Examining the Potential Impacts of Climate Change on Economies

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KAREN KARNIOL-TAMBOUR
DANIEL HOCHMAN
CHARLIE WOODLIEF
CARSTEN STENDEVAD

BRIDGEWATER

Climate change has become a topic investors need to address. A critical mass of regulators requires financial entities to measure and disclose the risks associated with it; a critical mass of investors is examining it, which will price its potential impacts into markets; and a rising number of governments are enacting policies to address it that will shape markets and economies. In this research, we focus on a set of questions about climate change that is especially relevant to us as macroeconomic investors—the impact of climate change on the major economies around the world. There is considerable uncertainty regarding the physical impacts of climate change on economies; as we surveyed expert views on the topic, we found a wide range of plausible outcomes for investors to consider. And while the physical impacts of climate change will take years to play out, the economic and market impacts of policy choices or other human responses to climate change are likely to take place much faster. Our findings so far:

- We are living through a tail event (in COVID-19), which underscores the need for humility in thinking through other events we have not experienced in our lifetimes. Viruses very similar to COVID-19 (e.g., MERS, SARS) occurred in the past that were manageable to contain, without much impact on economies and markets. However, a small variation in the characteristics of a new virus in today's interconnected world led to radically more severe outcomes. This speaks to the difficulty in forecasting how climate change may play out.
- Climate change is extremely challenging to model, and the range of potential outcomes is wide. We conducted a review of a range of expert estimates for the impact of climate change on economies and found considerable disagreement even assuming the same level of global warming (and how much warming occurs will depend on factors like policy choices). Some commonly cited models project that if emissions remain at roughly today's level going forward, economic losses will be moderate—just a few percent of global GDP over many years, the equivalent of a 0.2% drag on growth per year in the hardest-hit countries we trade (e.g., India, the Philippines, Indonesia, Thailand). But other researchers predict much more severe loss scenarios, 10x or more than more common models. For example, one predicts that if emissions continue growing in line with current practices, the growth rates of most emerging Asian and Latin American countries will fall by half (by 2-3% a year) and US growth will experience a drag of 0.5% a year. In other words, much more is unknown than known about the future impacts of climate change, so it is essential to be prepared for the wide range of potential outcomes.
- As we're experiencing with today's pandemic, policy responses can have much bigger impacts on economies and markets than the phenomena themselves. The bulk of the impact on markets and economies today stems from policy makers' response to the virus—shutdowns, border closures, etc., as well as fiscal and monetary measures to counteract these—rather than from the deaths directly caused by the virus. Similarly, policy responses to climate change (e.g., fiscal spending to upgrade infrastructure, tax policy, shifting regulatory regimes, macroprudential policy) may come much earlier than its physical impacts and be a meaningful driver of markets and economies in the coming years.
- Climate change is widely expected to hit hotter, lower-income regions disproportionately hard. As in the case of COVID-19, there will be winners and losers across countries, sectors, companies, and asset classes. As a result of its essentially regressive nature, climate change has the potential to also exacerbate social and political conflicts within and across countries. Such human responses to climate change (e.g., climate-driven migration) may have wide-ranging impacts on economies far greater than the physical impacts of the changing climate.

Reviewing the Range of Potential Outcomes of Climate Change

As humans continue to emit greenhouse gases that act as an insulating blanket on the planet, around a 3–3.5°C rise in average global temperature relative to a pre-industrial baseline is largely considered a base case for how the climate will evolve by the end of the century [1] [2] [3] [4].[1] In terms of predicting how the warming of the planet will translate to economies and markets, the table below illustrates the wide range of potential outcomes for investors by showing two estimates of the impact of climate change on economic output:

- A low-end impact estimate: This assumes temperatures will rise by 2.5°C by 2100 relative to a pre-industrial baseline, which would likely require some adjustments in policy to reduce emissions from their current pace. It projects moderate losses: a decrease in GDP of perhaps 10%–12% in the hardest-hit countries by the year 2100 relative to where GDP would otherwise have been, the equivalent of about a 0.2% yearly growth drag [5].[2]

- A high-end impact estimate: This assumes temperatures will rise by 4.5°C relative to a pre-industrial baseline, which is plausible if emissions continue to rise at the current trend, and makes more pessimistic assumptions about adaptation (worsening economic losses). It results in a dramatic hit to most emerging Asian and Latin American countries, effectively reducing their potential growth by half, and even US growth would experience an effective drag of ~0.6% (from much lower levels) under this scenario [6].

Country	Low-End Scenario %GDP Loss Given ~2.5°C Warming by 2100	High-End Scenario %GDP Loss Given ~4.5°C Warming by 2100	Low-End Scenario Avg Annual Growth Drag	High-End Scenario Avg Annual Growth Drag	Potential Growth (Without Drag)
India	-12%	-92%	-0.2%	-3.1%	7%
Philippines	-12%	-84%	-0.2%	-2.2%	6%
Indonesia	-12%	-85%	-0.2%	-2.3%	5%
Venezuela	-10%	-91%	-0.1%	-3.0%	3%
Thailand	-11%	-90%	-0.1%	-2.8%	4%
Colombia	-10%	-77%	-0.1%	-1.8%	2%
Malaysia	-10%	-87%	-0.1%	-2.6%	4%
Brazil	-10%	-83%	-0.1%	-2.2%	2%
Saudi Arabia	-8%	-96%	-0.1%	-3.9%	3%
Ecuador	-9%	-69%	-0.1%	-1.5%	4%
South Africa	-6%	-66%	-0.1%	-1.3%	3%
Mexico	-7%	-73%	-0.1%	-1.6%	2%
Peru	-8%	-51%	-0.1%	-0.9%	4%
Argentina	-5%	-53%	-0.1%	-0.9%	3%
China	-3%	-42%	0.0%	-0.7%	6%
Singapore	-7%	—	-0.1%	—	2%
Turkey	-3%	-17%	0.0%	-0.2%	3%
Australia	-5%	-53%	-0.1%	-0.9%	2%
Greece	-3%	-51%	0.0%	-0.9%	0%
Spain	-2%	-46%	0.0%	-0.8%	1%
Portugal	-3%	-41%	0.0%	-0.7%	1%
Italy	-2%	-26%	0.0%	-0.4%	1%
Japan	0%	-35%	0.0%	-0.5%	1%
United States	1%	-36%	0.0%	-0.6%	1%
Source:	Tol (2018)	Burke, Hsiang, Miguel (2015)			Bridgewater

[1] We arrive at this estimate by triangulating across discussions of the scientific literature from Nordhaus (2012) and Wagner and Weitzman (2015) as well as a discussion of the "Representative Concentration Pathways" scenarios used by the IPCC from van Vuuren et al. (2011).

[2] To be precise: a %GDP equivalent decrease in consumption, which includes some damages not counted in GDP.

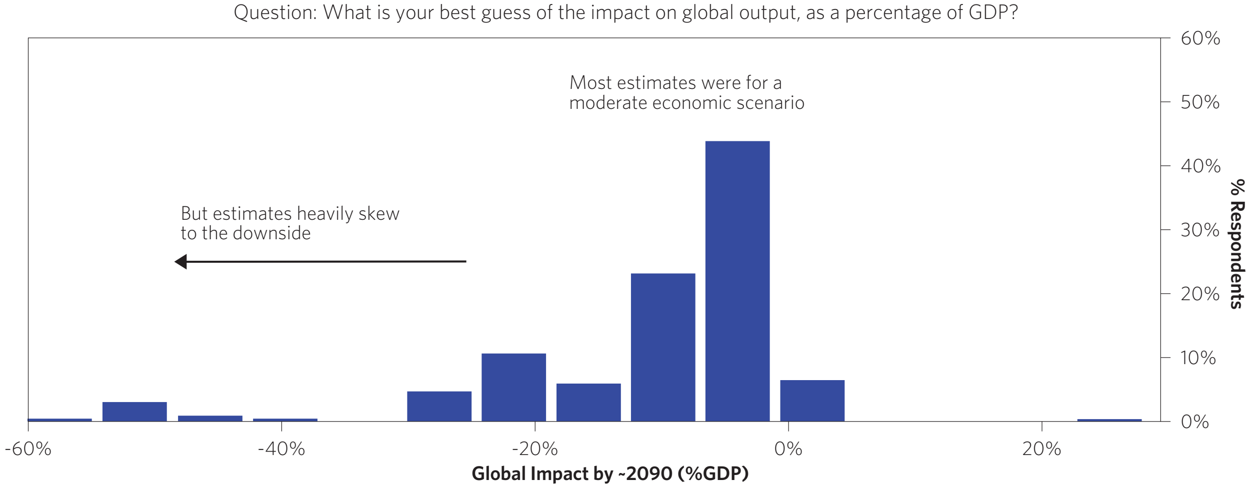
Note that in the table above, we focused on the countries with the largest expected losses who have large financial markets (i.e., those most relevant to most investors). In each country, the impacts are aggregated across many drivers, netting both the positive impacts of climate change on some regions or sectors with the negative impacts on others. A broader list of country climate risk exposures is shown in the Appendix.

As you can see, this table reflects a very wide range of plausible outcomes for investors to consider. The uncertainty stems from the fact that scientists can't run controlled experiments with the global climate, and there are limitations to any historical analogue for today's conditions [7]. Further, future outcomes will depend on human behavior like adaptation, policy choices, and innovation [3] [8]. Thus, there is meaningful uncertainty in every step of climate impact estimates: It's uncertain how large greenhouse gas emissions will be, how a given emission will translate to a change in temperature, and how a given change in temperature will affect the economy [2]. Below is a brief survey of the disagreement we encountered as we conducted a review of a range of expert estimates for the impact of climate change.

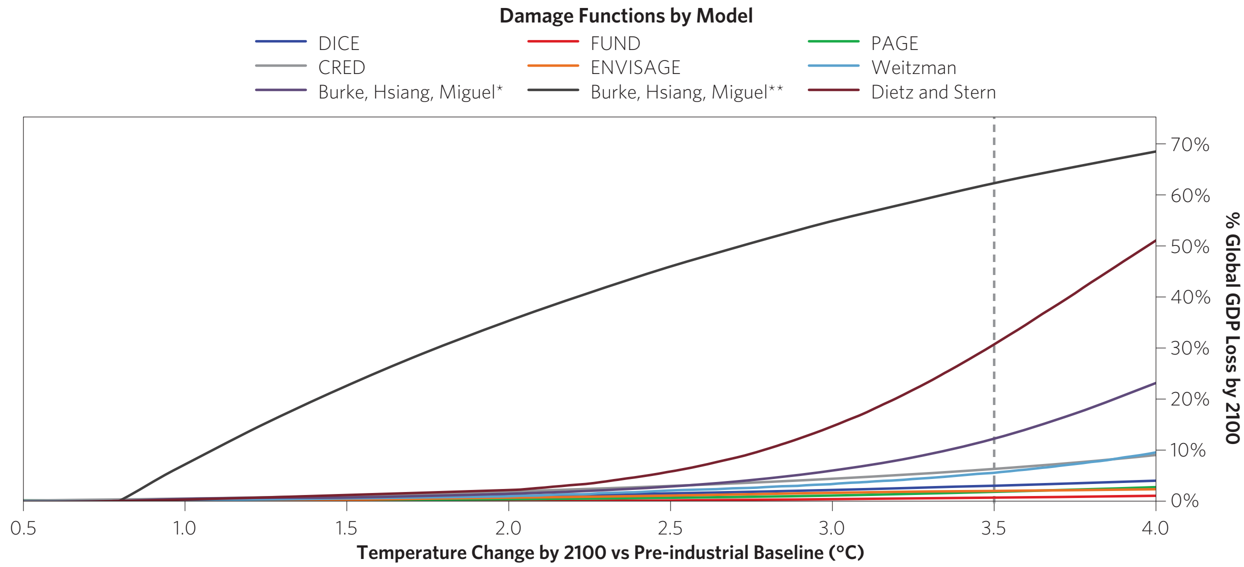
In 2015, the Institute for Policy Integrity conducted a survey of several hundred climate economics experts on the likely economic losses under a baseline scenario. The most common estimate was for largely moderate losses of 5%–10% of global GDP by near the century's end, but with a long tail of more severe expectations reaching up to 60% of global GDP [9]. This survey of experts is, unsurprisingly, reflective of the more formal models for the economic impact of climate change we reviewed.

Expert Consensus on the Economics of Climate Change, 2015 Survey

Scenario: Global mean temperature increases by 3°C relative to the pre-industrial era by ~2090
Question: What is your best guess of the impact on global output, as a percentage of GDP?



There are a range of models that attempt to aggregate the various ways that rising temperature can impact the economy—such as falling crop yields, sea level rise, storm damages, and temperature related morbidity—into a headline %GDP impact as a function of global temperature changes [9] [11]. More commonly cited models predict mild losses in the realm of 2% of global GDP by the end of the century, but there is an extremely wide range of outcomes, with some estimates suggesting up to more than 50% of GDP under a base case temperature rise [6] [9] [12]. As the chart and table below show, this amounts to the equivalent of a rounding error in global growth on the one hand versus a significant drag on the other. The DICE, FUND, and PAGE models are the most commonly cited and are also among the most sanguine, as they rely materially on the assumption that rising temperature expectations would spur investment in adaptation, limiting damages [9] [11]. In contrast, Burke, Hsiang, and Miguel (2015) forecast climate damages from warming using only the historical impact of temperature shifts, where the track record of adaptation was weaker (but might not represent the effect of shifting temperature expectations) [6]. This is just one methodological difference among many across these diverging models. It's worth also noting that some experts consider climate risk so uncertain (e.g., non-linear relationships, no historical precedent, importance of second-order effects) that they find these quantitative models too limited to provide much valuable insight [13] [14] [15].

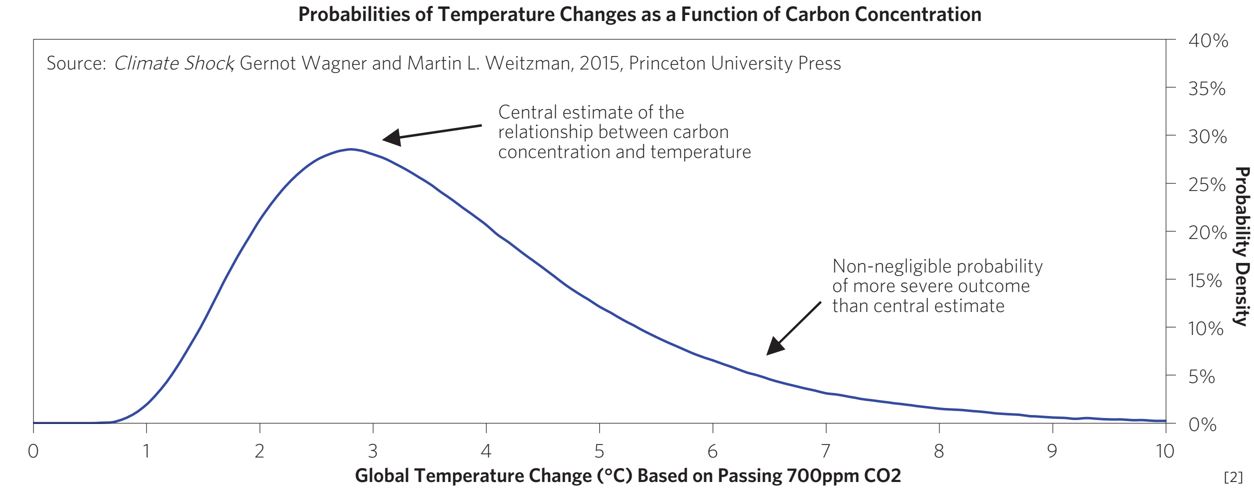


Damages at 3.5°C Global Temperature Increase by 2100

Global Impact by 2100 (%GDP)	Equivalent Annual Growth Drag	Model	
-1%	-0.01%	FUND	Commonly cited estimates are for mild damages over many years
-2%	-0.02%	PAGE	
-2%	-0.03%	ENVISAGE	
-3%	-0.04%	DICE	
-6%	-0.07%	Weitzman	
-6%	-0.08%	CRED	
-12%	-0.16%	Burke, Hsiang, Miguel*	Other estimates are much more extreme
-31%	-0.46%	Dietz and Stern	
-62%	-1.21%	Burke, Hsiang, Miguel**	

*Benchmark Model
**Alternate Specification
[1] [6] [16] [17] [18] [19] [20] [21]

Each of the estimates above works by taking a given rise in temperatures and then running it through a model of how this rise in temperatures will translate to losses. The rise in temperatures that will occur is not a known input, but itself uncertain. The amount of greenhouse gas emissions that will occur will depend on policy choices and how the economy will evolve. As an illustration, the chart below from Wagner and Weitzman (2015) shows probabilities of temperatures increasing to different levels given a baseline expectation for atmospheric concentration of carbon dioxide [2]. There is a central estimate of the relationship between carbon concentration and temperature but a non-negligible probability of a higher global temperature change than the base case.



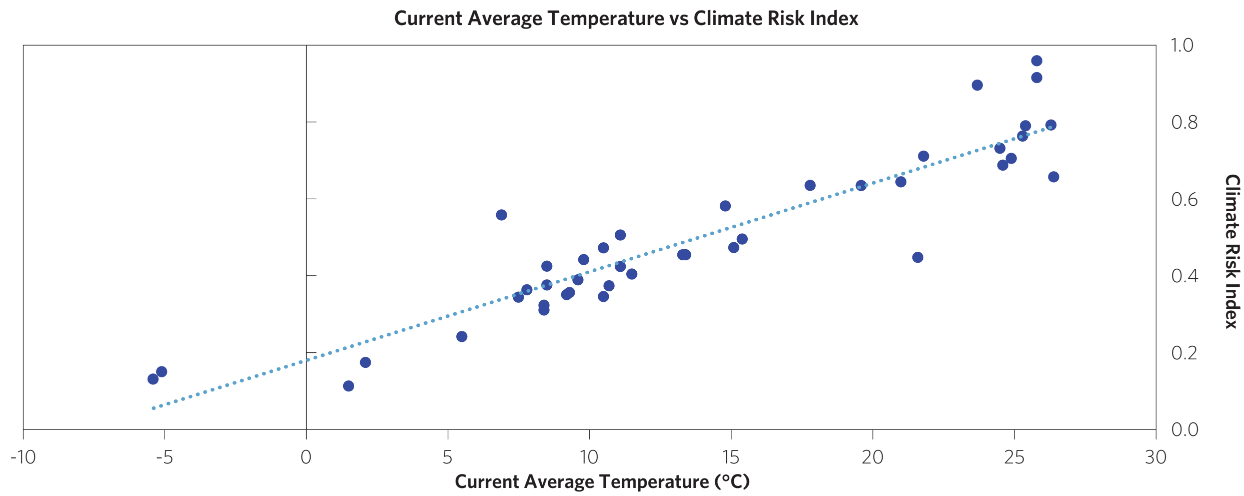
Where there is a good deal of agreement is that there is more room for climate to surprise on the downside than vice versa, because many of the dynamics involved have a downside skew [5] [20]. Additionally, there are a number of self-reinforcing feedback loops in the climate change process that, once triggered, could cause damages far worse than the central outcome [1] [8] [13]. This asymmetric risk is also exacerbated by a set of potential “tipping points”—events that, were they to occur, could trigger irreversible changes that would lead to catastrophic outcomes [1] [8] [15]. For example, if temperatures increased enough to thaw the permafrost layer in the global north, it would release massive quantities of trapped methane, which acts as a highly potent greenhouse gas [1] [15]. These events would accelerate losses, but we don’t know precisely at what threshold of global temperature increase they would occur or how large they would be, making loss estimates inherently unstable [1] [13]. This again underscores the need for investors to view climate risk as a wide range of outcomes, not just a central estimate.

Climate Change Will Hit Hotter, Lower-Income Countries Harder

While there are significant differences between models of how large the damage from climate change will be going forward, there is more agreement between estimates of where the damage will be most severe.

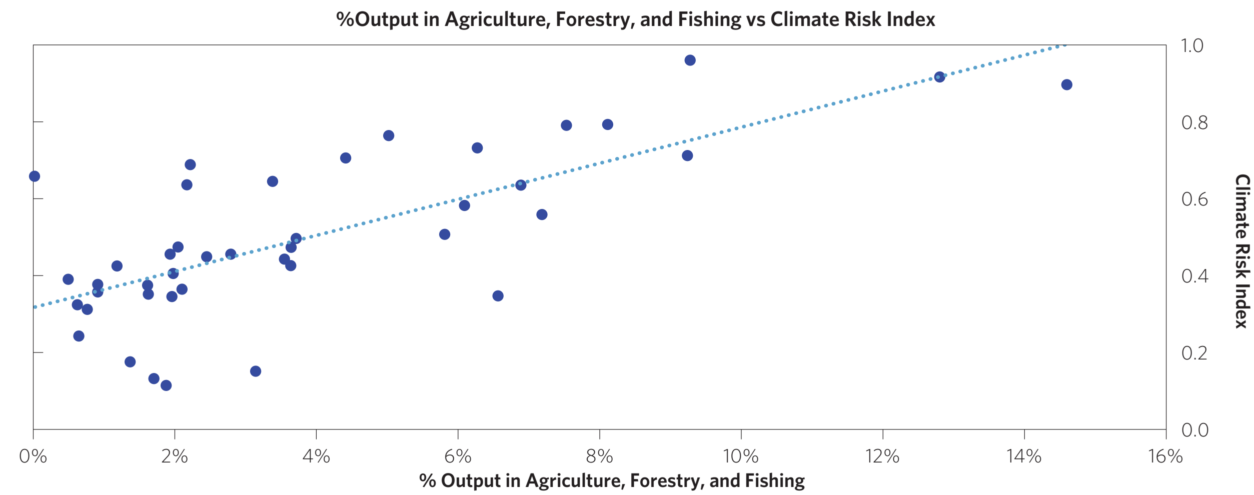
One significant driver of whether countries are especially vulnerable to climate change is whether the climate is already hot [5] [6] [22]. Being hotter today means you're closer to a threshold of inhospitable temperature from the start of the warming process [5] [6]. This is compounded by the fact that adaptive strategies haven't been developed as extensively for heat levels that have rarely been experienced [5]. To give a tangible example of how the expected damages from climate change might play out, take India—one of the most exposed countries in the world. The McKinsey Global Institute estimates that in India 50% of GDP and 75% of the labor force (380 million people) are "heat-exposed"—i.e., working conditions are outdoors or without access to air conditioning—in an already very hot country [23]. By 2030, they estimate 2.5%–4.5% of GDP losses just from the loss of productive working hours as temperatures rise [23]. A country like India must come up with new temperature management techniques since there is no present-day analogue for its future climate. By contrast, a place like the United Kingdom can just "import" the methods of a country like Spain, whose current climate its future climate may likely resemble [5].

The chart below illustrates the relationship between temperature and climate risk by plotting current temperature against our blend of several country-level impact estimates—what we call the "Climate Risk Index" throughout this section.[3]



Additionally, countries more concentrated in sectors especially affected by rising temperatures—like agriculture—are more vulnerable [5]. (Of course, lower-income countries are more likely to rely on these sectors for a larger share of their economies, so there's some overlap in this relationship with the fact that lower-income countries will likely be harder hit, as we'll discuss below [22].)

[3] The Climate Risk Index is a blend of risk measures from Tol (2018), Burke, Hsiang, and Miguel (2015), Kompas, Pham, and Che (2018), and Notre Dame's GAIN Country Index (2020) [5] [6] [24] [28].



Politics interact with countries' exposures as well. The table below shows the GAIN ratings of countries' exposure to climate change—a measure published by the University of Notre Dame Global Adaptation Initiative that breaks climate risk down into a range of subcategories relating to vulnerability, adaptive capacity, and readiness [24]. Countries that have significant "geophysical exposures" to climate change—threats to crop yields, risks to groundwater, lengthening warm season, flood hazard, sea level rise, etc.—can mitigate the potential impacts through investments to prepare. Singapore, for example, stands out as a country that has invested a lot in disaster preparedness, mitigating its severe geophysical exposure. In Venezuela, by contrast, especially poor governance (e.g., political instability and corruption) reduces adaptive readiness.

GAIN Indicators

Country	Aggregate Risk	Geophysical Exposure	Governance Quality	Disaster Preparedness
India	0.58	0.56	0.56	0.30
Philippines	0.57	0.56	0.59	0.40
Indonesia	0.54	0.58	0.55	0.34
Venezuela	**0.58**	0.44	**0.83**	**0.50**
Thailand	0.47	0.51	0.54	0.30
Colombia	0.49	0.50	0.55	0.26
Malaysia	0.43	0.52	0.43	0.21
Brazil	0.50	0.49	0.56	0.38
Saudi Arabia	0.46	0.30	0.50	—
Ecuador	0.55	0.55	0.62	0.21
South Africa	0.50	0.34	0.50	—
Mexico	0.49	0.44	0.59	0.23
Peru	0.49	0.48	0.54	0.34
Argentina	0.48	0.42	0.53	0.35
China	0.46	0.47	0.54	0.19
Singapore	0.31	0.67	0.11	0.06

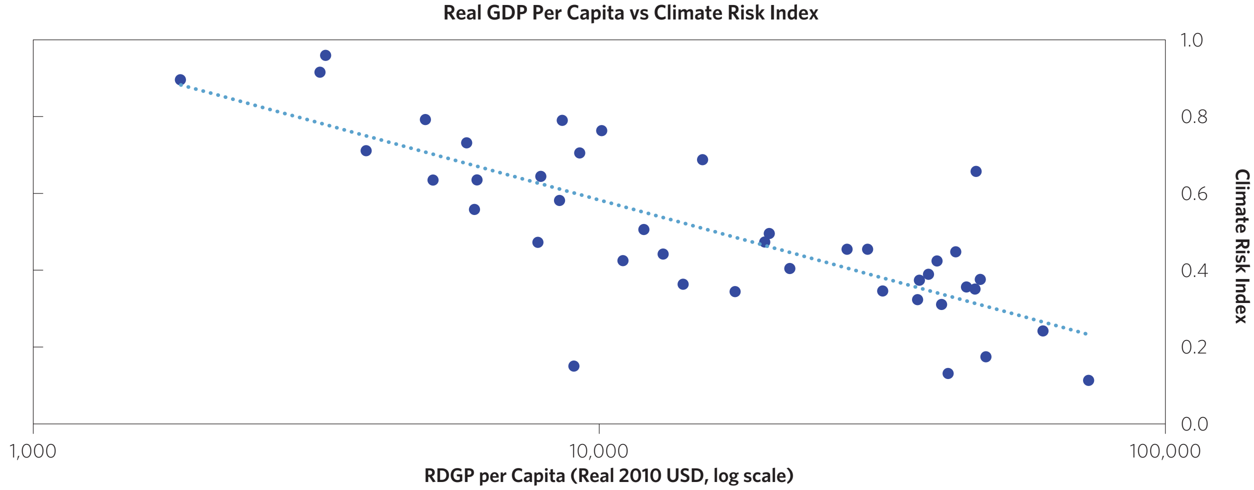
Weak institutions exacerbate risk... (Venezuela)

...while investment can mitigate exposure (Singapore)

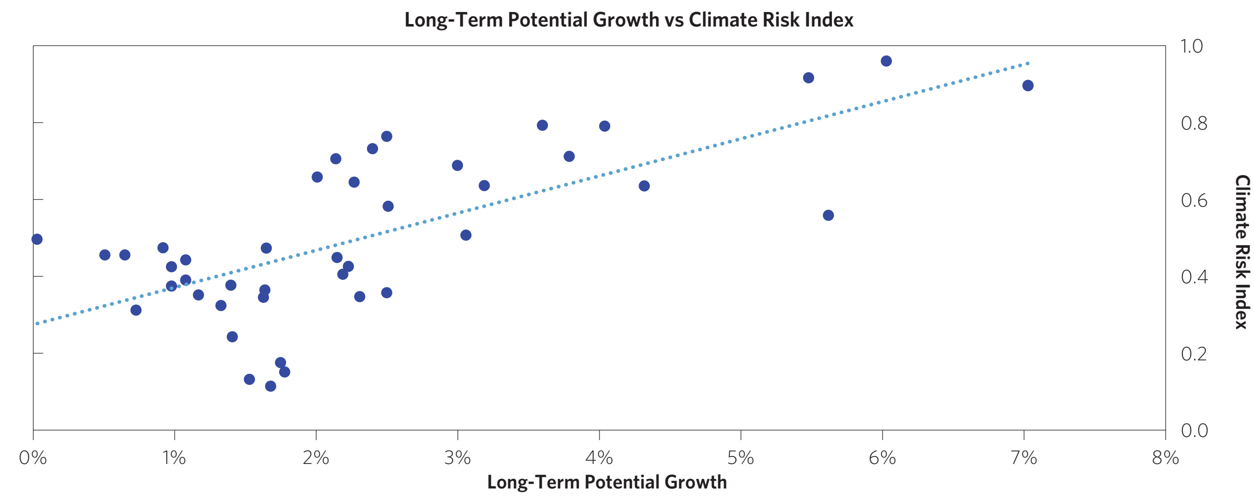
4

[4] "Geophysical Exposure" is Bridgewater's aggregation of GAIN Index sub-indicators for projected change of: Cereal Yields, Annual Runoff, Annual Groundwater Recharge, Deaths from Climate-Change-Induced Diseases, Length of Transmission Season of Vector-Borne Diseases, Warm Period, and Flood Hazard as well as Projection of Sea Level Rise Impacts and Population Living Under 5m Above Sea Level. "Governance Quality" is GAIN's combined measurement of Political Stability, Corruption, Rule of Law, and Regulatory Quality. "Disaster Preparedness" is GAIN's indicator for adaptive capacity to deal with climate-related natural disasters.

As the most exposed across a combination of these factors, lower-income countries generally rank as likely to suffer much greater impacts from climate change than higher-income countries [5] [6] [22]. This highlights the potential of climate change to exacerbate global inequalities, leading to potentially destabilizing second-order effects such as large-scale economic migration, as Europe has already experienced during droughts in Africa and the Middle East. With conflicts already elevated between and within countries around the world, these effects could further destabilize already strained political systems.



Adding it all up, this amounts to material risks to growth in countries that otherwise have high long-term growth potential, so it is worth considering as a factor affecting the trajectory of global growth.



Policy Responses to Climate Change Are Likely to Have Large Implications for Investors

As we're experiencing with today's pandemic, policy responses can have much bigger impacts on economies and markets than the phenomena themselves. Just as the bulk of the impacts on markets and economies today stems from policy makers' response to the virus—shutdowns, border closures, etc., as well as fiscal and monetary measures to counteract these—policy responses to climate change may come much earlier than its physical impacts and drive the most important impacts of climate change on economies and markets for investors.

There is a wide range of policy actions in response to climate change that could meaningfully impact financial assets, and we will not do them justice in this piece. Policy shifts to address climate change can be stimulative (e.g., direct government spending on new renewable infrastructure) or contractionary levers (e.g., strict regulatory regimes; legal liability for greenhouse gas emitters), and governments can be cooperative or antagonistic toward private capital in their approaches to addressing climate change. The impact on financial markets will depend on the shape of the political process. As one example, the UN PRI (Principles for Responsible Investment) has laid out what they consider to be the "Inevitable Policy Response" they believe will materialize through time, including:

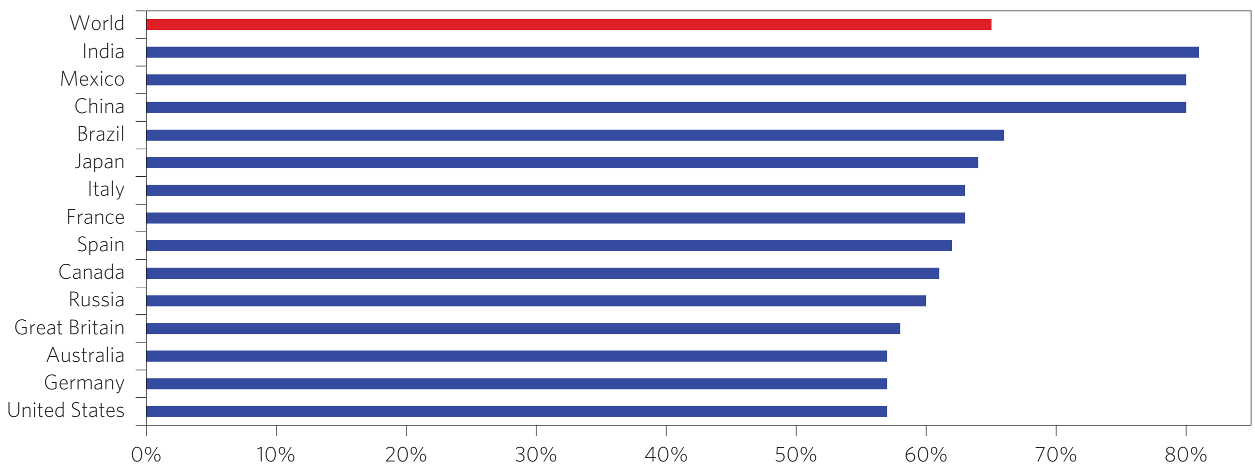
- Coal phase-out
- Fossil fuel cars phase-out
- Development of carbon pricing regimes
- Incentivization or regulation of carbon capture and storage in industry
- More renewable power (e.g., hydro, solar)
- Increasing regulation and incentives around energy efficiency
- Policy support for reforestation and other nature-based greenhouse gas removal
- Agriculture policy (R&D for agriculture technology to increase crop yields)

[25]

Importantly, in many countries around the world, a growing share of voters support government action on climate change. Surveys reflect that voters' interest in climate change has remained strong so far through the COVID-19 pandemic, and with the virus creating a larger role for direct government spending and fiscal stimulation, there may be political will in some places to take on ambitious climate programs. A recent global poll from Ipsos found that in many of largest economies, a majority of those surveyed supported government prioritization of climate change in the economic recovery after COVID-19 [26]. These forces are coalescing in Europe today, as green investment initiatives are likely to be a key focus of the European pandemic recovery fund. Even in the US, which has comparatively less widespread public support for climate action, recent polls show a strong upswing, with public support for government activity on climate change nearly doubling in the past decade [27].

Ipsos Poll, April 2020

In the economic recovery after COVID-19, it's important that government actions prioritize climate change



In this research, we focused on a particular set of questions about climate change that is especially relevant to us as macroeconomic investors—the impact of climate change on the major economies around the world. We also touched on the potential implications of policy to address climate change, a topic that will continue to evolve. There are many additional critical questions that we didn't focus on in this piece, including: important sectoral vulnerabilities (e.g., the resource sector's vulnerability to shifts in regulation intended to decarbonize the economy); how financial markets are currently pricing climate risk relative to the various possible scenarios; the potential for global flows of capital to rapidly shift in ways that "cut off" important players from the credit system, e.g., divestment raising the cost of capital for coal companies; how the ultimate exposures to climate risk are distributed—i.e., who is on the hook for different types of damage and whether they withstand a severe event; or how to measure climate risk at the portfolio level and stress test one's portfolio across plausible climate scenarios. We will continue to research these types of questions and bring you along as we learn more. As we do so, we would welcome your thoughts and feedback.

Appendix

Below, we show our Climate Risk Index for the largest economies globally and, for reference, our aggregation of geophysical risk indicators drawn from the GAIN Index as well as current temperature data from Tol (2018). The Climate Risk Index is a blend of several country-level climate risk measures we reviewed: Tol (2018), Burke, Hsiang, and Miguel (2015), Kompas, Pham, and Che (2018), and Notre Dame's GAIN Country Index (2020).

Country	Climate Risk Index	Geophysical Exposure	Average Temperature (°C)
Philippines	0.96	0.56	25.8
Indonesia	0.92	0.58	25.8
India	0.90	0.56	23.7
Thailand	0.79	0.51	26.3
Malaysia	0.79	0.52	25.4
Venezuela	0.76	0.44	25.3
Colombia	0.73	0.50	24.5
Ecuador	0.71	0.55	21.8
Brazil	0.71	0.49	24.9
Saudi Arabia	0.69	0.30	24.6
Singapore	0.66	0.67	26.4
Mexico	0.65	0.44	21.0
South Africa	0.64	0.34	17.8
Peru	0.64	0.48	19.6
Argentina	0.58	0.42	14.8
China	0.56	0.47	6.9
Turkey	0.51	0.38	11.1
Greece	0.50	0.43	15.4
Portugal	0.47	0.33	15.1
Bulgaria	0.47	0.34	10.5
Spain	0.46	0.36	13.3
Italy	0.46	0.42	13.4
Australia	0.45	0.46	21.6
Hungary	0.44	0.39	9.8
Chile	0.43	0.31	8.5
Japan	0.42	0.56	11.1
Korea	0.41	0.48	11.5
Belgium	0.39	0.32	9.6
United States	0.38	0.46	8.5
France	0.37	0.37	10.7
Poland	0.36	0.29	7.8
Ireland	0.36	0.40	9.3
Netherlands	0.35	0.42	9.2
New Zealand	0.35	0.42	10.5
Czech Republic	0.35	0.25	7.5
United Kingdom	0.32	0.37	8.4
Germany	0.31	0.31	8.4
Switzerland	0.24	0.26	5.5
Sweden	0.18	0.35	2.1
Russia	0.15	0.42	-5.1
Canada	0.13	0.36	-5.4
Norway	0.11	0.34	1.5
Source:	See Description	GAIN Index (2020)	Tol (2018)

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