Economic Risks of Climate Change: Implications for Financial Regulators
Welcoming Remarks

Solomon Hsiang

Chancellor’s Professor of Public Policy and Director of the Global Policy Laboratory, University of California at Berkeley, Co-Director of the Climate Impact Lab
Economic Risks of Climate Change: Implications for Financial Regulators
8:10 a.m. Climate Risk – A Perspective from the Federal Reserve – Glenn Rudebusch (Federal Reserve Bank of San Francisco)

8:25 a.m. Macroeconomic Risks of Climate Change to the US – moderated by Amir Jina, (University of Chicago, Climate Impact Lab)
   - Marshall Burke (Stanford University)
   - Tatyana Deryugina (University of Illinois at Urbana-Champaign)
   - Pete Klenow (Stanford University)

9:10 a.m. Regional Climate Risks: Flooding, Drought, Wildfires – moderated by Tamma Carleton (University of California, Santa Barbara, Climate Impact Lab)
   - Judd Boomhower, (University of California, San Diego)
   - Miyuki Hino (University of North Carolina at Chapel Hill)
   - Wolfram Schlenker (Columbia University)
   - Eric Tate (University of Iowa)

10:05 a.m. Break (10 mins)

10:15 a.m. Lunch Keynote – Robert Litterman, (Chairman, Commodity Futures Trading Commission Market Risk Advisory Committee’s Climate-Related Market Risk Subcommittee and Founding Partner, Rick Committee Chairman, Kepos Capital)

10:45 a.m. Managing Physical Risk to the US Financial System – moderated by Glenn Rudebusch (Federal Reserve Bank of San Francisco)
   - Lint Barrage (University of California, Santa Barbara)
   - Ricardo Correa (Division of International Finance, Federal Reserve Board)
   - Carolyn Kousky (University of Pennsylvania)

11:45 a.m. Break (15 mins)

   – moderated discussion with Trevor Houser (Rhodium Group, Climate Impact Lab)

12:50 p.m. Closing Remarks – Michael Greenstone (University of Chicago, Climate Impact Lab)
Major phases of collapse for the “Classic” Mayan empire

Empire of Angkor city-state collapses

Major dynastic transitions

Akkadian empire collapses

Migration period

Dolomite (%wt)

SYRIA & IRAQ

EUROPE

Celtic expansion

Roman conquest

30 Years War

Modern migration

CHINA

CAMBODIA

MEXICO

Hsiang, Burke, Miguel (Science, 2013)
Maximum surface wind speed during Hurricane Maria

Hsiang (2017)
In Just 12 Hours, an Economic Wipeout

Hurricane devastation in Puerto Rico is expected to have much worse economic effects than many other recent crises that unfolded over months or years.

<table>
<thead>
<tr>
<th>Economic Disaster</th>
<th>Years</th>
<th>Drop in Per Capita G.D.P.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian financial crisis: Thailand</td>
<td>1997-99</td>
<td>-25%</td>
</tr>
<tr>
<td>Great Recession’s effect on Nevada</td>
<td>2007-09</td>
<td>-22%</td>
</tr>
<tr>
<td><strong>Hurricane Maria in Puerto Rico</strong></td>
<td><strong>2017</strong></td>
<td><strong>-21%</strong></td>
</tr>
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<td>Asian financial crisis: Indonesia</td>
<td>1997-99</td>
<td>-21%</td>
</tr>
<tr>
<td>Great Recession’s effect on Arizona</td>
<td>2007-09</td>
<td>-18%</td>
</tr>
<tr>
<td>Great Recession’s effect on Michigan</td>
<td>2007-09</td>
<td>-13%</td>
</tr>
<tr>
<td>Average international financial crisis</td>
<td></td>
<td>-9%</td>
</tr>
<tr>
<td>Great Recession: U.S. overall</td>
<td>2007-09</td>
<td>-9%</td>
</tr>
<tr>
<td>U.S. recessions</td>
<td>1980-1982</td>
<td>-8%</td>
</tr>
<tr>
<td>Mexico peso crisis</td>
<td>1994-95</td>
<td>-8%</td>
</tr>
<tr>
<td>Average international banking crisis</td>
<td></td>
<td>-8%</td>
</tr>
<tr>
<td><strong>1-in-10 cyclone event</strong></td>
<td></td>
<td><strong>-7%</strong></td>
</tr>
<tr>
<td>U.S. recession</td>
<td>1990-1991</td>
<td>-7%</td>
</tr>
<tr>
<td><strong>Average cyclone event</strong></td>
<td></td>
<td><strong>-4%</strong></td>
</tr>
<tr>
<td>U.S. recession</td>
<td>2001</td>
<td>-3%</td>
</tr>
</tbody>
</table>

Nevada, Arizona and Michigan were among the hardest-hit states in the Great Recession of 2007-09.

Hsiang & Houser (NYT, 2017) based on Hsiang & Jina (NBER, 2014)
Revolutionary innovations in the technology of governance

c. 2000 BC - **Written law** (e.g. Code of Hammurabi)

c. 500 BC - **Voting** (e.g. Athenian democracy)

c. 600 - **Meritocracy** (e.g. Chinese civil service exams)

c. 1200 - **Limits on executive** (e.g. Magna Carta)

c. 1650 - **Assumption of equality** (e.g. the Enlightenment)

c. 1800 - **Secular state + Freedom of speech** (e.g. First Amendment)

c. 1920 - **International governance** (e.g. International Court of Justice)

c. 2020 - **Data science** (e.g. climate change management)
CLIMATIC CHANGE AND AGRICULTURAL EXHAUSTION AS ELEMENTS IN THE FALL OF ROME

SUMMARY

In history as in science the normal order is from obvious facts to hidden causes. The fact of the disastrous fall of Rome is so obvious that every intelligent person is aware of it. Its causes are so obscure that the world is still uncertain what they are. Among the many theories advanced in explanation of this great historical

Huntington (QJE, 1917)

An Optimal Transition Path for Controlling Greenhouse Gases

William D. Nordhaus

Designing efficient policies to slow global warming requires an approach that combines economic tools with insights from the natural sciences. The dynamic integrated climate-economy (DICE) model presented here, an intertemporal general-equilibrium model of economic growth and climate change, can be used to investigate alternative approaches to slowing climate change. Evaluation of five policies suggests that a modest carbon tax would be an efficient approach to slow global warming, whereas rigid emissions-climate-stabilization approaches would impose significant net economic costs.

The DICE Model
The DICE model is a dynamic optimization model for estimating the optimal path for reductions of GHGs (6). The basic approach is to estimate the optimal path for both capital accumulation and reductions of GHGs in the framework of the Ramsey model of intertemporal choice (9). The resulting trajectory can be interpreted as the most efficient path for slowing climate change given inputs and technologies; alternatively, the trajectory can be interpreted as a competitive market equilibrium in which externality or spillover effects are corrected with the use of appropriate social prices for GHGs.

In the DICE model, emissions include all GHGs but are most easily interpreted as CO2. Uncontrolled emissions make up a slowly declining fraction of gross output. Greenhouse-gas emissions, which accumulate in the atmosphere, can be reduced by an increase in the price of imports (such as energy) or outputs that are GHG-intensive. Greenhouse-gas emissions accumulate in technologies, which uses relations based on current climate models. The economic impacts of climate change are assumed to be increasing in the realized temperature increase.

In a more detailed derivation of the DICE model, the global economy is assumed to have an initial stock of capital and labor and a gradually improving technology. Population growth and technological change are exogenous, whereas capital accumulation is determined by optimization. In estimating the efficient path for capital accumulation and emissions reductions, the DICE model treats the world as a single economic entity and analyzes the optimal policy for the average individual (11).

The major driver of economic activity is the climate in the DICE model is whether to consume goods and services, to invest in productive capital, or to slow climate change. This choice is represented by a maximization of an objective function that is the discounted sum of the utilities of per capita consumption

$$\max \sum_{t=0}^{\infty} \frac{U(t)}{(1+r)^t}$$

Here, U is the utility of leisure or social well-being, and $r$ is the rate of consumption per capita at time $t$, $P(t)$ is the level of population at time $t$, and $\frac{r}{P(t)}$ is the rate of social time preference. The objective function is then the discounted sum of the utilities of consumption, $U(t, P(t), r(t))$ summed over the relevant time horizon from $t=1$ to $T$. The maximization is subject to two sets of constraints: first, a conventional set of economic constraints, and second, the specific set of emissions-capability constraints.

Economic constraints. The first set of constraints specifies the growth of output known as the Ramsey model. The first equation is the definition of utility, which is equal to the sum of population $P(t)$ times the utility of per capita consumption $U(t)$ (12). Preferences are represented by a constant-elasticity-of-substitution utility function

$$U(t) = \left( \frac{P(t) \cdot \sum_{i=1}^{n} x_i}{\alpha} \right) ^ {\frac{1}{\alpha}}$$

In this equation, $\alpha$ is a measure of the social valuation of different levels of consumption called the rate of inequality aversion. When $\alpha = 0$, the utility function is linear and there is no social aversion to inequality; as $\alpha$ gets larger, the social welfare function becomes increasingly egalitarian. In the experiments, $\alpha = 1$, which is the logarithmic or Bernoulli utility function (12).

Output $Q(t)$ is given by a consumption-capital production function in technology $A(t, t)$, capital $K(t)$, and labor, which is proportional to population

$$Q(t) = \alpha \cdot A(t) \cdot K(t)$$

The elasticity of output with respect to capital is given by $\alpha$, whereas the term $\alpha \cdot A(t)$ relates to technological impacts and will be described in Eq. 13.

Nordhaus (Science, 1992)
Climate Risk: A Federal Reserve Perspective

Glenn Rudebusch

Executive Vice President and Senior Policy Advisor in the Economic Research Department of the Federal Reserve Bank of San Francisco
Macroeconomic Risks of Climate Change in the United States

Panelists:

Marshall Burke Associate Professor, Department of Earth System Science and Deputy Director, Center on Food Security and the Environment, Stanford University

Pete Klenow Ralph Landau Professor of Economics, Gordon and Betty Moore Senior Fellow at Stanford Institute for Economic Policy Research, Dong Wei Fellow at the King Center for Economic Development, Stanford University

Tatyana Deryugina Associate Professor, University of Illinois at Urbana-Champaign

Moderated by Amir Jina Assistant Professor, Harris School of Public Policy, University of Chicago, Climate Impact Lab
Climate Change and Long Run Economic Growth

Comments by Pete Klenow

Conference on Economic Risks of Climate Change

December 2020
1. Technological change is a key driver of long run growth in incomes

- Severely diminishing returns to physical capital
  - Equipment and structures of the same quality

- Finite lives limit human capital accumulation
  - Schooling, training, experience

- Allocative efficiency has level effects
  - Labor, capital, and materials to firms and occupations
2. Ideas flow across countries

- Patents
  - Majority are filed by foreigners in every OECD country

- Equipment
  - Most countries get most of their equipment from the U.S., Germany and Japan

- Foreign direct investment

- Hybrid seeds
Parallel productivity growth paths

Productivity (TFP) relative to the U.S. in the same year by country deciles
3. Population growth sustains growth in research

- More ideas (e.g. patents) come from countries with more people
- The number of researchers rises along with the population
- Growth is flat, suggesting ideas are getting harder to find
- Only by having ever more researchers have we been able to sustain growth
Ideas are getting harder to find
4. Impact of climate change on long run growth

- Suppose climate change lowers the long run world population growth rate
  - Then this will slow the rate of technological progress

- Other mechanisms
  - A growing fraction of research going to mitigation and adaptation at the world level
  - Direct effects of climate change on (say) agricultural productivity at the country level
    - Need ever-rising temperature (say) to affect growth at the country level

- Do not expect to see growth effects at the world or country level from a permanent increase in (say) temperature at the world or country level
Temperature and the macroeconomy

Marshall Burke
Stanford University

Economic Risks of Climate Change, Dec 4th 2020
Temperature obviously plays some role.
Temperature obviously plays some role
Evidence from the cross section - global

Country level avg temp vs GDP/cap

GDP/cap (’000$ PPP) vs average temperature (C)
Evidence from the cross section – US cities

US MSA avg temp vs GDP/cap

GDP/cap (‘000$ PPP) vs average temperature (°C)
(More credible) Evidence from panel data

Dell Jones Olken 2012: run distributed lag panel models to look for growth effects
(More credible) Evidence from panel data

**Burke Hsiang Miguel 2015:**
Global non-linear effect of temperature on economic growth in a country-year panel model
(More credible) Evidence from panel data

Burke and Tanutama 2019:
Global non-linear effect of temperature on economic growth in a district-year panel model from high-quality NSOs
(More credible) Evidence from panel data

Burke and Tanutama 2019:

US response indistinguishable from global response
Macroeconomic Risks of Climate Change

TATYANA DERYUGINA
Temperature increases and aggregate income risk (Deryugina and Hsiang 2017)

Change in total income 1991-2100 (NPV median trajectory relative to no warming)

Change in total farm income 1991-2100 (NPV median trajectory relative to no warming)

full adaptation (cubic) model, stratifying counties by urban vs. rural

billions of 2011 US dollars in net present value (3% discount rate)
Hurricanes, growth, and fiscal outcomes (Hsiang and Jina 2014; Deryugina 2017)
Regional Risks of Climate Change in the United States

Panelists:

**Miyuki Hino** Assistant Professor, Department of City and Regional Planning and Adjunct Assistant Professor in the Environment, Ecology, and Energy Program, University of North Carolina at Chapel Hill

**Eric Tate** Associate Professor, Department of Geographical and Sustainability Sciences, University of Iowa

**Wolfram Schlenker** Professor, School of International and Public Affairs (SIPA) and the Earth Institute and Co-Director, Center for Environmental Economics and Policy, Columbia University

**Judd Boomhower** Assistant Professor, Department of Economics at the University of California San Diego

Moderated by **Tamma Carleton** Assistant Professor, Bren School of Environmental Science & Management at the University of California, Santa Barbara

Economic Risks of Climate Change: Implications for Financial Regulators
Climate change and coastal risk

Miyuki Hino
mhino@unc.edu
Physical risks from coastal storms are large and growing.

Record-setting 2020 Atlantic hurricane season ends
There were a record 30 named storms, 12 of which made landfall, surpassing the record of 28 named storms in 2005.

Hurricane Harvey Damages Could Cost up to $180 Billion

Eta and Iota left 200 dead, millions in financial losses across Central America
Damage estimates overlook long-term impacts

1. Indirect mental and physical health impacts (Bourque et al. 2006, Schwartz et al. 2017, many others)

2. Reductions in income and economic growth (Bertinelli and Strobl 2013, Hsiang and Jina 2014, Ishizawa et al. 2019)

3. Widening wealth gap in the recovery process (Howell and Elliott 2019)
Non-storm flooding is a growing problem

Sweet and Marra, 2016
Coastal risk is not experienced equally
Coastal risk is not experienced equally
Who Lives in the Floodplain?

Eric Tate
University of Iowa, Geographical & Sustainability Sciences
December 4, 2020
1. What is exposed to floods?

We have better understanding than ever of what is exposed to floods.

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**Fluvial hazard**

**Pluvial hazard**

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FEMA


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Tate, E., M.A. Rahman, C.T. Emrich, & C. Sampson (under review). Flood exposure and social vulnerability in the United States. *Natural Hazards*
2. How to measure social vulnerability to floods?

Understand underlying vulnerability processes & customize measures

<table>
<thead>
<tr>
<th>Index/Indicator</th>
<th>Descriptive</th>
<th>Explanatory</th>
<th>Flood focused</th>
<th>Mitigation focused</th>
</tr>
</thead>
<tbody>
<tr>
<td>SoVI (USC)</td>
<td>✓</td>
<td>?</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>SVI (CDC)</td>
<td>✓</td>
<td>?</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>LMI (CDBG)</td>
<td>✓</td>
<td>?</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
3. Who is exposed to floods?

We have a better understanding of **who** is most vulnerable

- “…impacts from flooding tend to fall disproportionately on the most vulnerable and resource-constrained members of society, including children, the elderly, disabled, poor, and renters.”

- “Poor, nonwhite, immigrants, and non-native English speakers disproportionately reside in flood-prone areas, but often have limited resources for flood mitigation and recovery.”
3. Who is exposed to floods?

We’re improving understanding of who is most vulnerable and where

<table>
<thead>
<tr>
<th>Avg. % Change</th>
<th>Indicator</th>
<th>Relationship w/ Social Vulnerability</th>
<th>Social Vulnerability Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>156.7</td>
<td>Mobile Homes (%)</td>
<td>+</td>
<td>Housing</td>
</tr>
<tr>
<td>115.3</td>
<td>Asian (%)</td>
<td>-</td>
<td>Race</td>
</tr>
<tr>
<td>102.4</td>
<td>Black (%)</td>
<td>+</td>
<td>Race</td>
</tr>
<tr>
<td>95.0</td>
<td>Households Earning &gt; $200,000 annually (%)</td>
<td>-</td>
<td>Income</td>
</tr>
<tr>
<td>84.0</td>
<td>Native American (%)</td>
<td>+</td>
<td>Race</td>
</tr>
<tr>
<td>64.8</td>
<td>Less than 12th Grade Education (%)</td>
<td>+</td>
<td>Education</td>
</tr>
<tr>
<td>53.7</td>
<td>Median Housing Value</td>
<td>-</td>
<td>Wealth</td>
</tr>
<tr>
<td>50.6</td>
<td>Female Headed Households (%)</td>
<td>+</td>
<td>Family structure</td>
</tr>
<tr>
<td>50.5</td>
<td>Poverty (%)</td>
<td>+</td>
<td>Income</td>
</tr>
<tr>
<td>48.6</td>
<td>Employment in Extractive Industries (%)</td>
<td>+</td>
<td>Employment</td>
</tr>
<tr>
<td>44.4</td>
<td>Per Capita Income</td>
<td>-</td>
<td>Income</td>
</tr>
<tr>
<td>42.6</td>
<td>Population without health insurance (%)</td>
<td>+</td>
<td>Health</td>
</tr>
</tbody>
</table>
Flood vulnerability is multidimensional and inherently spatial

Need baseline measures of current conditions to best understand climate futures

Federal investments based on economic loss likely to perpetuate inequities
  - Economic & social metrics
  - Eligibility rules & processes
  - Disaster outcomes
Climate Change, Agricultural Yields, and Rural Communities

Wolfram Schlenker

Columbia University - Center for Environmental Economics and Policy (CEEP)
National Bureau of Economic Research (NBER)

Economic Risks of Climate Change - December 4, 2020
Technological Progress: US Corn Yields 1866-2019

- Before 1940
  - Fluctuations around constant avg

- Since 1940
  - Remarkable technological progress
  - Steady upward trend in corn yields
  - Prices decreased in real terms

- Fluctuations around trend
  - Constant in percent terms
  - Weather still important

- Four basic staples
  - Corn, wheat, rice, soybeans
  - 75% of calories human consume
  - US market share $\approx 25\%$
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Wolfram Schlenker (Columbia & NBER)

Climate and Agriculture

December 4, 2020
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Extreme Heat (Temperature above 84°F) Key Driver

- Temperature effect on yields
  - Increase 10-29°C (50-84°F)
  - Decrease above 29°C (84°F)

- Highly asymmetric relationship
  - Moderate temperatures best
  - Being too hot worse than too cold

- Degree days above 29°C (84°F)
  - How much and how long temp exceed 29°C (84°F)
  - Explains more than half of year-to-year variability in yields

- Similar relationship for other crops
  - Soybeans, wheat, rice
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Climate Change Is Increasing Temperatures Over Corn Area

- Weather over corn area
  - Keeping area fixed over time

- Trends since 1980
  - Average temperature increased
  - Extreme heat not yet

- Climate models predict large increase
  - “Dust Bowl” new normal

Corn Area in 2010-2018
Climate Change Is Increasing Temperatures Over Corn Area

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![Graph showing temperature trends over time](image-url)
Takeaways

- Important nonlinearity between temperature and yields
  - Extreme heat is single best predictor of year-to-year yield fluctuations
  - Holds for other crops beyond corn, e.g., soybeans and wheat

- Observable over last four decades
  - Some parts of the world already show significant warming trend (not US agriculture)
    - Tamma Carleton: attributable increase in farmer suicide in India

- Medium-term
  - Crop insurance in US protects farmers against yield losses from weather shocks
  - Decrease in yields will increase prices (given US market share)
    - Bad for consumers, specifically in developing countries, but farmers might be ok

- Long-term
  - Climate models predict significant increases in extreme heat
  - Rural communities predicted to see population declines, further push towards cities
REGIONAL RISKS OF CLIMATE CHANGE:

WILDFIRES

Judson Boomhower
Economics Department
UC San Diego
• Clear increases in the size, frequency, and severity of wildfires in recent decades

• Why? Climate change, development in high risk locations, fuels management

• This overview discusses three types of economic impacts (of many)
  1. Structure loss
  2. Costs to prevent structure loss
  3. Air pollution via smoke
STRUCTURE LOSSES ARE DOMINATED BY CATASTROPHIC EVENTS

RISK IS CONCENTRATED IN PREDICTABLE HIGH RISK AREAS

Source: USDA Forest Service Wildfire Risk to Communities.
MAJOR ADDITIONAL COSTS TO PREVENT LOSSES

- Wildland firefighting
- Fuels management
- Public safety power shutoffs

Photo: Austin Catlin, Bureau of Land Management, Public Domain
Major Additional Costs to Prevent Losses

Annual firefighting expenditures by federal agencies. Does not include state and local costs. All costs are in 2017 dollars. Source: NIFC.
AIR POLLUTION IMPACTS ARE LARGE AND POORLY UNDERSTOOD

Keynote Address

Robert Litterman

Chairman, Commodity Futures Trading Commission Market Risk Advisory Committee’s Climate-Related Market Risk Subcommittee and Founding Partner, Rick Committee Chairman, Kepos Capital

Moderated discussion to follow with Hannah Hess
Senior Manager, Rhodium Group, Climate Impact Lab
Managing Physical Risk to the U.S. Financial System

Panelists:

Lint Barrage Assistant Professor, Department of Economics, University of California, Santa Barbara

Ricardo Correa Deputy Associate Director, Division of International Finance, Federal Reserve Board

Carolyn Kousky Executive Director, Wharton Risk Management and Decision Processes Center, University of Pennsylvania

Moderated by Glenn Rudebusch Executive Vice President and Senior Policy Advisor, Economic Research Department, Federal Reserve Bank of San Francisco
Climate Risks, Beliefs, and Coastal Housing Markets

Lint Barrage
U.C. Santa Barbara & NBER

Managing Physical Risk to the U.S. Financial System

December 4, 2020
Introduction

- What role do risk information and beliefs play in how housing markets will respond to a changing climate?

- Asset prices generally driven by beliefs about future

- Accurate beliefs → Efficient markets
  - Prices reflect risk, reward safety
  - Proper incentives for, e.g., (re)location of economic activity → Critical to minimizing costs of sea level rise (Desmet et al., 2018)

- U.S. markets: Evidence suggests incomplete risk capitalization (Daniel et al. 2009; Bin, Landry 2013; Bernstein et al. 2018; Baldauf et al. 2020; etc.)
Risk Beliefs and Housing Markets

"Flood Risk Belief Heterogeneity and Coastal Home Price Dynamics: Going Under Water?" joint with Laura Bakkensen, U. of Arizona

1 Door-to-door survey campaign in coastal Rhode Island
   ▶ Elicit beliefs about flood risk, damages, waterfront valuation, etc.

2 Develop quantitative coastal housing market model
   ▶ Project coastal home prices across belief, flood risk, policy scenarios
1) Coastal floodzone residents: Higher valuation of waterfront living, but significantly *less* worried about flood risk:

- 40% of high risk zone residents "not at all" worried about flooding
Survey Results

2) Lack of worry does not appear to be driven by expectations of lower damages or higher FEMA assistance in case of a flood

3) Majority (70%) of coastal residents perceive lower flood probability than house-specific estimate from inundation model (STORMTOOLS)

4) Past flood experience increases flood worry

5) "Very worried" respondents significantly more likely to intend to sell flood zone house in next 5 years
## Model Results

- **Case Study: Bristol County, RI**

<table>
<thead>
<tr>
<th>Population:</th>
<th>Emissions Scenario</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>RCP 4.5</td>
</tr>
<tr>
<td>0% Misinformed</td>
<td>-34%</td>
<td>-17%</td>
</tr>
<tr>
<td>35% Misinformed</td>
<td>-53%</td>
<td>-25%</td>
</tr>
</tbody>
</table>

Flood risk increases based on Kopp et al. (2014), Buchanan et al. (2017) (Newport). Model assumes flood insurance policy reform (effective belief convergence) by 2040.

**Disclaimer:** Figures are only illustrative of potential price impacts and not predictions of actual future housing market changes, which will further depend on many unmodeled factors.
Summary and Policy Implications

- Misperception of flood, climate risk → Overvaluation, bubble risk
  - Climate skepticism may be delaying market adaptation

1. **Accurate and forward-looking risk information** critical to stability, efficiency of coastal housing markets
  - FEMA flood maps: Vital but often out of date, backwards-looking
  - Leading the way: First Street Foundation
Find your home's Flood Factor

Past floods, current risks, and future projections based on peer-reviewed research from the world's leading flood modelers.
Summary and Policy Implications

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1. **Accurate and forward-looking risk information** critical to stability, efficiency of coastal housing markets
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   - Caveat: Information ≠ beliefs!
   - (Better) Disclosure laws
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2. **National Flood Insurance Program Reform**
   - Real-risk pricing, mandate enforcement could ensure risk internalization
   - Mitigate bubble risk, but other concerns (e.g., distributional)
Climate change, natural disasters, and loan pricing

Ricardo Correa
Federal Reserve Board

Managing Physical Risk to the U.S. Financial System

December 4, 2020

The views expressed on the slides and the associated remarks are those of the presenter and do not necessarily represent those of the Federal Reserve Board or the Federal Reserve System.
Remarks based on the following paper

“The rising tide lifts some interest rates: climate change, natural disasters, and loan pricing”

Ricardo Correa, Ai He, Christoph Herpfer, and Ugur Lel
Climate change can alter the pricing of financial instruments

- Large parts of literature focuses on estimating long run discount rates in long-term assets (equity, real estate) (Giglio, Maggiori, and Stroebel, 2015; Giglio, Maggiori, Rao, Stroebel, and Weber, 2018).
- In debt markets, climate risk began to be priced in municipal bonds (Goldsmith-Pinkham et al, 2019; Painter 2020).
- Our work: assess the more immediate effect of climate change, through natural disasters, on corporate funding costs in the syndicated loan market.
Banks are aware of the risk of natural disasters

2019 10-K filing:

<table>
<thead>
<tr>
<th>Bank</th>
<th>Climate disasters</th>
<th>Worsening trend</th>
<th>Specific disasters</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPMorgan Chase</td>
<td>Yes</td>
<td>Yes</td>
<td>Flooding, wildfire, heat, storm</td>
</tr>
<tr>
<td>Bank of America</td>
<td>Yes</td>
<td>Yes</td>
<td>Fire, hurricanes</td>
</tr>
<tr>
<td>Citi</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Wells Fargo</td>
<td>Yes</td>
<td>No</td>
<td>Hurricanes</td>
</tr>
<tr>
<td>Goldman Sachs</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Morgan Stanley</td>
<td>Yes</td>
<td>No</td>
<td>None</td>
</tr>
<tr>
<td>U.S. Bankcorp</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>Truist</td>
<td>Yes</td>
<td>Yes</td>
<td>Hurricanes, storms</td>
</tr>
<tr>
<td>PNC</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
</tr>
<tr>
<td>TD Bank</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
</tr>
</tbody>
</table>

- **PNC**: “Climate change may be increasing the frequency or severity of adverse weather conditions, making the impact from these types of natural disasters on us or our customers worse. [...] we could face reductions in creditworthiness on the part of some customers or in the value of assets securing loans.”
Research framework

Naïve approach: focus on **Firm B**, estimate effect of *direct* disaster hit on loan spreads

Confounding effects: the direct effect of the disaster on the borrower vs. lender’s expectation about the severity of these disasters
Our approach:

- Focusing on at-risk, indirectly affected firms
- Intuitively, we compare loans to completely unaffected firms (C) and at-risk but not directly hit ("indirectly hit", A) firms.
What do we find?

► We find that

1. Increasing severity of certain natural disasters associated with climate change is priced in the corporate loan market.
2. Firms at risk of climate disasters face spreads that are significantly higher than those who are not exposed. Much stronger pricing effects are also shown in the secondary market.
3. Attention channel: the interest rate spread for at risk firms almost doubles in years after major Intergovernmental Panel on Climate Change (IPCC) reports are released.

► Rule out many alternative stories

1. No comparable effect for disasters that are not climate change related
2. Not driven by customer supplier linkages
3. Not driven by bank capital transfers
4. Not driven by direct damages/rebuilding efforts
Lessons learned

- Parts of the financial system may already be pricing the effects of climate change through natural disasters.
- Further work is needed to assess whether these pricing changes are temporary, due to saliency, or more permanent.
- There is good data on natural disasters (SHELDUS) in the United States, but perhaps more work needed to homogenize some of these data, including weather information, across countries.
- There is a need for better data to assess the exposures of banks and firms to climate-related risks.
Economic Risks of Climate Change: Implications for Financial Regulators

Conference Resumes at 12 P.M. PST / 3 P.M. EST
Keynote Address

Senator Brian Schatz (D)

Senior U.S. Senator from Hawaii, Chair, Senate Democratic Special Committee on the Climate Crisis, Chief Deputy Whip

Moderated discussion to follow with Trevor Houser Partner, Rhodium Group, Co-Director of the Climate Impact Lab

Economic Risks of Climate Change: Implications for Financial Regulators
Keynote Address

Congressman Patrick McHenry (R)

Representing North Carolina’s 10th District, Ranking Member of the House Financial Services Committee

Moderated discussion to follow with Trevor Houser
Partner, Rhodium Group, Co-Director of the Climate Impact Lab

Economic Risks of Climate Change: Implications for Financial Regulators
Closing Remarks

Michael Greenstone

Milton Friedman Professor of Economics and Director of the Energy Policy Institute at the University of Chicago, Co-Director of the Climate Impact Lab
A New Generation of Climate Change Damages Estimation

Michael Greenstone, University of Chicago

Economic Risks of Climate Change: Implications for Financial Regulators

December 4th 2020
1. Existing IAM Damage Functions Are No Longer on the Scientific Frontier
“[M]uch of the research on which [the SC-IAMs] are based is dated....damage formulations do not in many cases reflect recent advances in the scientific literature.”


Source: Interagency Working Group on SCC, 2010
Existing IAMs Rely on Dated Evidence

Number of studies

- FUND
- DICE
- PAGE

www.impactlab.org  Climate Impact Lab
"A newer and substantial body of additional empirical and structural modeling literature is now available...[providing] immediate opportunities to update the SC-IAMs."

Existing IAMs are Geographically Coarse

DICE (1992):
1 global region
Existing IAMs are Geographically Coarse

FUND (1996):
16 regions
2. A new approach
We are an interdisciplinary team of \( \sim 30 \) climate scientists, economists, and computational experts.
The Climate Impact Lab and the Social Cost of Carbon

Climate Impact Lab outputs:

1. **Social Cost of Carbon**
   - empirically derived from latest scientific evidence
   - transparent & updatable
   - incorporates latest climate and socioeconomic projections

2. **Hyperlocal climate damage data**
   - 7 sectors underway
   - probabilistic
   - fully public data
3 principles for developing modern climate estimates

1. **Best Available Evidence**: Damage functions should be informed by best available empirical estimates.
3 principles for developing modern climate estimates

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2. **Reflect Damage from Around the World:** Should use data representing the global population (not just rich pop.).
3 principles for developing modern climate estimates

1. **Best Available Evidence:** Damage functions should be informed by best available empirical estimates.

2. **Reflect Damage from Around the World:** Should use data representing the global population (not just rich pop.).

3. **Reflect Adaptation and its Costs:** Should reflect that agents adapt given income & climate, include these costs.
Comprehensive granular data: Mortality
Comprehensive granular data: Energy Consumption


Residential, Commercial, and Industrial Consumption of Electricity and Other Fuels.

Observational unit is Country × Year × Sector × Energy source
2.1 An Empirical SCC is Now Possible
Current SCC calculations are out of touch with science

Scenario: RCP8.5 (high emissions)
Discount rate: 3%

Full all-sector SCC

Empirical SCC calculation: Mortality

Scenario: RCP8.5 (high emissions)
Discount rate: 3%

- Full all-sector SCC
- Sector-specific “partial” SCCs
  - SCC based on pre-2016 science
  - Current U.S. SCC
  - SCC based on post-2016 science

2020 USD per ton CO₂

Empirical SCC calculation: Energy

Scenario: RCP8.5 (high emissions)
Discount rate: 3%

**Full all-sector SCC**

**Sector-specific “partial” SCCs**

- SCC based on pre-2016 science
- Current U.S. SCC
- SCC based on post-2016 science

**Energy demand**

**Mortality**
Empirical SCC calculation: Agriculture

RCP8.5 Scenario (high emissions)
Discount rate: 3%

---

Full all-sector SCC

Sector-specific “partial” SCCs

- SCC based on pre-2016 science
- Current U.S. SCC
- SCC based on post-2016 science

---

Energy demand

Mortality

Agriculture

Hyperlocal estimates are now possible

Climate Impact Lab (2019)
25,000 regions
2.2. Hyperlocal estimates
Empirical estimates of mortality damages in 2100

We project these effects by combining statistics and computer science with data on over 400 million deaths worldwide.
Empirical estimates of change in energy consumption: 2100

25,000 regions

Impact of climate change on consumption in 2099 (GJ per capita)

Scenario: RCP 8.5 (high emissions)
Current global average consumption: 9 GJ per capita

www.impactlab.org  Climate Impact Lab
Empirical estimates of change in energy consumption: 2100

25,000 regions

Impact of climate change on consumption in 2099 (GJ per capita)

Other fuels

USA
EJ
-7%
10
20
0

India
EJ
-42%
10
20
0

2099 ∆ from warming
Current consumption

Scenario: RCP 8.5 (high emissions)
Current global average consumption: 25 GJ per capita

www.impactlab.org
Climate Impact Lab
Common interactions

**US prototype**
- **June 2017**

**Mortality & energy partial SCC**
- **June 2019**

**Version 1.0 (Empirically-founded 5-sector SCC)**
- **April 2021**
  - **Conflict, migration, integration**
- **November 2021**
  - **Expand number of sectors**

**Version 2.0 (7-10 sector SCC, incorporating inequality)**
- **December 2022**
- **December 2023**

www.impactlab.org
Climate Impact Lab
Economic Risks of Climate Change: Implications for Financial Regulators