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Research Briefing | Global

The economic impact of global warming

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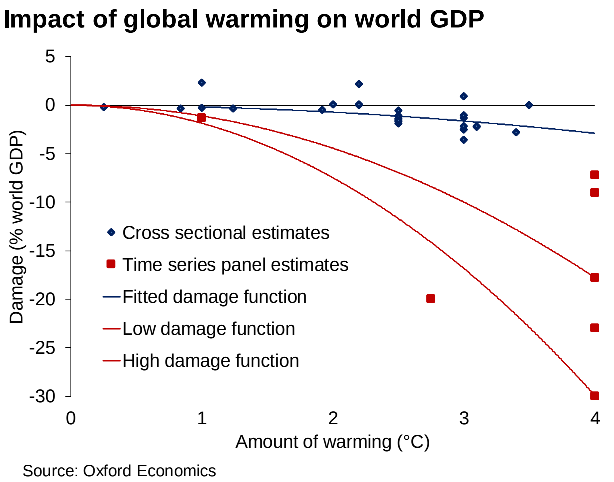
- **The impact of global warming is rarely included in standard macroeconomic forecasts, even over 20-30 year time horizons. This partly reflects the perception that the economic effects of global warming are unlikely to become significant until the second half of this century and even then, will cost no more than a few percentage points of world GDP.**
- **But these conclusions appear to be at odds with the latest scientific findings suggesting we are already experiencing profound alterations to the Earth's climate, including increases in drought, flooding and extreme weather. These changes are already affecting economic activity.**
- **In the last five years, we have seen the introduction of time series panel estimates of the relationship between GDP and climate, estimated over a large number of countries and a relatively long-time frame. The results from these studies place the economic effects of global warming an order of magnitude higher than the earlier studies.**
- **In the absence of efforts to curb greenhouse gas emissions, the Earth is currently on course to warm by around 4°C by 2100. The largest estimates now suggest this would strip 30% off the level of world GDP by that date.**
- **More immediately, according to our study the 2°C of warming expected by 2050 in a high emissions scenario might incur costs of between 2.5%-7.5% of global GDP, with the worst affected countries being in Africa and Asia. So, while over a 10-year horizon the costs seem unlikely to be significant enough to affect our forecasts, the window of indiscernibility looks to be closing rapidly.**
- **This report summarises the findings detailed in our White Paper "The Economic Impact of Global Warming", which reviews the latest scientific data on climate change alongside economic studies of the expected costs.**

Chart 1: Recent studies suggest the effects of global warming are much larger than previously estimated



Cross-sectional estimates (in blue) are significantly smaller than the largest time series panel estimates (in red) of the effects of global warming on GDP.

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Earlier studies have tended to estimate the effects of even 4°C of warming at no more than a few percent of global GDP

This year has already seen another slew of record-breaking temperatures, floods, and hurricanes. July 2019 was the hottest month ever recorded, with Europe and parts of India suffering record temperatures, while record temperatures in Alaska and Siberia contributed to an unprecedented loss of sea ice and a spate of forest fires. The US experienced its wettest 12-months on record, including weeks of record-setting floods throughout much of the central region.

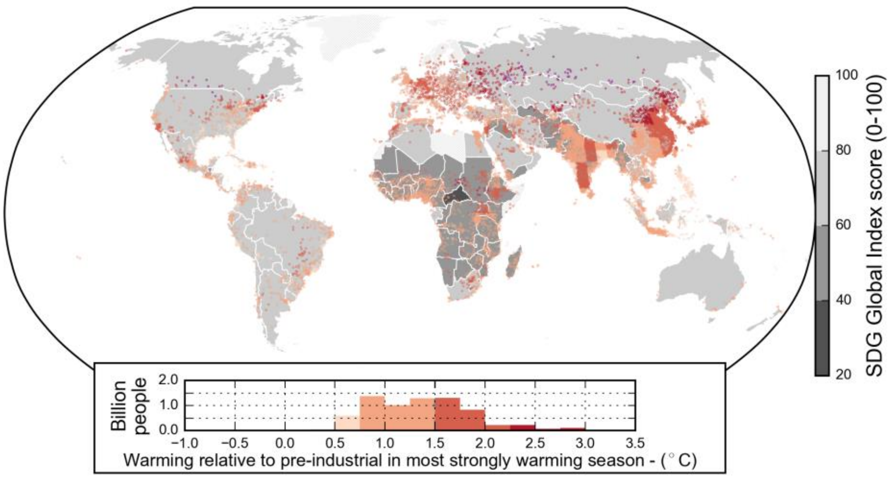
The trend of rising global temperatures has already pushed the global mean surface temperatures (GMST) about 1°C higher than the pre-industrial average (the annual global average temperature from 1850-1900). According to climate scientists, the rising temperature will trigger more frequent extreme weather events like the heat waves, droughts, and floods seen this year, while melting ice sheets and the thermal expansion of the oceans will cause sea levels to rise. Global warming is therefore pushing the world to new climate extremes that are already having a significant economic impact (**Chart 2**).

However, quantifying the economic consequences of climate change is conceptionally and computationally challenging. Temperature increases of the magnitude that could occur over the next century – and many other aspects of climate change, such as the rapid rise in sea levels, ocean acidification, and increased incidence of flooding – sit well outside recent historical experience and affect a large number of countries. Extrapolating from previously observed marginal changes is therefore problematic, as is the question of how to appropriately cost infrequent but potentially catastrophic tail risks.

This report summarises the findings in our white paper "The Economic Impact of Global Warming", which compares the emerging scientific conclusions on the effects of global warming with economic estimates of the costs. We find that economic research is essentially split between older cross-sectional studies that estimate the effects of even 4° or 5° of warming at no more a few percent of global GDP, and more recent time series panel estimates that place the economic impacts an order of magnitude higher.

The higher economic impact is particularly true when considering the impact of environmental degradation on natural capital and the risks to human health that are not included in market-based measures of GDP. There is therefore considerable uncertainty about the economic impact of climate change with economists at risk of significantly underestimating its economic impact. As reduced form estimates, the new time series based estimates potentially offer a more tractable means of incorportanting global warming into our economic model and our forecasts out to 2050.

Chart 2: Estimates of warming to date as a function of population density



Source: IPCC Special Report on Warming of 1.5°C, Chapter 1: https://www.ipcc.ch/sr15/

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The effects of global warming

Global warming is increasingly responsible for a broad pattern of human-induced climate change, which is driving an increased incidence of heatwaves and drought, flooding and extreme weather. Last year, in order to highlight the increasing impact of increasing CO_2 concentrations the Intergovernmental Panel on Climate Change (IPCC) published its Special Report on Global Warming of 1.5°C (SR1.5). This report identified ten channels through which future global warming is likely to have an impact both on the natural world and on the human activities that depend on affected ecosystems (**Table 1**). SR 1.5 concluded that that human induced global warming had already caused multiple changes in the climate system which included more frequent heatwaves and an increase in the frequency and intensity of heavy precipitation events.

Climatic factors directly affect a number of economic outcomes, most obviously agricultural output and critical economic resources, such as water and human health. But climate shifts can also impact indirectly on a wider range of economic activities, including manufacturing, energy production, transport and services such as tourism. Inflationary pressures might arise from a decline in the supply of goods or from productivity shocks caused by weather related events such as droughts, floods, storms or sea level rise. These events can potentially result in large financial losses, while the investment aimed at necessary adaption may lead to a significant global increase in the demand for loanable funds, which may in turn put upward pressure on interest rates. Also, the macroeconomic implications of climate change will differ across countries, with more advanced economics typically more able to finance the necessary adaptions, while less developed countries are more likely to suffer more directly the economic costs of climate-related risks.

Regarding the prime cause of anthropogenic warming, greenhouse gas emissions, estimating the economic cost of these is challenging for a number of reasons. While emissions are local (or national), the effects are global and vary across both time and space. Secondly, today's emissions will continue to have an impact for serval centuries raising difficult questions about how we should value the future and what is an appropriate response to high levels of uncertainty.

Table 1: The effects of global warming

Impact	Projected change at 1.5°C (and 2°C)	Regions affected
1. Global warming	1.5°C by 2040 with a recent warming trend of about 0.2°C (±0.1°C) per decade	Mid latitudes and polar regions will warm more than global average
2. Temperature extremes	Increases of up to 3°C (4°C) in the mid-latitude warm season and up to 4.5°C (6°C) in the high-latitude cold season	Central & eastern North America, central & soutern Europe, northern & southern Africa and Near East, western & central Asia
3. Heavy precipitation	Increases in frequency and intensity of heavy precipitation	Northern Europe, north & eastern Asia, eastern & northern North America
4. Drought	Increase in evaporation and precipitation deficits, longer duration of drought	Mediterranean, southern Africa, Western Austrialia
5. River Flooding	Expansion of the global land area with a increase in runoff and risk of flooding	High northern latitudes, south east Asia, East Africa, north western Europe
6. Tropical Storms	Increases in heavy precipitation associated with tropical cyclones	Southern North America, east Asia and Japan
7. Ocean circulation and temperature	Further increases in ocean temperatures, including more frequent marine heatwaves	Atlantic meridional overturning circulation (AMOC) will weaken over the 21st century
8. Sea ice extent	One sea-ice-free Arctic summer every 100 years (every 10 years)	Arctic
9. Sea level rise	Sea level expected to rise by 0.43m under RCP2.6 by 2100 and by 0.84m under RCP 8.5	Asia, espcially China, India and Indonesia
10. Ocean acidification	Surface pH is projected to decrease by 0.3 pH units by 2081-2100 under RCP 8.5	Polar and subpolar aragonite shell forming species, eastern boundary upwelling.

Source: IPCC Special Report on Global Warming of 1.5°C ; Special Report on the Ocean and Cryosphere in a Changing Climate

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Estimating the economic effects of climate change

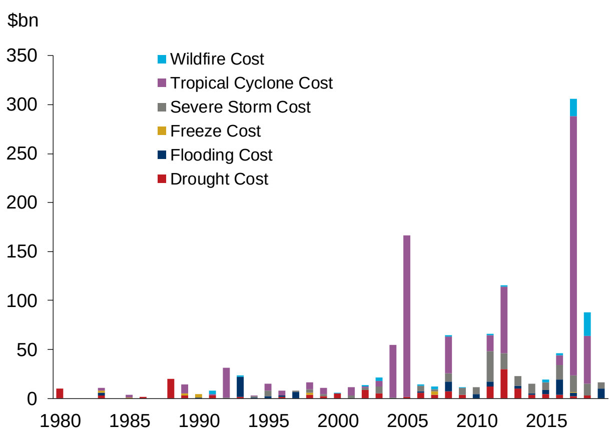
Perhaps the most obvious approach to estimating the costs of climate change is simply direct measurement, using estimates of the cost or damage inflicted by weather related disasters. The National Oceanic and Atmosphere Administration (NOAA) for example, tracks and evaluates weather and climate related disasters in the US. This puts the estimated cost of weather and climate related disasters in the US in 2017 at $306bn, which amounts to 1.6% of GDP, with tropical cyclones being by far and away the most damaging. That figure is stochastic, with the current five-year moving average (which is still heavily inflated by 2017) running at a more modest $100bn per year (**Chart 3**).

In Europe, similar data are collated by the European Environment Agency. Without the huge damages caused by hurricanes, the European figures are an order of magnitude lower; between 1980-2017, combined losses from climate related events amounted to €453bn (in 2017 prices), an average of €12bn per year (i.e. less than 0.1% of GDP per year). However, to put the US and European figures into context, a recent paper by Burke and Tanutama (2019) estimates that since the year 2000, global warming has already cost both the US and the EU at least $4 trillion in lost output.

From an economic point of view this damage is not necessarily simply subtracted from GDP. To the extent that infrastructure and the housing stock is damaged by extreme weather events and has to be rebuilt, it is highly likely that these damages will provide a boost to GDP in the short run. However, in so far as this damage represents accelerated depreciation or replacement investment, they are in effect resources that are not being used productively to increase the existing capital stock and hence boost future productive capacity in the long run.

The alternative to direct loss estimates is to take an econometric approach. Historically, cross-sectional regressions have been used to estimate the impact of changing temperatures on various sectors. Aggregate damage functions are then constructed via meta analysis that calcuates economic damage as function of temperature. Over the years this kind of cross-sectional approach has been applied to numerous sectors and a number countries. However, it is not without its limitations with the resulting estimates potentially subject to omitted variable bias. This approach also implicitly assumes costless adaptation to climate change – when in reality the inclusion of new costs (like irrigation or flood defences) that were not encountered before is exactly what we are trying to gauge.

Chart 3: Tropical cyclones are responsible for the costliest weather-related damage by far



Source: Oxford Economics/NOAA

There is some evidence that the cost of weather and climate-related disasters is rising in the United States.

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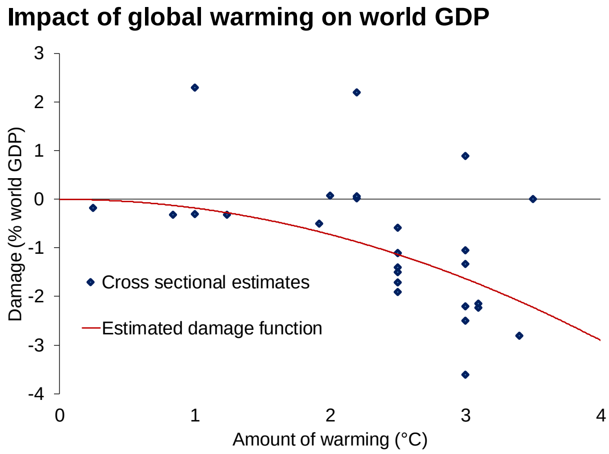
The economic effects of global warming will vary by latitude, by industrial structure and by geography

Despite these limitations, this cross-sectional approach forms the basis of the damage functions embedded in the main integrated assessment models (IAMs). Nordhaus and Moffat (2017) for example survey a range of cross-sectional estimates of climate damage, then fit an aggregate damage function to the resulting scatter plot of estimates. Having dropped 'outliers', their preferred damage function takes the form $D = -0.18T^2$ where D is the percentage loss in the level of world GDP and T is the increase in global warming. After making an additional judgmental adjustment of 25%, their estimated impact is -2% of GDP at 3°C of warming, rising to -8% of GDP at 6°C. The studies used in the paper and the fitted damage function is shown in Chart 4 below.

In response to the problems with the cross-sectional approach, the last ten years have seen a rise in the number of studies using longitudinal panel data. There are now a number of reduced form panel estimates of GDP growth across countries as a function of annual temperature variations. Dell, Jones and Olken (2012) look at the effects of annual temperature and precipitation changes on 125 countries from 1950-2003. They find that in poorer countries, a 1°C temperature increase reduces GDP by about 1.3%. One obvious problem with this approach is that countries can, over time, adapt to higher temperatures and hence estimates that do not take this adaptation into account may overstate the economic impact. To counter this criticism, the paper also examines the impact of temperature as a distributed lag and find that the impact persists over time. This suggests that higher temperatures may reduce the growth rate and not simply the level of output of poor countries particularly.

In what is probably the benchmark study of this new literature, Burke, Hsiang and Miguel (2015) pursue a similar panel data strategy looking at data from 166 countries over the period 1960-2010. They find that productivity (GDP per capita) is a function of temperature, with productivity peaking at an annual average temperature of 13°C and declining strongly at higher temperatures. In colder (and typically rich) countries productivity increases as temperature increases up to an annual average temperature of 13°C. Productivity then declines gradually with further warming and this decline increases at higher temperatures. If future adaptation is the same as observed in the historical data then unmitigated global warming is expected to reduce global GDP per capita by 23% by 2100 in a high emissions scenario (**Chart 5**). Using a similar approach but a more disaggregated dataset of 11,000 districts across 37 countries, Burke and Tanutama (2019) find that local level growth in GDP responds to temperature across all regions with 'peak' productivity effects occurring earlier, at 10°C. A full survey of the recent estimates is included in our white paper.

Chart 4: Historical damage functions have tended to suggest the costs of higher temperatures are relatively modest



Source: Oxford Economics / Nordhaus and Moffat (2017)

Nordhaus and Moffat (2017) fit a quadratic 'damage function' (in red) to a number of individual cross-sectional estimates of the costs of climate change (in blue).

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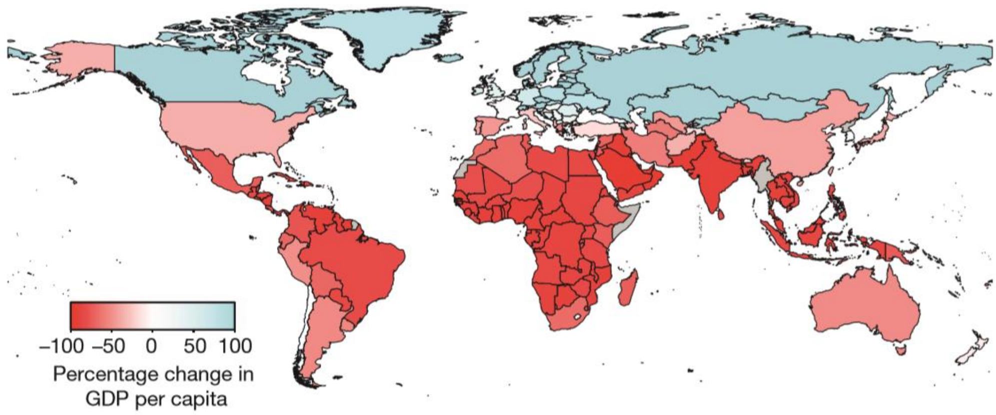
In contrast to the quadratic functions in the IAMs, the estimated damage functions constructed by Burke, Hsiang and Miguel (2015) are “roughly linear.” This approximate linearity results from the fact that the broad distribution of initial country temperatures remains unchanged as temperatures increase along different parts of a smooth response function, causing the average derivative of productivity to change little as countries warm. Hence the intuition that global economic damage will be non-linear because micro-level responses are non-linear may not be correct.

Hsiang et. al (2017) employ a remarkably sophisticated (and computational heavy) approach to estimating economic damages, at county level for the US. Nationally, aggregated total damage is represented by a quadratic function that places the impact of the 4°C increase in GMST at between 1.5%-5.6% of GDP. Approximating this damage function with a linear relationship suggests losses of about 1.2% of GDP per 1°C.

Overall, the results of these time series panel estimates are up to an order of magnitude higher than the typical damage functions included in the main IAMs. Focusing solely on the recent reduced form estimates suggests a significantly steeper damage function. Notwithstanding the comments about a linear relationship above, **Chart 1** shows two representative quadratic functions that might be considered as an illustrative range. Hence the 2°C of warming expected by 2050 in a high emissions scenario might incur costs of between 2.5% and as high as 7.5% of global GDP. These effects are therefore big enough to be considered in our short-term economic forecasts for the first half of this century.

Chart 5: Central America, Africa and SE Asia are likely to see the biggest declines in GDP per capital relative to unchanged temperatures

Projected effect of temperature changes: Country level estimates by 2100 for 4°C of warming



Source: Burke, Hsiang and Miguel (2015)

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