Citi GPS

Managing the Financial Risks of Climate Change

Some Regulators Are Ahead of the Game

- **Climate change is a concern for financial regulators:** Greenhouse gas emissions, global warming, and climate change are not only existential issues for those concerned with the future of humanity, they are also immediate concerns for financial regulators. Climate change poses a ubiquitous risk to financial bottom lines, even for corporations that do not have any direct exposure to ESG issues.
- **The good news is that some key financial regulators and supervisors across the world are aware of these risks and are acting upon it.** One leading central banker has recently argued that central banks should take into account climate risks not only to ensure financial stability in their roles as regulators and supervisors, but also when conducting monetary policy in the pursuit of price stability or of a dual mandate like price stability and full employment.
- **Financial risks associated with climate change can be divided into two broad categories:** (1) financial risks associated with effective policies and other public and private efforts to contain climate change (transition risk or mitigation risk associated with a transition to a low(er) carbon future); and (2) financial risks associated with a failure to address climate change effectively (physical risk associated with adaptation to a high(er) carbon future). Mitigation risk — stranded assets — is the price of success in the fight against global warming. Physical risk is the price of failure.
- **Both risks have the potential to be huge.** However, there remains significant uncertainty regarding: (1) the precise manner in which these risks may materialize; (2) the likely transition or adaptation outcomes; and (3) the valuation of the possible losses (and, for some assets, gains) that could be involved.
- **We don't consider it likely that climate risks will be treated by corporates as a separate risk class.** Instead it is likely to be treated as a threat amplifier to existing risks. Climate science can help us get a better understanding of the evolving distributions of climate risks and their expression in weather-related disasters.

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Introduction

Paying careful attention to climate change risks should be viewed as a conventional financial risk management issue

Greenhouse gas emissions, global warming, and climate change are not only existential issues for those concerned with the future of humanity, they are also immediate concerns for financial regulators.[1] Paying careful attention to climate change risks should be viewed not just as a problem of corporate social responsibility but also as a conventional financial risk management issue. Climate change poses a ubiquitous risk to financial bottom lines, even for corporations that do not have direct exposure to ESG issues. Instead, these links are reflections of the pervasive role of *natural capital*[2] in the economy and the vulnerability of real commercial assets to climate change.

Some key financial regulators and supervisors across the world are aware of these risks and are acting upon it

The good news is that some key financial regulators and supervisors across the world are aware of these risks and are acting upon it. Indeed, one leading central banker has recently argued that central banks should take into account climate risks not only to ensure financial stability in their roles as regulators and supervisors, but also when conducting monetary policy in the pursuit of price stability or of a dual mandate like price stability and full employment.[3]

Two broad financial risks associated with climate change are mitigation risk and physical risk

Financial risks associated with climate change can be divided into two broad categories: (1) financial risks associated with effective policies and other public and private efforts to contain climate change (transition risk or mitigation risk associated with a transition to a low(er) carbon future), and (2) financial risks associated with a failure to address climate change effectively (physical risk associated with adaptation to a high(er) carbon future). Mitigation risk is the price of success in the fight against global warming. Physical risk is the price of failure.[4]

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[1] We use the terms greenhouse gas (GHG) emissions and CO_2 emissions interchangeably. Greenhouse gases are gases that absorb infrared radiation (net heat energy) emitted from the surface of the earth and reradiate it back to the surface of the earth. In addition to carbon dioxide this includes methane, water vapor, ozone, nitrous oxide, chlorofluorocarbons, hydrofluorocarbons and perfluorocarbons. CO_2 is by far the most significant GHG directly affected by anthropogenic (human) activity.

[2] "Natural capital is the world's stock of natural resources, which includes geology, soils, air, water, and all living organisms. Some natural capital assets provide people with free goods and services, often called ecosystem services. Two of these (clean water and fertile soil) underpin our economy and society and make human life possible." Wikipedia https://en.wikipedia.org/wiki/Natural_capital .

[3] See Reuters (2019).

[4] Carney (2015) adds a further category of financial climate change: liability risks: "the impacts that could arise tomorrow if parties who have suffered loss or damage from the effects of climate change seek compensation from those they hold responsible. Such claims could come decades in the future, but have the potential to hit carbon extractors and emitters — and, if they have liability cover, their insurers — the hardest." (Carney (2015)) We include these risks under financial physical risks. Physical damage caused by climate change to one set of physical assets can impair the value of other assets that are not themselves physically affected, but whose value depends on the physically damaged assets. An example is the destruction by a hurricane of the only bridge to an Island and the resulting loss of value for physically intact properly on the island. We would treat this as a physical risk.

Both risks are likely to be realized to some degree; the longer we wait, the more severe the physical risks and associated costs are likely to be. The balance between the two kinds of risks will be significant; each respective set of costs has a very different global distribution.

Stranded asset risk is the focus of mitigation risk

The mitigation risk we shall focus on is *stranded asset* risk — the risk of a sharp decline in the value of real assets that are physically unimpaired (see Citi GPS (2015)) due to a material change in the demand for the asset. These declines can be driven by changes in legislation, regulation, taxation, technology, tastes, input prices, and market structure.

Asset destruction is the focus of physical risks

Financial physical risks are the risks of asset value destruction through climate change-induced damage to real, physical assets — both commercial assets and non-commercial natural assets. The agents of destruction can be a wide range of natural disasters: wildfires, heat waves, tropical cyclones, droughts and other extreme weather events, floods (especially in low-lying coastal areas), and species extinctions that cause a decline in biodiversity. Assets at risk include infrastructure, property and other privately and publicly owned structures, land, and water resources. The risks of a physical stranding of real commercial assets, due to floods, droughts, and other problems caused by global warming, are best treated as physical risks.[5] Physical risks to humans (injury and loss of life) also have financial dimensions, including, but not limited to, the exposure of providers of life insurance and medical insurance.

Both sets of risk have the potential to be huge. However, there remains significant uncertainty regarding: (1) the precise manner in which these risks may materialize; (2) the likely transition or adaptation outcomes; and (3) the valuation of the possible losses (and, for some assets, gains) that could be involved.[6]

Translating long term data into a localized, shorter-term picture of warming and increasing frequency of extreme weather events is difficult

On the first point, while the long-term data relay a story of warming and an increasing frequency of extreme weather events, translating this into a localized, shorter-term picture is difficult. Extreme weather events are, by their nature, sporadic. Non-linearities and the potential for feedback effects associated with, for example, the destruction of the permafrost or growing oceanic acidity, mediate the rate and scale of global warming. The associated impact on other economically essential ecosystems is also highly uncertain.

The future path of climate change and ease of adjustment and thus the balance between adjustment and physical risks are hotly contested

Second, the future path of climate change and ease of adjustment and thus the balance between adjustment and physical risks are hotly contested. With regards to the balance between adjustment risk and physical risk, just one example illustrates how much even the experts disagree. Blakers and Stocks (2018), both from the Australian National University, argue solar photovoltaic and wind power will replace fossil fuels within 20 years. James Temple, senior editor for energy at MIT Technology Review, argues in Temple (2018) that at the current rate at which carbon-free energy capacity is being added, it's going to take nearly 400 years to transform the global energy system to a carbon-free one.

[5] See footnote 4.

[6] If a low-carbon future were to rely heavily on electric cars, say, the value of reserves of raw materials used in battery production (such as cobalt, lithium, graphite and nickel) is likely to be boosted.

If the Blakers and Stocks scenario materializes, mitigation risk becomes mitigation certainty and stranded coal, oil, and gas assets are likely to be vast. If the Temple scenario turns out to be the relevant one, we are likely to see an average global temperature increase above pre-industrial levels that is well above 2°C. Mitigation risk is reduced — there will be fewer stranded assets — but physical risks are bound to be higher and so are the risks of financial losses to those that own physically damaged assets or insure them.

Even if humanity chooses the path of transition and mitigation, the specific path we follow will affect which assets fall in value and which see their valuations sustained. Here carbon dioxide removal (CDR) is a good example of how the specific path will be key. What will be the future evolution of carbon capture and storage (CCS) costs and, beyond that, the scope for future creation of viable technologies for removing CO_2 from the atmosphere — a form of geoengineering or climate engineering?[7] Seawater capture (extracting CO_2 from seawater) can indirectly reduce atmospheric CO_2 concentrations; reducing the CO_2 concentration of the ocean induces water to absorb more carbon from the air. Direct air capture is a method of carbon capture and storage that separates carbon from atmospheric air, as opposed to point-source CCS which captures carbon only from flue-gas stacks that emit CO_2 in much more concentrated form.

Some scientists advocate the serious consideration of 'cloud seeding', which would steer more radiation into space rather than towards the earth, where it adds to global warming (see e.g. Storelvmo et. al. (2014)). All this is highly speculative at this point, even as a matter of science — let alone one of economically viable engineering. But it would not be wise to assign a zero probability to a mitigation technique that has a low probability of being successful — we should prepare for the risk of a miracle as well as for the risk of a disaster. We must, however, continue to heed the precautionary principle: "*When there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"[8]

Climate risk is not likely to be considered a separate risk class, but a threat amplifier to existing risks

We do not consider it likely that climate risk will be treated by corporates as a separate risk class, alongside market risk, credit risk, counter-party risk, liquidity risk, and reputational risk, which financial institutions and other corporates try to quantify, hedge, and provision for on a daily basis. Instead it is likely, as suggested by Habahbeh (2019), to be treated as a threat amplifier to existing risks. Global warming increases the likelihood and destructive impact of extreme weather events — tornados, hurricanes, storms, droughts, and floods. It will remain impossible to attribute any particular weather-driven natural disaster to global warming. It is always possible that this disaster would have struck even if the average global temperature had remained at its 1750 level. Climate science can help us get a better understanding of the evolving distributions of climate risks and their expression in weather-related disasters.

[7] The second form of geoengineering is solar radiation management. Where carbon dioxide removal addresses the cause of global warming by removing GHGs from the atmosphere, solar radiation management attempts to cause the earth to absorb less solar radiation, thus offsetting the effects of increased GHG concentrations on global temperatures.

[8] 1992 Rio Declaration on Environment and Development, https://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm

Section 2: Stranded Assets Risk

We have moved from a world where the risk of running out of fossil fuel within decades was a dominant concern to a world where a significant number of people hold views on human-caused global warming that imply that, if we are to meet the 2°C Paris Agreement target (let alone the 1.5°C target), we will have to leave large quantities of fossil fuel in the ground forever.[9] To get a sense of the magnitude of the likely stranded fossil fuel asset problem we may face, we need the appropriate carbon budget, the carbon content of the available reserves and resources of fossil fuels, and the historical record of human emissions of carbon dioxide.

Carbon Budgets

Carbon budget is the demand for carbon under a specific global average temperature scenario

A carbon budget (also called emissions budget, emissions quota, or allowable emissions) is an upper limit on total cumulative carbon dioxide emissions consistent with remaining below a specific global average temperature for a given period with a given likelihood. It can be viewed as the demand for carbon under a specific global average temperature scenario.

Carbon dioxide make up > 75% of total greenhouse gas emissions

Anthropogenic (human-made) emissions of greenhouse gasses are the predominant driver of global warming. Carbon dioxide is at the center of this, constituting over 75 percent of total greenhouse gas emissions.[10] Between the start of the industrial era and 2011[11], cumulative human emissions of carbon dioxide have amounted to around 2,040 gigatons of CO_2 ($GtCO_2$) (IPCC (2014)). Annual human CO_2 emissions in 2011 were 34.8 $GtCO_2$ (IPCC (2014)) and they averaged 34.5 $GtCO_2$ over the decade 2008-2017 (Le Quéré et. al. (2018)).[12] The Global Carbon Project estimates global CO_2 emissions from fossil fuels and industry to have been 36.2 $GtCO_2$ in 2017 and 37.1 $GtCO_2$ in 2018 (Global Carbon Budget (2018)).

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[9] The scientific consensus on the reality of human-caused global warming is overwhelming. According to Gustafson and Goldberg (2018) 97% of climate scientists are convinced that human-caused global warming is happening. They base this on J. Cook, et. al. "Consensus on consensus: a synthesis of consensus estimates on human-caused global warming, "Environmental Research Letters Vol. 11 No. 4, (13 April 2016); DOI:10.1088/1748-9326/11/4/048002. Quotation from page 6: "The number of papers rejecting AGW [Anthropogenic, or human-caused, Global Warming] is a miniscule proportion of the published research, with the percentage slightly decreasing over time. Among papers expressing a position on AGW, an overwhelming percentage (97.2% based on self-ratings, 97.1% based on abstract ratings) endorses the scientific consensus on AGW."

[10] The literature often breaks up the carbon budget into a carbon budget from the present (or some recent date) until around 2050 and a carbon budget for 2050 until 2100 (and sometimes later). The IPCC budgets apply until the point of carbon neutrality (net zero carbon dioxide emissions). This is 2038 for the case of keeping the temperature increase below 1.5ºC with a 66 percent probability) and 2048 for the case of keeping the temperature increase below 2.0 percent with a 66 percent probability. The budget through to 2100 as a whole is assumed to be 100 $GtCO_2$ lower. This is to account for permafrost thawing and future potential methane release.

[11] In most of the climate change literature, the industrial era is assumed to have started in 1750. The IPCC uses the reference period 1850–1900 to approximate pre-industrial global mean surface temperature.

[12] Human-induced global warming likely reached approximately 1°C above pre-industrial levels in 2017, and is currently increasing at 0.2°C per decade." IPCC (2018).

While there is a degree of uncertainty associated with the transient climate response to cumulative emissions of carbon (TCRE), there can be no doubt that the carbon budget for keeping global warming permanently below 2°C (let alone below 1.5°C) always implies severe emission reductions in the coming decades and net zero CO_2 emissions over the medium to long term.

Carbon budget estimates differ based on a number of temperature trajectories

We now report some estimates of the carbon budgets deemed consistent with a number of temperature trajectories. These are illustrative examples, not an exhaustive listing.

According to the IPCC in 2014, cumulative CO_2 emissions from 2011 onwards consistent with keeping the temperature increase below 1.5°C with a 66 percent probability are 400 $GtCO_2$. Cumulative CO_2 emissions from 2011 consistent with keeping the temperature increase below 2°C with a 66 percent probability are 1,000 $GtCO_2$ and cumulative CO_2 emissions from 2011 consistent with keeping the temperature increase below 3°C with a 66 percent probability are 2,400 $GtCO_2$ (IPCC (2014), Table 2.2).

Similar figures can be found in IPCC (2018), which states that the remaining carbon budget from 2018 (excluding additional earth system feedbacks) consistent with limiting the temperature rise to 1.5°C is 420 $GtCO_2$ for a 66% probability of not exceeding 1.5°C.[13] It is about 580 $GtCO_2$ if we accept a 50% probability of not exceeding 1.5°C.

According to the UN's Emissions Gap Report 2018 (UN Environment (2018)), to prevent global warming of 2°C by 2100, annual CO_2 equivalent (CO_2e) emissions, which includes all greenhouse gasses, cannot exceed 40 $GtCO_2e$ by 2030 (with a 66% chance). To keep global warming down to 1.5°C by 2100, total annual CO_2e emissions cannot exceed 24 $GtCO_2e$ by 2030 (with a 66% chance).

According to Rogelj et. al. (2016), to limit global warming to below 2°C with greater than 66% probability, the remaining CO_2 budget from 2015 onwards is between 590 and 1,240 $GtCO_2$. This is equivalent to between 15 and 31 years of CO_2 emissions at 2014 levels. The comparable IPCC figure is 1,170 $GtCO_2$ (IPCC (2018)). Including estimates of the potential benefits of carbon capture and storage, the IPCC estimate that to have a better than 50 percent chance of keeping global temperatures below 1.5 degrees, annual emissions will have to fall to around 20 $GtCO_2$ by 2030 and have passed net zero by 2050. For 2°C, the equivalent figures are 29 $GtCO_2$ by 2030 and 9.9 $GtCO_2$ by 2050.

[13] "The remaining carbon budget is defined here as cumulative CO_2 emissions from the start of 2018 until the time of net zero global emissions for global warming defined as a change in global near-surface air temperatures. Remaining budgets applicable to 2100 would be approximately 100 $GtCO_2$ lower than this to account for permafrost thawing and potential methane release from wetlands in the future, and more thereafter."; "Staying within a remaining carbon budget of 580 $GtCO_2$ implies that CO_2 emissions reach carbon neutrality in about 30 years, reduced to 20 years for a 420 $GtCO_2$ remaining carbon budget" (high confidence).IPCC (2018, Chapter 2, page 96). Carbon neutrality means zero net emissions.

The 'Supply' of Carbon

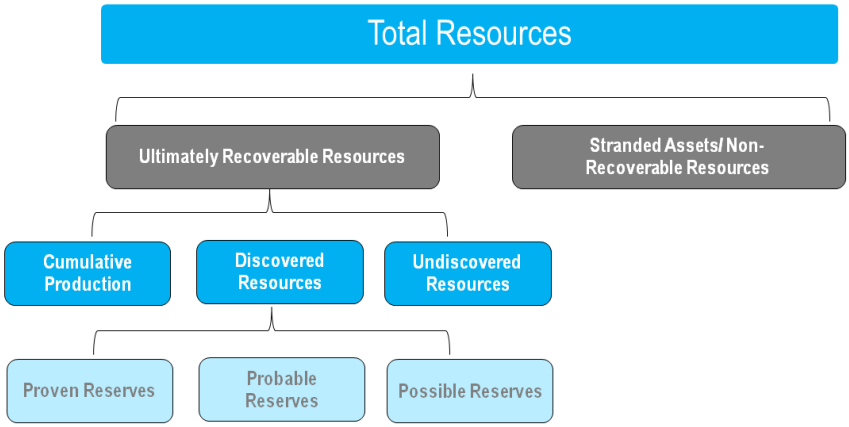
Carbon budget thought of in terms of demand and supply of fossil fuels

The carbon budget can be translated into demand for the various sources of CO_2 emissions — mostly fossil fuels. This demand is then compared with the 'supply' of fossil fuels — reserves and resources — to infer the amount of fossil fuel assets that will be left stranded (unused) if the carbon budget is adhered to.

It is worth noting this doesn't necessarily specify which fossil fuels will be left behind, merely the aggregate quantity of CO_2 that will not be emitted from all fossil fuel resources combined.

The literature distinguishes several kinds of 'supply' of non-renewable natural resources. The ultimately recoverable resource (URR) is an estimate of the total amount of a fossil fuel that will ever be recovered and produced. It is the sum of cumulative production, discovered reserves, and undiscovered resources. Cumulative production is an estimate of the oil produced up to a given date and the concept closest to economic supply is remaining ultimately recoverable resources (RURR), which is ultimately recoverable resources minus cumulative production. RURR are determined by geology, the laws of physics, technology (both current and future), regulation (current and future), input and output prices, and taxes and subsidies (current and future). This is illustrated in Figure 1.

Figure 1. Decomposing the Stock of Available Resources



Source: Citi Global Perspectives & Solutions (2015)

A lower carbon budget associated with a smaller peak global temperature increase would, in Figure 1, boost the size of 'stranded assets/non-recoverable resources' at the expense of 'ultimately recoverable resources' (URR). The stranded asset increase equals the fall in the sum of 'discovered resources' and 'undiscovered resources'.

Reduced 'discovered resources' would mean lower reserves, which are typically broken down into three categories: proven reserves, probable reserves, and possible reserves. 'Discovered resources' are an estimate of future production from known fields. They are typically defined in terms of a probability distribution. 'Discovered reserves' are the sum of proven, probable, and possible reserves. 'Undiscovered resources' are resources the existence of which is only postulated, on the basis of, say geological information.

To get a sense of the possible magnitude of future stranded assets under different global climate scenarios we would have to compare carbon budgets with carbon emissions that would occur if the existing stocks of coal, oil, and natural gas reserves were to be used in full.

Many studies show effective mitigation could have major financial implications for carbon-intensive industries

A number of studies reach the conclusion that effective mitigation could have major financial implications for carbon-intensive industries. A 2015 study in *Nature* by (McGlade and Ekins (2015)) estimated that in order to reach the Paris Agreement goal of limiting global warming to less than 2°C, one third of known global oil reserves, half of gas reserves and more than 80 percent of coal reserves would remain unused between 2010 and 2050. In addition, the study also argued that development of resources in the Arctic and any increase in unconventional oil production are incommensurate with efforts to limit average global warming to 2°C. Bos and Gupta (2019) conclude "The Paris Agreement's 2°C objective requires that more than 80% of all proven fossil fuel reserves become stranded resources, and investments in such resources may become stranded assets for industrialized and developing countries".

Decisive steps toward a low-carbon economy would involve some combination of corrective actions

Prompt corrective action means decisive steps now toward a low-carbon economy. This would mean some combination of carbon emissions taxation, cap and trade schemes with emissions trading systems, and regulation to limit carbon emissions. Governments can encourage and/or fund directly research and development of innovative techniques that help close the emissions gap. But, this will inevitably involve some write downs of assets that currently have a positive value.

Greenhouse gas-emissions reducing programs are, if they involve taxes or rationing, likely to be politically unpopular. Among the issues motivating the Gilets Jaunes (Yellow Vests) movement in France was the unpopularity of a proposed hike in fuel taxes. Carbon taxes on fuels such as gasoline, diesel, natural gas, and cooking or heating oil tend to be regressive and unpopular. The federal carbon pricing policy in Canada is a politically contentious issue in a number of fossil-fuel producing provinces.

There is material political opposition to measures to contain climate change

There is material political opposition to measures to contain climate change. A prominent example occurred on June 1, 2017, when President Trump announced the U.S. would withdraw from the 2015 Paris Agreement on climate change mitigation.[14] U.N. Secretary General António Guterres said during a trip to New Zealand to draw attention to climate change that the political will to fight climate change seems to be fading at the same time that things are getting worse for those feeling the effects.[15]

If this opposition persists or strengthens, mitigation risks are likely to decline while physical risks rise

If this political opposition to a transition to a low-carbon economy persists or strengthens, mitigation risks are likely to decline while physical risks rise. There are two separate political forces driving these developments. The first, reflected in the Gilets Jaunes movement, is the new challenge associated with domestic reform when popular distrust of the governing elites seems to be rising.

[14] The earliest possible effective withdrawal date is November 4, 2020, four years after the Paris Agreement came into effect in the United States.
[15] Nick Perry, Washington Post, May 12, 2019, https://www.washingtonpost.com/world/un-leader-arrives-in-new-zealand-on-climate-change-trip/2019/05/12/ff3a723c-7480-11e9-9331-30bc5836f48e_story.html?utm_term=.9e9ef8bb9c6a

The second trend — an international one — is one of institutional erosion of the unitary, multilateral Bretton Woods framework and the associated, growing difficulties in achieving interstate cooperation.

Carbon emissions are a classic negative public good (or public bad): non-rival and non-excludable

It is not surprising that it is difficult to coordinate carbon emissions policies across a wide range of countries. Carbon emissions are a classic negative public good (or public bad): non-rival and non-excludable. There is an obvious free rider problem ('after you') with reducing greenhouse gas emissions that contribute to global warming. Whatever the reason, given current carbon emissions the world appears likely to end up with an average global temperature increase relative to pre-industrial levels of at least 3 percent.

Section 3: Physical Risks

Like the costs of mitigation, some realization of physical risk associated with climate change is now unavoidable

Like the costs of mitigation, some realization of physical risk associated with climate change is now unavoidable. We may indeed have already been exposed to the materialization of physical risk from climate change. According to the UN Emissions Gap Report of 2017, full implementation of the unconditional Nationally Determined Contributions (NDCs) of the 2015 Paris Agreement would imply an average global temperature increase of 3.2°C by 2100, relative to pre-industrial levels. If the conditional NDCs were to be also implemented, this would bring the temperature rise down to 3%. The report also points out that most G20 countries will require new policies and actions to achieve their NDC commitments, conditional and unconditional. However, in 2017 global CO_2 emissions rose after three years of stagnation. Part of this reflected a cyclical uptick in global GDP growth. As noted, global carbon emissions in 2018 are likely to have hit an all-time high of 37.1 $GtCO_2$ according to the Global Carbon Project.[16] The International Energy Agency's data also show rising CO_2 emissions in 2018.[17]

How Damaging Are the 1.5, 2.0, and 3.0 and Beyond Scenarios?

Environmental damage and wealth destruction associated with 3.0°C global warming is likely to be vast

Judging from reports of the IPCC on the environmental impact of keeping global warming down to 2°C or 1.5°C, even those much lower than 3°C global warming outcomes would be seriously damaging and disruptive. The environmental damage and wealth destruction associated with more than 3.0°C global warming is likely to be vast. If these risks are recognized and insurable (not plagued by moral hazard and adverse selection), most of the financial risks will fall on insurance companies, reinsurance companies, and any entity exposed to these companies. If these risks are uninsured, the owners of the damaged real assets will pay the price. If the state provides financial relief to those who have been exposed to uninsured physical risk, the taxpayer and/or beneficiary of public spending will bear the cost.

Key questions concerning financial physical risks are: which assets are vulnerable to (catastrophic) climate change? Which assets are resilient? Are any of these vulnerable assets insured and if so, by whom?

[16] See Global Carbon Project, Carbon Budget (2018), Global Carbon Budget, Summary Highlights, https://www.globalcarbonproject.org/carbonbudget/18/highlights.htm
[17] See Global Energy & Co_2 Status Report; The latest trends in energy and emissions in 2018, https://www.iea.org/geco/

Among the potential consequences of global warming are glacier retreat, sea level rises, declines in Arctic sea ice, and increases in climate extremes including extreme weather events. According to NASA, the Arctic is likely to become ice-free during the summer before mid-century.[18] Ocean acidification, while not caused by global warming, is directly caused by rising atmospheric carbon dioxide concentrations. Increasing acidity of the oceans has a variety of potentially damaging consequences for marine life, including causing coral bleaching. After rising by about 8 inches since 1980, the sea level is projected to rise by another 1 to 4 feet by 2100. Storm surges and high tides are therefore likely to increase the risk of flooding in many low-lying coastal regions.

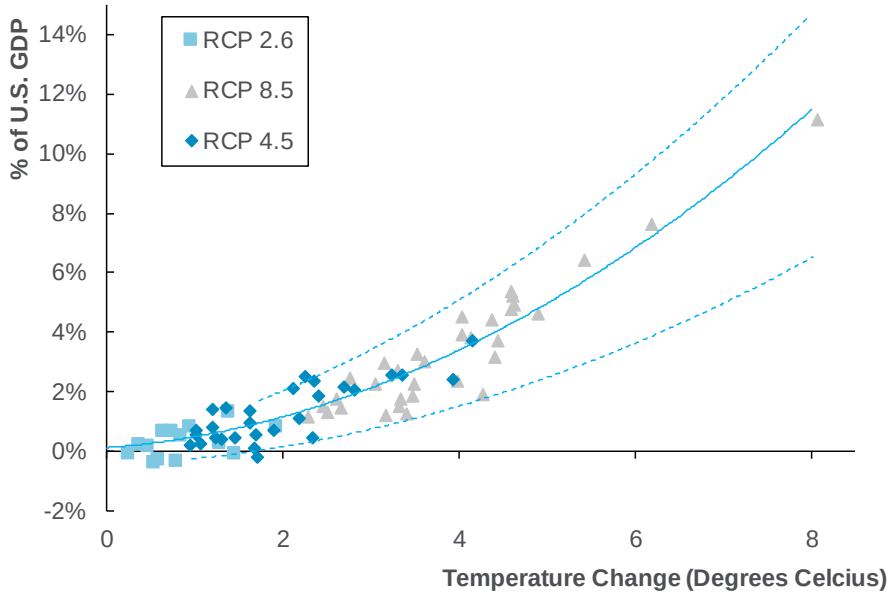
Changes in precipitation patterns are forecast to be prevalent. In the U.S. the recent trend towards increased heavy precipitation events is expected to continue in certain regions while other regions could see droughts and heat waves. Hurricanes could also become stronger and more intense and given the size of its coastline, the U.S. would share in a rise in global sea levels.

Not all the effects of global warming will be negative. Higher temperatures may on balance benefit northern countries like Russia, Canada, Norway, Sweden, and Finland. There can be some benefits for parts of the U.S. because the frost-free season and growing season could lengthen. The available evidence leads many to conclude that "*Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time*", IPCC (2014). The Fourth National Climate Assessment, released on November 23, 2018 argues U.S. GDP could be curtailed by as much as 10 percent (relative to the benchmark) on average during the last two decades of the 21st Century if global warming continues apace (U.S. Global Change Research Program (2018)). This is, admittedly, based on a very pessimistic emissions scenario in which weak rates of technological improvement combine with an absence of climate change policies and the U.S. climate responds in a particularly sensitive fashion. In this scenario, temperatures increase by 8°C on average between 2080 and 2099 (relative to the 1851-1900 benchmark). Figure 2 illustrates this scenario, which has the increase in temperature in degrees Celsius on the horizontal axis. The RCP numerical values in Figure 2 refer to the 'radiative forcing values' (measures of the cumulative human emissions of GHGs from all sources expressed in watts per square meter) in 2100.[19]

[18] https://climate.nasa.gov/effects/

[19] A qualitative list of global warming impacts is provided by the Union of Concerned Scientists in UCSUSA (2019). NASA (2019) publishes a similar list (see also the Fourth National Climate Assessment of the U.S. Global Change Research Program (2018) and, for a global perspective, UN Environment Annual Report (2017, 2018)).

Figure 2. Estimates of Total Direct Economic Damage from Climate Changes, U.S.



Note: RCP = Representative Concentration Pathway, a scenario for anthropogenic GHG emissions.
Source: Hsiang, S.R., A. June, J. Rising, M. Delagado, S. Mohan, D.J. Rasumussen, R. Muir-Wood, P. Wilson, M. Oppenheimer, K. Larsen, and T. Houser (2017)

Carbon emissions in the U.S. cost the economy about $250 billion per year, according to a recent study

A recent study by Ricke et. al. (2018) concludes that U.S. carbon emissions cost the U.S. economy about $250 billion per year. This is based on a social cost of carbon for the U.S. alone of about $50 per metric ton of CO_2 emitted. This estimate is much higher than those used today by the U.S. Environmental Protection Agency (EPA), but even at a social cost of carbon of $10 per metric ton of CO_2, the damage to the U.S. economy would be $50 billion per year. [20]

Globally, the economic impact of climatic disruption is starting to become evident. The economic costs from natural disasters have exceeded the 30-year average in 7 of the last 10 years. Since the 1980s, the average number of extreme weather events per year has more than tripled (Munich Reinsurance Company, 2018 and 2019). In addition, these risks seem to be most acute in the warmer parts of the world, where the poorer nations (emerging markets and less developed countries) are concentrated.

[20] The current EPA estimate of the social cost of carbon to the U.S. alone is reported to be between $1 and $10 per metric ton (see EPA (2017, Table 3-7)). This refers only to damages incurred within the borders of the U.S. and uses discount rates of 3 percent and 7 percent for valuing costs and benefits over time. The Environmental Defense Fund states that "The current central estimate of the social cost of carbon is roughly $40 per metric ton". See EDF (2019).

Section 4: Enter the Financial Regulators

The Bank of England was the first financial regulator to break the ice on addressing climate change

Given the pervasive climate change risk and uncertainty, ensuring confidence in the robustness of the financial system and key financial institutions is essential. The financial consequences of climate change is one area where financial regulators may well be ahead of the industry and the markets. Among the leading central bankers and supervisors, Mark Carney, Governor of the Bank of England, was the first to break the ice with regard to climate change.[21] In 2015 the U.K.'s Prudential Regulation Authority (PRA) (headed by Mr. Carney) addressed the impact of climate change on the U.K. insurance sector in an extensive report and followed up with another report in 2018.[22] In March 2019, Mr. Carney stated there appeared to be a "cognitive dissonance" between insurers' careful assessment of the risks posed by climate change to the liabilities they insured and their much more superficial approach to the assets in which they invested (Carney (2019)). In 2018 and 2019 the PRA addressed the impact of climate change on the U.K. banking sector.[23] The PRA and Financial Conduct Authority (FCA) established the Climate Financial Risk Forum (CFRF) to support the integration of climate-related factors into the financial decision making of insurance and reinsurance firms, building societies, and PRA-designated investment firms through appropriate modifications in the supervisory and regulatory framework.

Also in 2015, the Financial Stability Board (FSB), headed by Mark Carney, established the private sector Task Force on Climate-related Financial Disclosure (TCFD) under the leadership of Michael Bloomberg. In 2017 the TCFD came up with recommendations for voluntary disclosures of material, decision-useful climate-related financial risks targeted at all companies that raise capital. More than 100 leading companies (including Citi) and credit agencies signed a statement of support for the TCFD recommendations in 2017.

Citi and other leading banks participate in a banking-sector pilot project to implement TCFD recommendations

Citigroup's 2018 Global Citizenship Report contains a description of Citi's participation, together with 15 other leading banks and the UN Environment Finance Initiative, in a banking-sector pilot project to implement the TCFD recommendations related to climate scenario analysis. Figure 3 reproduces the Summary of Citi's TCFD Banking-Sector Pilot Results from the Citigroup report.

[21] Carney (2015), Carney (2018).
[22] PRA (2015), PRA (2018b).
[23] PRA (2018a), PRA (2018b), PRA (2019).

Figure 3. Summary of Citi's TCFD Banking-Sector Pilot Results

Transition Risk

Scenario*	Key Assumptions	Impacts – 2030 to 2040**
2°C	**Carbon Price:** **2030: $68** **2040: $111** • Use of fossil fuels continues throughout the century but at a declining rate as they are replaced by renewables • Carbon capture and storage is commercial after 2030 • Electricity prices increase as growing electric vehicle adoption and electrification of transport increases demand • In the short term, oil and gas serve as substitutes as the world transitions from coal, and oil remains an important transport fuel as transport demand grows	**Utilities (U.S.)** • Regulated low-carbon utilities: no change to 1 notch downgrade • Regulated heavy-carbon utilities: 1–2 notch downgrade • Unregulated low-carbon utilities: 1–2 notch downgrade • Unregulated heavy-carbon utilities: 2–3 notch downgrade **Oil & Gas Exploration & Production (U.S. and Canada)** • Offshore: no change • Shale and non-conventional: no change • Conventional: no change
1.5°C	**Same Assumptions, but Higher Carbon Price:** **2030: $117** **2040: $190**	**Oil & Gas Exploration & Production (U.S. and Canada)** • Offshore: 1–2 notch downgrade • Shale and non-conventional: 1–2 notch downgrade • Conventional: no change

Physical Risk

Scenario	Impacts – 2040
2°C	**Utilities** • Production declines 9.5–15.1% with an average decline of 11% by 2040, driven primarily by incremental (chronic) climate change • Half of companies have 1 notch downgrade due to productivity decline
4°C	**Utilities** • Production declines 10.7–15.1% with an average decline of 13.2% by 2040, driven primarily by incremental (chronic) climate change • Half of companies have 1 notch downgrade due to productivity decline

* Citi used the assumptions and outputs of the "REMIND CD-LINKS" scenarios developed by PIK.
** Ratings refer to Citi's internal credit ratings.

Source: Citigroup Global Citizenship Report 2018

The TCFD's purpose in coming up with its recommendations was to establish guidelines aimed at issuers, investors, lenders, insurers, and regulators for more effective climate-related disclosures that: "*could promote more informed investment, credit, and insurance underwriting decisions*" and, in turn "*would enable stakeholders to understand better the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks.*" (TCFD (2017)). It made four disclosure recommendations, under the headings Governance, Strategy, Risk Management, and Metrics and Targets. These four recommendations are supported by specific disclosures organizations should include in financial filings and other reports to provide useful information to investors and others. Supplemental guidance was added not just for financial industries (banks, insurance companies, asset managers and asset owners) but also for non-financial groups that account for the largest proportion of GHG emissions, energy usage, and water usage: e.g., energy, transportation, materials and buildings, and agriculture, food and forest products.

The NGFS called for action on climate change as a source of financial risk

The Banque de France, in 2017, brought together central banks and supervisors (now numbering 34 members and 5 observers) in a Network of Central Banks and Supervisors for Greening the Financial System (NGFS). In its first comprehensive report the NGFS called for action on climate change as a source of financial risk. It also provided six recommendations to central banks, supervisors and policymakers (NGFS (2019), see also Villeroy de Galhau (2019)): (1) Integrating climate-related risks into financial stability monitoring and micro-supervision; (2) Integrating sustainability factors into the own-portfolio management of central banks; (3) Bridging the data gaps; (4) Building awareness and intellectual capacity and encouraging technical assistance and knowledge sharing; (5) Achieving robust and internationally consistent climate and environment-related disclosure; and (6) Supporting the development of a taxonomy of economic activities.

It announced a three-point plan and judged all three Basel 'pillars' called for regulatory intervention and management of climate risk by regulated industries

It also announced a three-point plan to develop: (1) a handbook on climate and environment-related risk management for supervisory authorities and financial institutions; (2) voluntary guidelines on scenario-based risk analysis; and (3) best practices for incorporating sustainability criteria into central banks' portfolio management (particularly with regard to climate-friendly investments).

The NGFS also judged that all three of the Basel 'pillars' called for regulatory intervention in and modification of the management of climate risk by the regulated industries — and sometimes beyond that.

It is easy to see why climate change-related financial risks will prompt banking sector regulators to act under all three Basel III Pillars. Looking at Pillar 1, if climate change-related risk exposures of banks upon closer inspection are greater than expected, more capital will need to be held by the banks.[24] This holds both for mitigation-related risks (e.g., through direct or indirect exposure to long-cycle oil and gas projects and the stranded asset problems this can bring with it) and for adaption-related risks (e.g., through exposure to insurance companies that have insured real assets likely to be damaged and impaired as a result of climate change, or to other assets threatened by climate change).

Pillar 2 deals with firm-wide governance and risk management. It is clear that for many if not most banks, climate-related financial risks should be routinely addressed by senior management and the Board. Climate risk awareness should be a given wherever strategic and important operational decisions are made concerning exposure to stranded asset risks of mitigation and/or physical risks of adaptation.

Pillar 3 is about disclosure requirements. Without adequate disclosure about a bank's direct or indirect exposure to climate change risk, it is clear that Pillar 1 and Pillar 2 have feet of clay. Ensuring that management and the Board have the key facts about climate change exposure at their disposal will be a necessary condition for Pillar 2 to be effective and for adequate capital to be held.

[24] French central bank governor François Villeroy de Galhau has said that central banks should take climate risks into account when they evaluate the financial risks attached to collateral that banks post with them. See Reuters (2019). Indeed the soundness of the balance sheets of central banks themselves will depend on the timely recognition of climate change risks they are exposed to, directly or indirectly.

The Poseidon Principles incentivize shipping owners and operators to explore projects to decarbonize

Banks are also actively involved now in incentivizing some of their clients, by integrating climate change considerations into lending decisions, to pursue effective decarbonization strategies. A recent example is the involvement of 11 major shipping banks, including Citi, supported by a number of industry strategic partners, including Lloyd's Register, in the creation and implementation of the *Poseidon Principles*. These Principles aim to operationalize the Greenhouse Gas strategy of the United Nations International Maritime Organization (IMO) by providing financial incentives for owners and operators to explore a wide range of different technologies and projects to decarbonize.

To meet the IMO's initial GHG 2050 strategy, which requires the maritime industry to reduce total annual GHG emissions by at least 50% of 2008 levels by 2050, zero-emission vessels need to be in place by 2030 — a formidable challenge. The eleven founding signatories account for around 20% of global shipping finance and a bank shipping loan portfolio of around $100 billion.[25] Some of the Poseidon Principles-driven activities are educational. They make the shipping companies involved aware of their past and present contributions to global warming and of the existence of effective decarbonization strategies for the industry. The provision of financial incentives to owners and operators to adopt lower carbon strategies is an attempt to get the shipping industry to internalize the externalities of GHG emissions. For this to be fully effective, government intervention is likely to be required in the form of targeted taxes or subsidies, cap-and-trade emissions permits or regulatory constraints — preferably at the global level.

Government is exposed to climate change risk through physical risk to natural assets owned by the government and through negative impact on tax receipts of natural disasters and as insurer-of-last-resort in some cases

Insurance contracts for natural hazards include both indemnity-based contracts and parametric insurance products where payments are based on some publicly verifiable index, such as the amount of rainfall, the temperature level, or the magnitude of an earthquake in a specific location.[26] Of course the payment received under such a parametric insurance contract can fall short of or exceed the loss incurred by the policy holder — there remains a residual, uncovered 'basis risk'. In the U.S., the federal government operates the National Flood Insurance Program under which it provides, since 1968, subsidized insurance for homeowners living in locations with high risk of floods. Should global warming increase the frequency and severity of flooding and cause flooding risk to spread to areas that have hitherto been unaffected, this insurer-of-last resort-role of the federal government could become a meaningful financial burden. All levels of government are exposed to climate change risk in two further ways. The first exposure is the physical risk to the real commercial and natural assets (including real estate) owned by the government. The second, indirect exposure comes from the negative impact on tax receipts of climate change-driven natural disasters.

Bond market regulators are interested in climate change-driven risks due to the existence of cat bonds

Bond market regulators too are taking an interest in climate change-driven risks because of the existence of catastrophe bonds (cat bonds) and similar securities. Cat bonds are an example of insurance securitization, i.e. insurance-linked securities. Cat bonds pay regular interest, principal, or both to the holder during normal times. They compensate the issuer for losses if a contractually predefined catastrophe happens.

[25] See "Major shipping banks to launch the Poseidon principles in line with IMO's Greenhouse Gas Strategy", PortNews, 18 June 2019, http://en.portnews.ru/news/278749/

[26] Indemnity insurance is a contractual agreement in which one party guarantees compensation for actual or potential losses or damages sustained by another party.

In that case, the investor may lose all or part of the principal or interest. There are four possible types of triggers for a cat bond making the catastrophe payout: indemnity, industry loss, modeled loss, and parametric.[27]

In mid-2019 the amount of cat bonds outstanding was $38.8 billion

They can be an efficient way for primary insurers, reinsurers, state catastrophe funds, governments, and multilateral organizations (e.g., the World Bank) to transfer risk to the bond markets.[28] The amount of cat bonds outstanding on June 17, 2019 was a record $38.8 billion.[29] Cat bonds can be bought and sold through brokers active in the cat bond market. However, pricing these insurance-linked securities is no simple matter, especially since the underlying distribution function of the relevant insured natural disasters is changing — often in unpredictable ways — as a result of global warming. Other financial instruments for sharing the weather risk manifestation of global warming have been proposed including 'collateralized weather obligations' which could be constructed by pooling suitable cat bonds and traunching them (see (Habahbeh (2019)).

Cross-border regulatory arbitrage is still possible in cat bonds which could be a risk

It is important that financial innovation does not get too far ahead of financial supervisors and regulators. Despite the lessons that ought to have been learned from the Great Financial Crisis and its aftermath, there remains extensive scope for regulatory arbitrage including, but not limited to, cross-border regulatory arbitrage. State insurance regulators in the U.S. are responsible for supervising the issuance of cat bonds by insurance and reinsurance companies based in the U.S.[30] Special purpose vehicles (SPVs) that intermediate the cat bond issuance are based in countries like Bermuda and are regulated and supervised by the local regulator/supervisor. If the investor of the SPV is London-based yet another regulator will be involved on top of the U.S. and local regulator. The wider economic usefulness of the cat bond markets and other ILS markets as risk-sharing instruments would be enhanced if both the ultimate issuers and the ultimate holders could be drawn from diversified global populations. A global version of the EU's Solvency II — a global version of Basel III adapted to the insurance industry — would be most helpful in expanding what remains still a quite modest cat bond market.[31]

Climate change risks could also affect things like traditional 30-year mortgages

Climate change, global warming, and the associated potential for increased frequency and severity of natural disasters like floods could impact the market for such traditional financial instruments as the 30-year fixed-rate mortgage in the U.S. The lender will want the collateral (the residential property) to be safe or properly insured. The borrower (and owner of the property) will have to agree terms with the insurer that accurately reflects the risks of physical damage to the property.

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[27] Indemnity triggers base payouts on the actual insured losses experienced by the issuer. Industry loss triggers base payouts on aggregate losses to the insurance industry; they employ a third party to provide an independent estimate of these losses. Modeled loss is a generalization of a parametric loss trigger that uses a model instead of an index function to trigger the compensation for the issuer (see Polacek (2018) and RMS (2012)).

[28] The governments involved thus far are 16 Caribbean nations through the Caribbean Catastrophe Reinsurance Facility, Mexico, Chile, Colombia, Peru, Singapore, and China.

[29] See www.artemis.bm and the Insurance Information Institute https://www.iii.org/fact-statistic/facts-statistics-catastrophe-bonds

[30] Insurers and reinsurers don't issue the cat bonds directly themselves. Instead they create an SPV (typically in tax-efficient and regulation- light jurisdictions like Bermuda) that intermediates between the (re)insurance company and the ultimate holders of the cat bonds.

[31] Solvency II is a risk-based capital regime for insurers and reinsurers in the EU.

Global warming is likely to change the distribution of devastating outcomes in ways that are hard, if not impossible, to predict. Certain properties could become uninsurable and therefore unacceptable as collateral for mortgages. Pressure to expand the scope and scale of the U.S. National Flood Insurance Program is bound to mount should this occur.

Equity-type products, including straight common stock, can be useful instruments for trading and sharing risks, including the risks associated with climate change. The private and social benefits of risk sharing through the stock market depend on how informed the assessments by both the issuers and the holders are concerning the nature, magnitude, and likelihood of the risks (including climate-change-related risks) the issuing entity faces.
Regulators of exchange-traded stocks should require all corporates they cover to provide regular updates on climate-related risks they face.

Ideally, such Basel III-type mandatory information sharing for corporations traded on stock exchanges would be coordinated through a common set of practices agreed at the global level. We are still a long way from achieving an operational consensus on this.

Conclusion

The fact that key financial regulators and supervisors are making the assessment and quantification of climate change-related risks a part of the normal operating procedure for banks, insurers, and investors has to be good news

There will always be uncertainty about the magnitude and severity of the stranded asset problem. How much, if any, of this risk is current priced in by the markets and perceived by carbon-intensive non-financial corporations, corporations, banks, other asset managers, and insurers? Likewise the physical asset destruction associated with continued global warming is uncertain in magnitude and hard to value. Nevertheless, the fact that key financial regulators and supervisors are making the assessment and quantification of climate change-related risks a part of the normal operating procedure for banks, insurers, and investors has to be good news. It may be the case that, for once, this time is indeed different and a new category of risks is recognized and managed properly before they are realized in full. The absence of similar progress when it comes to the provision of relevant climate risk-related information by issuers, investors, and market makers active in the bond markets and stock markets is, however, a cause for concern.

Finally, there is a growing awareness among central bankers that the likely materialization of climate change risks could have a first-order depressing effect both on aggregate demand and on potential output. The net effect could well be a sequence of stagflationary shocks — boosting inflation and depressing output. It makes climate change risk relevant not only for central banks' financial stability mandate but also for the conduct of monetary policy in the pursuit of price stability or of the dual mandate of price stability and full employment.[32] This could well result in the time-horizons and forecasting horizons of central banks for monetary policy (typically 2 to 3 years) being extended. It behooves the private sector to heed these warnings and to adjust their own business models and practices accordingly. Financial risk from climate change is here to stay. Prepare now or pay later.

[32] This point has been made forcefully by the French central bank governor Villeroy de Galhau who concludes that central banks should push out their forecast horizons in order to properly allow for climate change risk (see Reuters (2019)).

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IMPORTANT DISCLOSURES