

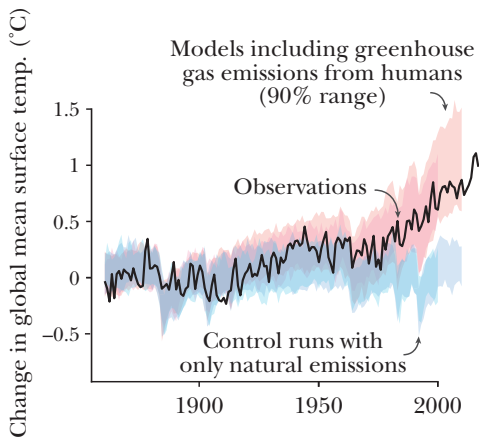
Some Growth Effects of Climate Change

Solomon Hsiang

Global Policy Laboratory
University of California, Berkeley

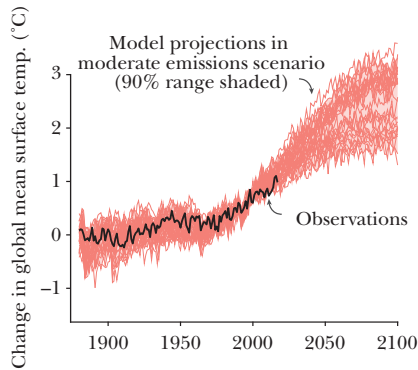
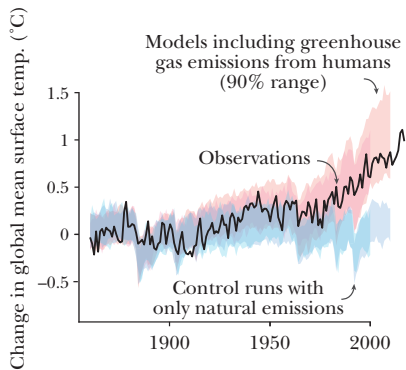
International Monetary Fund
December 11, 2019

How do we know we are changing the climate?



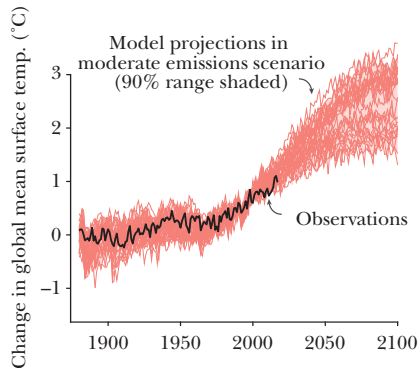
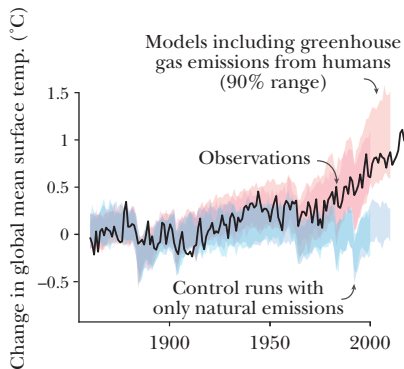
Gentle introduction → “An Economist’s Guide to Climate Change Science”
Hsiang & Kopp (JEP, 2018)

Climate change in context



Moderate emissions: +1C over next 30 years

Climate change in context



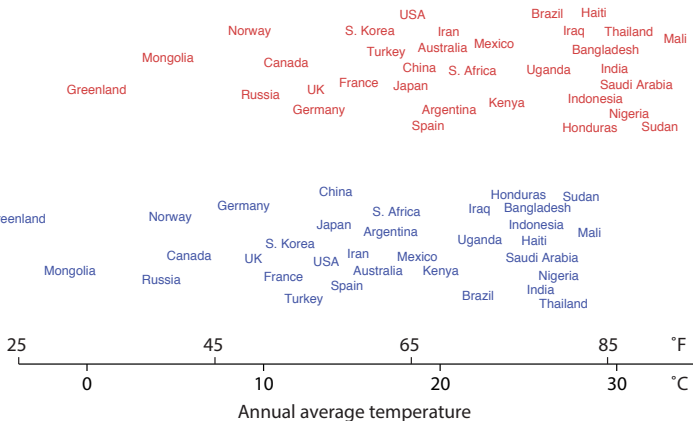
Moderate emissions: +1C over next 30 years

$$= +0.033 \text{ C / yr} = +\frac{1}{10,000} \text{ C / day}$$

Climate change in context

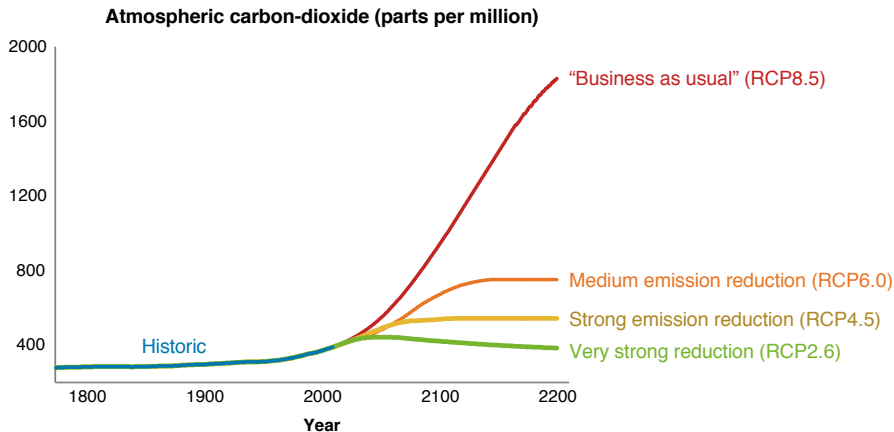
**2080–2099
high emission
(RCP 8.5) scenario**

**1981–2010
(Historical)**



Hsiang & Kopp (JEP, 2018)

Climate change as an economic problem



The resources used to mitigate climate change should reflect the benefit of these investments to society.

Core scientific problem

The resources used to mitigate climate change should reflect the benefit of these investments to society.

Ultimately, this requires that we distinguish between

Hypothesis 1: The climate has small impact on modern human society.

Hypothesis 2: The climate has a large impact.

(Thinkers have debated this issue for centuries.)

Core scientific problem

The resources used to mitigate climate change should reflect the benefit of these investments to society.

Ultimately, this requires that we distinguish between

Hypothesis 1: The climate has small impact on modern human society.

Hypothesis 2: The climate has a large impact.

(Thinkers have debated this issue for centuries.)

This is a hard problem because

- climate is high-dimensional
- human society is high-dimensional
- many confounding factors

Tackling the problem through research design

The Ideal Experiment

1. Take two identical planets.
2. Change the climate of one (treatment).
3. Compare to control planet.

Tackling the problem through research design

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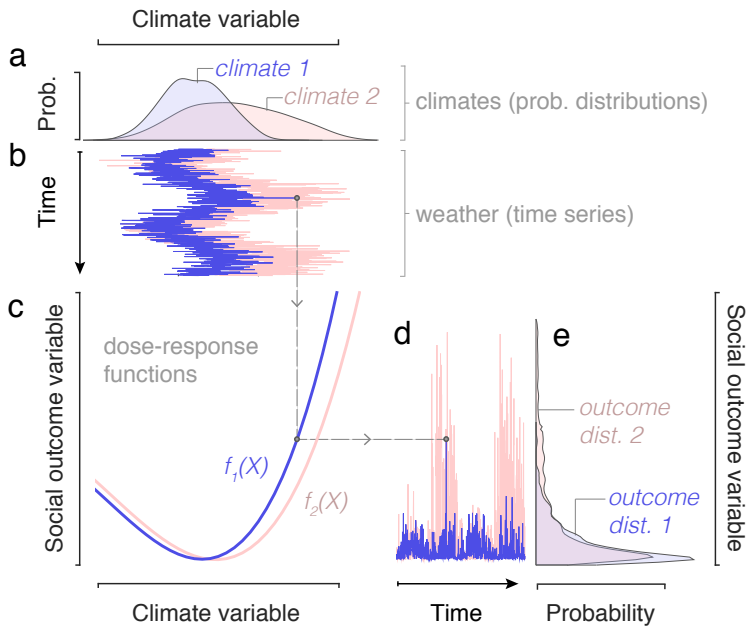
The Quasi-Experiment (that we can actually do)

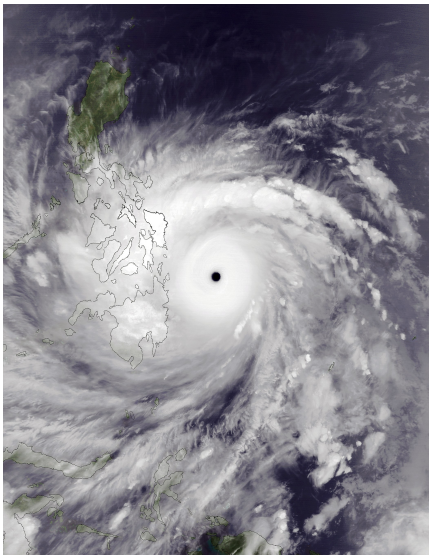
Step one: Reconstruct a history of each population's physical exposure to climatic conditions.

Step two: Estimate the effect of changes over time for each population:

High climate exposure - "treatment"

Low climate exposure - "control"





Typhoon Haiyan – how do you rebuild after such destruction?

The devastation caused in the Philippines will take years to repair. Previous efforts in Haiti, Japan and elsewhere point the way, but how can we build back better?

Vittorio Infante
The Guardian, Friday 15 November 2013 19.04 GMT

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No quick fix ... an entire neighbourhood is destroyed in Tacloban after Typhoon Haiyan. Photograph: Kevin Frayer/Getty Images AsiaPac

World news

[Typhoon Haiyan](#) · [Natural disasters and extreme weather](#) · [Haiti](#) · [Americas](#) · [Japan](#) · [Japan disaster](#)

Environment

[Fukushima](#) · [Nuclear power](#) · [Climate change](#)

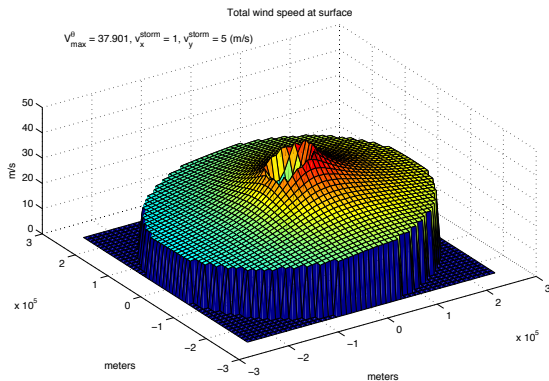
More features

More on this story



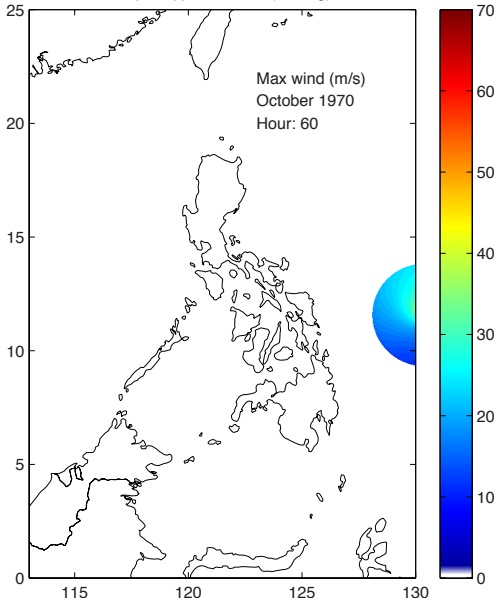
[Typhoon Haiyan storm](#)

Limited Information Cyclone Reconstruction and Integration for Climate and Economics (LICRICE)

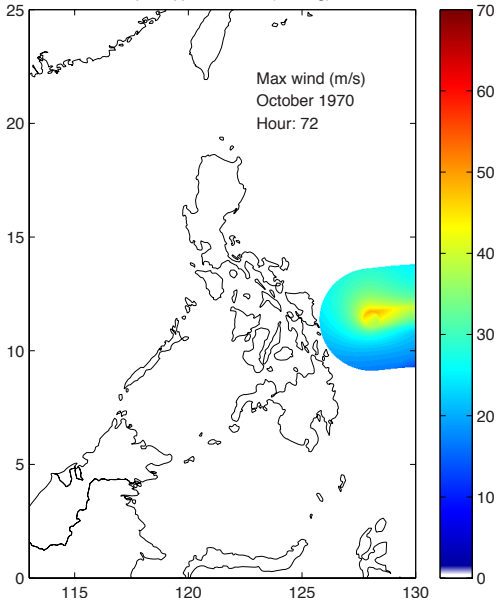


Hsiang (PNAS, 2010)

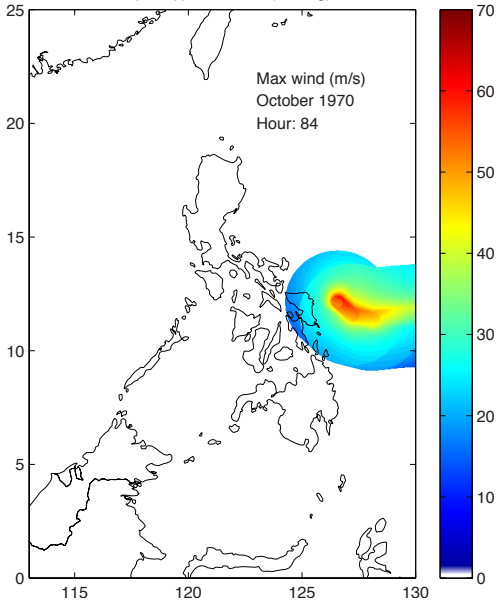
Super Typhoon Joan (Sening)



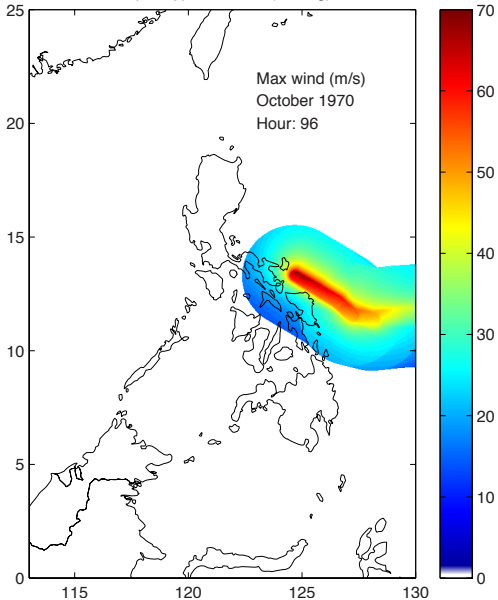
Super Typhoon Joan (Sening)



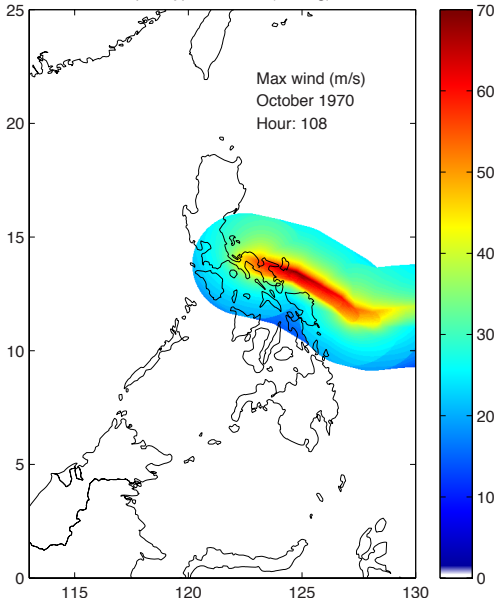
Super Typhoon Joan (Sening)



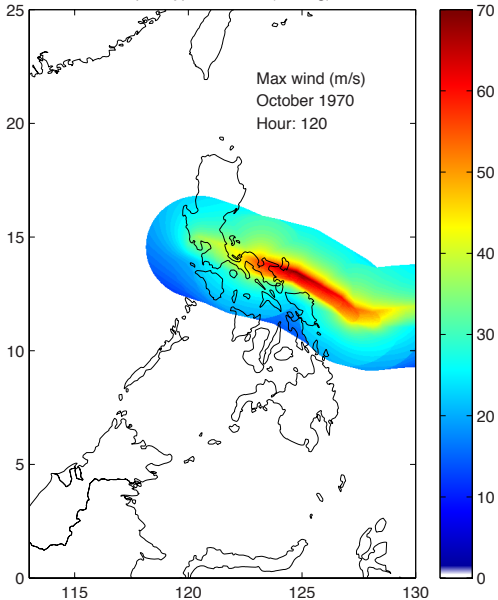
Super Typhoon Joan (Sening)



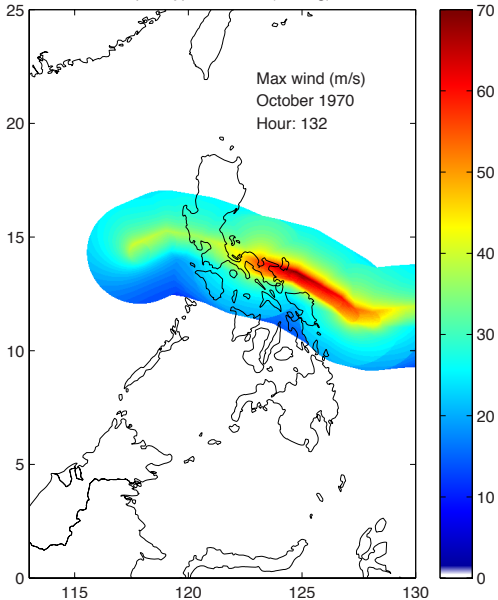
Super Typhoon Joan (Sening)



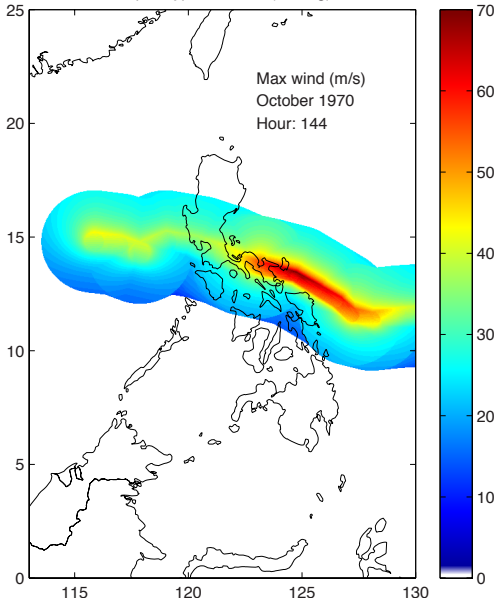
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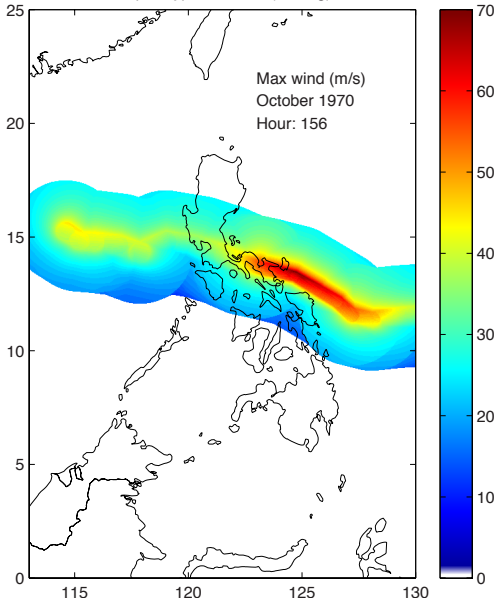
Super Typhoon Joan (Sening)



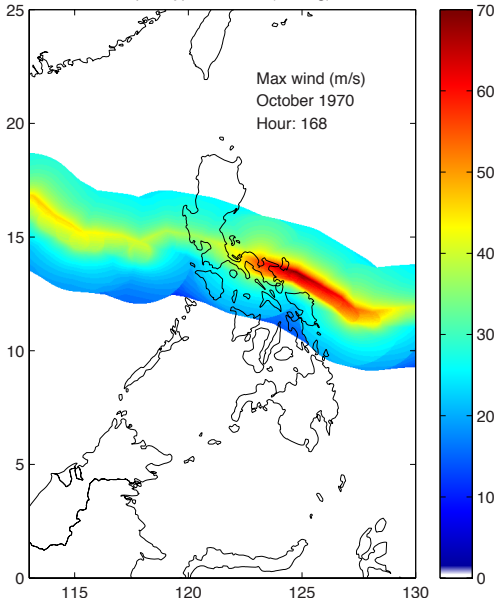
Super Typhoon Joan (Sening)



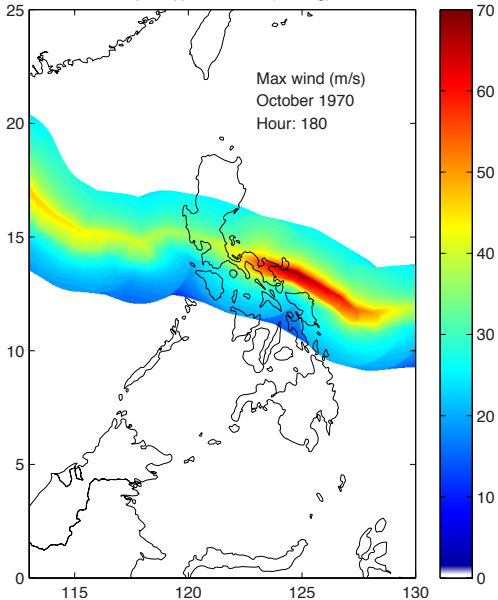
Super Typhoon Joan (Sening)



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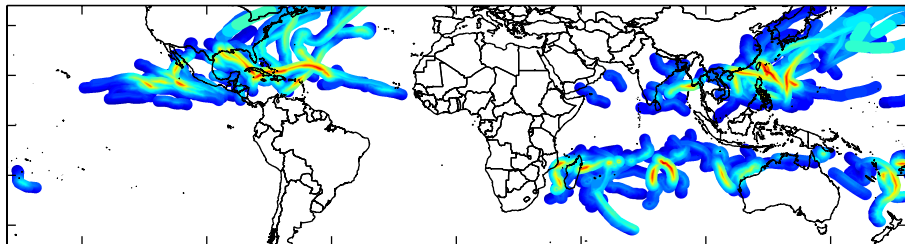


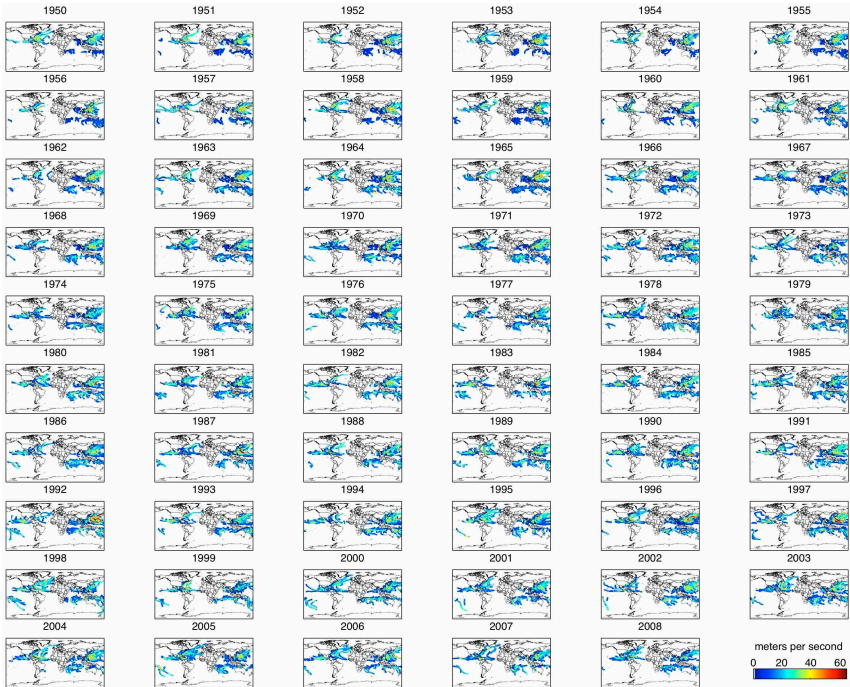
Super Typhoon Joan (Sening)



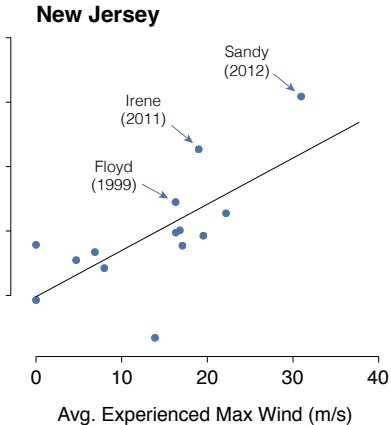
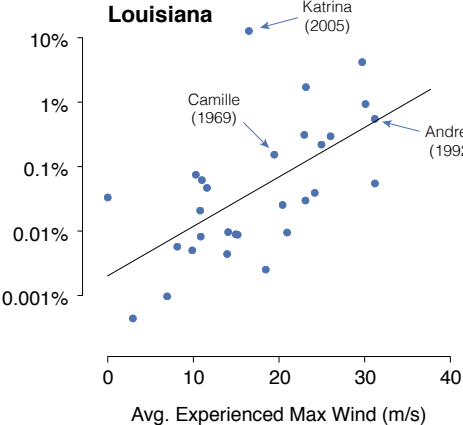
All storms within a year (LICRICE)

Maximum Wind Speed (m/s) 2008



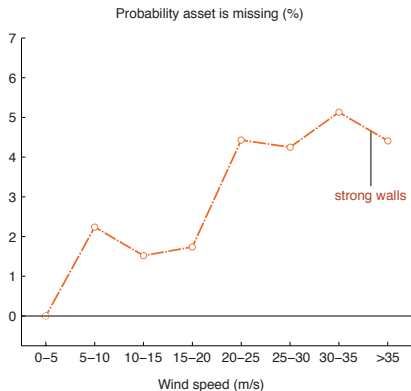


Direct damage: Insured loss in % state GDP (USA)



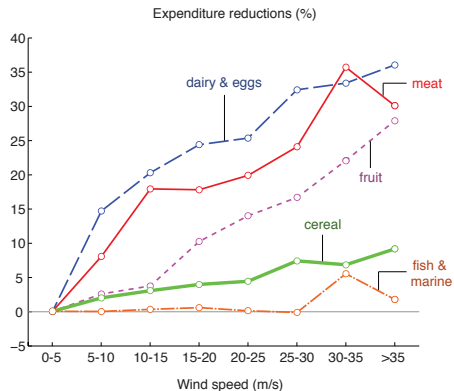
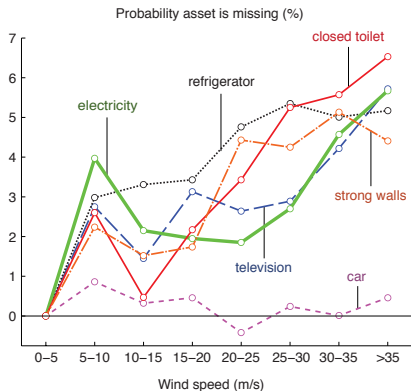
Bolliger, et al (in prep)

Household economics after a typhoon (Philippines)



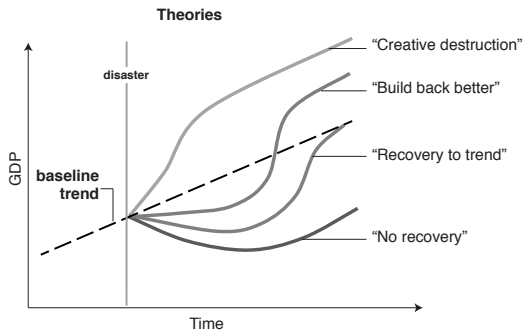
(Anttila-Hughes & Hsiang, 2012)

Household economics after a typhoon (Philippines)



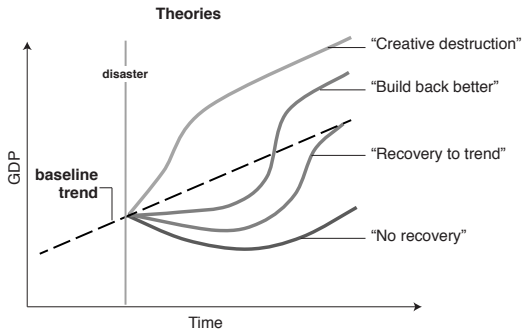
(Anttila-Hughes & Hsiang, 2012)

Macroeconomics: Theories vs. Evidence

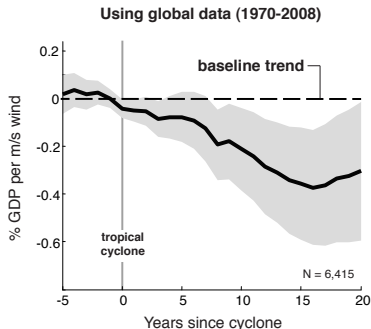


(Hsiang & Jina, 2014)

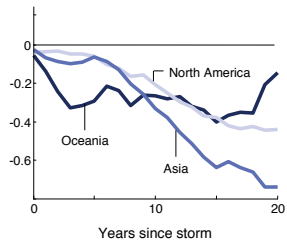
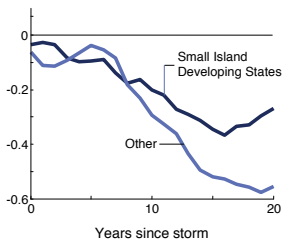
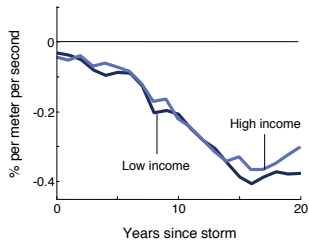
Macroeconomics: Theories vs. Evidence



(Hsiang & Jina, 2014)



Global generalizability



(Hsiang & Jina, 2014)

Repeated shocks slow growth

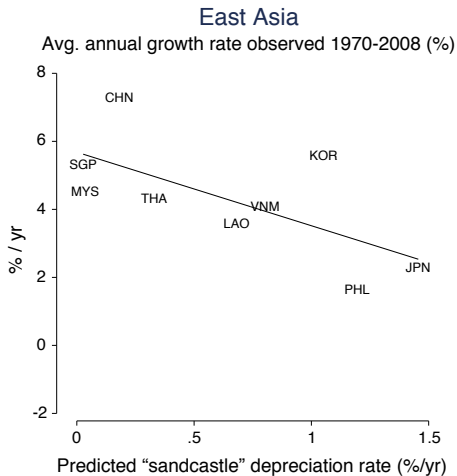
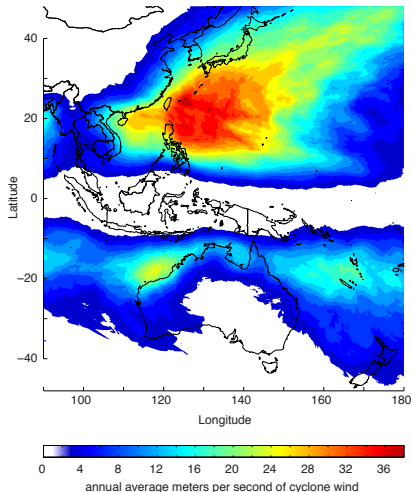
“Sandcastle depreciation”: $\bar{\delta} \approx \frac{1}{s_2 - s_1} \int_{s_1}^{s_2} \delta(t) dt$

$growth = investment - \bar{\delta} - pop_growth - tech_growth$



Hsiang & Jina (AER, 2015)

Long run evidence consistent w/ “sandcastle depreciation”



Hsiang & Jina (AER, 2015)

Comparing cyclones to other macroeconomic events

Event	Growth	Duration	Risk
Temperature \uparrow ($+1^{\circ}\text{C}$)* ¹	-1.0%	10 yrs	6.4%
Civil war ²	-3.0%	10 yrs	6.3%
Taxes \uparrow ($+1\%$ GDP)** ³	-3.1%	4 yrs	\uparrow 16.8%
1-σ cyclone	-3.6%	20 yrs	14.4%
Currency crisis ²	-4.0%	10 yrs	34.7%
Executive constraints \downarrow ²	-4.0%	10 yrs	3.7%
90-percentile cyclone	-7.4%	20 yrs	5.8%
Banking crisis ²	-7.5%	10 yrs	15.7%
Financial crisis ⁴	-9.0%	2 yrs	<0.1%
99-percentile cyclone	-14.9%	20 yrs	0.6%
Democratization ⁵	+21.2%	30 yrs	1.4%

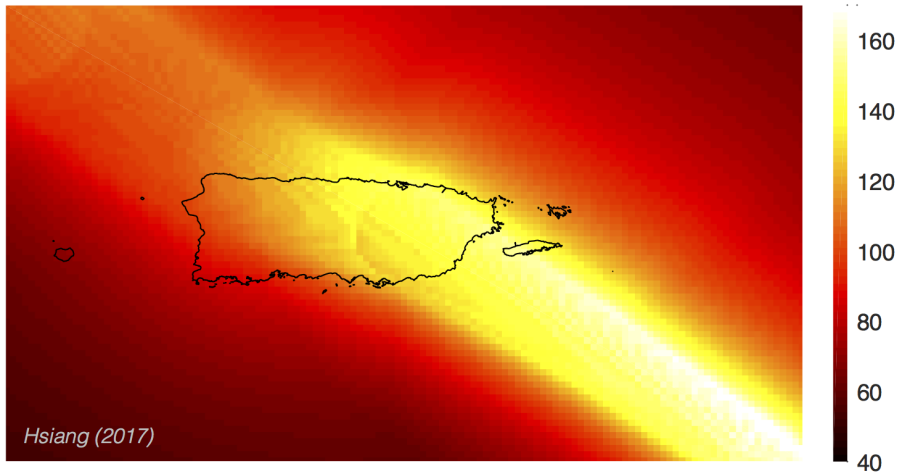
*Poor countries only. **USA only. \uparrow Number of quarters with any tax change.

¹Dell, Jones & Olken (AEJ: Macro, 2012), ²Cerra & Saxena (AER, 2008),

³Romer & Romer (AER, 2010), ⁴Reinhart & Rogoff (AER 2009), ⁵Acemoglu, Naidu, Restrepo, Robinson (NBER, 2014)

Entering a “new normal” ?

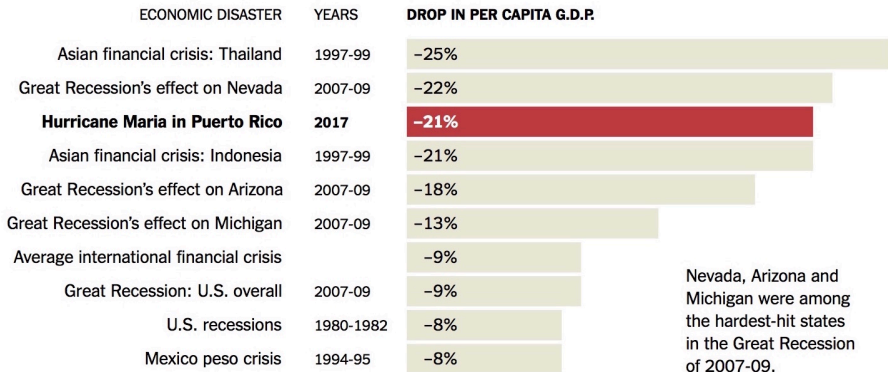
Maximum surface wind speed during Hurricane Maria



Undoing 26 years of Puerto Rican growth in 12 hours

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.



Climate Change → Δ Hurricanes → Δ Growth

NPV roughly \$9.7 trillion (3% discount rate)

Climate Change → Δ Hurricanes → Δ Growth

NPV roughly \$9.7 trillion (3% discount rate)

Climate Change → Δ Temperature → Δ Growth?

Why might temperature matter?

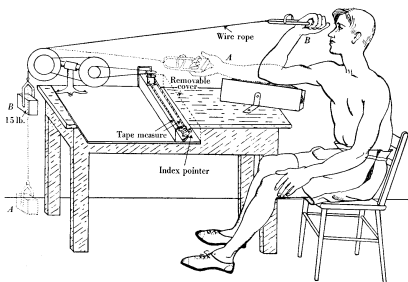


Fig. 1. Pull test apparatus.

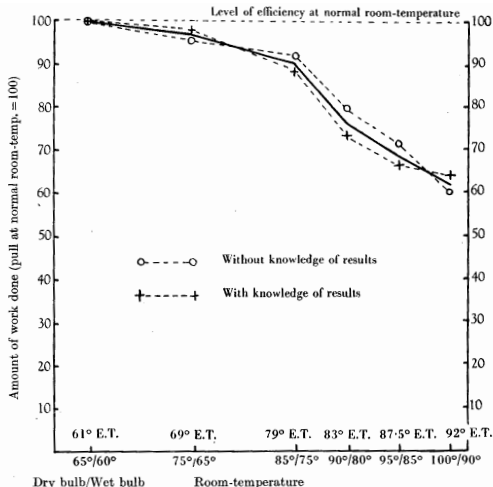
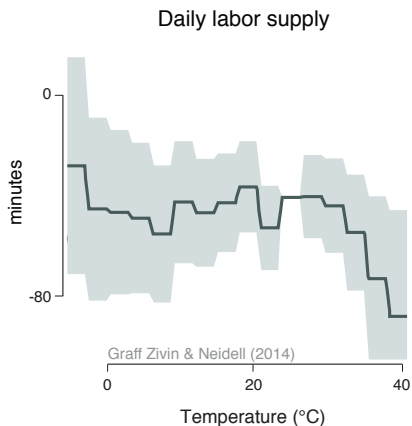
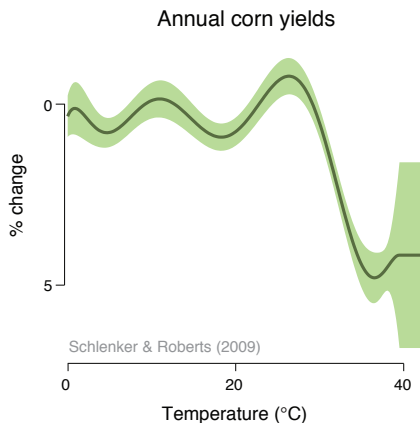


Fig. 3. The same *proportional* deterioration for high as for low incentive conditions when atmospheric temperature is raised.

British Naval Experiments
C. Mackworth (1947)
British Journal of Psychology

Temperature affects productivity of labor & capital



Carleton & Hsiang (Science 2016)

Building a macro-economy from temperature-sensitive units

T_d - temperature on day d of year t

K_j - capital in sector j with productivity A_j^K

L_j - labor in sector j with productivity A_j^L

Each day, based on temperature, capital and labor may be optimally reallocated between sectors:

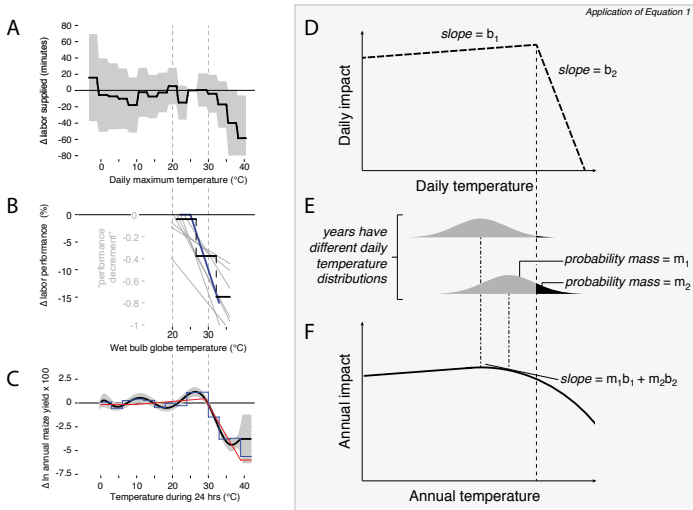
$$q_j(T_d) = (A_j^K(T_d)K_j(T_d))^\alpha (A_j^L(T_d)L_j(T_d))^{1-\alpha}$$

Optimal supply (q^*) and temperature-sensitive demand affects prices (p).

Repeated daily:

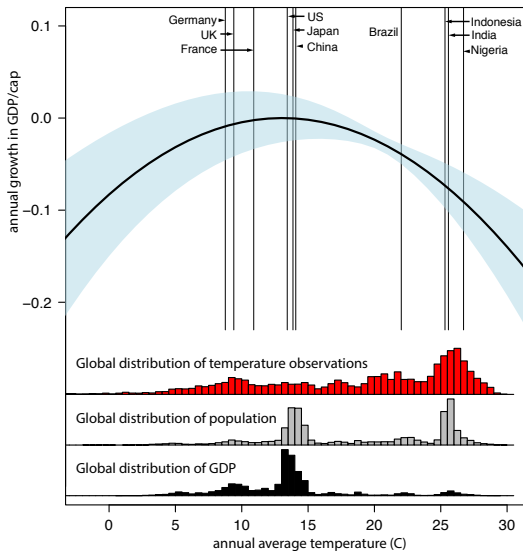
$$annual_revenue_t = \sum_{d=1}^{365} \sum_j \underbrace{p_j(T_d) \cdot q_j^*(T_d)}_{\text{daily income sector } j}$$

How should micro productivity map to macro?

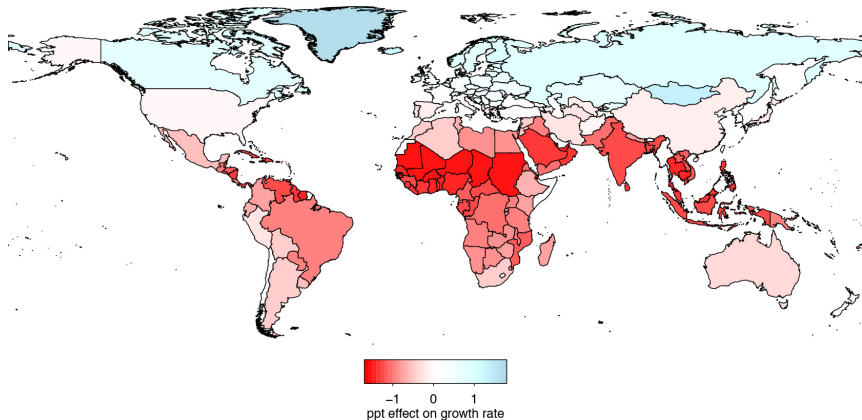


Burke, Hsiang, Miguel (Nature, 2015)

Global non-linear response of growth to temperature

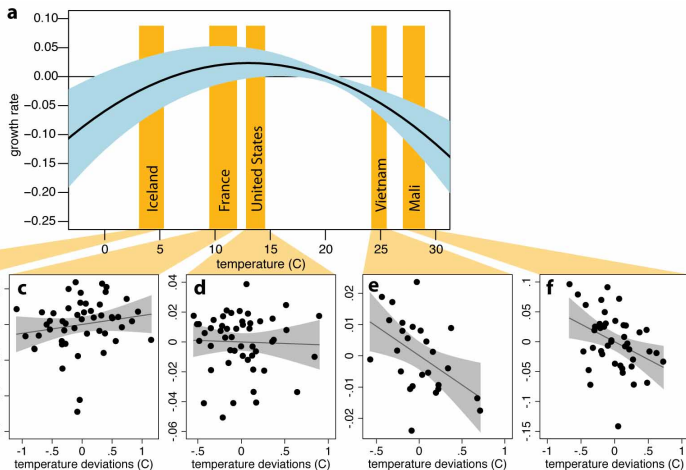


Historical marginal effect of +1C temperature on growth



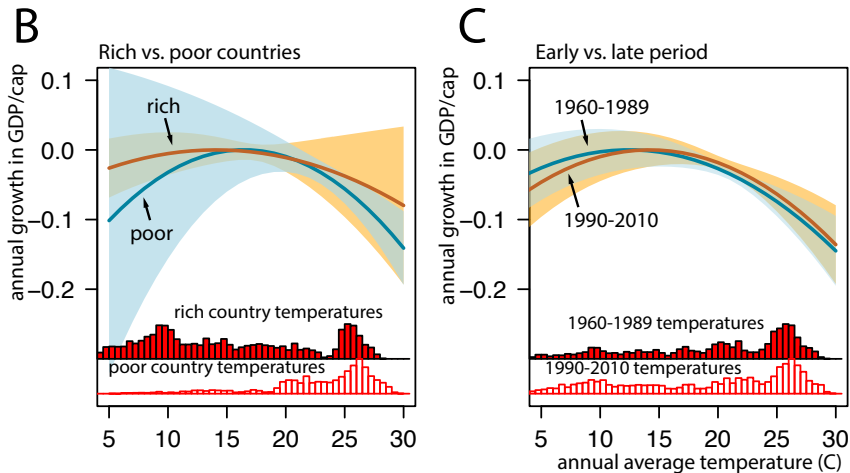
Burke, Hsiang, Miguel (2015)

Using within-country variation to estimate a global function



Burke, Hsiang, Miguel (Nature, 2015)

Rich vs Poor? Early vs late?

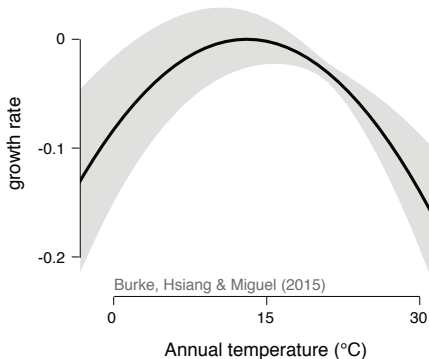


Burke, Hsiang, Miguel (2015)

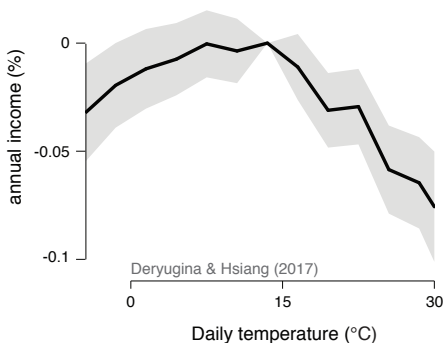
Really in rich countries? Check in USA

Income per person

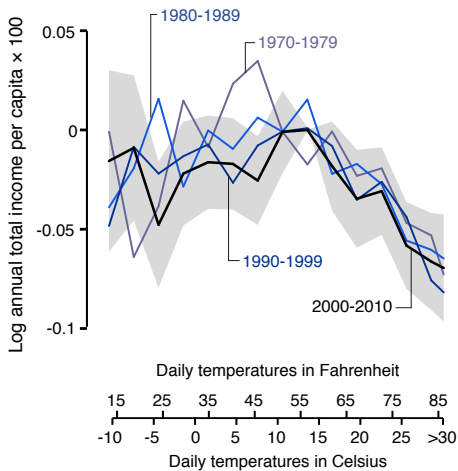
Globally (countries)



United States (counties)

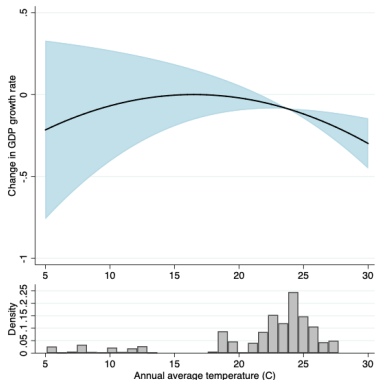


Effect in USA is stable over time



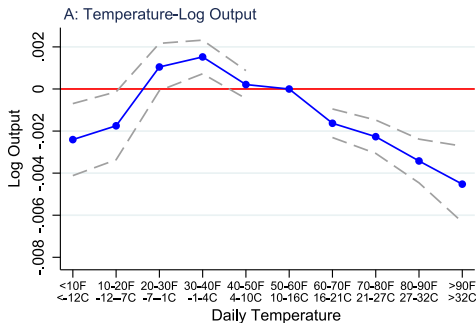
Replication with alternative data sets & samples

India



Jain et al (2019)

China

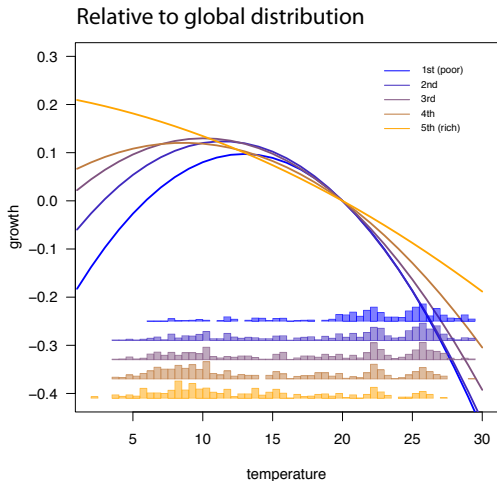


Zhang et al (2018)

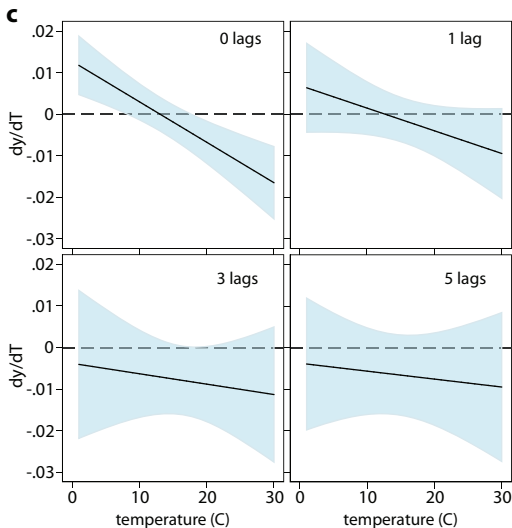
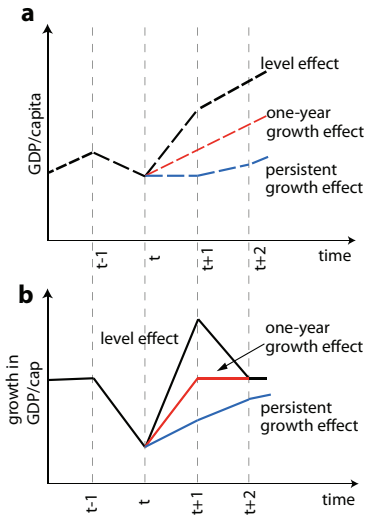
Also: Brazil, Indonesia, Europe, etc.

962 World Bank HH surveys + WPID dataset

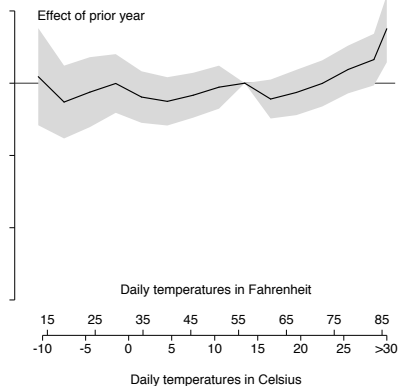
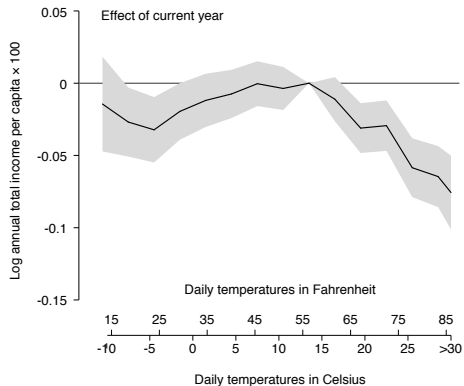
9620 country-year-decile observations 1977-2012



Is it really a growth effect? (Global)



Is it really a growth effect? (USA)



Deryugina & Hsiang (2017)

How to account for adaptation?

1. Adaptations to climate may alter (attenuate) climate impacts.
2. But the costs of these adaptations must be accounted for as a burden.
3. Full accounting is fundamentally difficult because adaptation involves many unobserved adjustments.

How to account for adaptation?

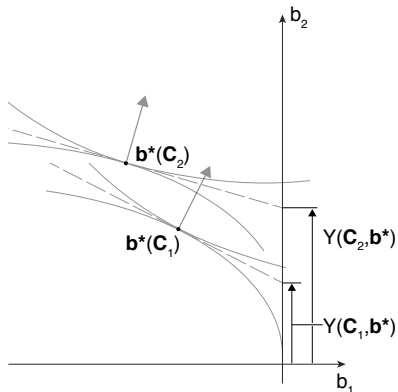
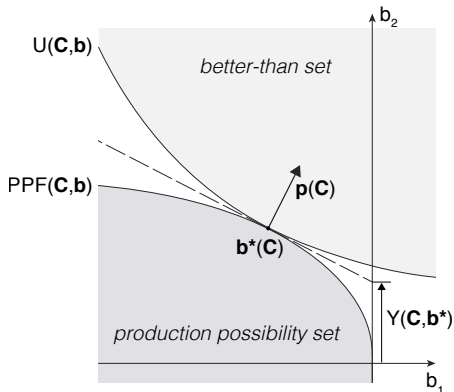
1. Adaptations to climate may alter (attenuate) climate impacts.
2. But the costs of these adaptations must be accounted for as a burden.
3. Full accounting is fundamentally difficult because adaptation involves many unobserved adjustments.

One solution: Take a “top down” view of the macroeconomy and estimate the “marginal product of climate.” (Deryugina & Hsiang, 2017)

Why this works: All adaptations are reallocations of resources, with costs equal to *opportunity costs*.

→ The net benefit of all adaptations will be captured in total revenue of the economy.

Revenue maximization in general equilibrium



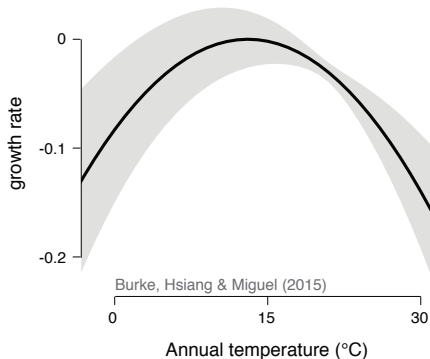
Markets endogenously maximize total revenue in general equilibrium (Koopmans, 1957):

$$\mathbf{b}^*(\mathbf{C}) = \arg \max_{\mathbf{b}} Y(\mathbf{C}, \mathbf{b}(\mathbf{C})) \mid \mathbf{p}(\mathbf{C}), U(\mathbf{C}, \mathbf{b})$$

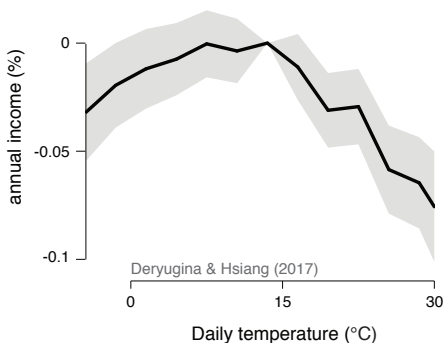
The “Marginal Product of Climate”

Income per person

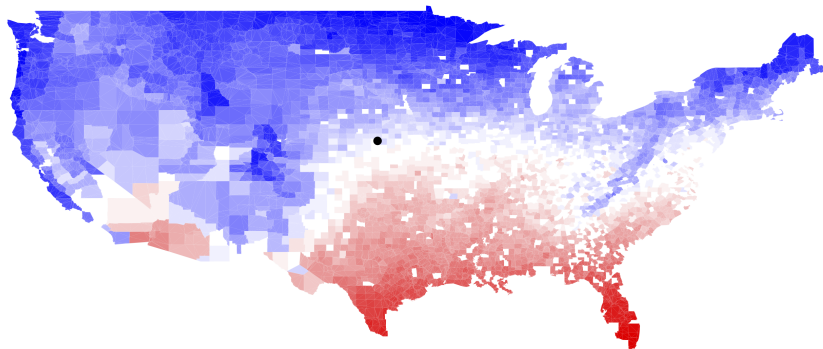
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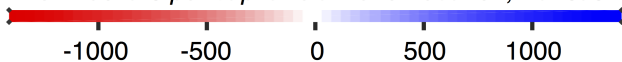
United States (counties)



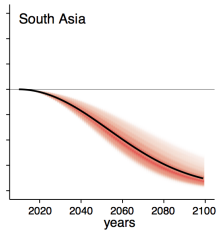
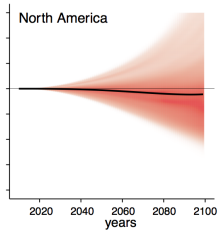
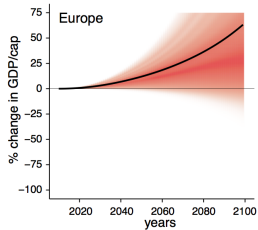
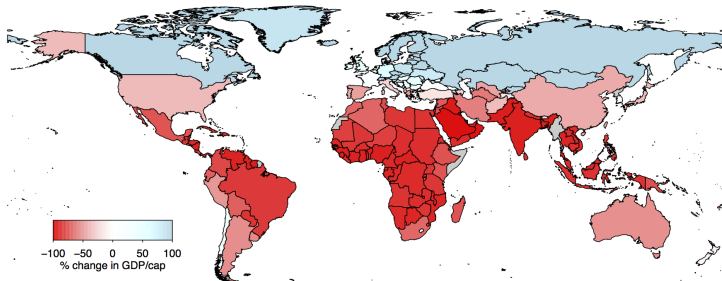
Valuation of historical temperatures (1968-1990) in current annual income



2011 dollars per capita relative to Lebanon, Kansas

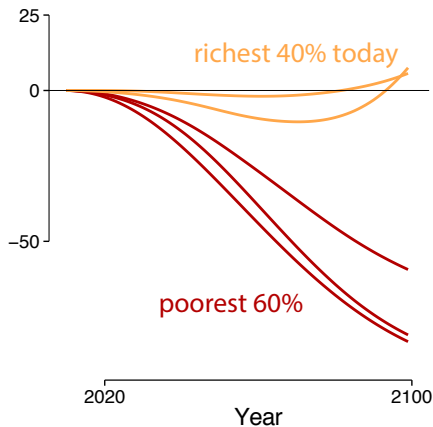
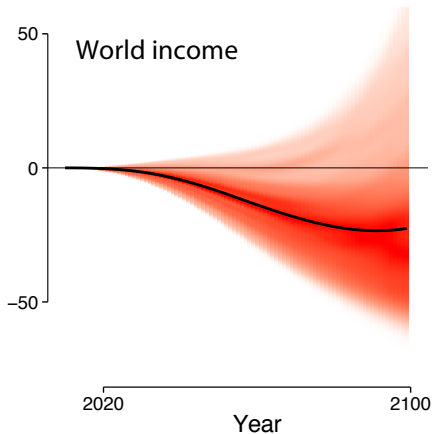


Projecting forward: avg loss = 23% World GDP



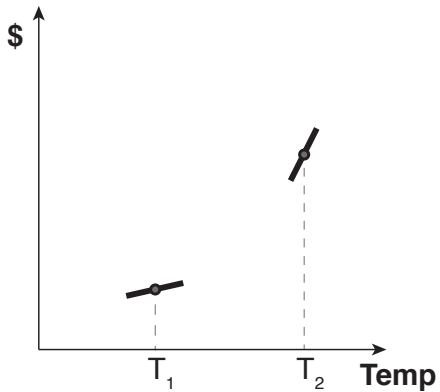
A poorer, more uncertain, more unequal world

Income per person (% change)

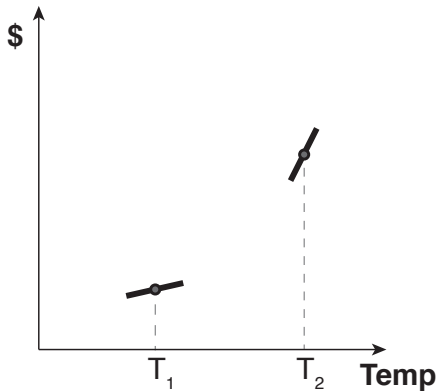


Thank you

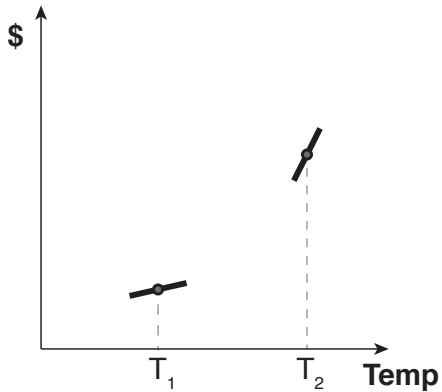
`www.globalpolicy.science`



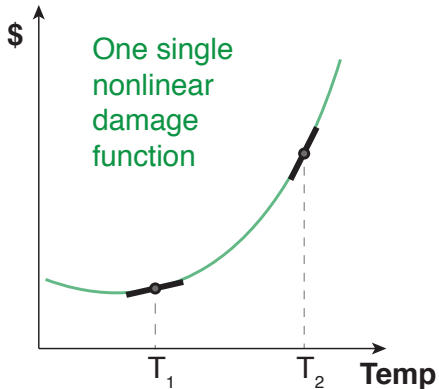
Model 1



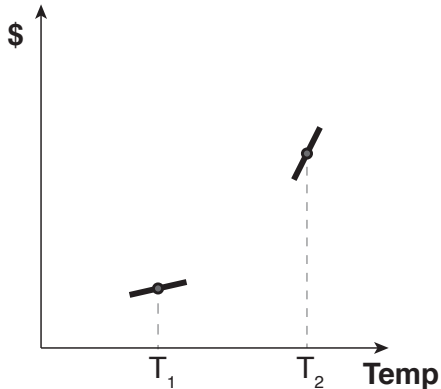
Model 2



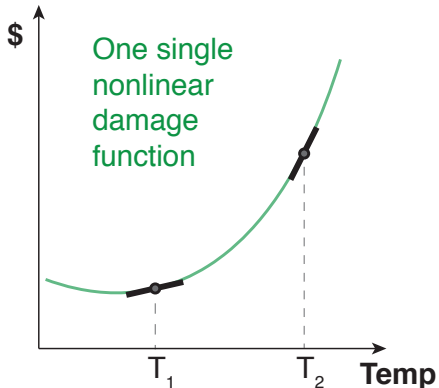
Model 1



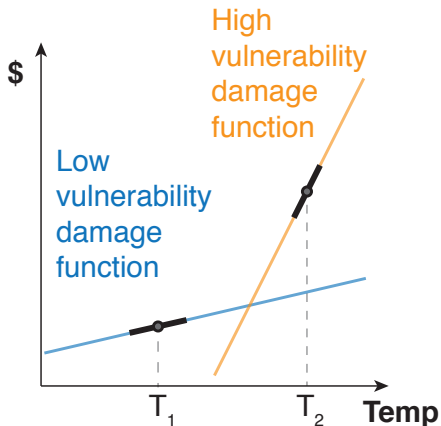
Model 2



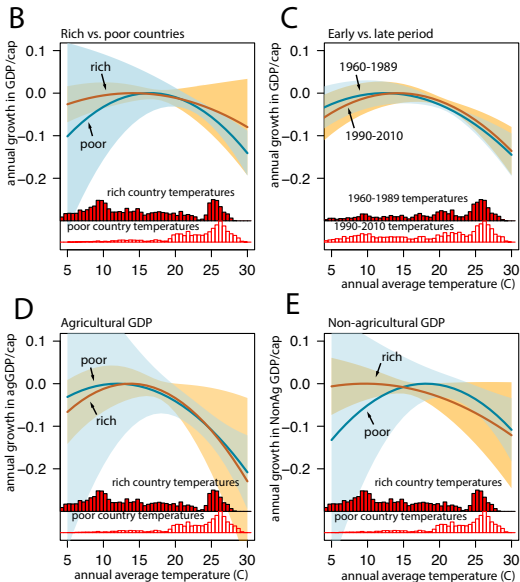
Model 1



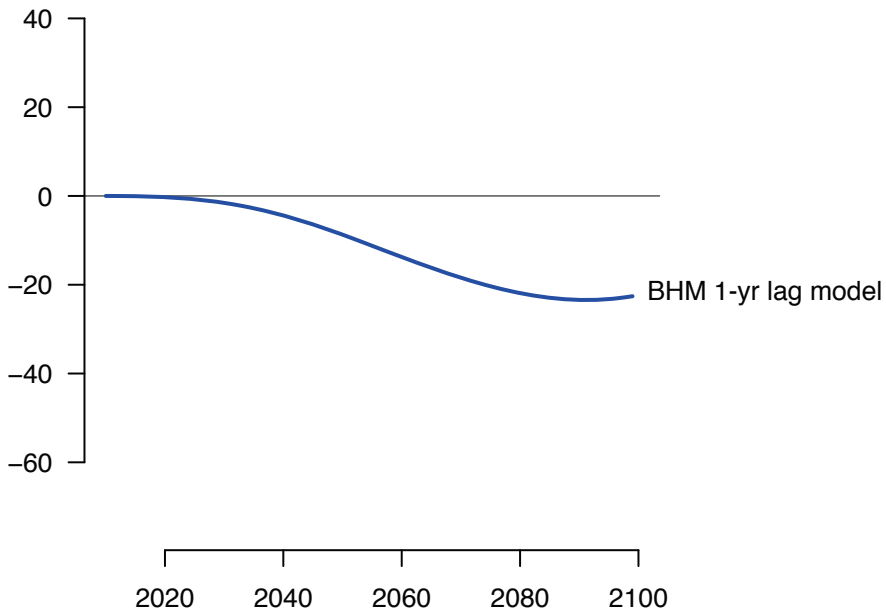
Model 2



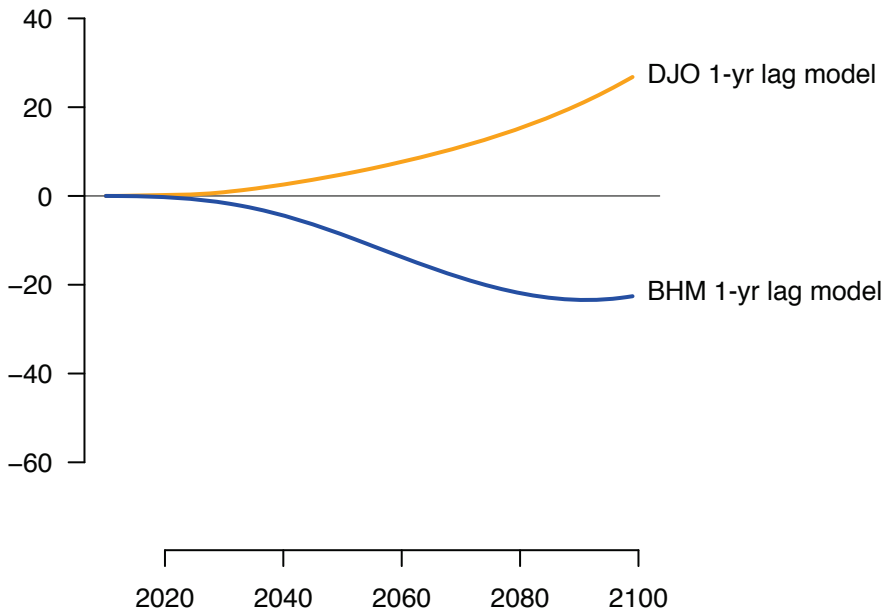
Differences over space or time?



Change in global GDP/cap (%)



Change in global GDP/cap (%)



Change in global GDP/cap (%)

