Rising Temperatures, Melting Incomes, Falling Ratings!

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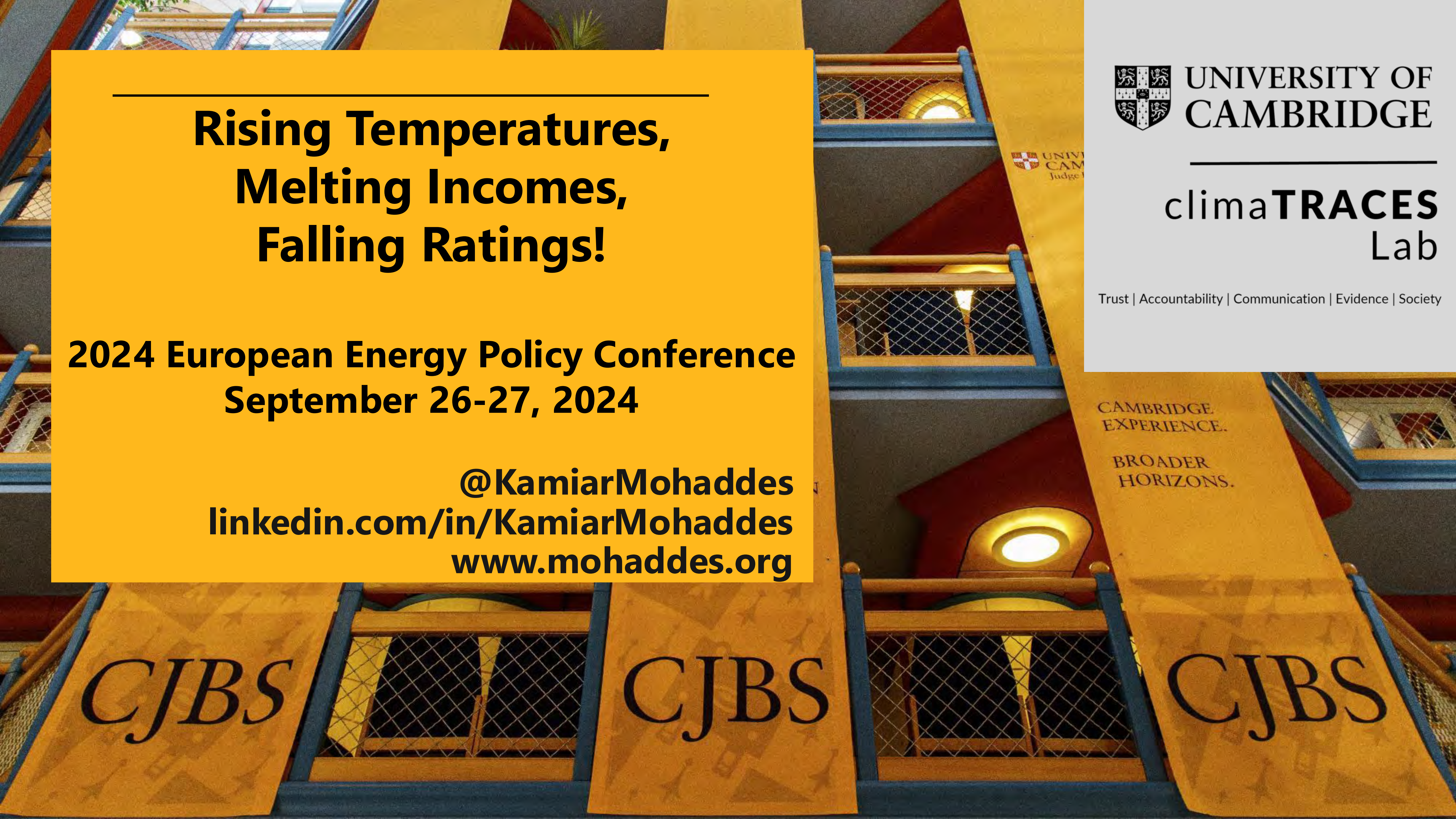

Some important questions that we will be discussing today:

- How large are the effects of **climate change** on **economic activity**?
- Does climate change have **level or growth** effects, including in the **long-term**?
- Are the effects larger for **poor (hot)** countries? Are they **asymmetric**?
- What are the **channels of impact** and **which sectors** are affected the most?
- How can we **make risk metrics useful**?
- What are the net **cost of inaction**?

Based on several papers and work with the following colleagues

- Rising Temperatures, Melting Incomes: Macroeconomic Effects of Climate Change Scenarios **(with Mehdi Raissi)**

- Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis
- Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness
- Climate Change and Fiscal Sustainability: Risks and Opportunities
- Climate Change and Economic Activity: Evidence from U.S. States

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Matthew E. Kahn (University of Southern California)
Moritz Kraemer (LBBW Bank)
M. Hashem Pesaran (Cambridge & USC)
Joe Stiglitz (Columbia University)
Ulrich Volz (SOAS, University of London)
As well as many colleagues from **BCG**

Matt Burke (University of Sheffield)
Patrycja Klusak (Heriot-Watt University)
Ryan N. C. Ng (BP)
Mehdi Raissi (International Monetary Fund)
Jui-Chung Yang (National Taiwan University)
Dimitri Zenghelis (Cambridge & LSE)

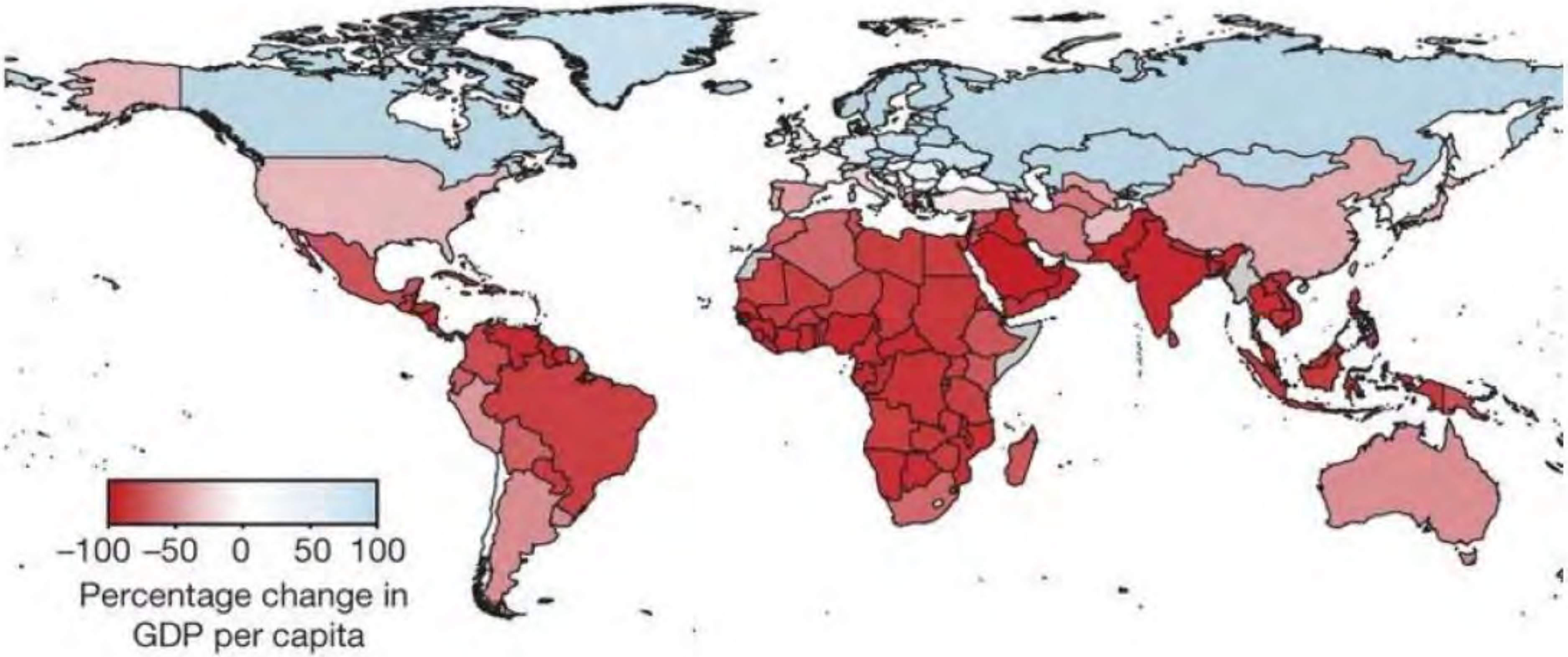
What do other studies suggest?

- The most used estimates in the literature **differ by an order of magnitude**. This wide range arises from a disagreement about whether a temperature increase will affect GDP levels or GDP growth rates, and from different model specifications:

    - Most papers that relate temperature to GDP levels yield income loss estimates that are relatively small;

    - More recent studies, that relate temperature to GDP growth (possibly nonlinearly), show that a shift to a higher (non-decreasing) temperature reduces per capita output growth significantly (with compounding level effects over time) compared to a “no further warming” baseline.

Some studies suggest that countries might even benefit significantly from climate change?!



Source: Figure 4(a) in Burke et al. (2015). Global Non-Linear Effect of Temperature on Economic Production. *Nature* 527, 235–239.

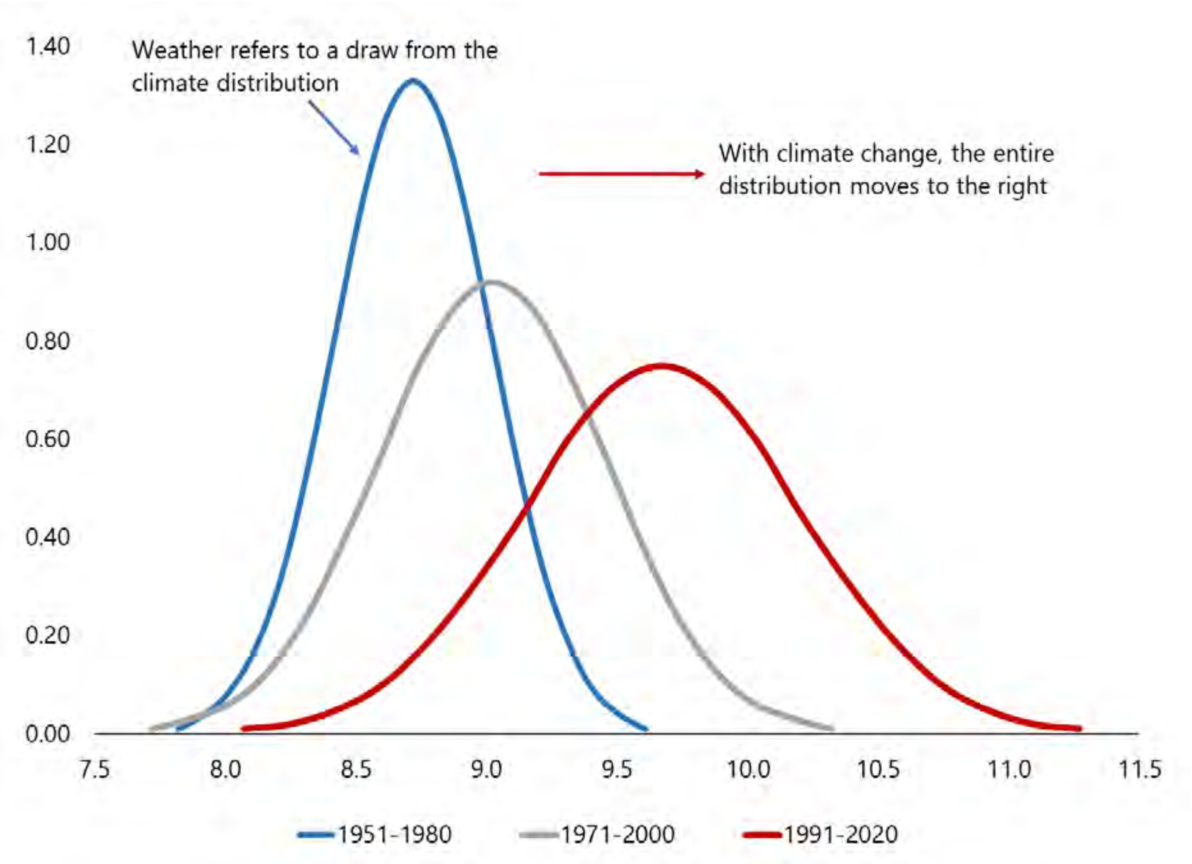
Terminology:

- **Weather** refers to atmospheric conditions over short periods of time (e.g., temperature and precipitation).

- **Climate** refers to the long-term average and variability of weather.

- **Climate change** is a shift "in the state of the climate that can be identified (e.g., via statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer", (IPCC 2014).

Distribution of Annual Average Temperature in United States
(Degrees Celsius)



Source: World Bank Group, Climate Change Knowledge Portal

Contributions

- We link “deviations” of temperature (**weather**) from its 30-year moving averages (**climate**) to GDP per capita and show that a persistent increase in temperature above its historical norm for an extended period (i.e., **climate change**) is associated with lower economic growth in the long run.

- Our econometric strategy differentiates between **short-term and long-run effects**.

- By using "deviations", while allowing for nonlinearity, **we model changes in the distribution of weather patterns** (average temperature and its variability) and **avoid the econometric pitfalls** associated with the use of trended variables (i.e., temperature) in growth equations.

- We **model adaptation** by choosing **the speed with which norms are formed** and by tracking the elasticity of per capita GDP to climate variables over time.

Contributions

- We allow for **country-specific** and **time-varying climate thresholds (or norms)** and test for **asymmetric** weather effects.

- We perform several **counterfactual exercises** to study the cumulative income effects of climate change up to the year 2100.

- We investigate the **long-term** macroeconomic effects of climate change in a panel of **174 countries** over 1960-2014 as well as a panel of 48 **U.S. states** over 1963-2016.

- We estimate **country-specific annual per-capita GDP losses** from global warming based on the methodology in Kahn et al. (2021) but using a wider and more up-to-date set of climate scenarios under different **mitigation**, **adaptation**, and **climate variability** (i.e., fluctuations in natural weather patterns) assumptions.

- We compare our income loss estimates with those from select papers in the literature using a **common baseline**.

Climate change and long-run income losses:

We estimate the following panel ARDL model using the half-panel Jackknife FE (HPJ FE) estimator of Chudik et al. (2017):

$$\Delta y_{it} = a_i + \sum_{\ell=1}^{p} \varphi_\ell \Delta y_{i,t-\ell} + \sum_{\ell=0}^{p} \beta_\ell^{'} \Delta \tilde{\mathbf{x}}_{i,t-\ell} + \varepsilon_{it}, \quad (1)$$

where y_{it} is the log of real GDP per capita of country i in year t, $\tilde{\mathbf{x}}_{it}(m) = [|\tilde{T}_{it}(m)|, |\tilde{P}_{it}(m)|]'$, $\tilde{T}_{it}(m) = \left(\frac{2}{m+1}\right)\left[T_{it} - T^*_{i,t-1}(m)\right]$ and $\tilde{P}_{it}(m) = \left(\frac{2}{m+1}\right)\left[P_{it} - P^*_{i,t-1}(m)\right]$ are measures of temperature and precipitation relative to their historical norms per annum, T_{it} and P_{it} are the population-weighted average temperature and of precipitation country i in year t, and $T^*_{i,t-1}(m) = \frac{1}{m}\sum_{\ell=1}^{m} T_{i,t-\ell}$ and $P^*_{i,t-1}(m) = \frac{1}{m}\sum_{\ell=1}^{m} P_{i,t-\ell}$ are the time-varying historical norms of temperature and precipitation over the preceding m years in each t.

The long-run effects, θ, are calculated from the estimates of the short-run coefficients in equation (1): $\boldsymbol{\theta} = \phi^{-1}\sum_{\ell=0}^{p} \boldsymbol{\beta}_\ell$, where $\phi = 1 - \sum_{\ell=1}^{p} \varphi_\ell$.

Climate change and long-run income losses

Long-Run Effects of Climate Change on per Capita Real GDP Growth, 1960–2014

	Specification 1			Specification 2		
	$m = 20$	$m = 30$	$m = 40$	$m = 20$	$m = 30$	$m = 40$
$\widehat{\theta}_{\Delta\vert\tilde{T}_{it}(m)\vert}$	-0.523***	-0.836***	-0.981***	-0.529***	-0.841***	-0.996***
	(0.201)	(0.284)	(0.361)	(0.201)	(0.284)	(0.361)
$\widehat{\theta}_{\Delta\vert\tilde{P}_{it}(m)\vert}$	-0.125	-0.131	-0.404	-	-	-
	(0.335)	(0.527)	(0.709)	-	-	-
$\widehat{\phi}$	0.604***	0.604***	0.603***	0.604***	0.604***	0.604***
	(0.0448)	(0.0449)	(0.0449)	(0.0449)	(0.0449)	(0.0449)

Climate change and long-run income losses

- The marginal effects of weather shocks are larger in low-income countries because they have lower capacity to deal with the consequences of climate change.

- However, this **does not mean that rich nations are immune from the effects of climate change.**

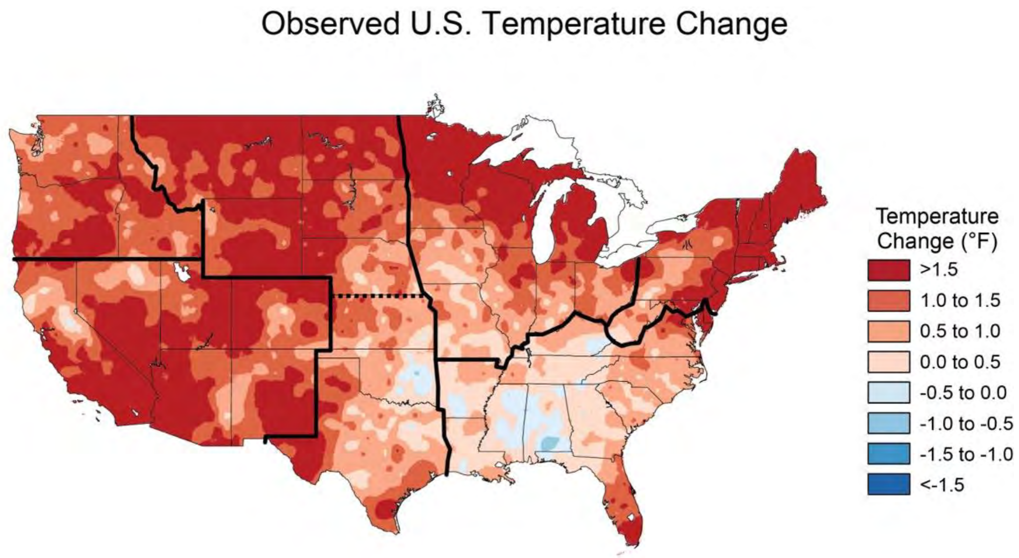
Historical Norm:	Excluding $\Delta\bar{y}_{w,t-1}$			Including $\Delta\bar{y}_{w,t-1}$		
	$m=20$	$m=30$	$m=40$	$m=20$	$m=30$	$m=40$
(a) All 130 Countries						
$\hat{\theta}_{\Delta\lvert\tilde{T}_{it}(m)\rvert}$	-0.447*	-0.487	-0.521	-0.706***	-0.918**	-1.051**
	(0.234)	(0.367)	(0.473)	(0.237)	(0.393)	(0.519)
(b) Cold ($\bar{T}_i < 33th$ $Percentile$)						
$\hat{\theta}_{\Delta\lvert\tilde{T}_{it}(m)\rvert}$	-0.227**	-0.230*	-0.198	-0.238**	-0.342**	-0.457**
	(0.101)	(0.128)	(0.175)	(0.105)	(0.151)	(0.169)
(c) Temperate or Hot ($\bar{T}_i \geq 33th$ $Percentile$)						
$\hat{\theta}_{\Delta\lvert\tilde{T}_{it}(m)\rvert}$	-0.665***	-0.780***	-0.613	-0.842***	-1.180***	-1.212**
	(0.193)	(0.302)	(0.431)	(0.222)	(0.371)	(0.504)
(d) Poor (Low-Income Developing Countries)						
$\hat{\theta}_{\Delta\lvert\tilde{T}_{it}(m)\rvert}$	-0.603**	-0.759*	-0.855*	-1.020***	-1.463***	-1.703***
	(0.270)	(0.406)	(0.488)	(0.262)	(0.429)	(0.547)
(e) Rich (Advanced Economies and G20 Emerging Markets)						
$\hat{\theta}_{\Delta\lvert\tilde{T}_{it}(m)\rvert}$	-0.586***	-0.849***	-1.047***	-0.587***	-1.003***	-1.280***
	(0.195)	(0.272)	(0.373)	(0.209)	(0.310)	(0.392)

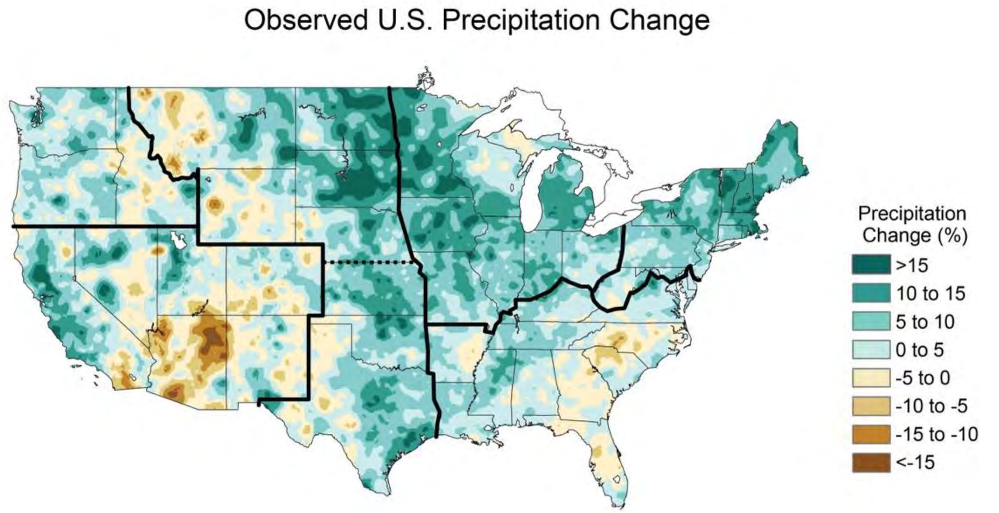
A within-country study: United States

- The **geographic heterogeneity** of the U.S. enables us to compare whether economic activity in the "hot" or "dry" states responds to a temperature increase in the same way as economic activity does in "cold" or "wet" states.

- Focusing on different **sectors/industries** also helps shed light on the **channels** through which climate change affects the United States economy.

- Considering the richness of U.S. data, we can examine the long-run impact of climate change on labour productivity and employment growth directly.





Long-Run Effects of Climate Change on the Growth Rate of Major Economic Indicators for the United States

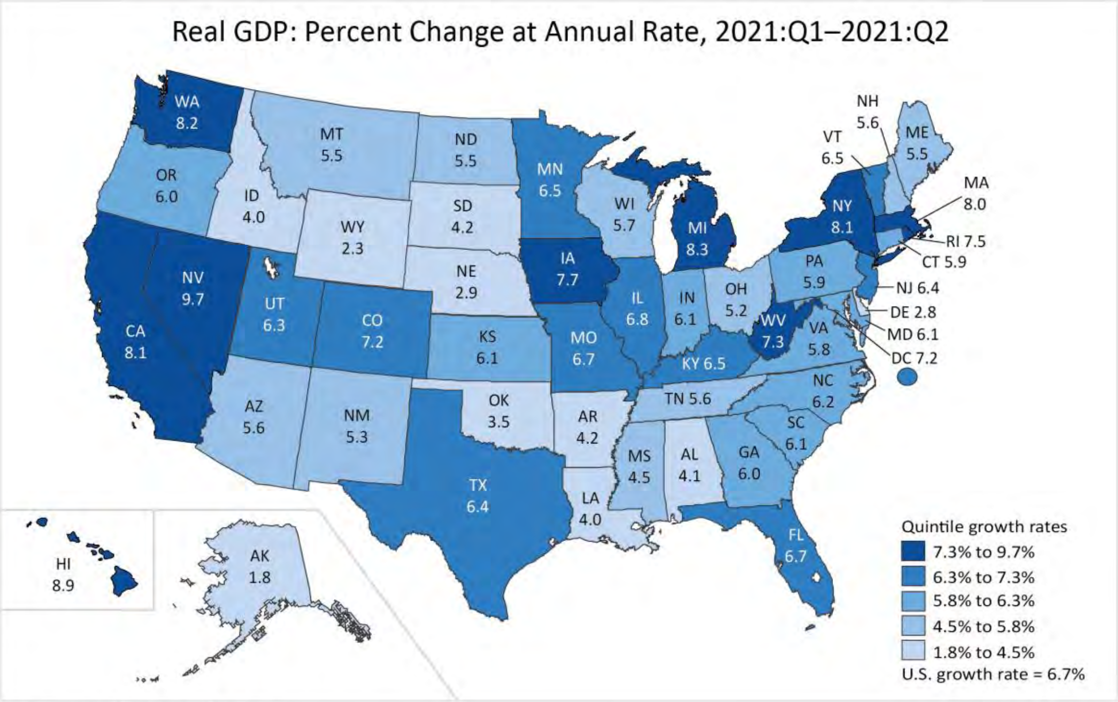
	Real GSP	Real GSP per Capita	Real GSP per Employed	Employment
$\widehat{\theta}_{\Delta\left(\mathcal{T}_{it}-\mathcal{T}^{*}_{i,t-1}\right)^{+}}$	-0.0379***	-0.0273***	-0.0190***	-0.0135**
	(0.0107)	(0.0083)	(0.0067)	(0.0062)
$\widehat{\theta}_{\Delta\left(\mathcal{T}_{it}-\mathcal{T}^{*}_{i,t-1}\right)^{-}}$	-0.1951***	-0.1505***	-0.0779***	-0.0954***
	(0.0358)	(0.0259)	(0.0191)	(0.0205)
$\widehat{\theta}_{\Delta\left(\mathcal{P}_{it}-\mathcal{P}^{*}_{i,t-1}\right)^{+}}$	-0.0002**	-0.0001***	-0.0000	-0.0001**
	(0.0001)	(0.0000)	(0.0000)	(0.0000)
$\widehat{\theta}_{\Delta\left(\mathcal{P}_{it}-\mathcal{P}^{*}_{i,t-1}\right)^{-}}$	-0.0003***	-0.0002***	-0.0001	-0.0003***
	(0.0001)	(0.0001)	(0.0000)	(0.0001)
$\widehat{\phi}$	-0.5016***	-0.6301***	-0.7035***	-0.4382***
	(0.0504)	(0.0530)	(0.0756)	(0.0444)
No. of states (N)	48	48	48	48
T	36	36	36	36
$N \times T$	1728	1728	1728	1728

Evidence from U.S. sector level data

- The evidence seems to suggest that (at least for now) **adaptation has had limited effects** in dampening the negative effects of climate change in the United States.

- Given that adaptation is relatively easier and more effective to implement in some industries compared to others, **we exploit these inter-industrial differences** to shed more light on the matter of adaptation to climate change in the U.S. economy.

- Instead of Gross State Product, we make use of data on output for ten individual sectors at the state level.

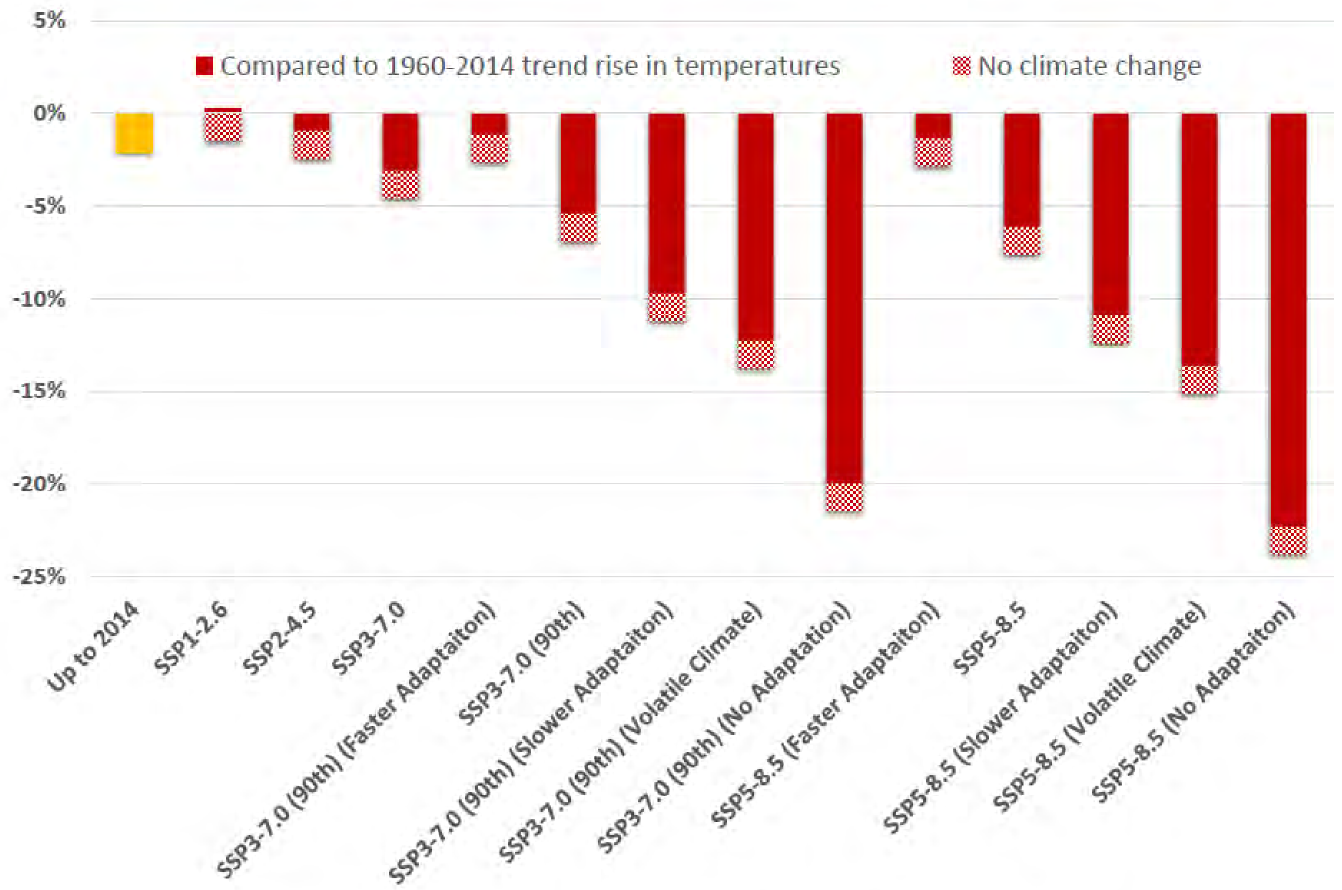


U.S. Bureau of Economic Analysis

Evidence from U.S. sector level data

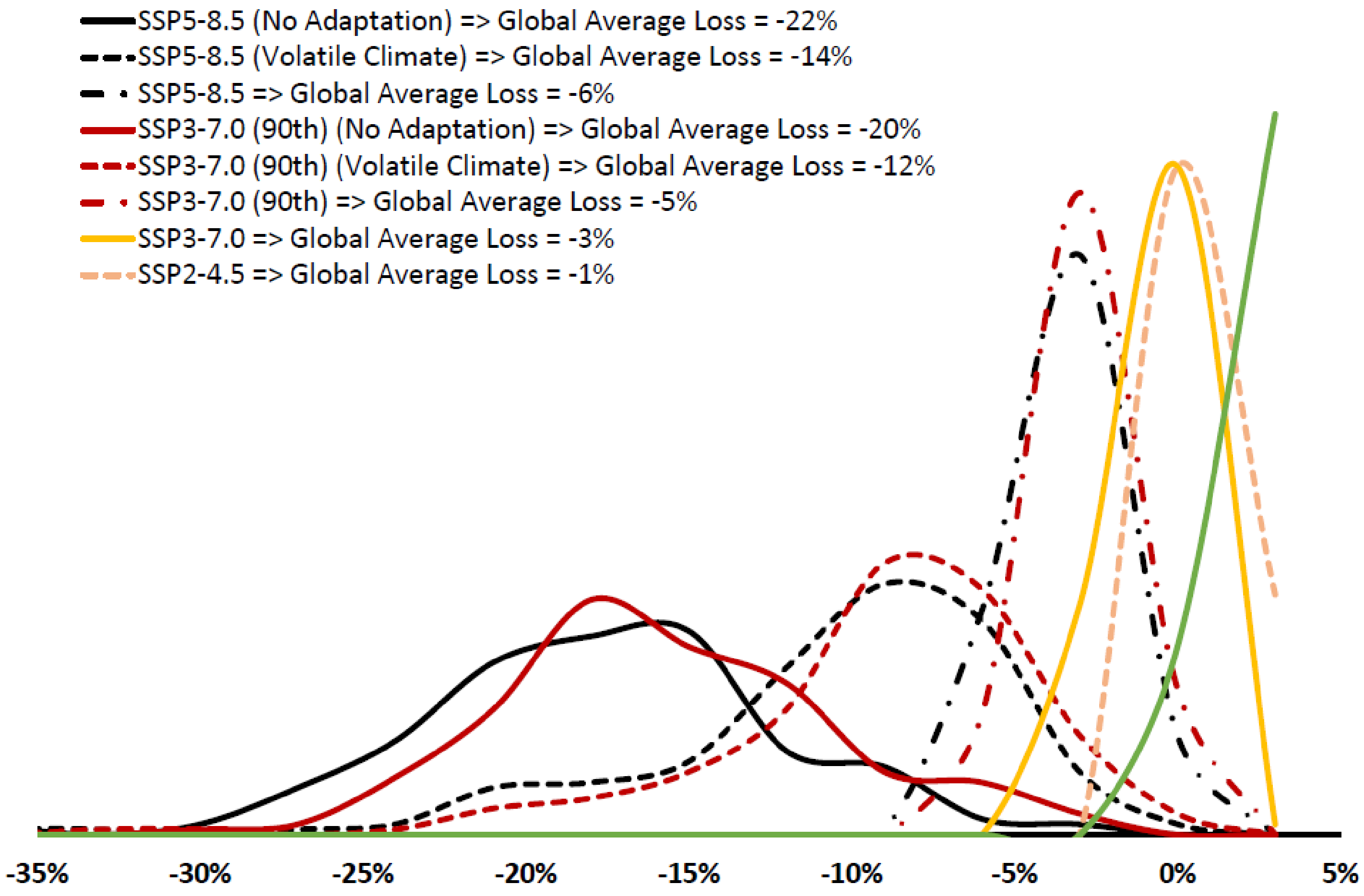
	Agriculture Forestry Fisheries	Mining	Construction	Manufacturing	Transport Communication Public Utilities	Wholesale Trade	Retail Trade	Finance Insurance Real Estate	Services	Government
$\widehat{\theta}_{\Delta(\mathcal{T}_{it}-\mathcal{T}^*_{i,t-1})^+}$	-0.0323*	-0.0030	-0.0587***	-0.0666***	-0.0261**	-0.0628***	-0.0531***	0.0730***	-0.0336***	0.0182*
	(0.0178)	(0.0400)	(0.0204)	(0.0163)	(0.0112)	(0.0209)	(0.0126)	(0.0161)	(0.0110)	(0.0107)
$\widehat{\theta}_{\Delta(\mathcal{T}_{it}-\mathcal{T}^*_{i,t-1})^-}$	-0.0184	-0.1887***	-0.1777***	-0.1136***	-0.0633***	-0.2365***	-0.1674***	0.0050	-0.1201***	-0.0446**
	(0.0315)	(0.0728)	(0.0400)	(0.0270)	(0.0175)	(0.0389)	(0.0237)	(0.0309)	(0.0252)	(0.0199)
$\widehat{\theta}_{\Delta(\mathcal{P}_{it}-\mathcal{P}^*_{i,t-1})^+}$	-0.0003***	-0.0006***	-0.0002**	-0.0002***	0.0001**	-0.0001	-0.0001	-0.0000	-0.0001*	0.0000
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
$\widehat{\theta}_{\Delta(\mathcal{P}_{it}-\mathcal{P}^*_{i,t-1})^-}$	-0.0005***	-0.0003	-0.0002	-0.0003***	-0.0001	-0.0003**	-0.0002***	0.0000	-0.0001*	0.0000
	(0.0001)	(0.0003)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
$\widehat{\phi}$	-1.8892***	-0.8133***	-0.6412***	-0.9599***	-0.8536***	-0.4830***	-0.5787***	-0.5944***	-0.4135***	-0.3902***
	(0.0843)	(0.0459)	(0.0331)	(0.0726)	(0.0581)	(0.0394)	(0.0312)	(0.0546)	(0.0414)	(0.0458)
No. of states (N)	48	47	48	48	48	48	48	48	48	48
T	48	48	48	48	48	48	48	48	48	48
$N \times T$	2304	2256	2304	2304	2304	2304	2304	2304	2304	2304

Global Income Losses from Rising Temperatures by 2100



Notes: We consider persistent increases in temperatures based on various climate scenarios in Figure 5. Solid-color bars are PPP GDP weighted averages of $\Delta_{ih}(d_i)$, see equation (9), with $h = 86$ (corresponding to the year 2100). Pattern-fill bars show global income losses from a continuation of 1960-2014 trend temperature increases compared to a baseline scenario without climate change. For "Faster Adaptation", $m = 10$. For "Slower Adaptation", $m = 50$. For "No Adaptation", $m = 100$. For "Volatile Climate", $\sigma^1_{Ti,j} = (\mu^1_{Ti,j}/\mu^0_{Ti})\,\sigma^0_{Ti}$.

Frequency Distribution of Income Losses Across 174 Countries by 2100



Notes: We consider income losses from increases in temperatures under various IPCC climate scenarios relative to a baseline in which temperatures increase according to their 1960-2014 trends. Numbers are PPP GDP weighted averages of $\Delta_{ih}(d_i)$, see equation (9), with $h = 86$ (corresponding to the year 2100). Under the "No Adaptation" assumption, historical norms are formed over 100 years (i.e., $m = 100$). We keep $\sigma^1_{Ti,j} = \left(\mu^1_{Ti,j}/\mu^0_{Ti}\right)\sigma^0_{Ti}$ under the "Volatile Climate" assumption.

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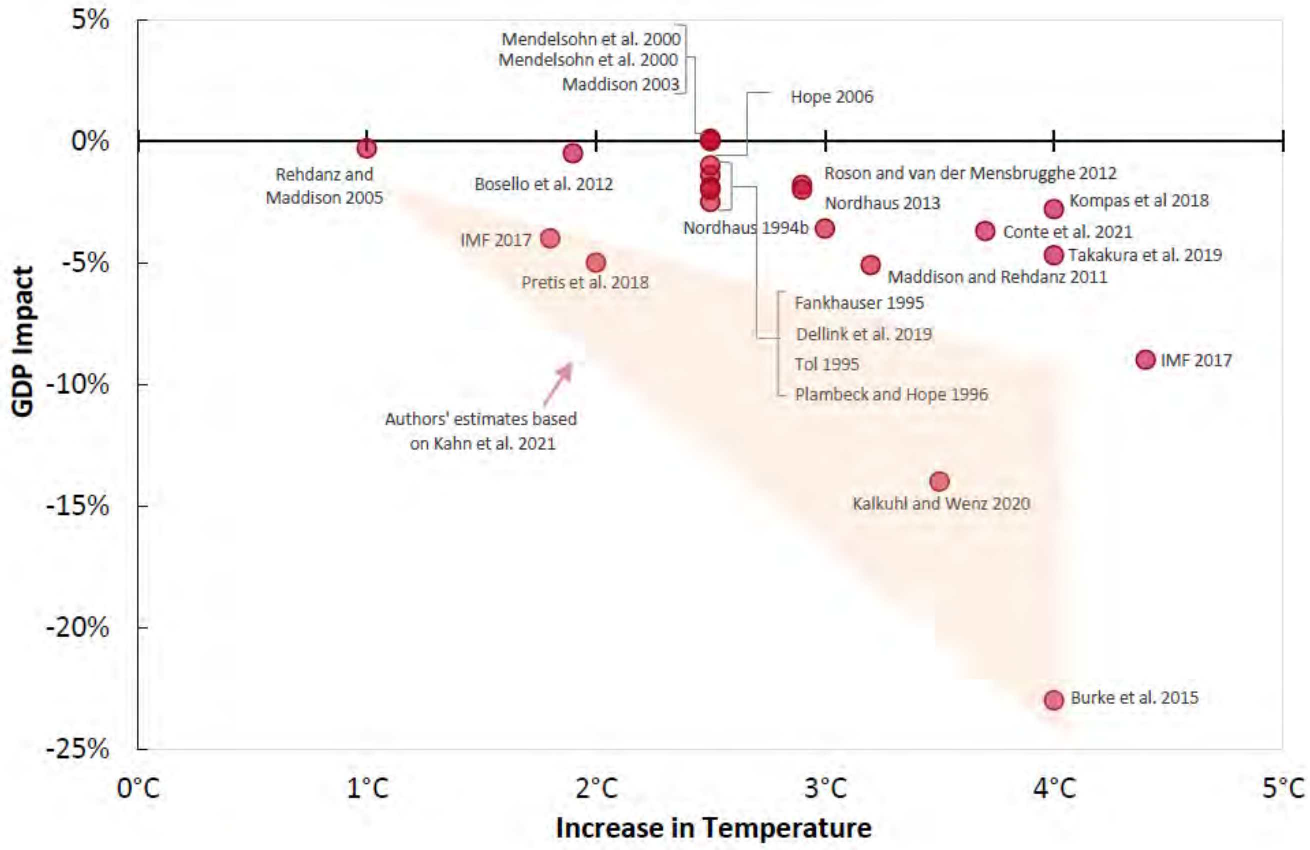
The costs associated with climate change are substantial

- Note that we estimate and provide **country-specific annual per-capita GDP losses from climate change** using the most-recent climate scenarios of the IPCC under different mitigation, adaptation, and climate variability assumptions.

- These **country-specific losses** are in turn directly used in, for instance, country (region) work at the IMF and the World Bank.



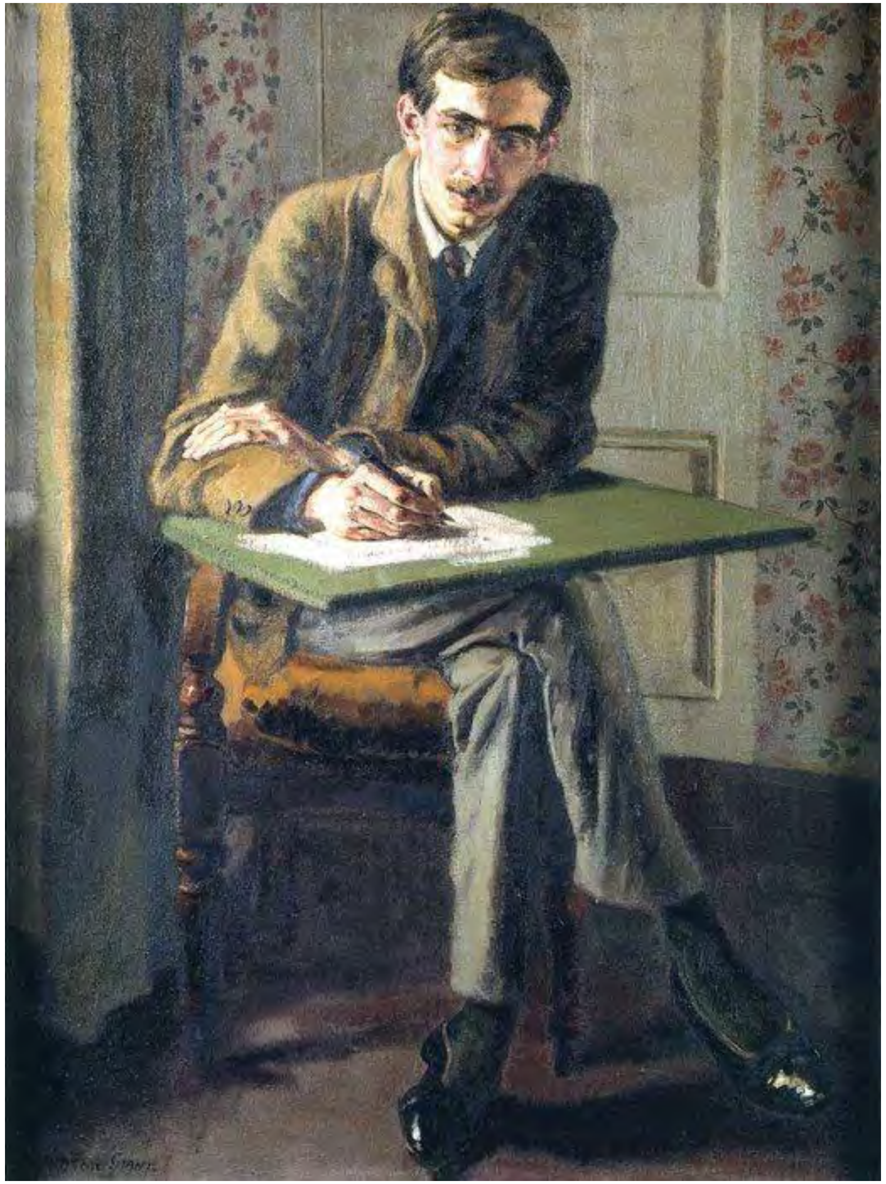
Sources: Kahn et al. (2021a), Tol (2024), and authors' estimates (shown as the shaded area in the chart). Notes: Projected GDP impact is for some future year, typically 2100. The shaded area represents the GDP per capita losses from our counterfactual exercise in Section 3 with the upper bound based on $m = 30$ and the lower bound based on $m = 100$.

The long-run is made up by short-runs!

In 1937, in the New Statesman and Nation, Keynes writes:

"... **in the long run we are all dead**. But I could have said equally well that it is a great advantage of 'the short run' that in the short run we are still alive. **Life and history are made up of short runs.**"

Tragedy of Horizons!



Making risk metrics useful

- Beyond impacts on aggregate output, the environmental, social and policy consequences of climate change will directly impact **firms**, **investors**, and **regulators**.

- Possible transmission pathways include:
  - **physical damages** from extreme weather events,
  - **consumer movements** (including boycotts, protests, in reputational risks),
  - **transition risks** (e.g., from regulations and asset stranding), and
  - **litigation risks** (e.g., lawsuits over environmental damages).

Making risk metrics useful

- Financial markets face growing pressure to factor these climate impacts into decision making and to mobilise capital in pursuit of a **Just Transition towards a low carbon future**.

- Whilst enthusiasm for '***greening the financial system***' is welcome, a fundamental challenge remains: investors and businesses lack the necessary information.

Green washing!?

Making risk metrics useful

To green the financial system, it is **not enough to know that climate change is bad**.

- Firms, investors, financial institutions, and regulators need **scientifically credible information on how climate change translates into material financial risks**, how to **price those risks**, and how to **manage them**.

- Growing demand for climate risk disclosures comes from **private investors**, **activist shareholders**, **universal owners**, public **regulators**, **treasuries** and **central banks**.

Making risk metrics useful

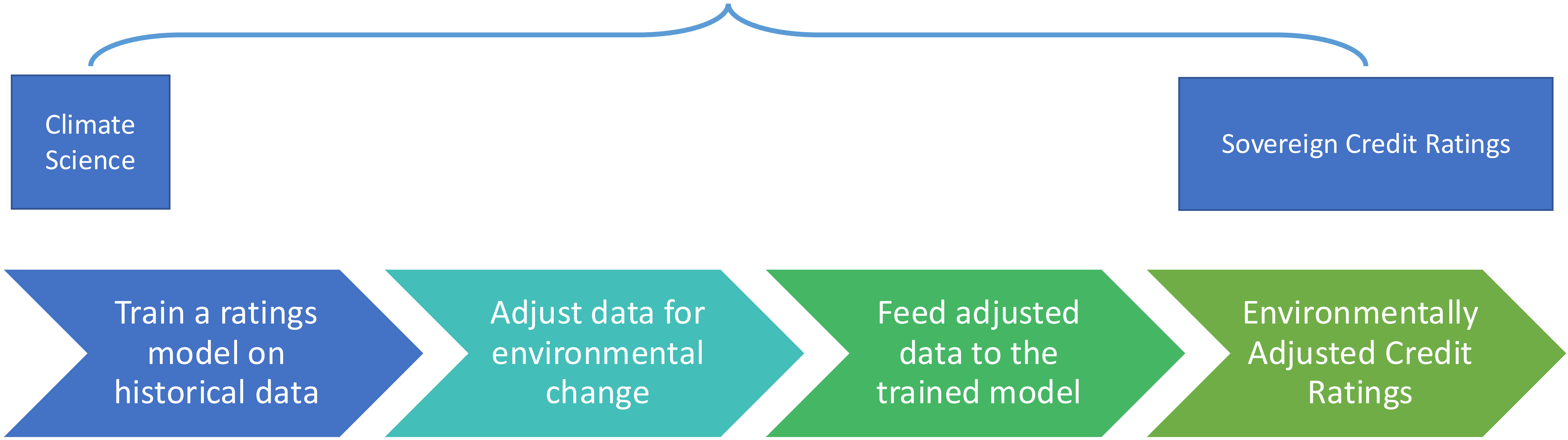
backward

- Investigate the effect of environment on sovereign ratings over the past 20 years.
- CRA methodologies **do not include environment as a ratings factor**.
- But maybe environment has crept in as an "implicit factor" by influencing other credit-relevant variables.
- **Caveat**: future environmental change may differ from past trends, making any results difficult to interpret.

forward

- Extending the ratings methodology from a leading CRA to explicitly incorporate **nature and climate-related risks** under a range of future scenarios.
- This approach offers a '**forward-look**', and is capable of providing insights into the **future** creditworthiness of nations.
- This approach will provide the foundations for an enhanced sovereign credit risk methodology.

Can we bridge this gap?



Use a machine learning technique referred to as **random forest classification**.

1. Process macroeconomic & credit ratings data using a random forest model.
2. Adjust the input data for env change (climate or biodiversity).
3. Run the model on new data to predict ratings.

Overarching principle

Natural science

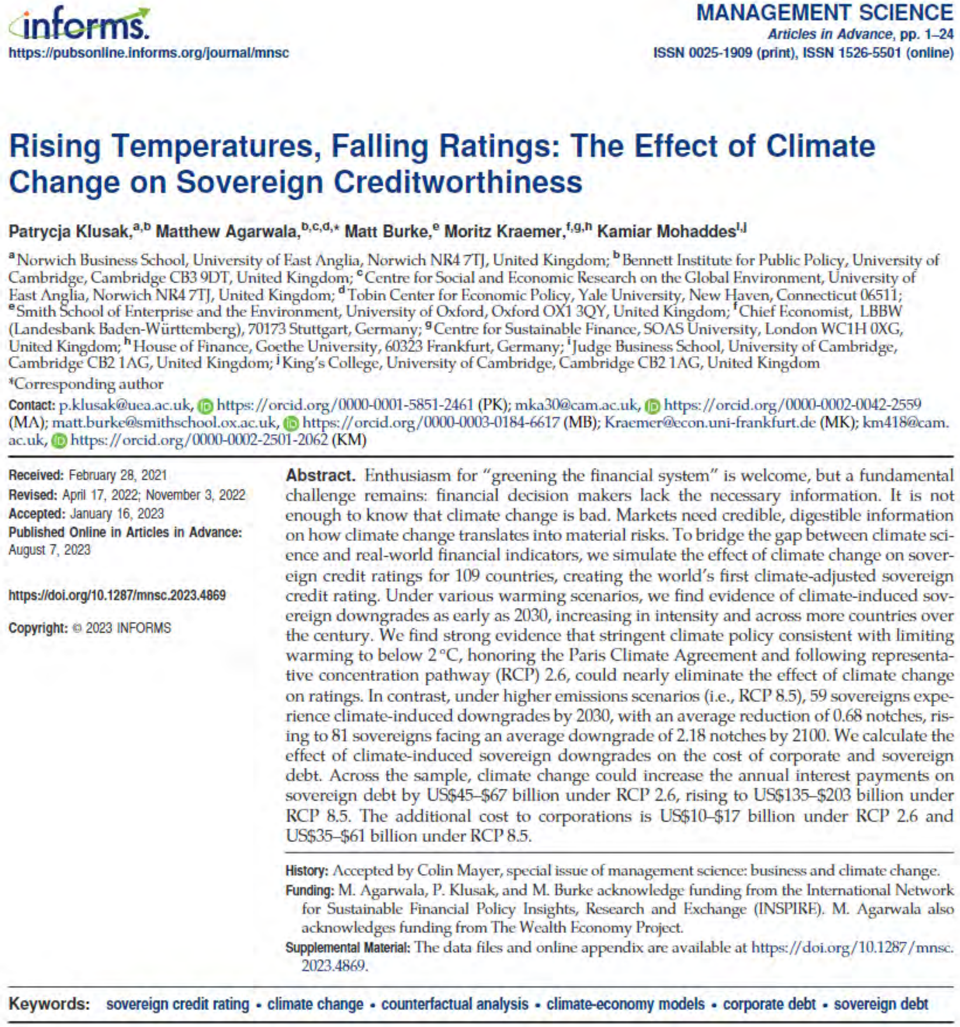
Remain as close as possible to natural science!

Economic principles

Use best available climate economics.

Real life ratings

Remain as close as possible to S&P's actual credit rating methodology.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Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness

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Abstract. Enthusiasm for "greening the financial system" is welcome, but a fundamental challenge remains: financial decision makers lack the necessary information. It is not enough to know that climate change is bad. Markets need credible, digestible information on how climate change translates into material risks. To bridge the gap between climate science and real-world financial indicators, we simulate the effect of climate change on sovereign credit ratings for 109 countries, creating the world's first climate-adjusted sovereign credit rating. Under various warming scenarios, we find evidence of climate-induced sovereign downgrades as early as 2030, increasing in intensity and across more countries over the century. We find strong evidence that stringent climate policy consistent with limiting warming to below 2 °C, honoring the Paris Climate Agreement and following representative concentration pathway (RCP) 2.6, could nearly eliminate the effect of climate change on ratings. In contrast, under higher emissions scenarios (i.e., RCP 8.5), 59 sovereigns experience climate-induced downgrades by 2030, with an average reduction of 0.68 notches, rising to 81 sovereigns facing an average downgrade of 2.18 notches by 2100. We calculate the effect of climate-induced sovereign downgrades on the cost of corporate and sovereign debt. Across the sample, climate change could increase the annual interest payments on sovereign debt by US$45–$67 billion under RCP 2.6, rising to US$135–$203 billion under RCP 8.5. The additional cost to corporations is US$10–$17 billion under RCP 2.6 and US$35–$61 billion under RCP 8.5.

History: Accepted by Colin Mayer, special issue of management science: business and climate change.
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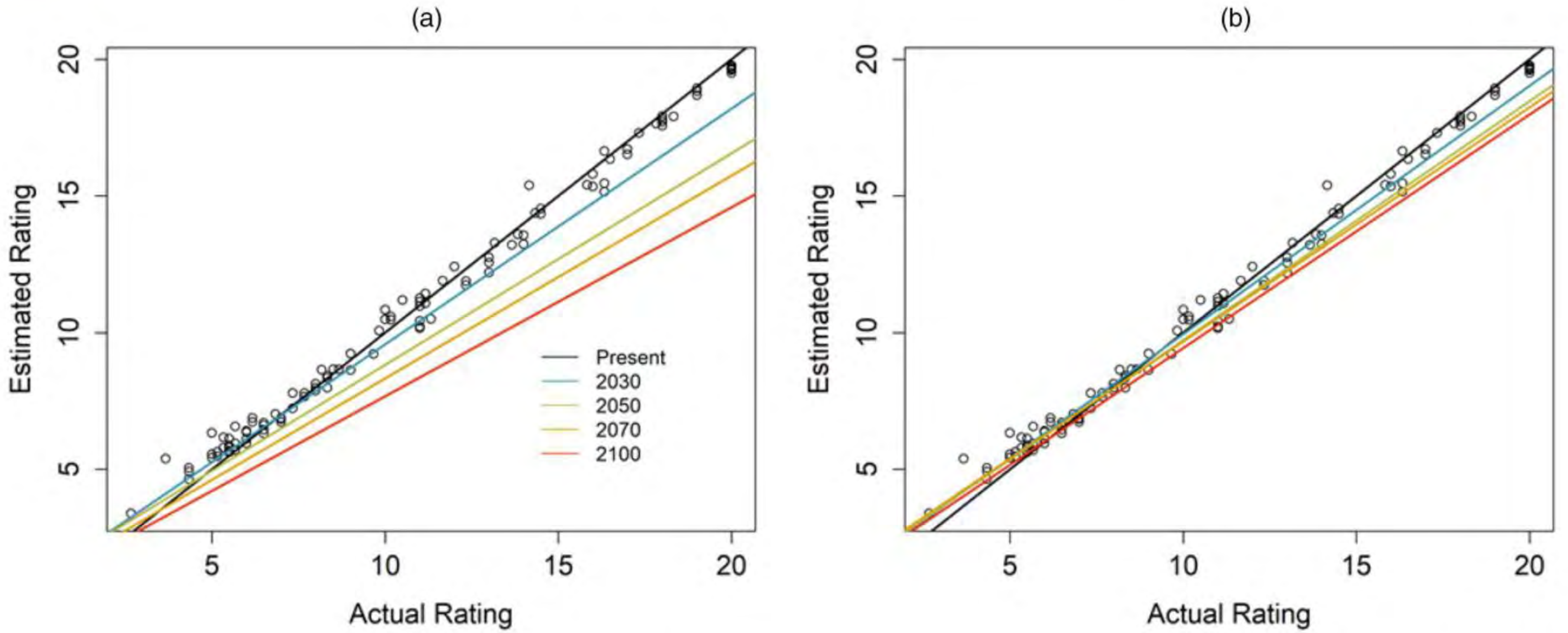
Supplemental Material: The data files and online appendix are available at https://doi.org/10.1287/mnsc.2023.4869.

Keywords: sovereign credit rating • climate change • counterfactual analysis • climate-economy models • corporate debt • sovereign debt

Climate smart sovereign ratings

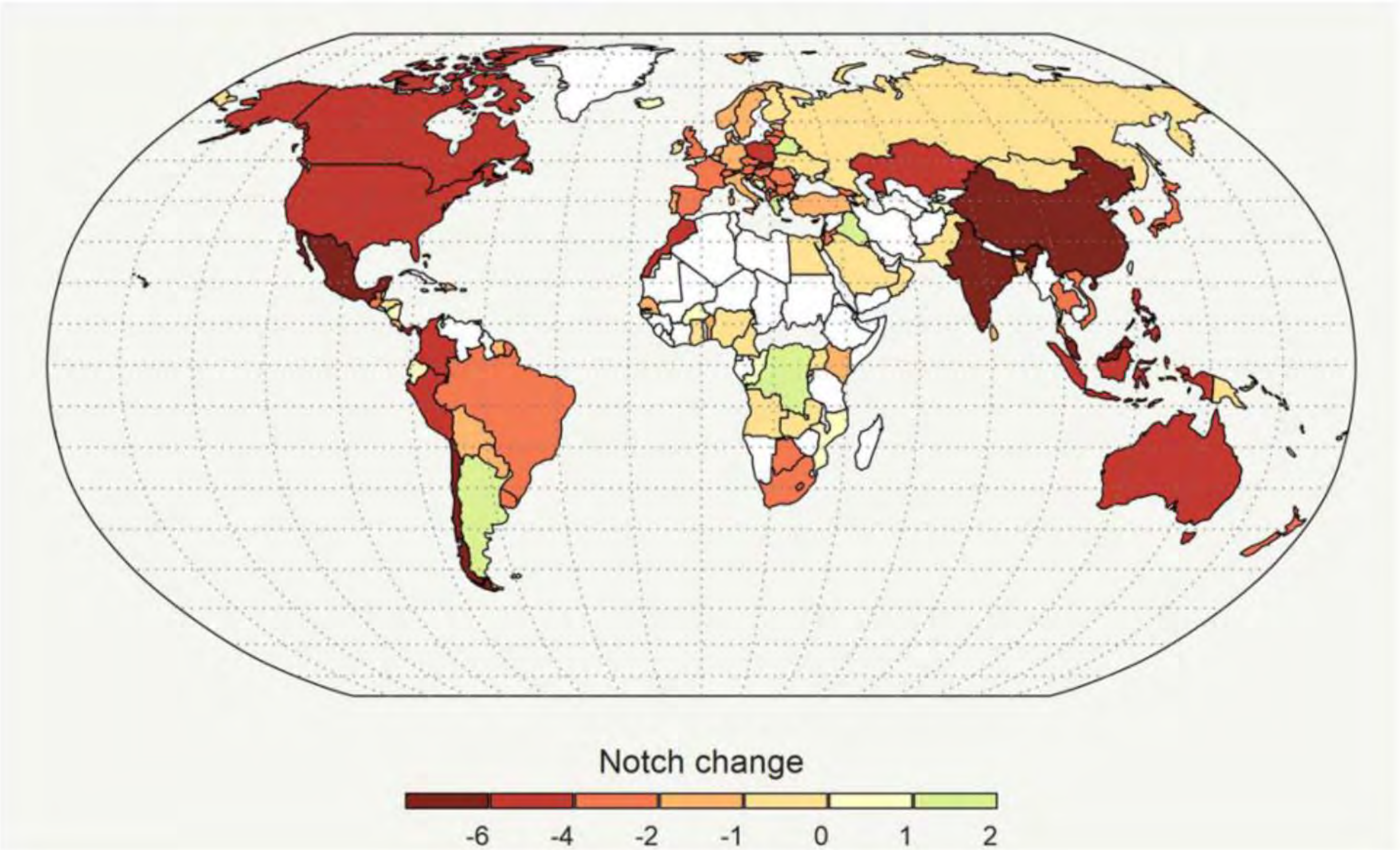
Figure 14. (Color online) Climate-Adjusted Ratings with Increased Temperature Volatility (RCP 8.5 vs. 2.6)



Notes. This figure introduces rising temperature volatility into climate-adjusted predicted ratings under RCP 8.5 (a) and RCP 2.6 (b) by 2030, 2050, 2070, and 2100. The thick black line indicates there is no difference between the actual rating observed in 2020 (x axis) and the predicted rating (y axis). Compared with Figure 11, the same trends hold but are exacerbated. For further results, see Online Appendix E.

Climate smart sovereign ratings

Figure 13. (Color online) Global Climate–Induced Sovereign Ratings Changes (2100, RCP 8.5)



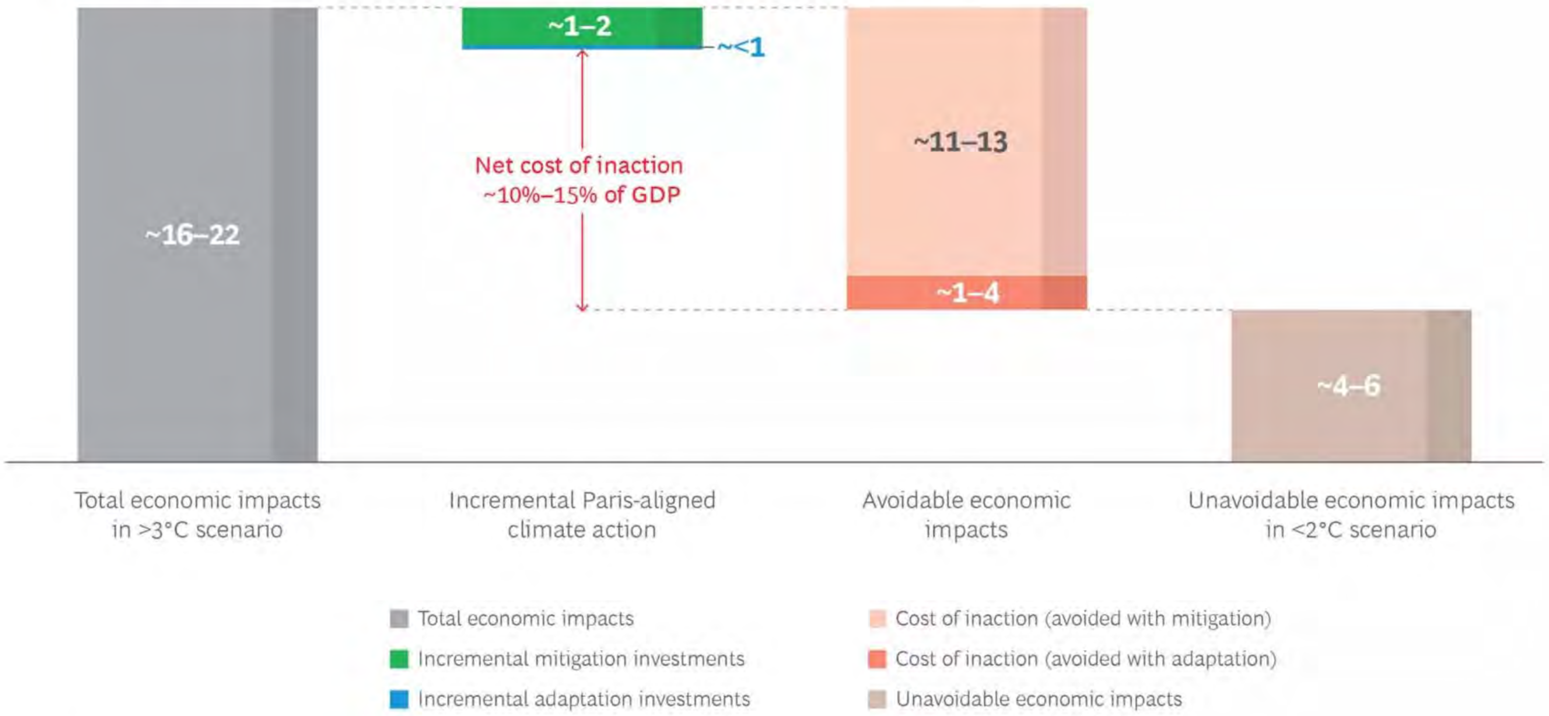
Notes. This figure depicts climate-induced sovereign downgrades by 2100 under RCP 8.5. Under this scenario, 81 sovereigns face downgrades by 2100, with an average ratings loss of 2.18 notches on the 20-notch scale. Chile and China face the largest downgrades: 7.43 and 6.53 notches, respectively. Downward pressure on ratings is widespread across latitude, income level, economic structure, and political systems.

The economic case for climate action…

While climate action is economically rational at a global level, three main barriers have led to **a significant gap between ambition and action**:

- the cost of inaction is not yet fully understood
- the impact of climate change is unevenly distributed across the globe
- innate human biases toward focusing on the short-term delay action on long-term challenges.

Climate change costs and investments as a share of cumulative GDP until 2100 (%)



Source: BCG analysis.

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Summing up

- The **costs associated with climate change** are substantial.

- Given decades of procrastination and signs of falling short on ambitious Paris Agreement targets, the world needs to **act fast on reducing emissions**.

- Our **empirical findings pertain to almost all countries** (albeit to varying degrees) as economic growth is affected not only by persistent increases in temperatures (and the pace with which they are rising) but also by the degree of climate variability.

- The findings emphasize the importance of mitigating climate change and implementing adaptation measures to lower these negative effects.

- However, even with adaptation policies, the long-term growth effects of climate change are likely to persist, particularly in countries with hotter climates and lower incomes.

- Urgent action is needed to protect economies from further income losses from climate change.

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