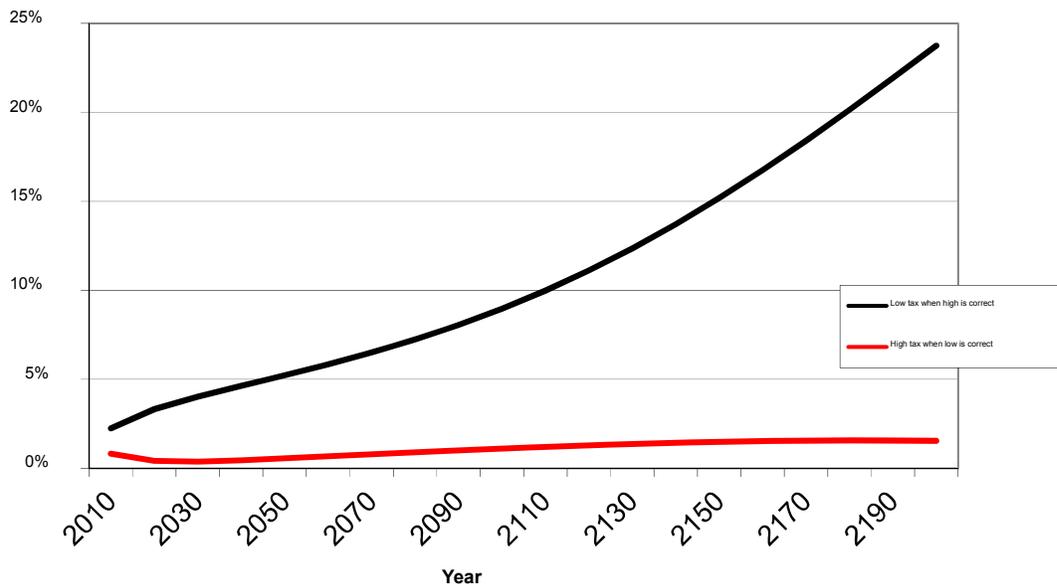
Consider again Bangladesh. Here we run a risk – if we operate through trade threats the entire rest of the world may ignore us and trade with each other: the economy of China is now as big as Europe, and it isn't clear which side the USA would join up with. So as well as ethical considerations practical considerations suggest that rather than buying a bunch of electric buses we ought to pay Bangladesh to use cleaner technologies. We could for example, pay for a kind of negative carbon tax: if a poor country installs a power plant that will produce some number of KWH over its lifetime we can compute how much carbon would have been produced by an equivalent coal plant and subsidize the power plant by the carbon tax for the amount of carbon saved.

Risk, Coal, and the Low Lying Fruit

I hope it is clear that there is a great deal of risk involved with climate change. From the Tol graph our best estimate of the damages for 3.5C is anywhere from 0% to 12%. From the IPCC graph in RCP6 the temperature increase in 2200 is anywhere from 2.5C to 4C. In the face of uncertainty there are two kinds of mistakes. We might assume the worst: 12%, 4C and that might turn out to be wrong, perhaps it is 0% and 2.5C and we have wasted resources fighting a problem that turns out not to exist. On the other hand we might assume the best: 0% and 2.5C and do nothing. If that turns out to be wrong we will find ourselves on the wrong side of RCP8.5 with a serious problem.

Three distinguished economists, John Hassler, Per Krusell and Conny Olovsson, have recently analyzed the consequences of both types of errors.³⁵ The graph below contains the key findings from their research.

Consumption loss



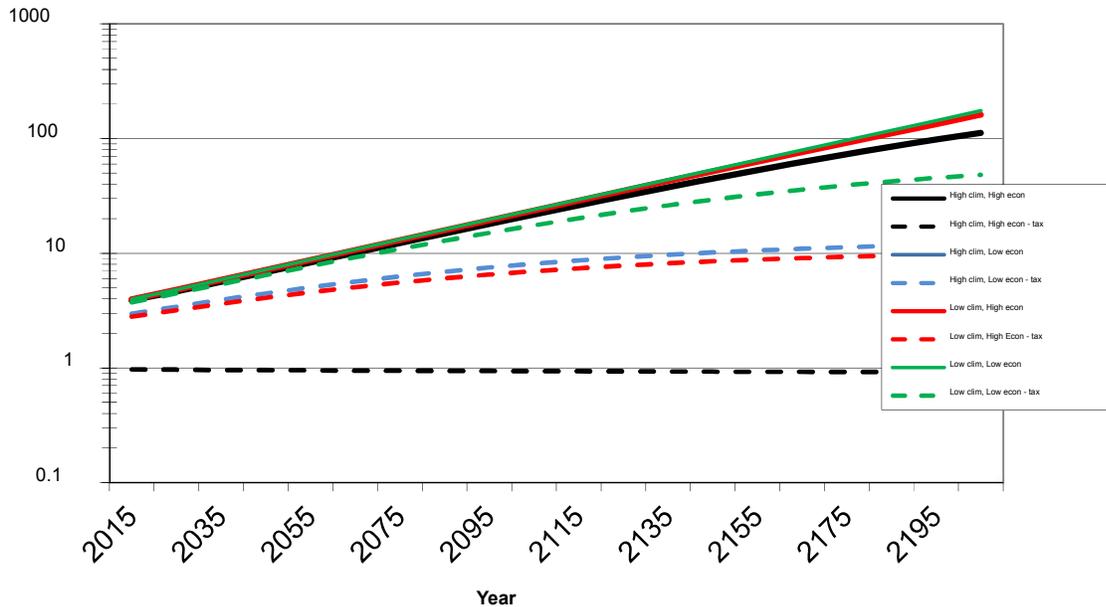
35 Hassler, J., Krusell, P., and Olovsson, C. [2018]: "The consequences of uncertainty: climate sensitivity and economic sensitivity to the climate," *Annual Review of Economics* 10: 189-205.

The horizontal axis is time, running now from 2010 to 2200. The vertical axis is consumption loss – the same idea as damages, but computed now from a dynamic emissions model and with the higher numbers representing losses rather than gains. Both curves assume that we use the best carbon tax. The red line shows what happens if we assume the worst and have a high carbon tax, but in fact it turns out that things are for the best. In this case we'll have wasted resources combating a problem that turns out to be unimportant – but as you can see from the graph, not many. The black line shows what happens if we assume the best, set a low carbon tax, and things turn out for the worst. As you can see that curve rises pretty fast and neither our children nor grandchildren will thank us for that. The choice is pretty clear: it isn't costly to prepare for the worst so we should do that. If we don't we may get lucky and things will turn out for the best, but then again, whatever you think of the IPCC and climate science, unless you are totally gaga, you have to believe there is a chance they are right.

The best estimates of economists, accounting for the risks and uncertainty involved, is not that we should do nothing. Nor is it that we should engage in a crash program cut carbon emissions to zero in the next twenty years. That would be horribly costly for growth – and I hope by now you realize how important that is for places like Bangladesh. The recommendation is to pick the low-lying fruit, to look for low cost policies that have a lot of impact. It turns out that the low lying fruit is coal. Oil has a self-limiting element that is perhaps not well understood by some climate scientists. We may or may not run out of oil like the peak oil aficionados think, but as we are forced to ever more costly extraction technologies the price has risen and continues to rise. The cost of green energy, by contrast, is declining. No government policy will be needed to force hard-headed business firms to replace oil with green when oil is more expensive.

There is a lot of coal and it is cheap to extract and burn. That is why China grew by installing so many dirty coal power plants. The thing is: it isn't that much cheaper than greener alternatives. That makes it a low-lying fruit. A modest carbon tax will make coal uncompetitive. Since the tax is modest even if we don't need it the cost is low. On the other hand, holding coal use to its current level will do a lot of good if it turns out we are in a bad scenario. This is shown in the graph below.

Coal use



Here the horizontal axis is again time. The vertical axis is the level of coal use with three being the current level. The solid lines show what happens if we do nothing (no carbon tax): we have a coal use growing to almost a hundred times the current level in two hundred years. As oil grows expensive, we replace it with coal which is much worse, and as the economy grows we support it by building coal power plants. In a bad scenario this results in a great deal of damage.

The dashed lines represent what happens if we implement the best carbon tax under different scenarios. The green dashed line is the best case: climate isn't very sensitive to CO₂ emissions and the damage of warming is small. In this case we don't need to do much, and the green dashed line is quite close to the solid lines. The black dashed line is the worst case: climate is highly sensitive to CO₂ emissions and the damage of warming is great. The recommendation of interest is that if we suspect the worst case we should bring coal down by replacing older plants and plants that are relatively expensive to operate and then stop installing new ones. That is: we don't need to try to get the Chinese to replace all their coal plants, but need to try to get rid of aging plants and inefficient plants and stop building new ones. This we can do with a moderate carbon tax that will not create great harm to growth or prosperity. If we don't and things go bad our children and grandchildren will have reason to curse us.

Conclusion

From my reading of the literature, accepting the best estimates of scientists and analyzing critically – and accepting – the best estimates of economists, to engage in extreme measures to combat climate change would be foolish. It would also be foolish not to pick the low lying fruit and introduce moderate measures that protect us from the risk that our best estimates turn out to be optimistic.

It is also important in combating climate change not to squander resources. There is a great deal of insularity: most countries focus on their own use of carbon. It may seem a problem only for the

Swedes that they choose to set an excessively high carbon tax and phase out plants that do little to contribute to global warming, or that the countries waste money replacing diesel buses with electrical ones. It is not: that same money subsidizing green energy in developing countries would play a real role in improving the future.

That climate warming does not pose an existential risk to civilization is not an excuse for ignoring it. Diabetes is not an existential risk to civilization either but of course we spend money and do research into curing diabetes. We march and vote and raise money for many good causes. Climate change is a greater problem than most: there is every reason not to subsidize meat and fossil fuel production, every reason not to burn down forests and not to burn coal, every reason to investigate technologies that will mitigate climate change, and every reason to introduce a moderate global carbon tax in rich countries and an anti-carbon subsidy in poor ones. If, on the one hand, we shouldn't lose sight of other problems in our effort to mitigate climate change, so, on the other hand, we should not lose sight of climate change in the press of solving other problems.

Further Reading

My goal in this essay has been to emphasize that off-the-cuff remarks of experts in climate and temperature are not to be confused with the serious and sober estimates of economists about the human consequences of global warming. Here is some further reading for those who would like to learn more about the economics.

Much in parallel with the climate science, there are two strands of the economic literature. Just as climate scientists seek to assess the mechanisms by which climate change works, so economists seek to elucidate the direct and indirect impacts of climate change on human systems. Just as climate scientists then use their knowledge of these mechanisms to develop integrated assessment models to forecast the impact of emissions on climate change, so economists use the assessment models of climate scientists and their knowledge of the impacts of climate change to develop integrated economic assessment models to forecast the impact of emissions on human systems and to develop recommendations for policies that balance the benefits of growth against the cost of climate change. There are a variety of integrated economic assessment models – some are global, others are regional, and they differ in the way they treat risk and uncertainty. The general conclusions are similar, but the details matter a great deal for policy so research is ongoing.

If you would like to learn more about the views of economists working in the field I recommend a podcast <https://www.buzzsprout.com/201104/775975> by Per Krusell who is one of the leaders in integrated economic assessment models. For the more technically minded his article³⁶ with John Hassler and Jonas Nycander “Climate Policy” provides a very accessible overview of how integrated economic assessment models combine warming models from climate science and damage models from economics and discusses what they tell us about policy.

If you want a broader picture of what economists have done and are doing from an economist who has worked across a broad range of climate change issues from detailed damage assessments to

36 Hassler, J., Krusell, P., and Nycander, J. [2016]: “Climate policy,” *Economic Policy* 31: 503-558.

integrated economic assessment models I can recommend Richard Tol's 2009 article "The economic effects of climate change" in the *Journal of Economic Perspectives*.