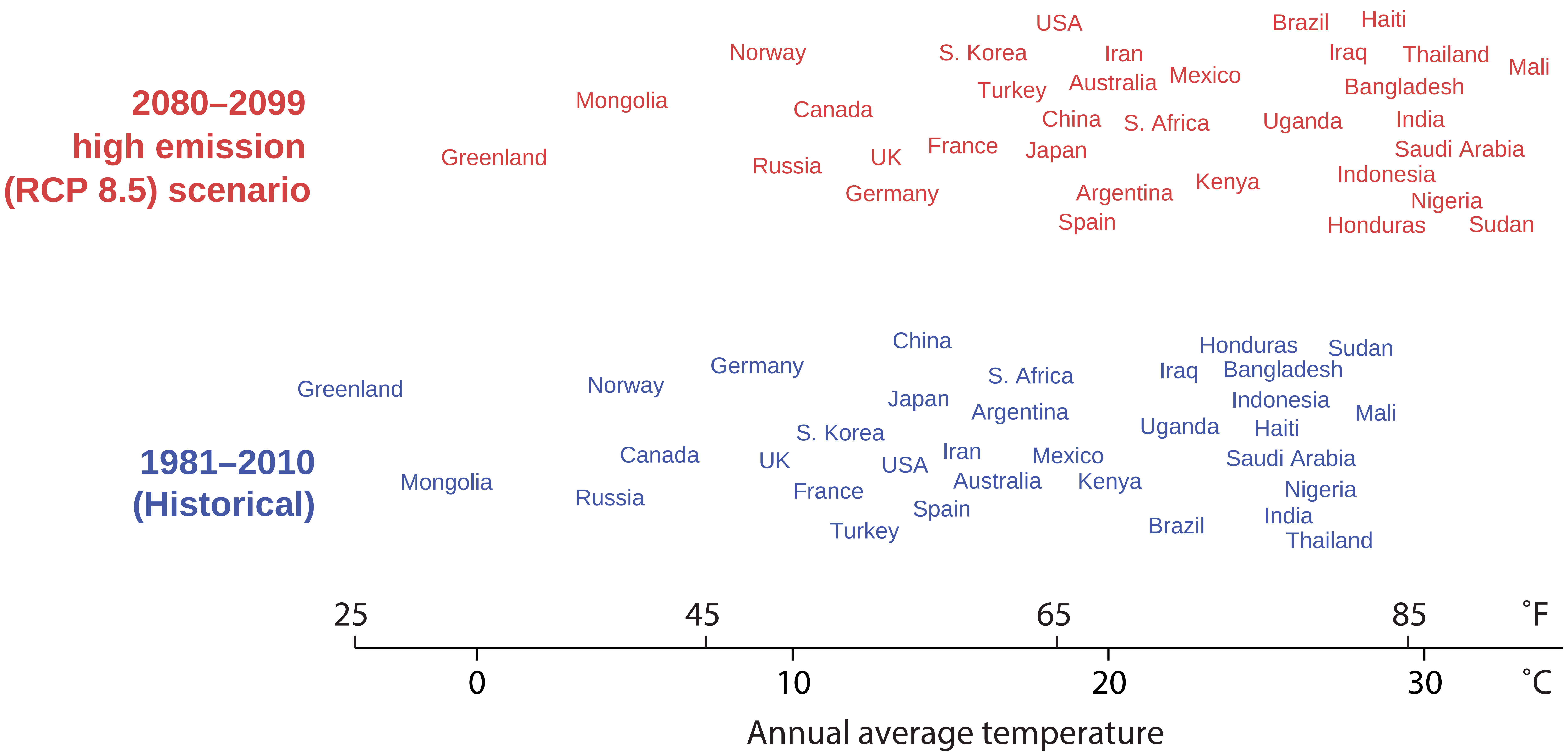
Economics of Climate Change

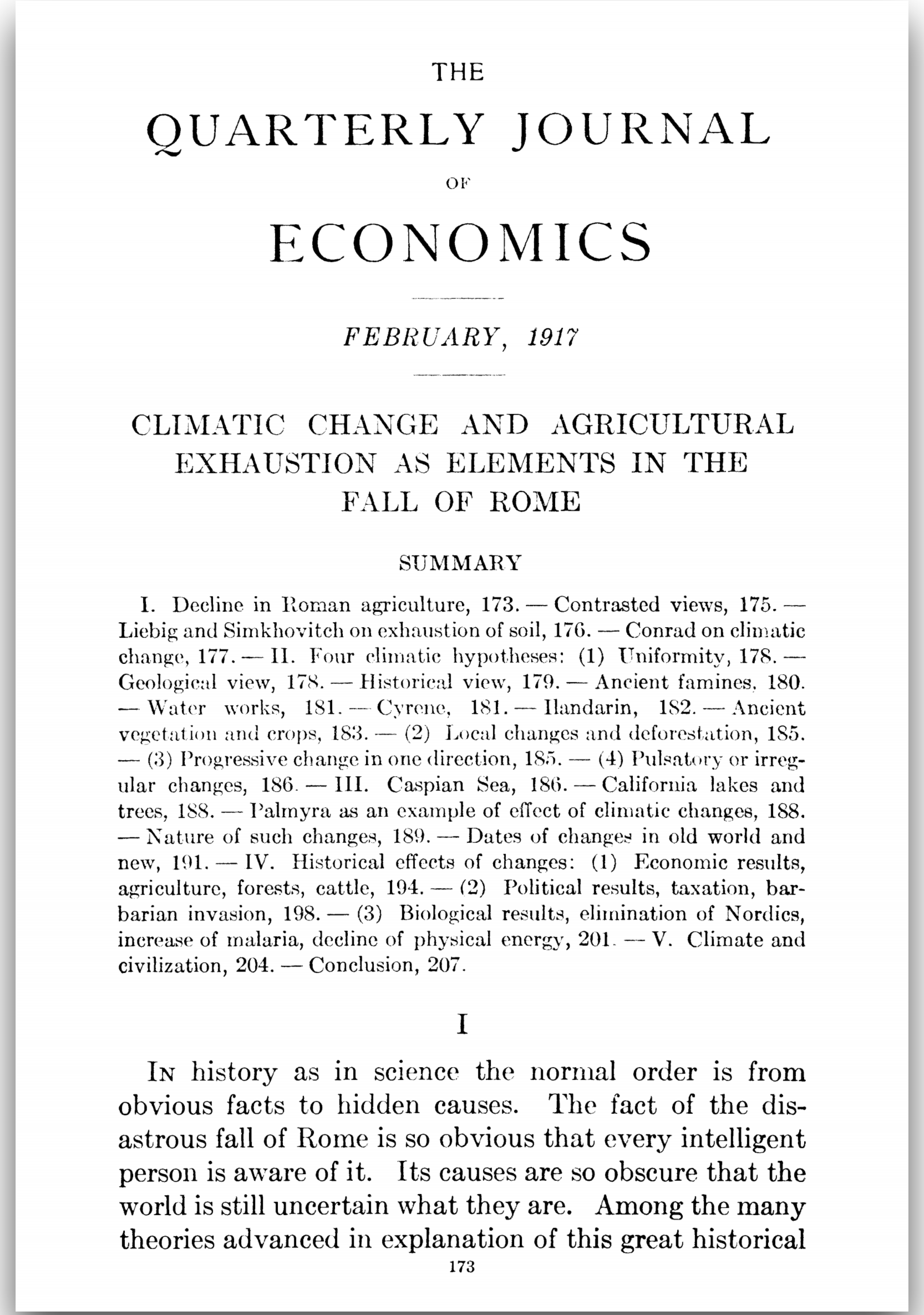
Some Recent Progress and Future Directions

Solomon Hsiang
UC Berkeley

Once you start thinking about climate change you can't think about anything else



Hsiang & Kopp (JEP, 2018)



THE

QUARTERLY JOURNAL

OF

ECONOMICS

FEBRUARY, 1917

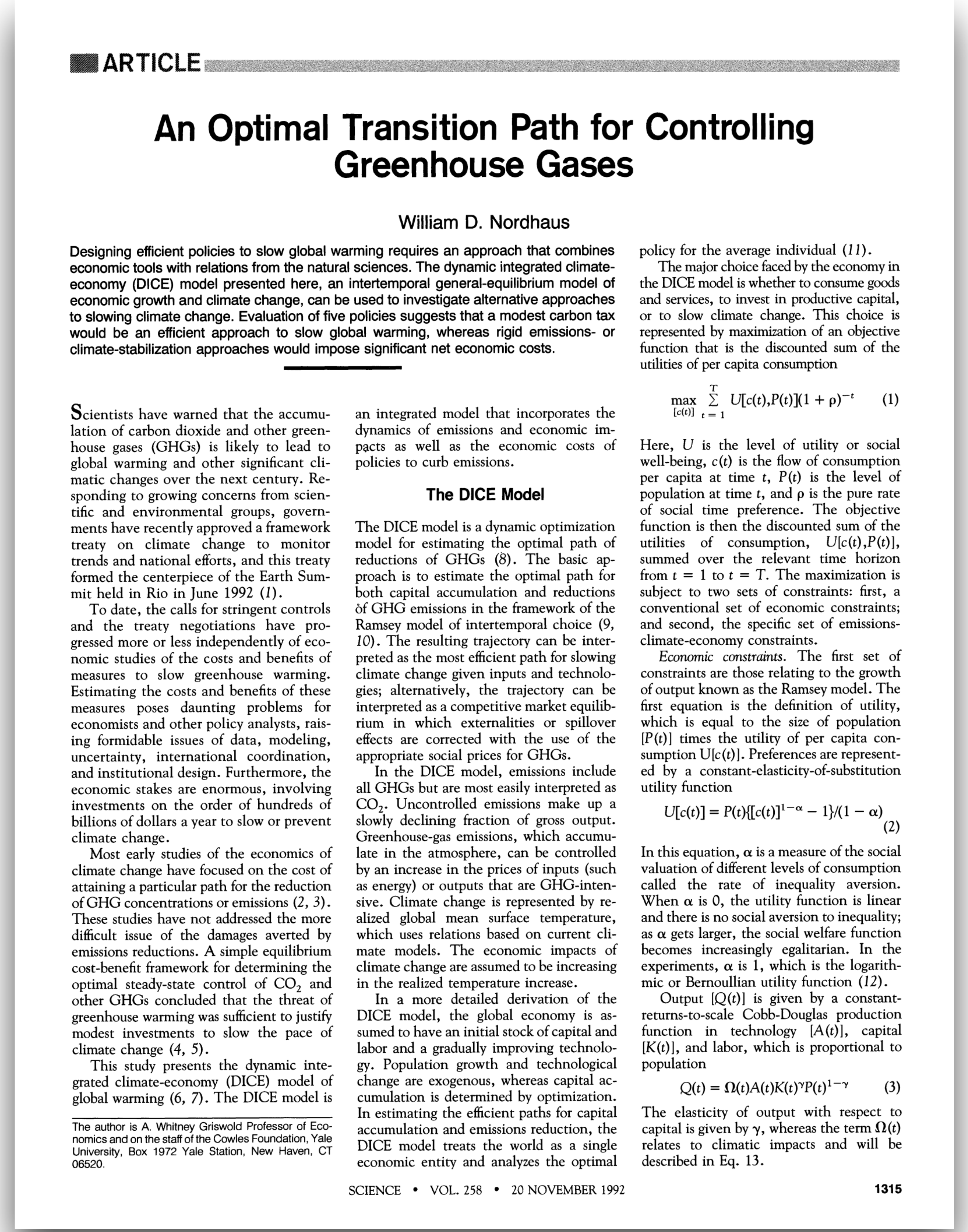
CLIMATIC CHANGE AND AGRICULTURAL EXHAUSTION AS ELEMENTS IN THE FALL OF ROME

SUMMARY

I

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)



ARTICLE

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 relations 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- or climate-stabilization approaches would impose significant net economic costs.

Scientists have warned that the accumulation of carbon dioxide and other greenhouse gases (GHGs) is likely to lead to global warming and other significant climatic changes over the next century. Responding to growing concerns from scientific and environmental groups, governments have recently approved a framework treaty on climate change to monitor trends and national efforts, and this treaty formed the centerpiece of the Earth Summit held in Rio in June 1992 (*1*).

To date, the calls for stringent controls and the treaty negotiations have progressed more or less independently of economic studies of the costs and benefits of measures to slow greenhouse warming. Estimating the costs and benefits of these measures poses daunting problems for economists and other policy analysts, raising formidable issues of data, modeling, uncertainty, international coordination, and institutional design. Furthermore, the economic stakes are enormous, involving investments on the order of hundreds of billions of dollars a year to slow or prevent climate change.

Most early studies of the economics of climate change have focused on the cost of attaining a particular path for the reduction of GHG concentrations or emissions (*2, 3*). These studies have not addressed the more difficult issue of the damages averted by emissions reductions. A simple equilibrium cost-benefit framework for determining the optimal steady-state control of CO_2 and other GHGs concluded that the threat of greenhouse warming was sufficient to justify modest investments to slow the pace of climate change (*4, 5*).

This study presents the dynamic integrated climate-economy (DICE) model of global warming (*6, 7*). The DICE model is an integrated model that incorporates the dynamics of emissions and economic impacts as well as the economic costs of policies to curb emissions.

The author is A. Whitney Griswold Professor of Economics and on the staff of the Cowles Foundation, Yale University, Box 1972 Yale Station, New Haven, CT 06520.

The DICE Model

The DICE model is a dynamic optimization model for estimating the optimal path of reductions of GHGs (*8*). The basic approach is to estimate the optimal path for both capital accumulation and reductions of GHG emissions in the framework of the Ramsey model of intertemporal choice (*9, 10*). 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 externalities or spillover effects are corrected with the use of the appropriate social prices for GHGs.

In the DICE model, emissions include all GHGs but are most easily interpreted as CO_2. Uncontrolled emissions make up a slowly declining fraction of gross output. Greenhouse-gas emissions, which accumulate in the atmosphere, can be controlled by an increase in the prices of inputs (such as energy) or outputs that are GHG-intensive. Climate change is represented by realized global mean surface temperature, 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 paths for capital accumulation and emissions reduction, the DICE model treats the world as a single economic entity and analyzes the optimal policy for the average individual (*11*).

The major choice faced by the economy 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 maximization of an objective function that is the discounted sum of the utilities of per capita consumption

$$\max_{[c(t)]} \sum_{t=1}^{T} U[c(t), P(t)](1+\rho)^{-t} \quad (1)$$

Here, U is the level of utility or social well-being, $c(t)$ is the flow of consumption per capita at time t, $P(t)$ is the level of population at time t, and ρ is the pure rate of social time preference. The objective function is then the discounted sum of the utilities of consumption, $U[c(t),P(t)]$, summed over the relevant time horizon from $t = 1$ to $t = T$. The maximization is subject to two sets of constraints: first, a conventional set of economic constraints; and second, the specific set of emissions-climate-economy constraints.

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

$$U[c(t)] = P(t)\{[c(t)]^{1-\alpha} - 1\}/(1-\alpha) \quad (2)$$

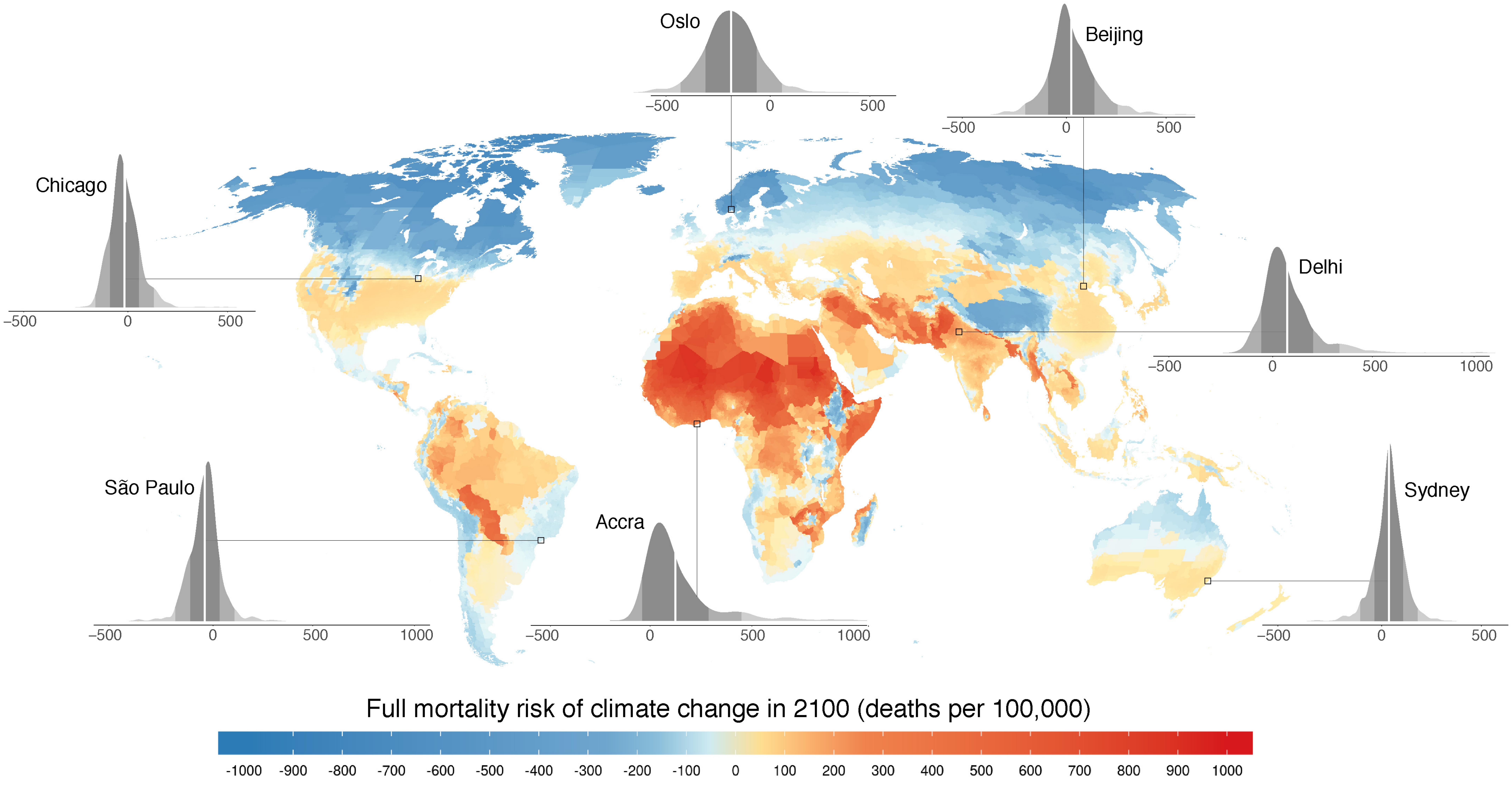
In this equation, α is a measure of the social valuation of different levels of consumption called the rate of inequality aversion. When α is 0, the utility function is linear and there is no social aversion to inequality; as α gets larger, the social welfare function becomes increasingly egalitarian.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

Output $[Q(t)]$ is given by a constant-returns-to-scale Cobb-Douglas production function in technology $[A(t)]$, capital $[K(t)]$, and labor, which is proportional to population

$$Q(t) = \Omega(t)A(t)K(t)^{\gamma}P(t)^{1-\gamma} \quad (3)$$

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

Nordhaus (Science,1992)



Carleton et al. (QJE, 2022)

This talk

- Recent Progress + Future Directions

- New Directions

- What might happen by 2030?

Recent progress

+ future directions

How does the climate affect economic activity and outcomes?

How does the climate affect economic activity and outcomes?

	Agriculture	Energy	Labor	Health	Trade	...	Twitter
Avg Temp	β	β	β	β	β	…	β
Avg Rainfall	β	β	β	β	β	…	β
Cyclones	β	β	β	β	β	…	β
Wild fires	β	β	β	β	β	…	β
....	…	…	…	…	…	…	…
Kurt(Rainfall)	β	β	β	β	β	…	β
Atlantic Multidecadal Oscillation	β	β	β	β	β	…	β

What we want to know

How does the climate affect economic activity and outcomes?

Recent Progress

	Agriculture	Energy	Labor	Health	Trade	...	Twitter
Avg Temp	β	β	β	β		…	β
Avg Rainfall	β	β				…	β
Cyclones				β		…	
Wild fires				β		…	
....	…	…	…	…	…	…	…
Kurt(Rainfall)	β					…	
Atlantic Multidecadal Oscillation						…	

What we actually know

How does the climate affect economic activity and outcomes?

Future Directions

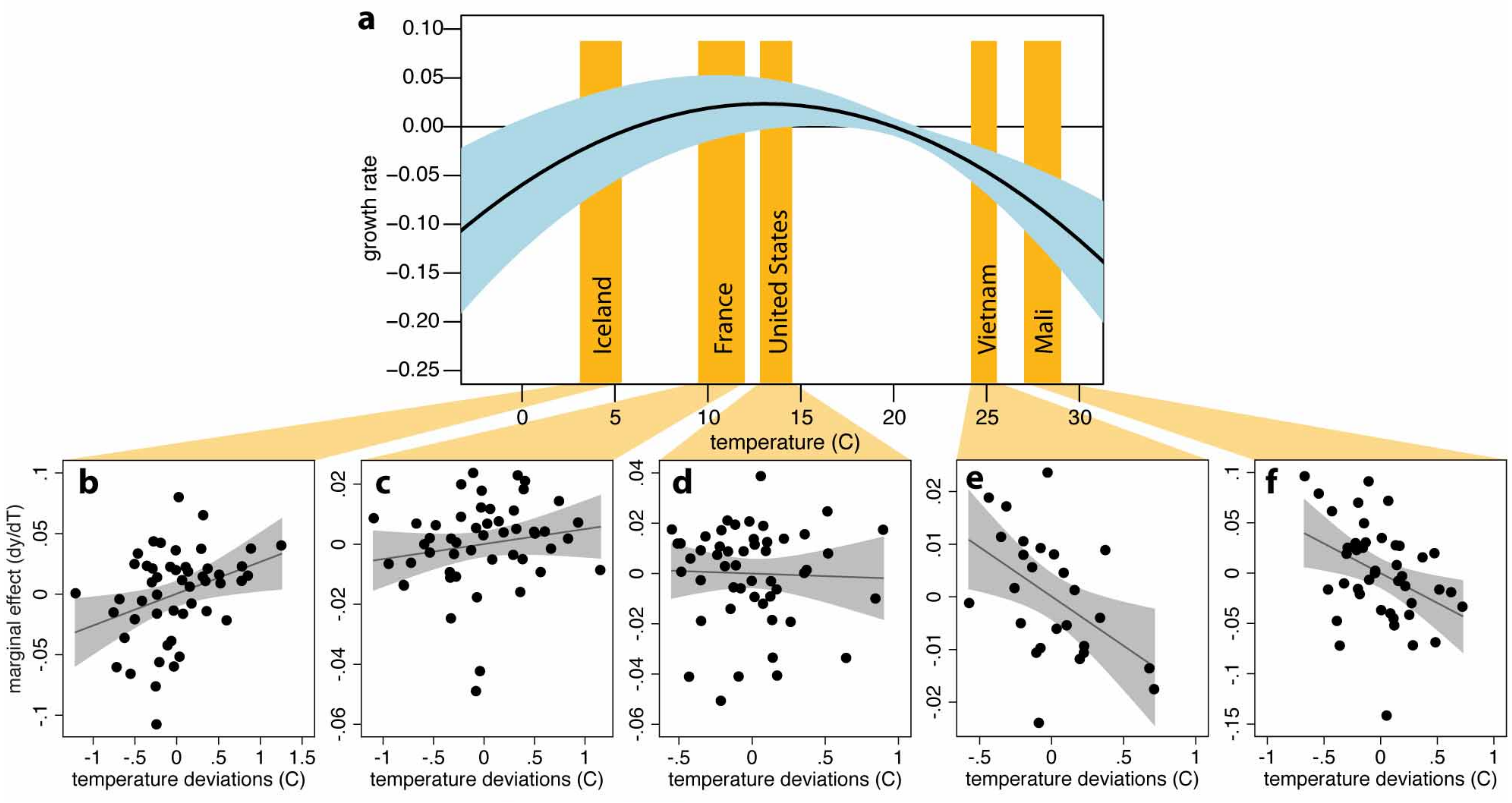
	Agriculture	Energy	Labor	Health	Trade	…	Twitter
…	…	…	…	…	…	…	…
Ecosystem responses						…	
Biodiversity	β					…	
Ocean Acidification						…	
Sea Level Rise						…	
Dust				β		…	
…	…	…	…	…	…	…	…

What we aren’t thinking much about

Climate change and economic growth

Climate change and economic growth

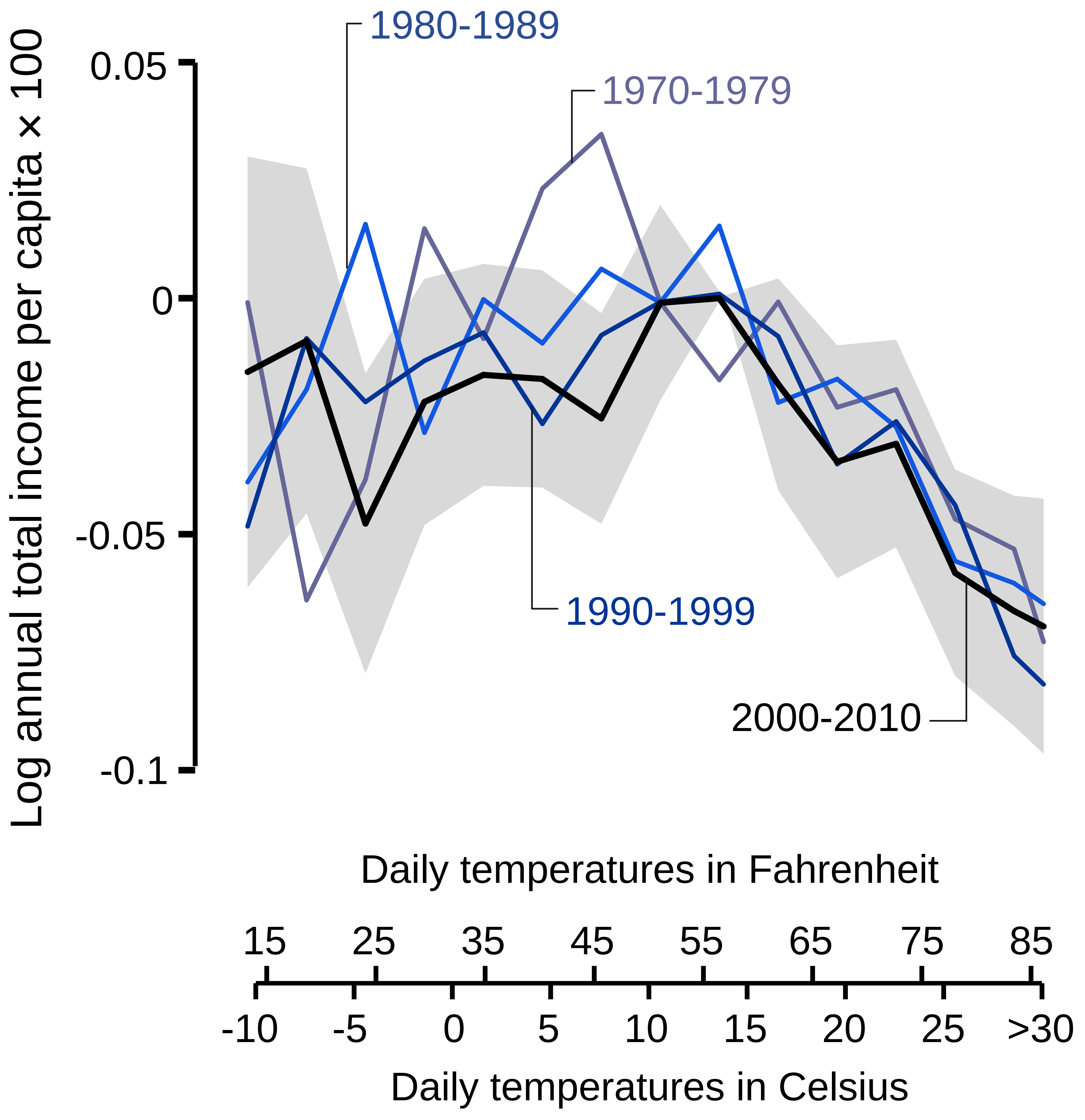
Recent Progress



Burke et al. (Nature, 2015)

Climate change and economic growth

Recent Progress

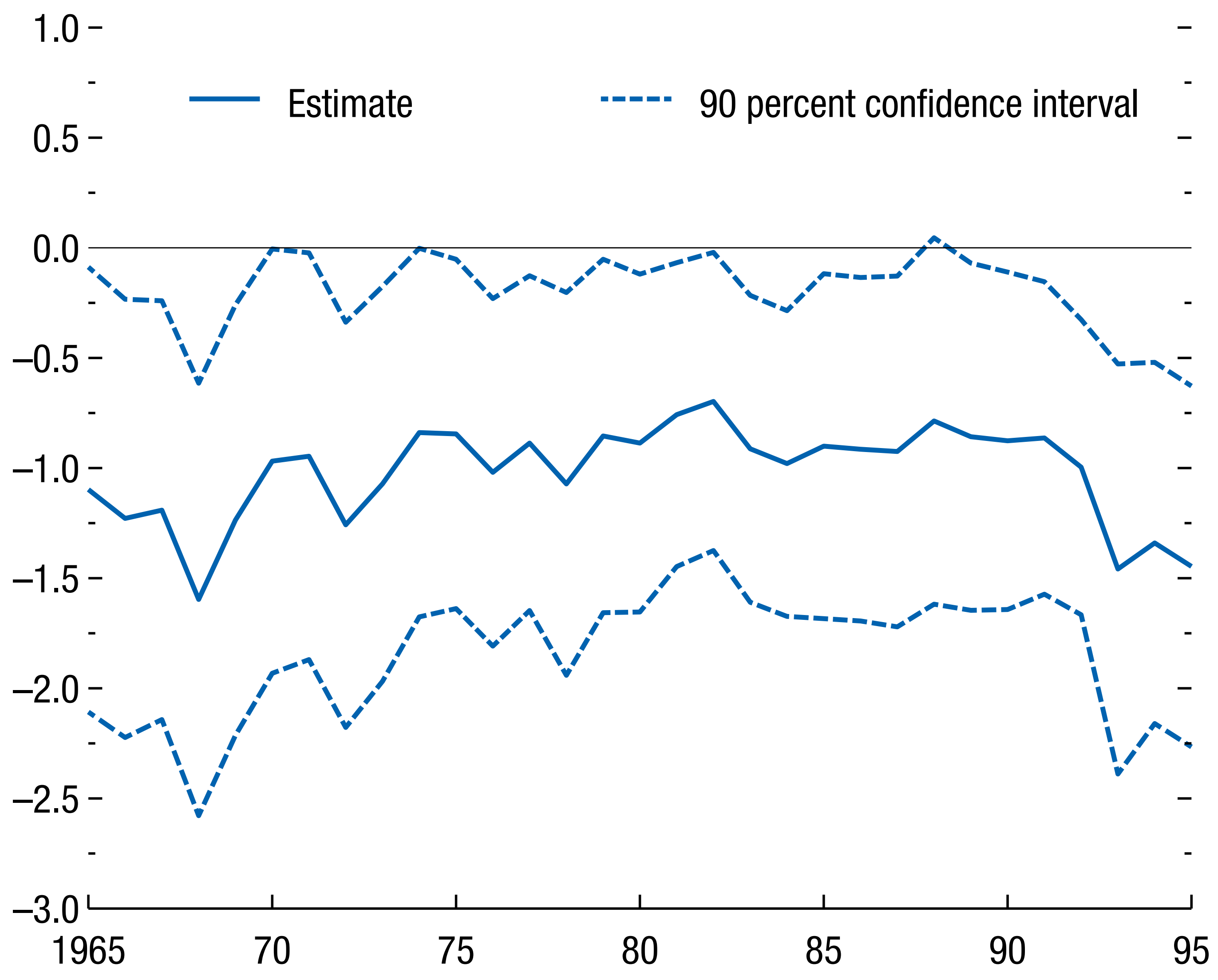


Deryugina & Hsiang (NBER, 2016)

Figure 3.11. Effect of Temperature Increase on Real per Capita Output Estimated at the Temperature of the Median Low-Income Developing Country over Time

(Percent; years on x-axis)

The contemporaneous effect of temperature shocks on per capita output has remained relatively constant over time.



Source: IMF staff calculations.

Note: The figure depicts the effect of a 1°C increase in temperature at horizon 0 estimated at the median low-income developing country temperature (25°C), over a 20-year rolling window. Each point estimate is for a period (t, t + 20).

IMF WEO (Oct 2017)

Climate change and economic growth

Future Directions

- What is going on?!

- Can all results be reconciled?

  Panel vs Cross Section

  Micro vs Macro

- How persistent are GDP effects? (80 yrs > 5 yrs)

- Can policy do anything to alter this linkage?

Social stability

Social stability

Recent Progress

Type of violence	**Institutional**	**Intergroup** – **more organized**	**Intergroup** – **less organized**	**Interpersonal**		**Intrapersonal**
Examples	institutional change population collapse civilization collapse	coups civil conflict civil war interstate conflict	riots ethnic expulsion land invasions	gang killings sports violence	homicide assault rape road rage	suicide
Selected literature	Haug et al (2003) Buckley et al (2010) Kuper & Kröpelin (2006)	Harari & La Ferrara (2018) Kim (2016) Burke et al (2009)	Hidalgo et al (2010) Bohlken & Sergenti (2010)	Larrick et al (2011) Baysan (2018)	Ranson (2014) Jacob et al (2007)	Carleton (2017) Burke et al (2018) Mullins & White (2019)

Baysan et al. (JEBO, 2019)

Social stability

Recent Progress

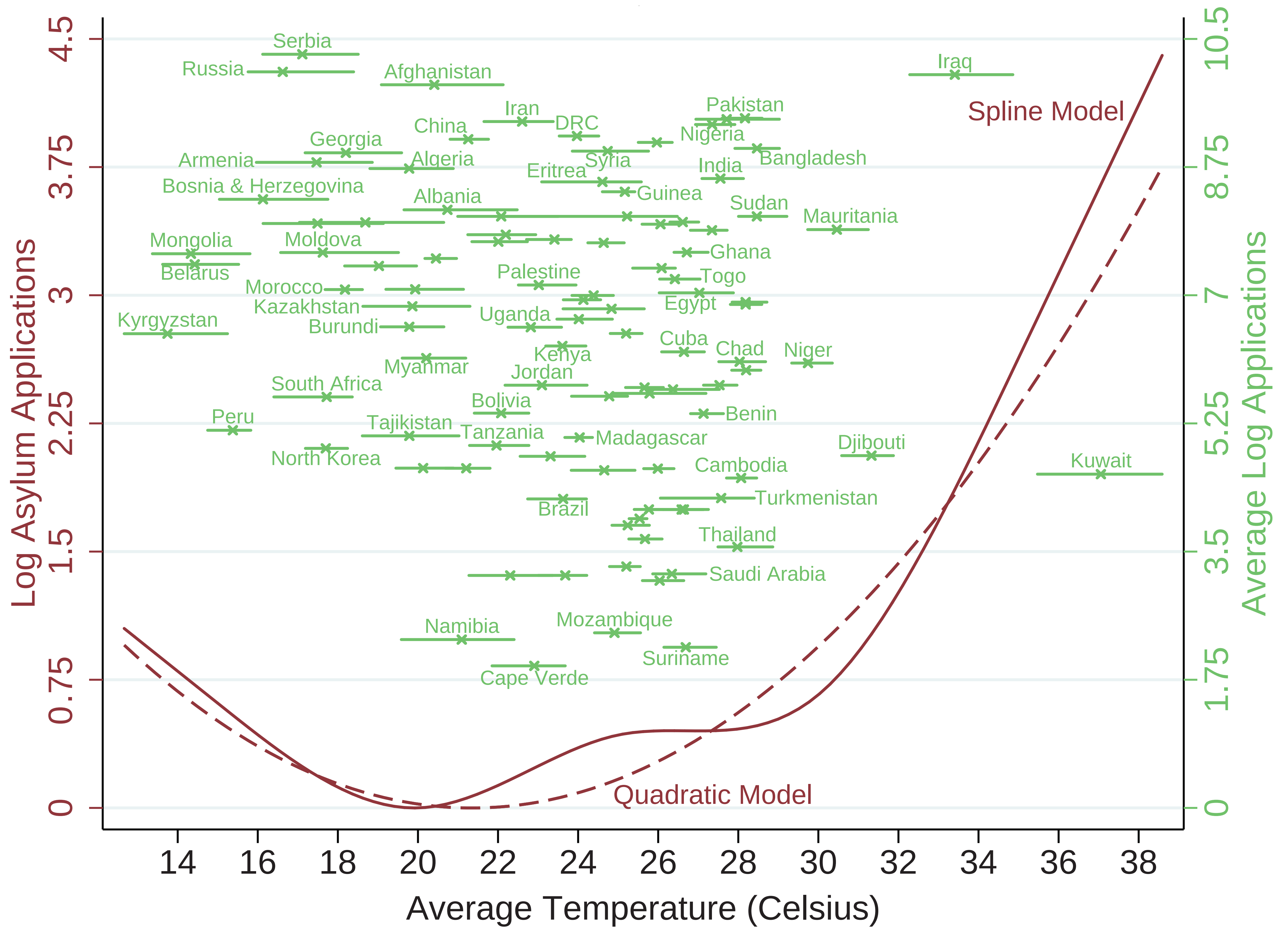
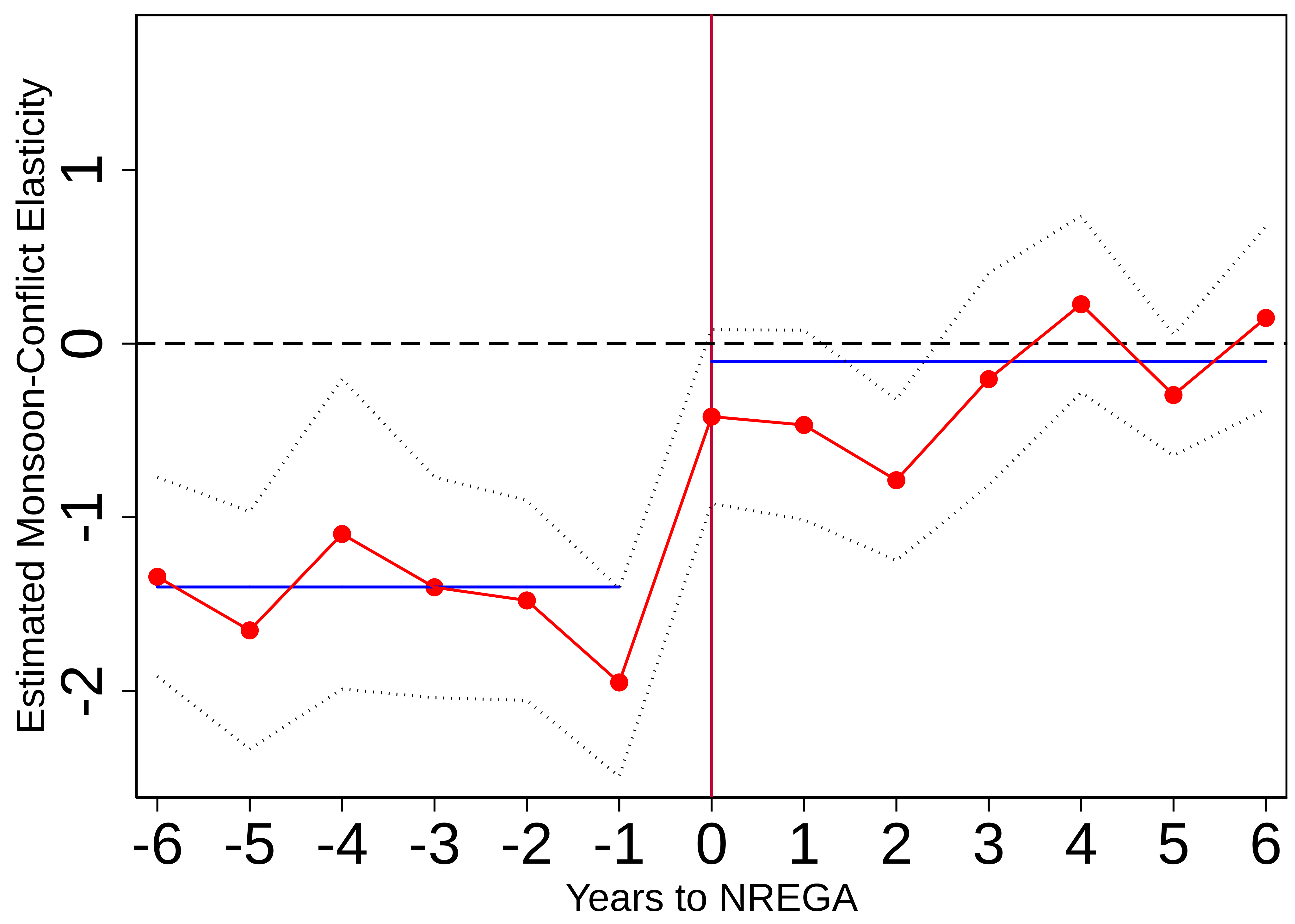


Fig. 1. Response of asylum applications to the EU with respect to the annual average temperature over the maize growing season.

Panel A: Total Number of Events



Missirian & Schlenker (Science, 2017)

Fetzer (JEEA, 2020)

Social stability
Future Directions

- What are the mechanisms?

  Economic vs. Gov’t capacity vs. Logistics vs. Psychology

- What is actually going to happen with migration?

- How have / will political systems respond?

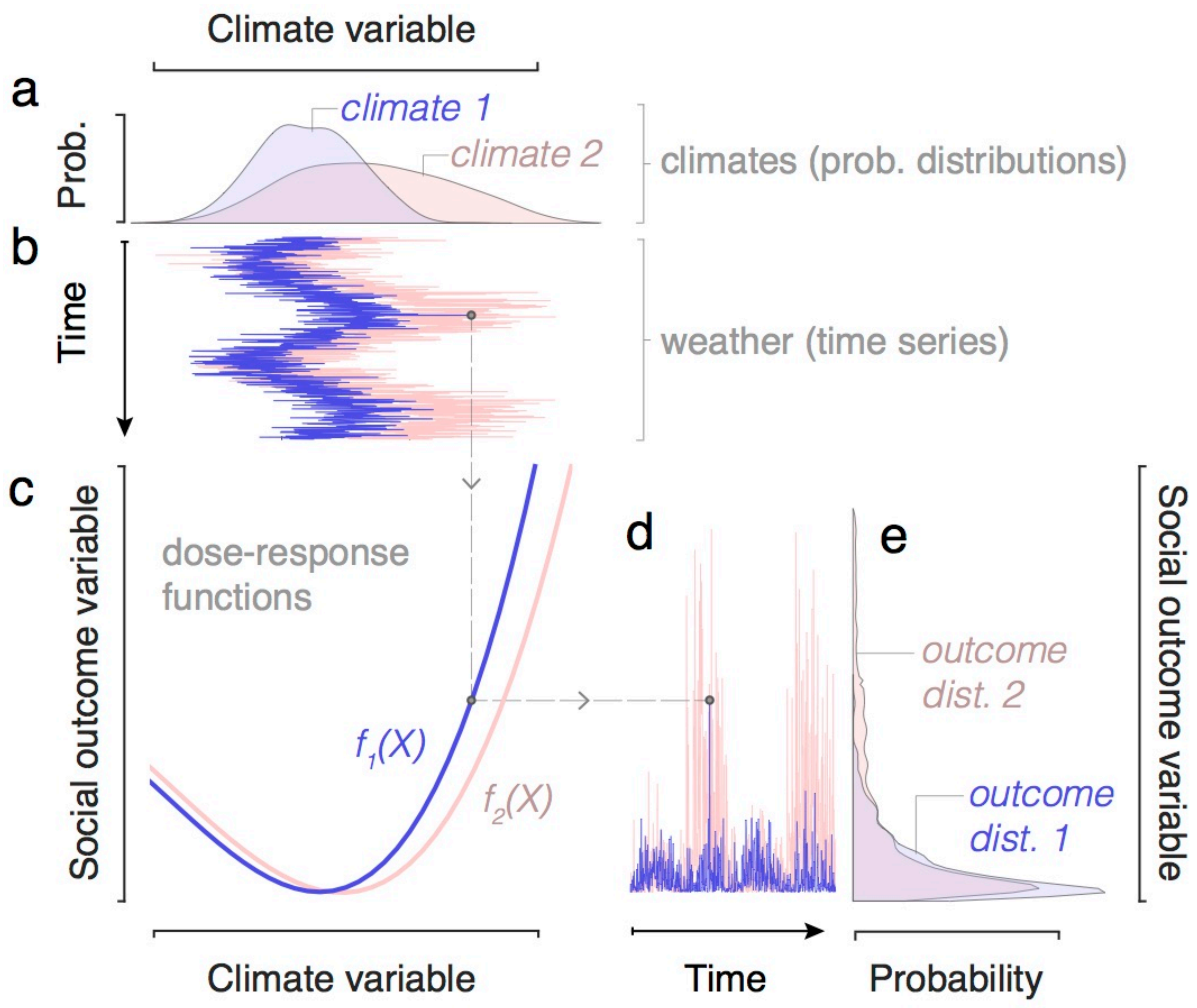
- What stabilizer policies can be deployed sustainably?

  Likely an important role for machine-learning

Adaptation

Adaptation

Recent Progress

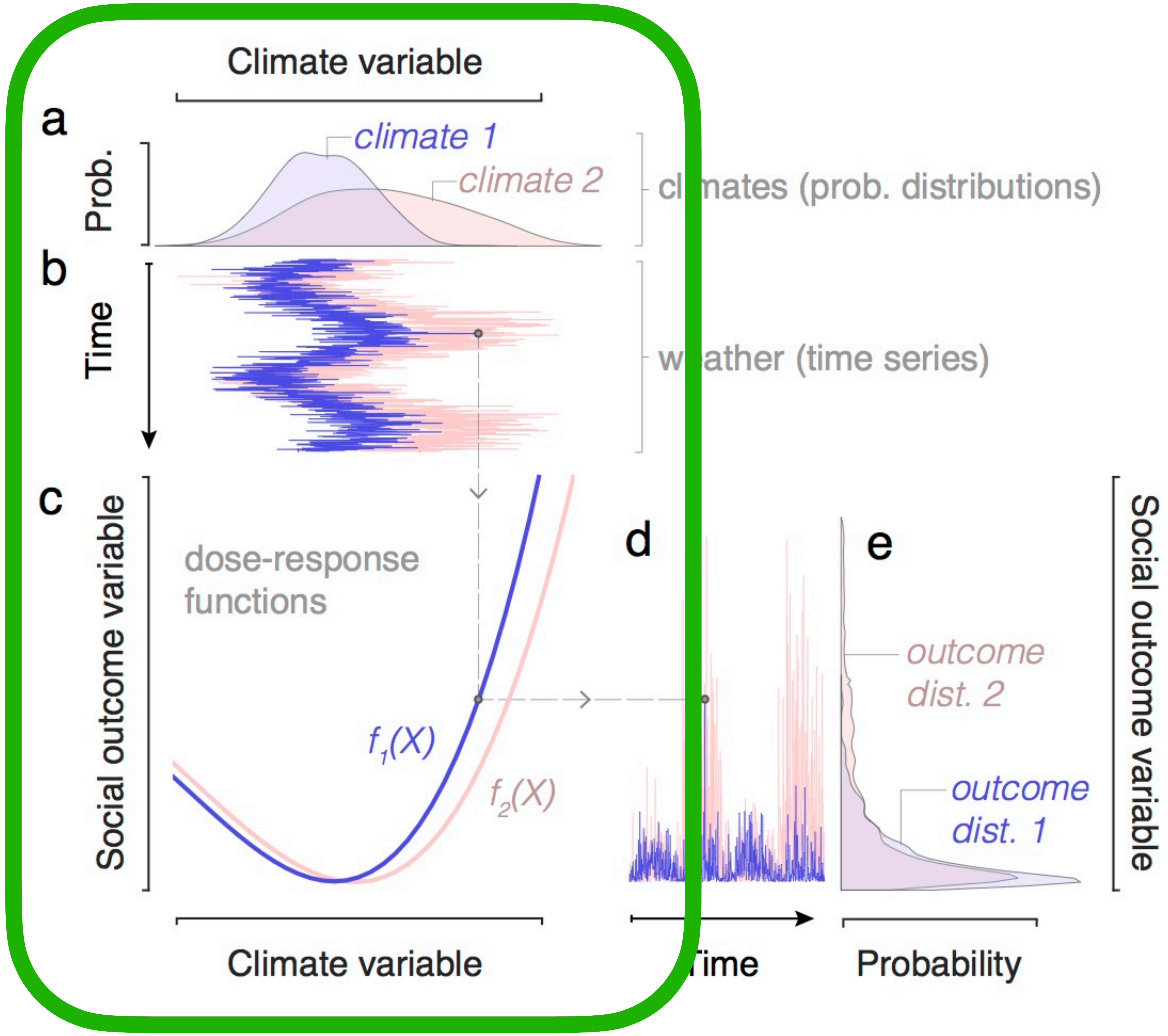


Carleton & Hsiang (Science, 2016)

Adaptation

Recent Progress

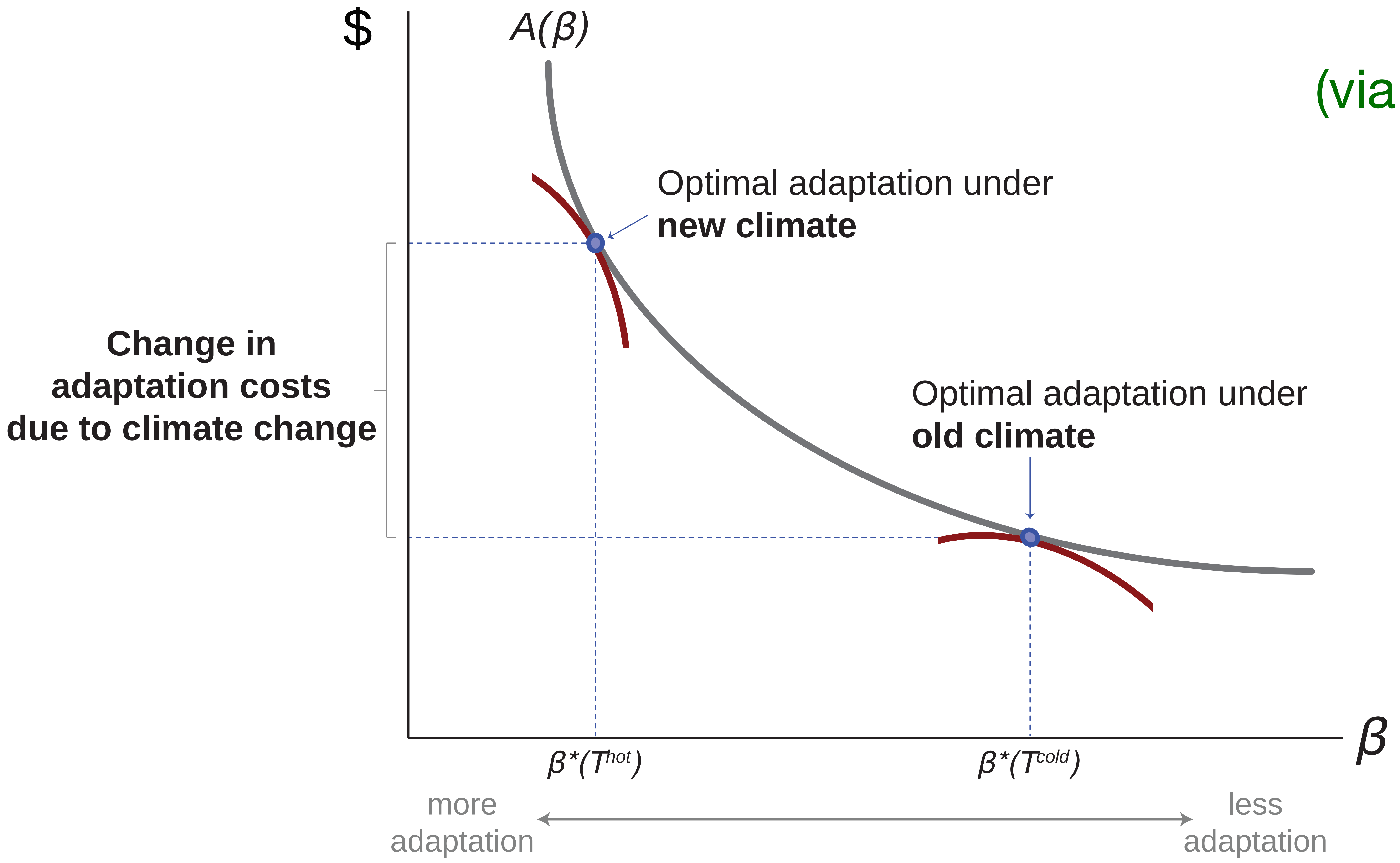
Adaptation benefits



Carleton & Hsiang (Science, 2016)

Adaptation

Recent Progress

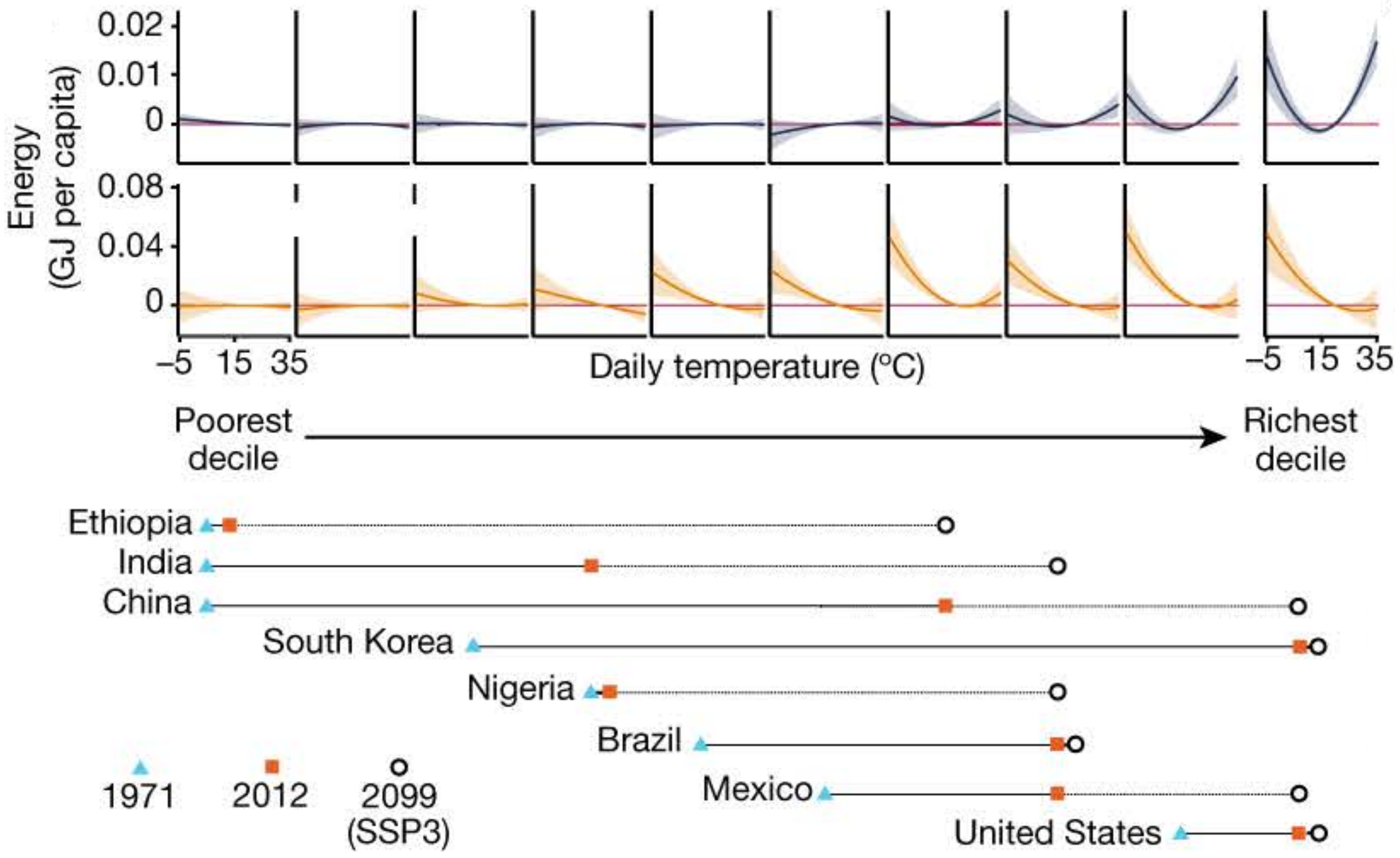


Adaptation costs
(via revealed preference)

Carleton et al. (QJE, 2022)

Adaptation

Recent Progress



Rode et al. (Nature, 2021)

Adaptation
Future Directions

- How much does the information known by agents matter?

  Currently, the “perfect information” assumption is doing a lot of work

- Must go beyond “mechanisms” (e.g. ‘income’) to understand actual actions (technologies + policies) that are effective.

- Can deployment of tech + policies be replicated and cost effective?

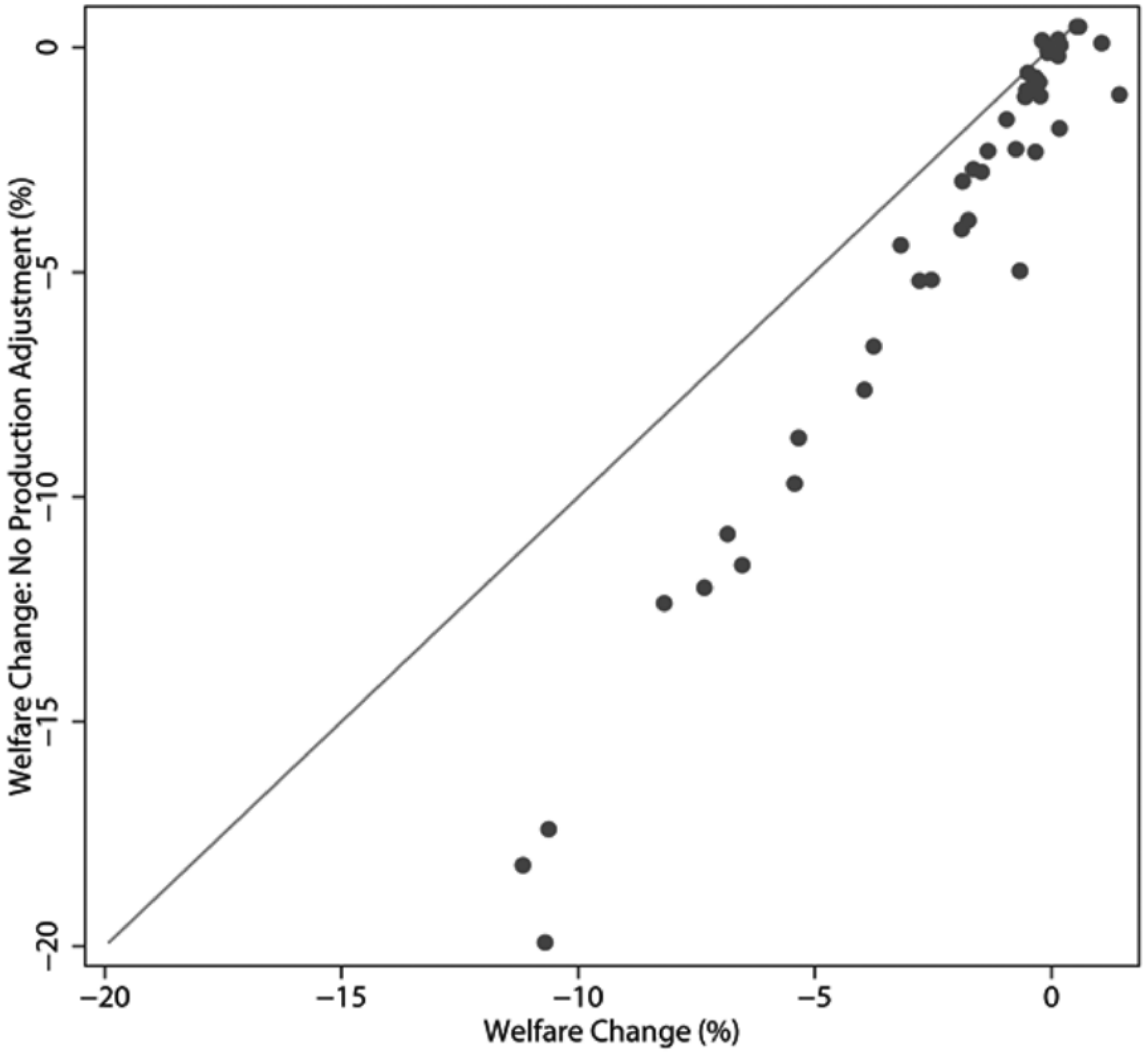
  Think: field experiments

- Decision-makers need practical guidance for planning that balances costs + benefits of investments

Trade

Trade

Recent Progress



Panel (a) – Full Adjustment vs. No Production Adjustment

Costing et al (JPE, 2016)

TABLE 2: CLIMATIC EFFECTS ON EXPORTS TO THE UNITED STATES BY 2-DIGIT PRODUCT CATEGORY

SITC code	Product category description	Coefficient	SE	T–stat	P–value
Panel A: Negative and Statistically Significant Products					
88	Photo equipment, watches, and clocks	−17.93	2.00	−8.98	< 0.001
02	Dairy products and eggs	−12.35	2.13	−5.81	< 0.001
61	Leather	−12.81	2.83	−4.53	< 0.001
85	Footwear	−19.31	4.28	−4.52	< 0.001
04	Cereals and preparations	−12.24	2.99	−4.09	< 0.001
63	Wood manufactures (excl. furniture)	−14.19	3.91	−3.63	< 0.001
89	Misc manufactured goods[a]	−10.33	2.88	−3.58	< 0.001
77	Electric machinery and appliances[a]	−10.19	3.03	−3.37	0.001
62	Rubber manufactures[a]	−10.79	3.21	−3.36	0.001
81	Plumbing, heating, and light fixtures	−17.84	6.30	−2.83	0.005
74	General industrial machinery[a]	−14.79	5.24	−2.82	0.005
65	Textile yarn and fabrics	−9.44	3.39	−2.79	0.005
08	Feeding stuff for animals	−14.26	5.56	−2.56	0.010
75	Office machines	−13.59	5.48	−2.48	0.013
71	Power generating equipment	−17.32	7.28	−2.38	0.017
69	Metal manufactures[a]	−6.65	2.85	−2.34	0.020
95	War firearms	−19.71	9.24	−2.13	0.033
83	Travel goods	−11.19	5.44	−2.06	0.040
11	Beverages	−8.97	4.43	−2.02	0.043
34	Gas	−22.20	11.22	−1.98	0.048
Panel B: Positive and Statistically Significant Products					
53	Dyes	20.57	10.25	2.01	0.045
21	Hides	37.66	11.24	3.35	0.001

Jones & Olken (AER, 2010)

Trade

Recent Progress

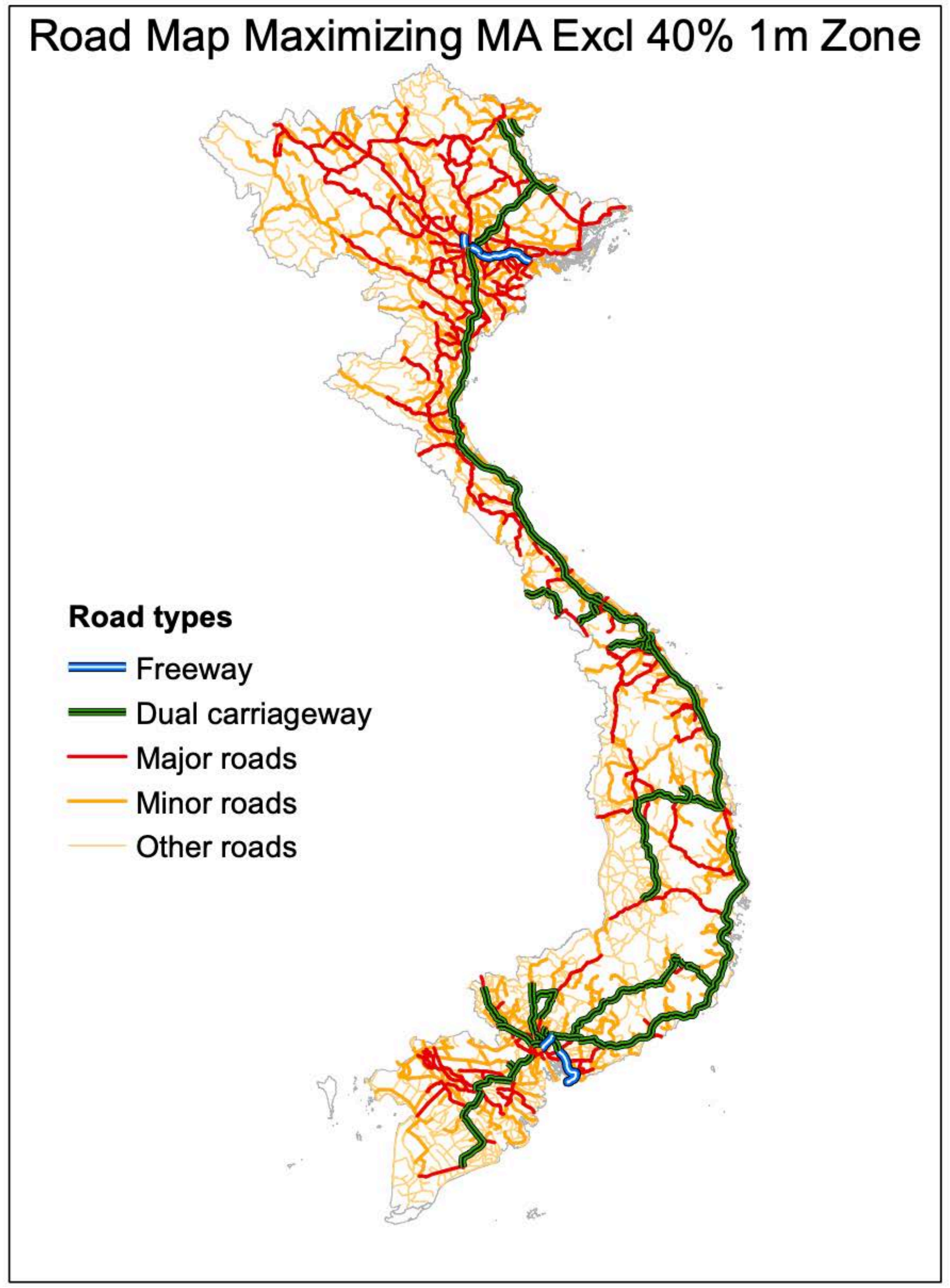
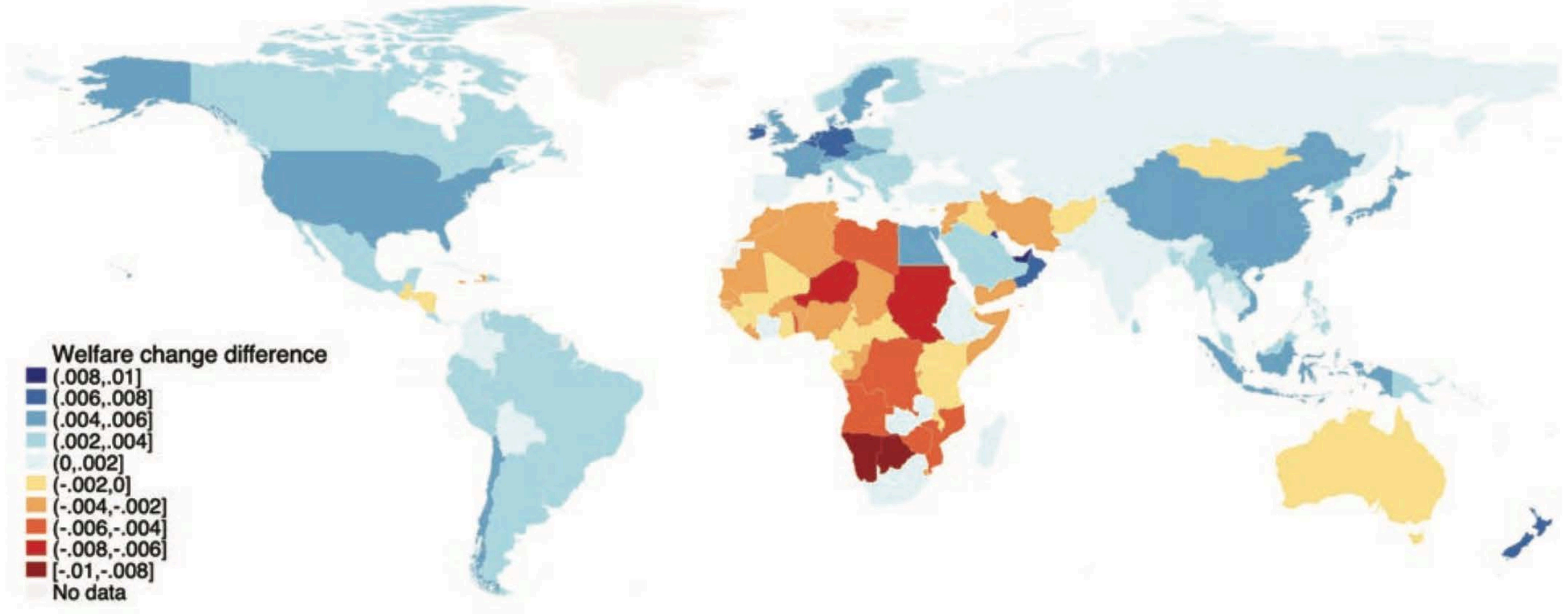


Figure 11: Differences in projected welfare changes due to change in spatial correlation (2013–2099)



Balboni (AER, R&R)

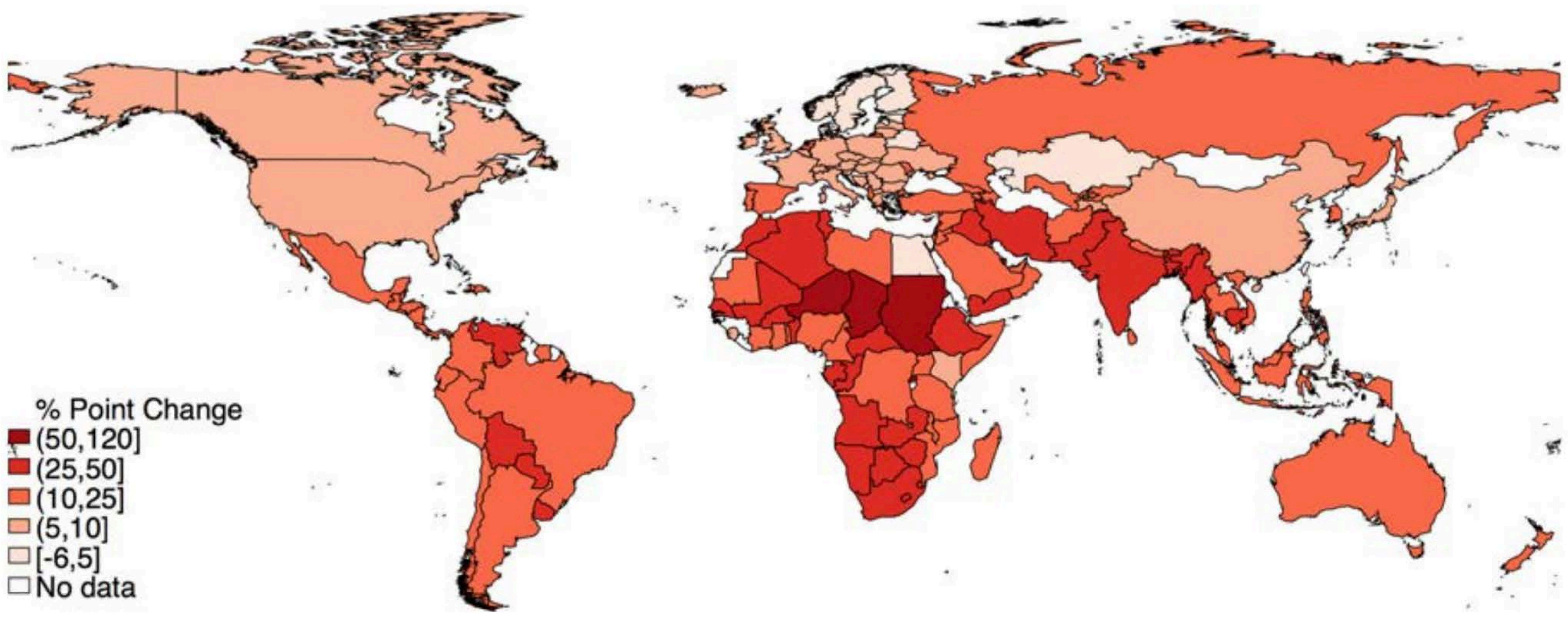
Dingel et al (NBER, 2021)

Trade

Future Directions

- What are the underlying costs that guide adjustments and control prices?
- Are there trade-related policies beyond openness that facilitate adaptation?
- Supply-chain design
- How to adjust infrastructure planning to guide location choice

Figure 12: Projected Percentage Change in Food Prices

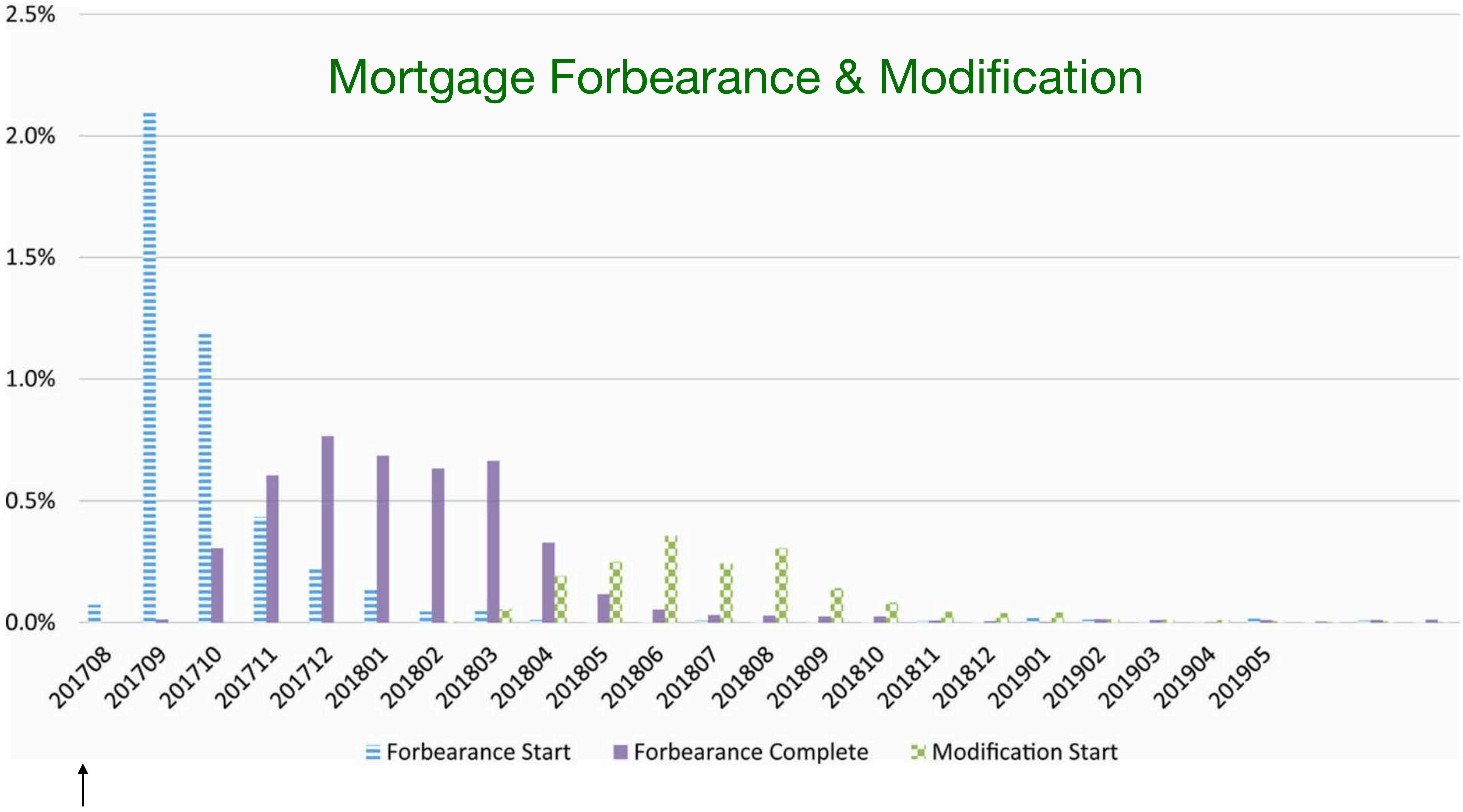


Nath (NBER, 2020)

Fiscal Planning

Fiscal Planning

Recent Progress



Hurricane Harvey

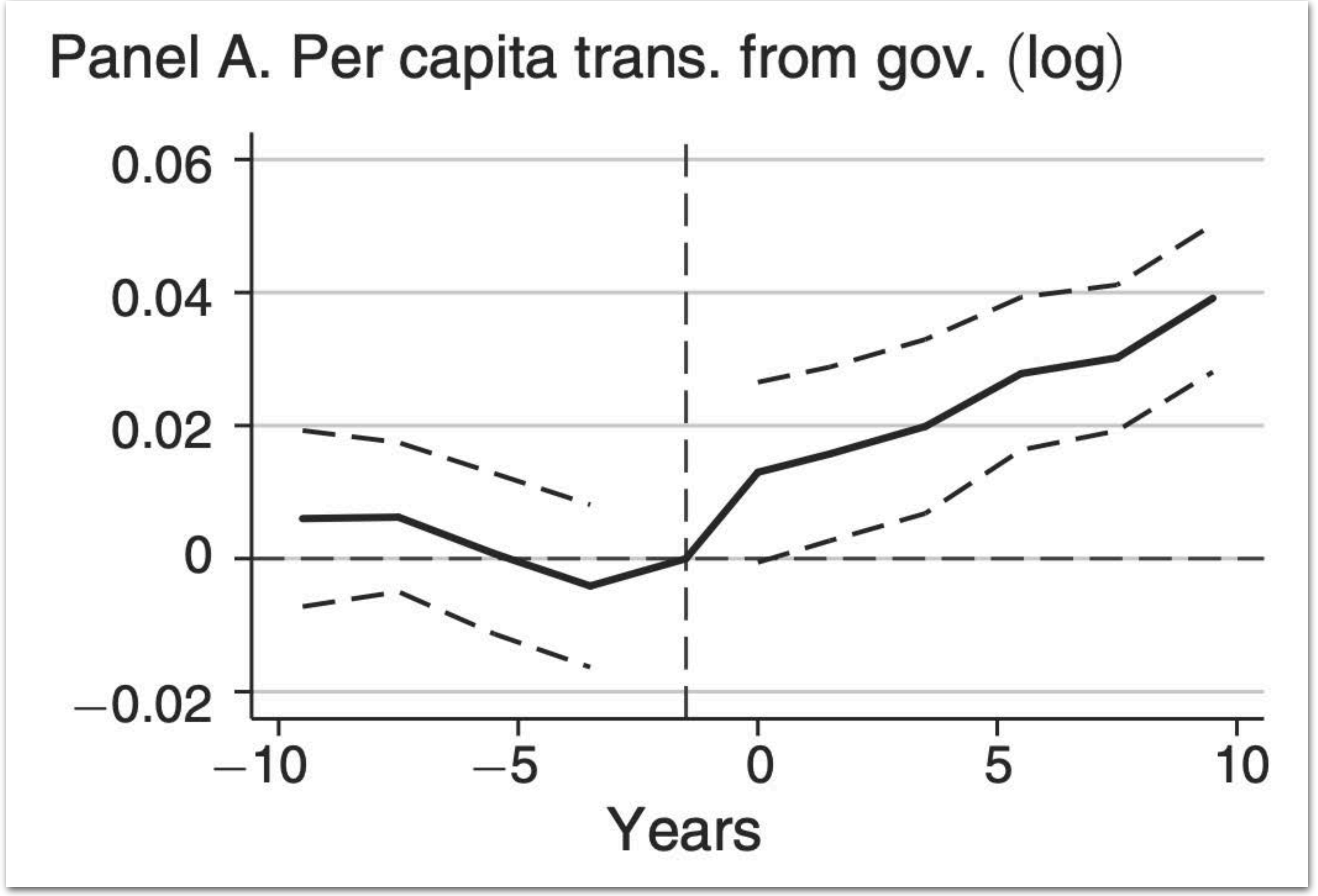
Kousky et al (JHR, 2020)

Fiscal Planning

Recent Progress

Table 2—Main Results: Fiscal and Welfare Impacts of Climate Policy

Policy scenario: Income taxes	Policy scenario: Carbon and energy	Capital tax τ_k	Labor tax τ_l	MCF	Public expenditures: Y-adapt. (%GDP)	Public expenditures: U-adapt. (%GDP)	Public expenditures: %ΔGov. cons.	Carbon tax ($/mtC) 2015	ΔWelfare
		Average 2025–2205							
First-best (i)	No[a]	0	0	1.00	0.65%	0.11%	1.1%	0	
	Opt.	0	0	1.00	0.22%	0.05%	0.8%	76	$21.7 tril.
Opt. (ii)	No[a]	3.5%[b]	42.7%	1.07	0.68%	0.09%	1.1%	0	
	Opt.	3.6%[b]	42.4%	1.06	0.24%	0.05%	0.8%	62	$23.3 tril.
Fixed $\bar{\tau}_l$, vary τ_k (iii)	No[a]	37.5%	38.4%	1.53	0.68%	0.07%	1.1%	0	
	Opt.	33.7%	38.4%	1.42	0.24%	0.04%	0.8%	51	$28.8 tril.
Vary τ_l, fixed $\bar{\tau}_k$ (iv)	No[a]	34.6%	38.9%	1.06	0.67%	0.09%	1.1%	0	
	Opt.	34.6%	38.5%	1.06	0.24%	0.05%	0.8%	61	$22.4 tril.



Hurricane

Barrage (AER, 2020)

Deryugina (AEJ Policy, 2017)

Fiscal Planning

Future Directions

- Comprehensive evaluation of existing support systems that “bear the weight” of climate-related costs.

  e.g. social insurance vs. private insurance vs. consumption vs. …

- What are the indirect consequences of myopic responses in the reallocation of public funds?

  e.g. reductions in funding for education / health investments

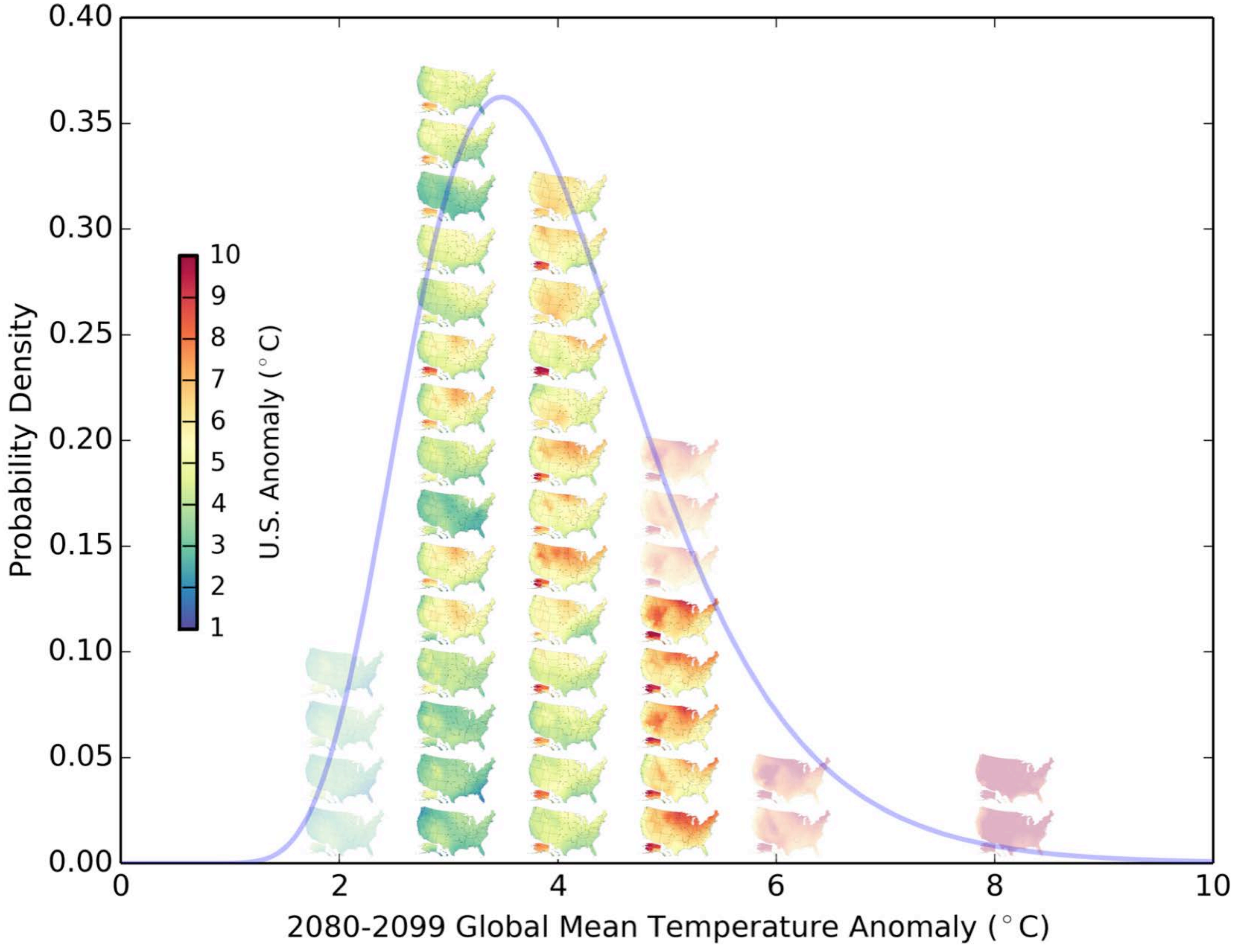
- How can / should budgets be indexed against climate change to improve fiscal sustainability?

- Should existing systems / programs expand to manage costs or should we design + deploy new ones?

Risk

Risk

Recent Progress

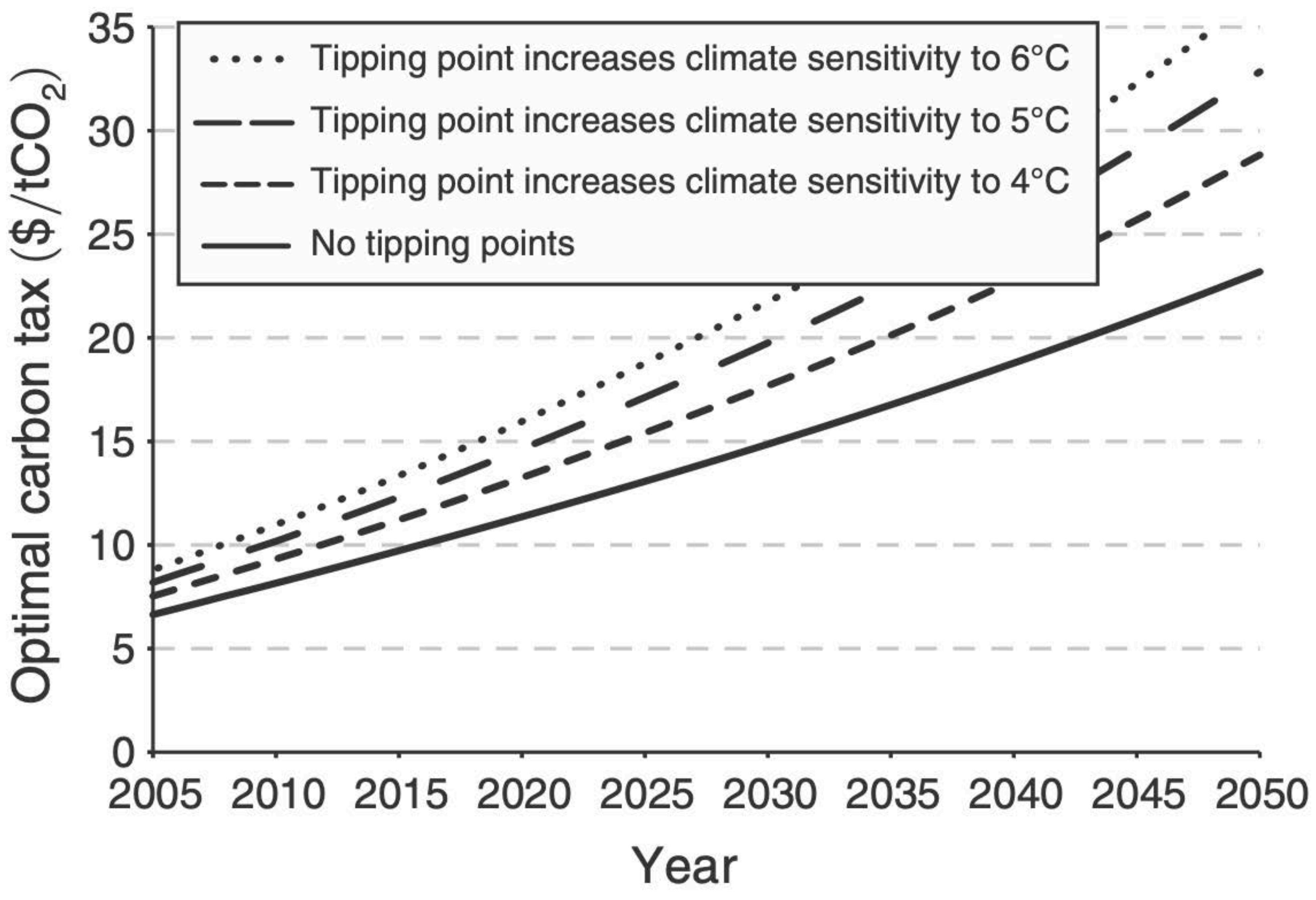


Hsiang et al. (Science, 2017)

Risk

Recent Progress

Panel A. Climate feedback tipping point



Lemoine & Traeger (AEJ: Policy, 2014)

V. The Dismal Theorem

Let $E[M|\lambda]$ represent the expected value of a stochastic discount factor $M(C)$ given by formula (3) when $C \geq D(\lambda)$ (or, equivalently, $Y \geq \ln D(\lambda)$) and given by $M(C) = (D(\lambda))^{-\eta}$ when $C < D(\lambda)$ (or, equivalently, $Y < \ln D(\lambda)$), where $D(\lambda)$ is defined by equation (16). The following "dismal theorem" (hereafter sometimes abbreviated "DT") shows under quite general circumstances what happens to the price of future consumption $E[M|\lambda]$ when λ might be *very* big.

Theorem 1. *For* **any given** *n and k,*

$$\lim_{\lambda \to \infty} E[M|\lambda] = +\infty. \quad (17)$$

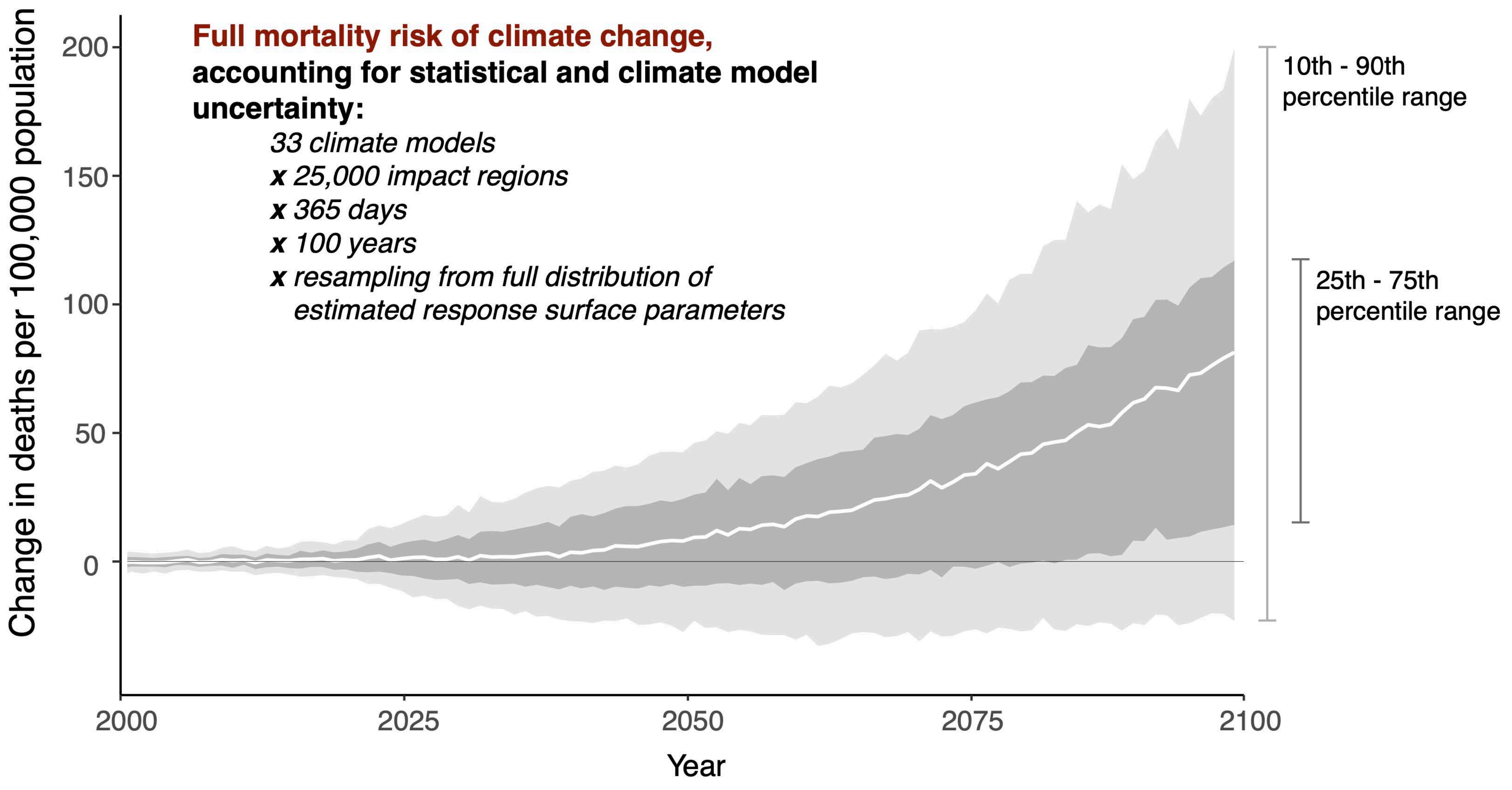
Weitzman (ReStat, 2009)

Risk

Future Directions

- Should different “flavors of uncertainty” be managed / valued using the same tools?
    - Parameter uncertainty
    - Scientific uncertainty
    - Uncertain state of the world

- How do we manage globally aggregate risk?

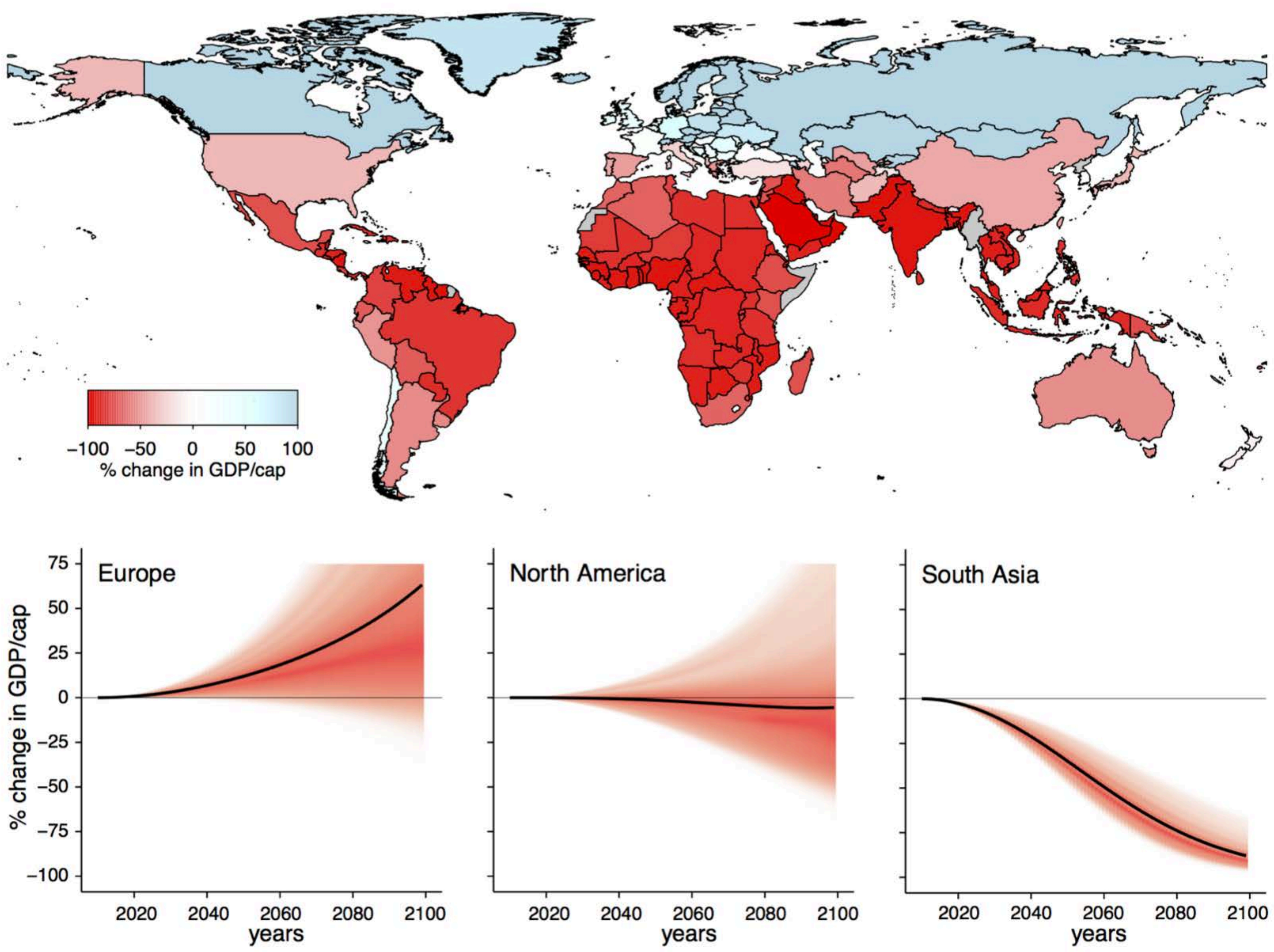


Carleton et al. (QJE, 2022)

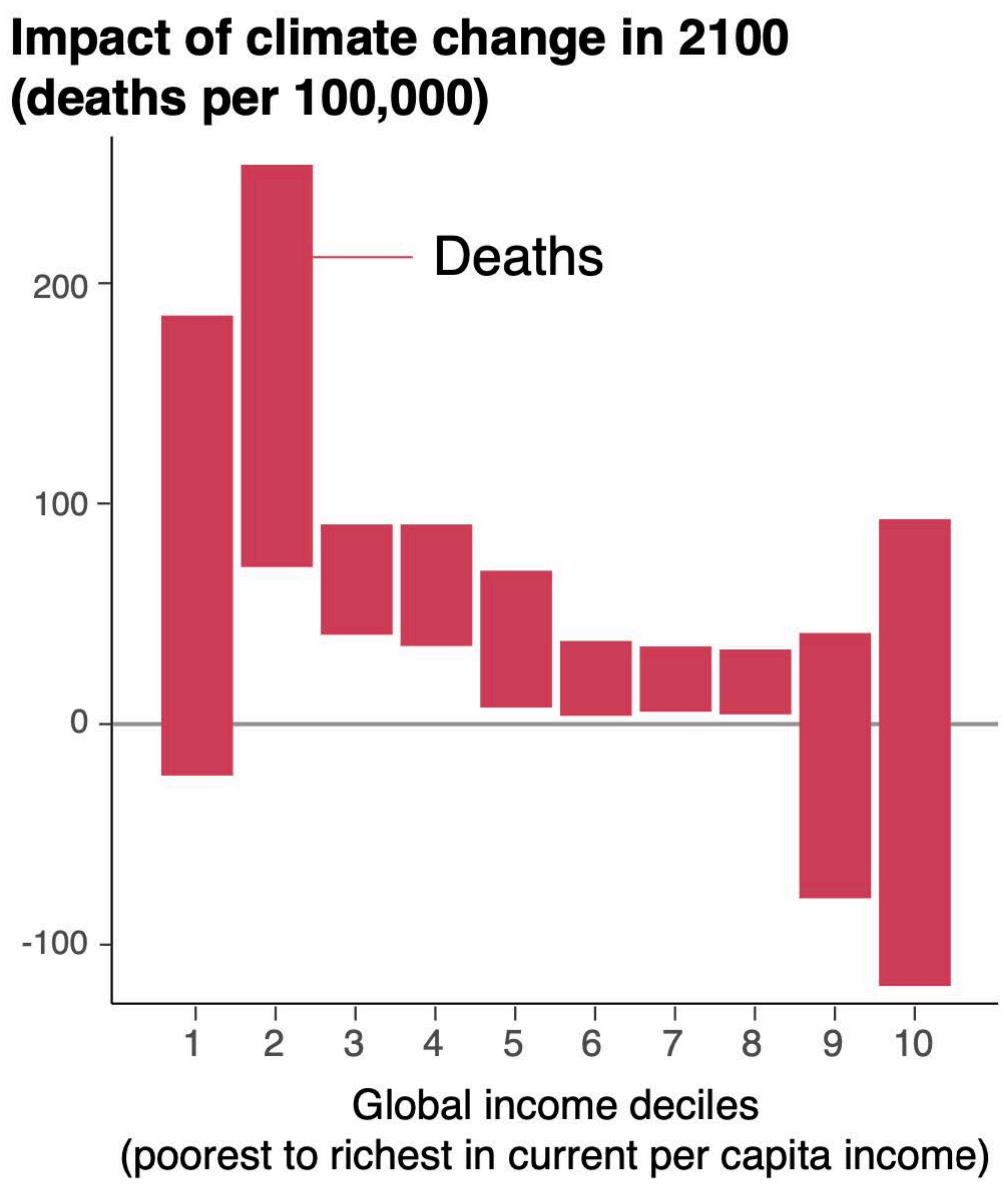
Inequality

Inequality

Recent Progress



Burke et al. (Nature, 2015)



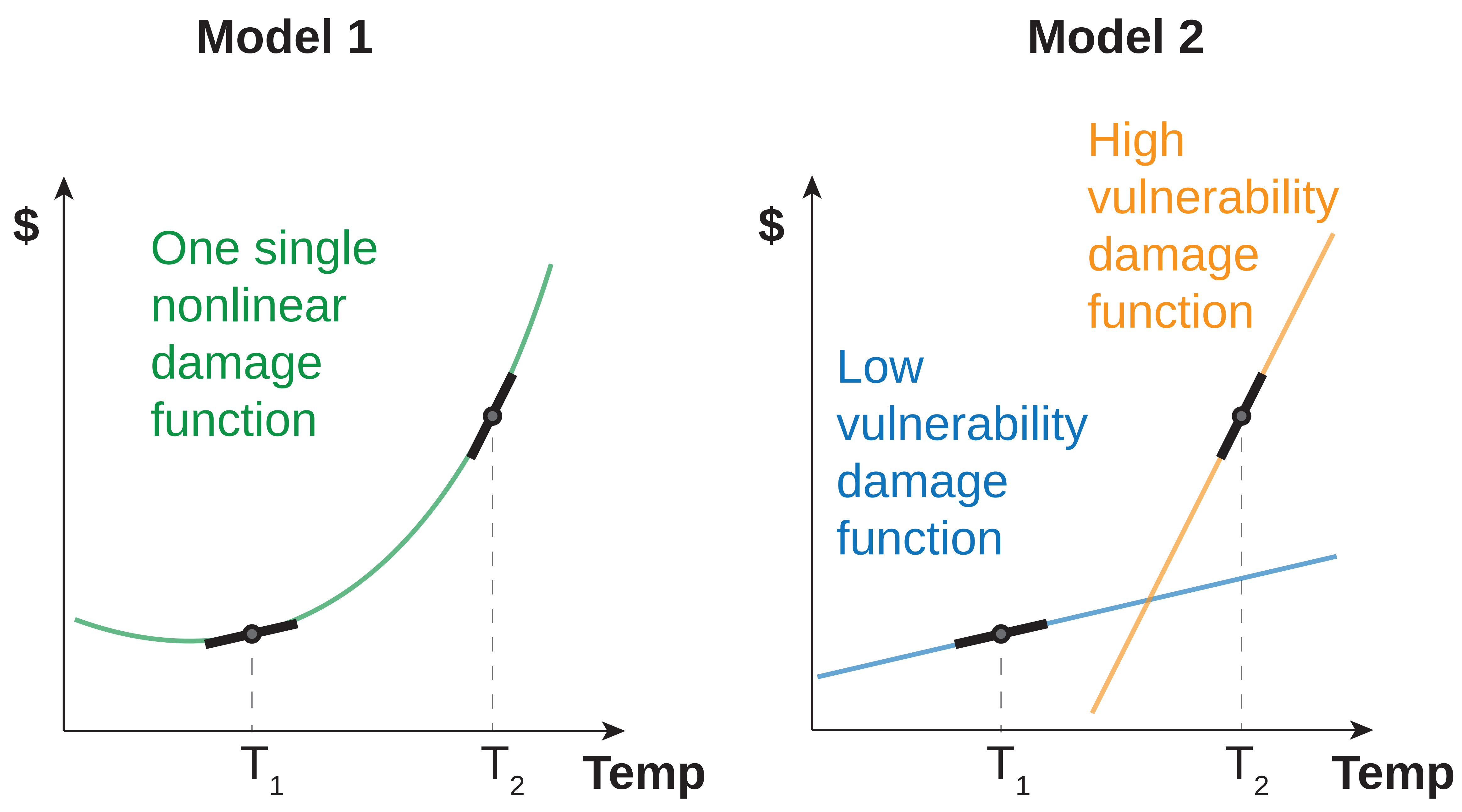
Carleton et al. (QJE, 2022)

Inequality

Future Directions

- Systematically identify causes of unequal effects
- Gradual extinction of representative agents
- Elimination of “Negeshi weights” from models (explicit down weighting of poor populations)
- Explicit discussion of how inequality is valued

Recall: discounting debates



Hsiang et al. (REEP, 2019)

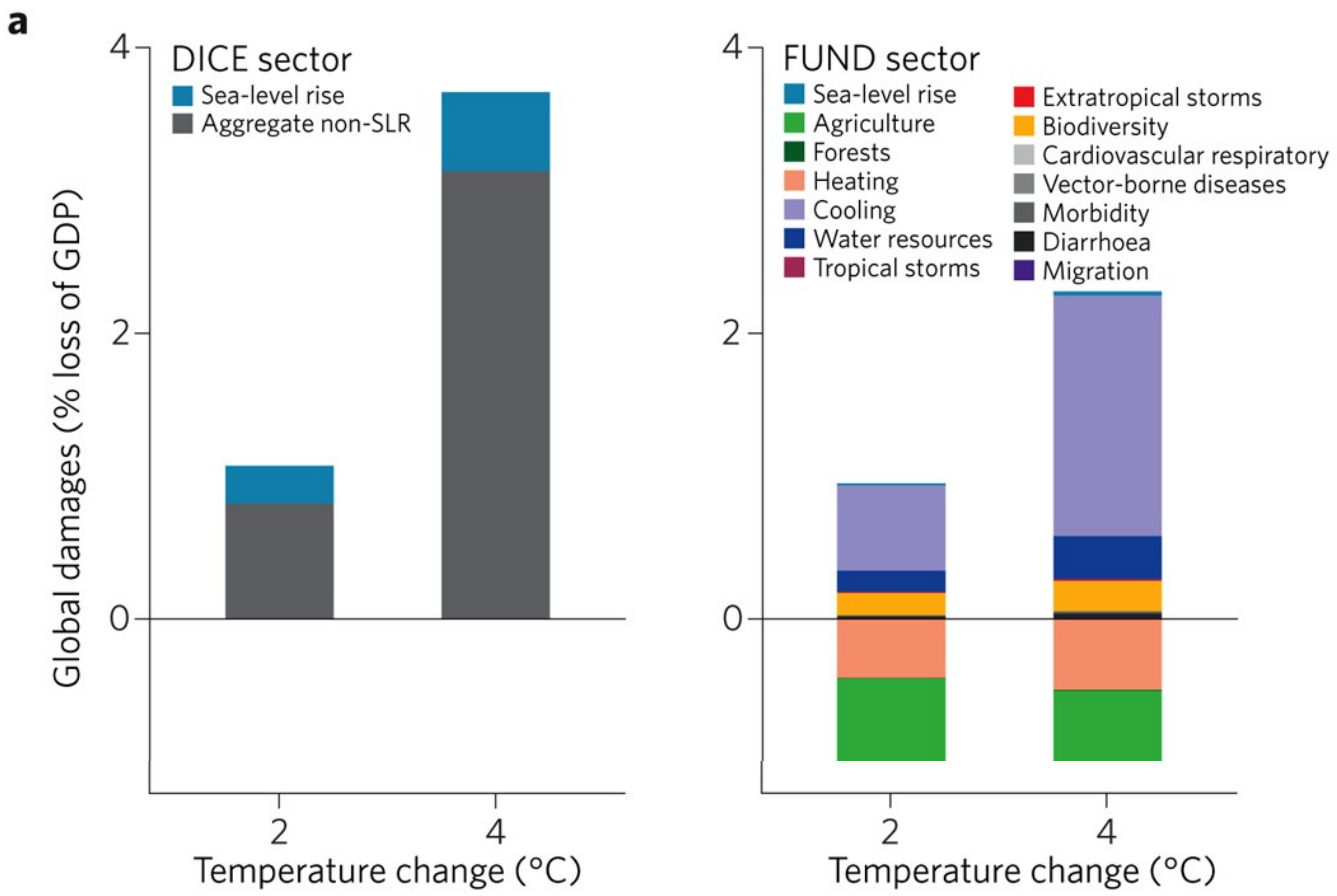
Integrated Assessment + Social Cost of Carbon

Integrated Assessment + Social Cost of Carbon

Recent Progress

DICE (1992)
1 region

FUND (1996)
16 region

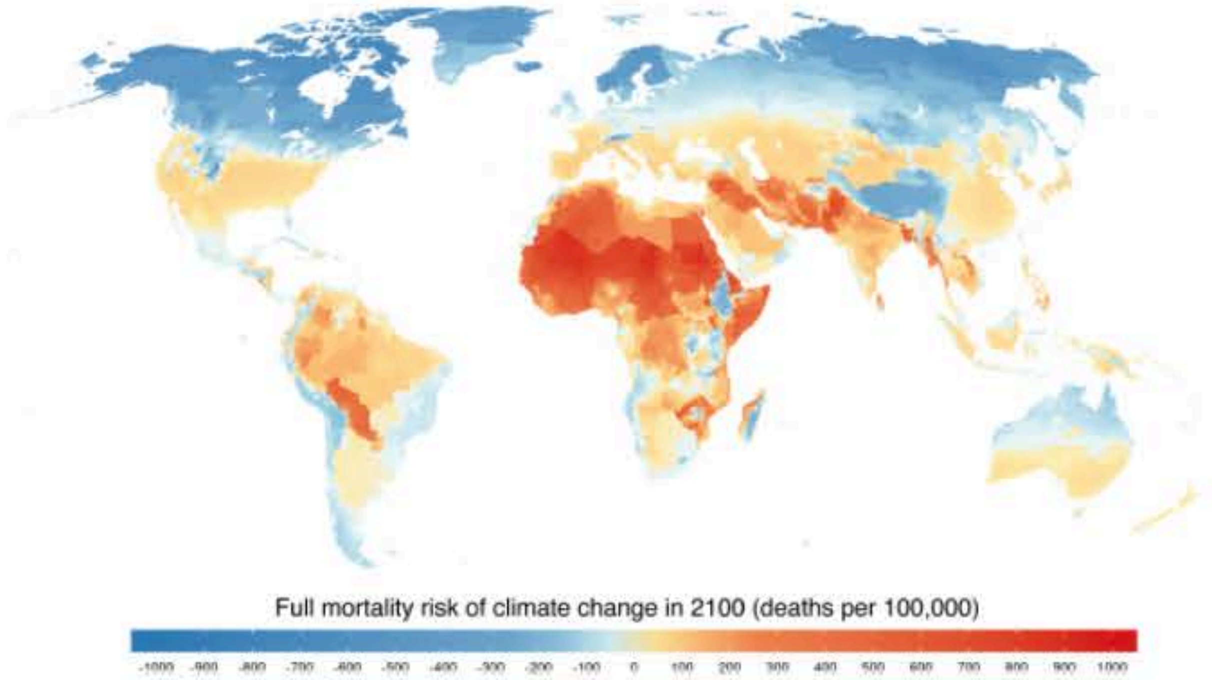


Diaz & Moore (Nature Climate Change, 2017)

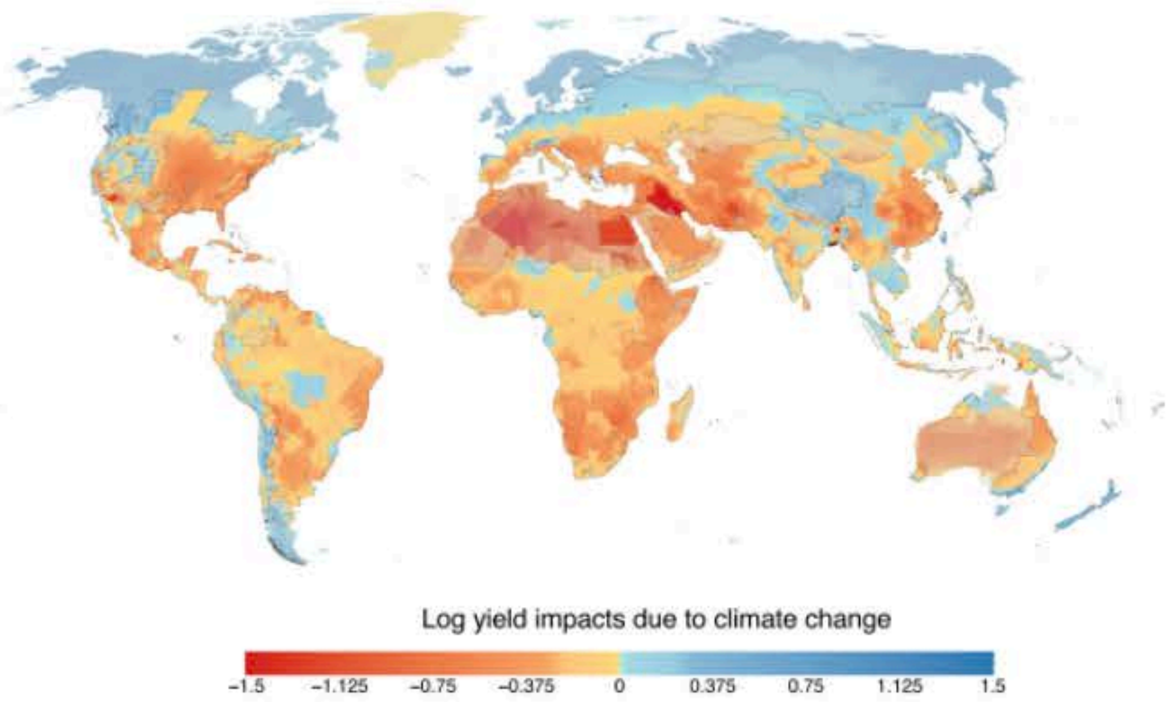
Integrated Assessment + Social Cost of Carbon

Recent Progress

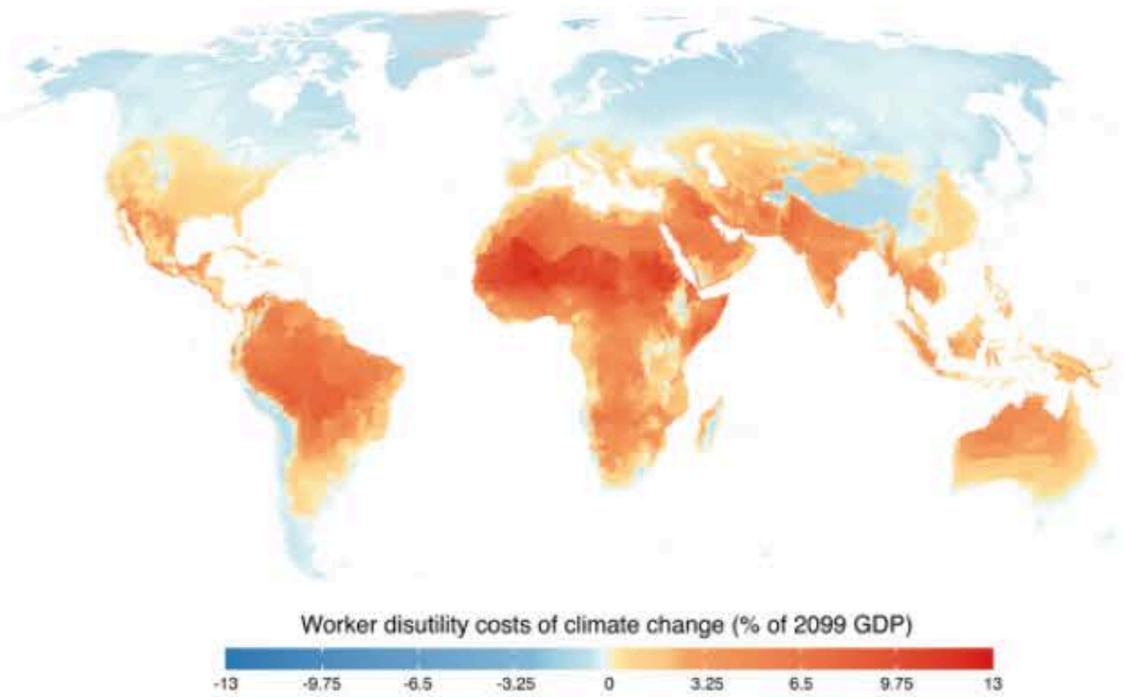
All Cause Mortality



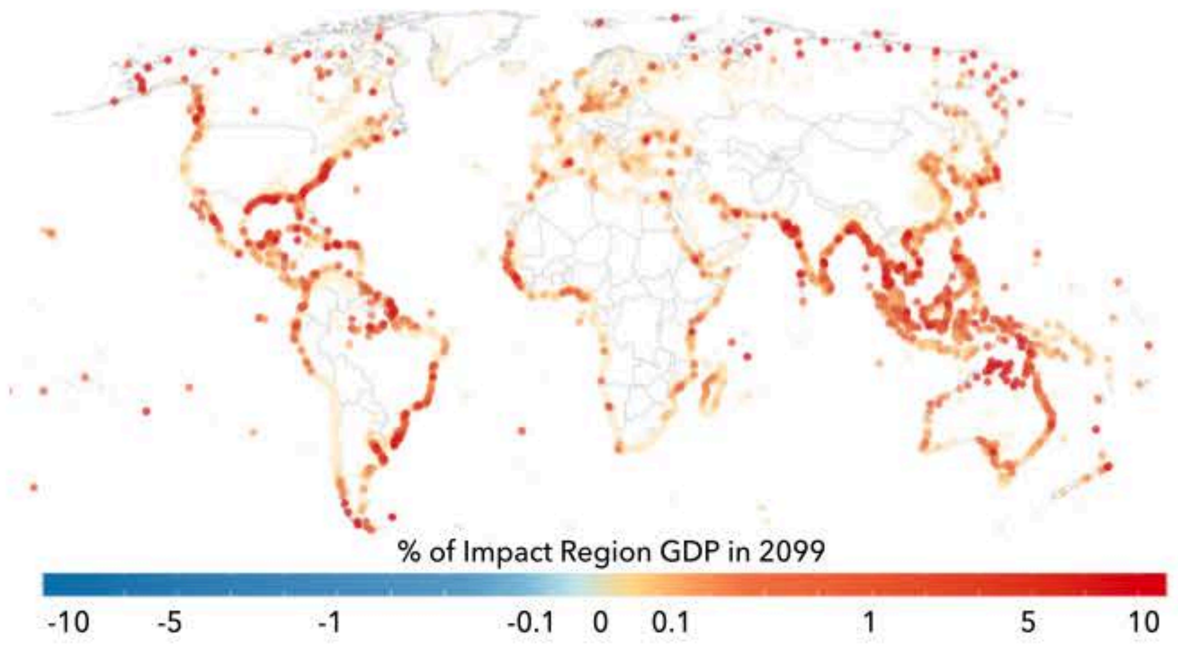
Agriculture (e.g. Maize)



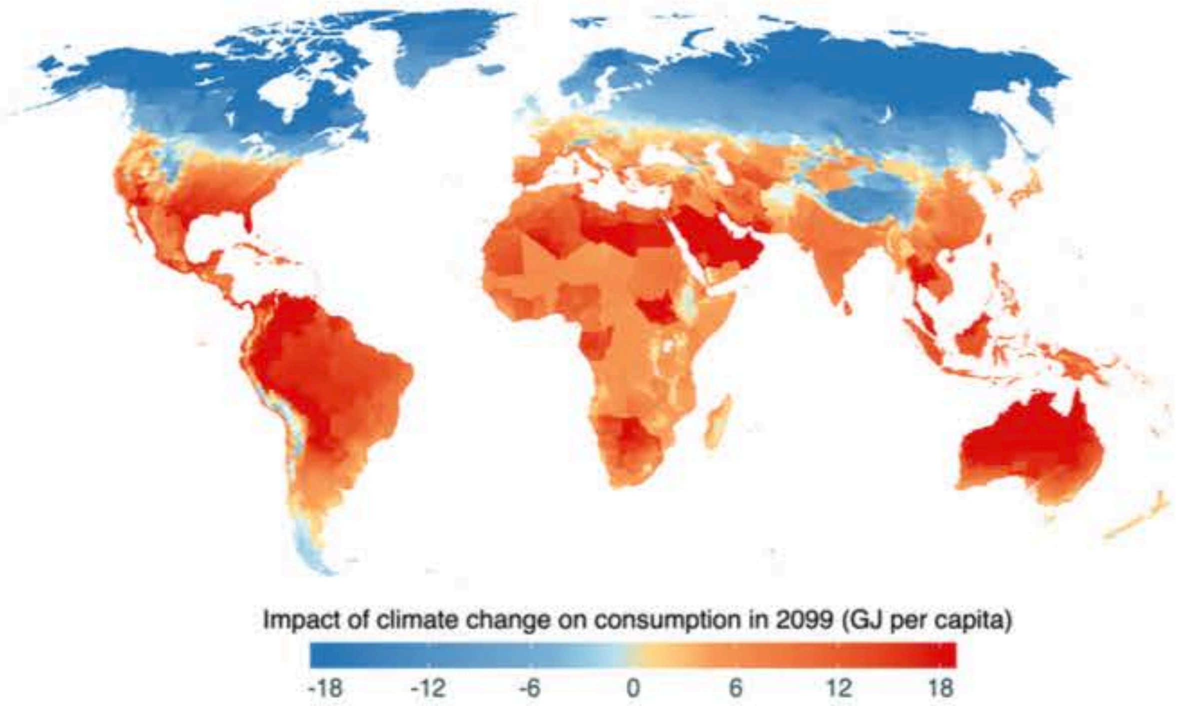
Labor



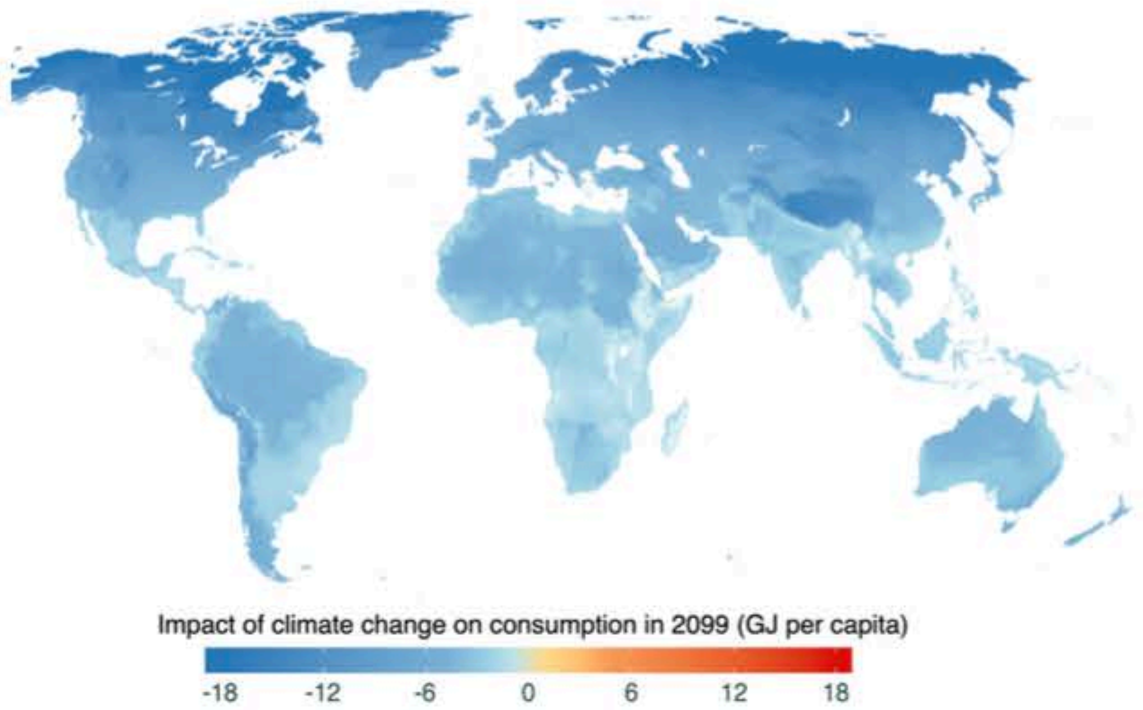
Sea Level Rise



Electricity



Other Fuels

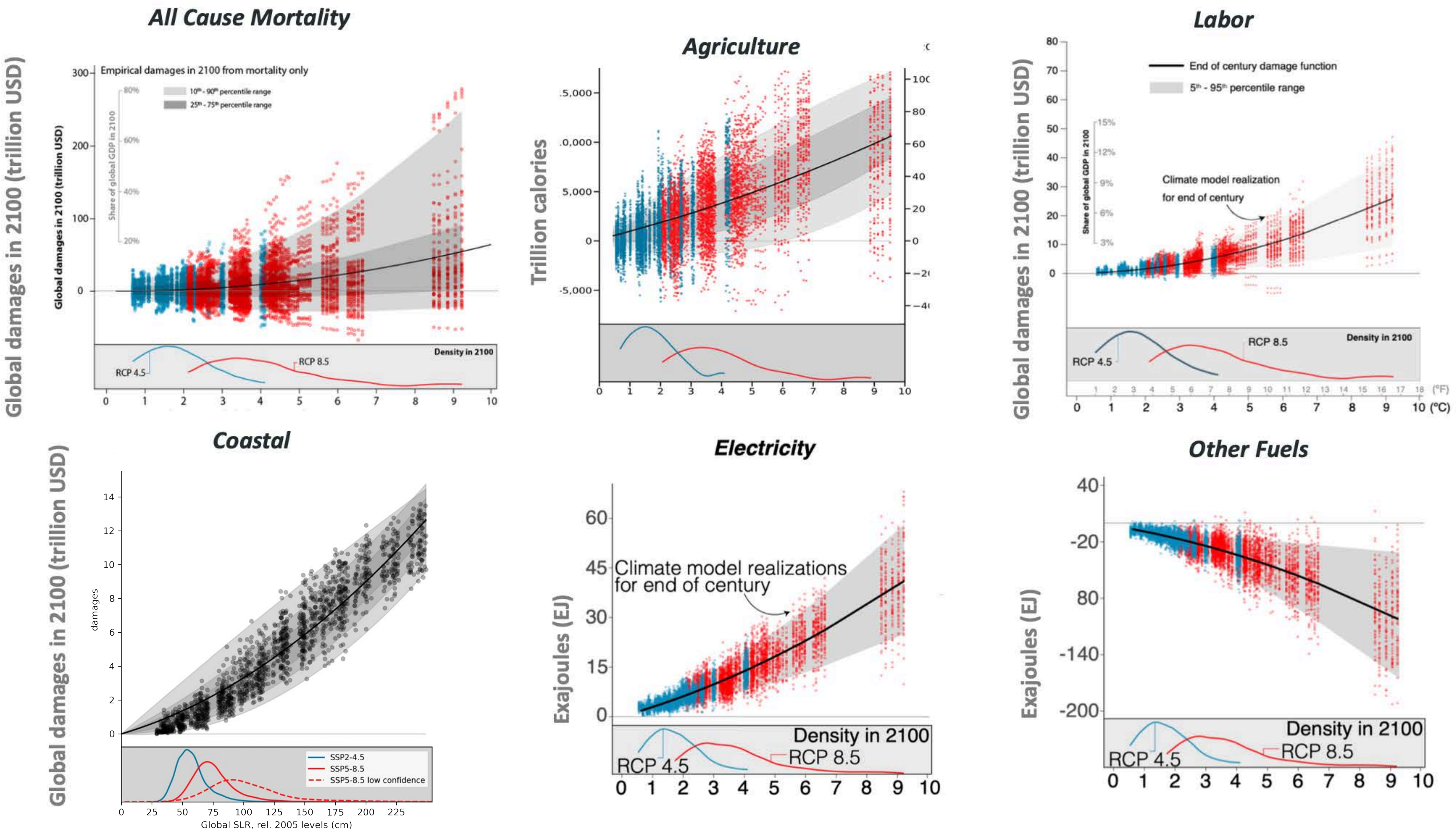


Rode et al (Nature, 2021), Carleton et al (QJE, 2022), Depsky et al (GMD, 2022), Hultgren et al (2022), Rode et al (2022)

Integrated Assessment + Social Cost of Carbon

Recent Progress

Damages scaled to change in GMST (°C above 2001-2010 average), change in GMSL (cm relative to 2005)



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Integrated Assessment + Social Cost of Carbon

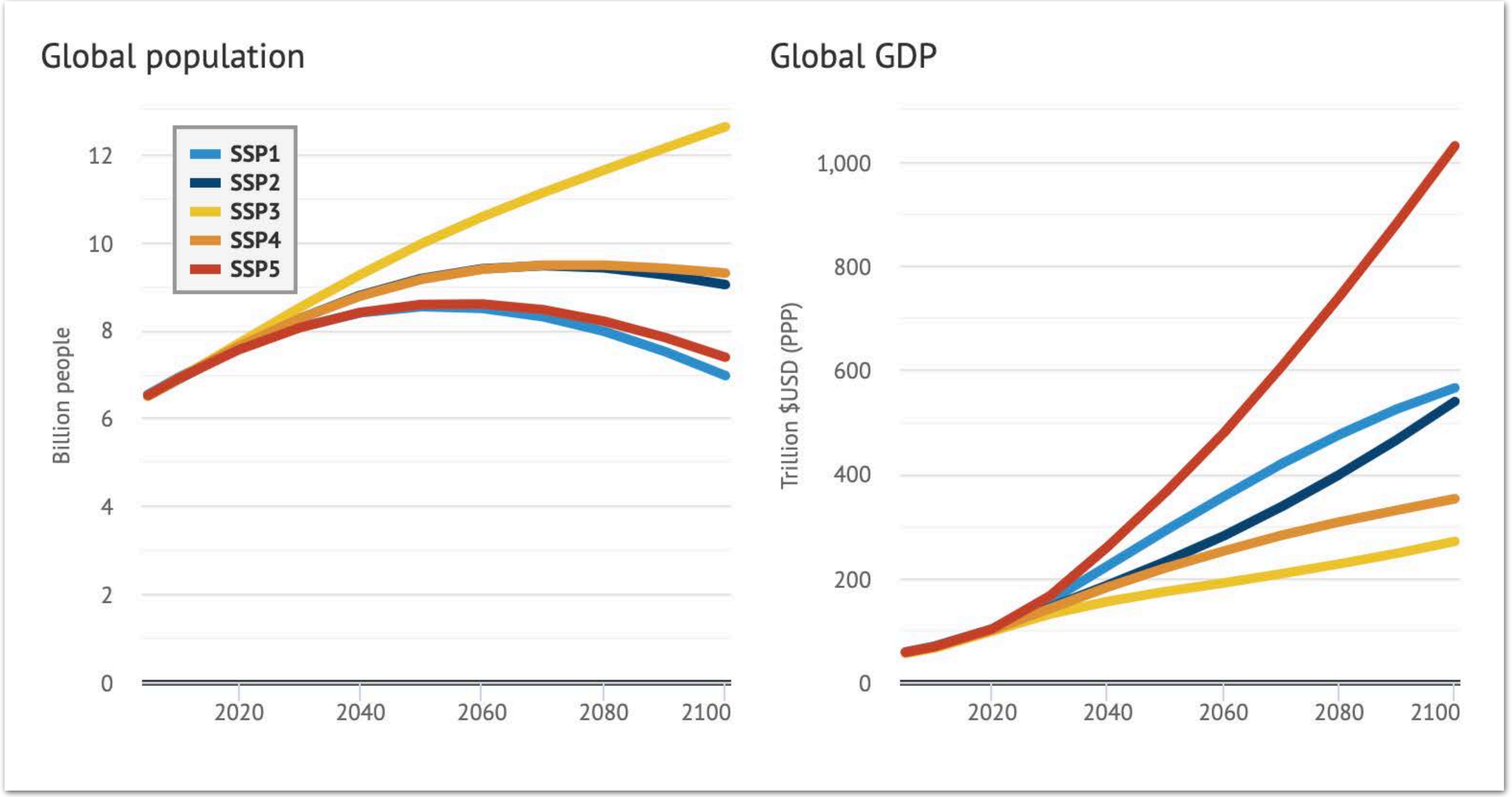
Future Directions

- Simultaneously valuing inequality and uncertainty
- Systematize updating of the SCC
- Practical international harmonization
- Integration with UNFCCC concept of “Loss & Damage”

New Directions for Research

Long-term Economic Projections
(New Directions)

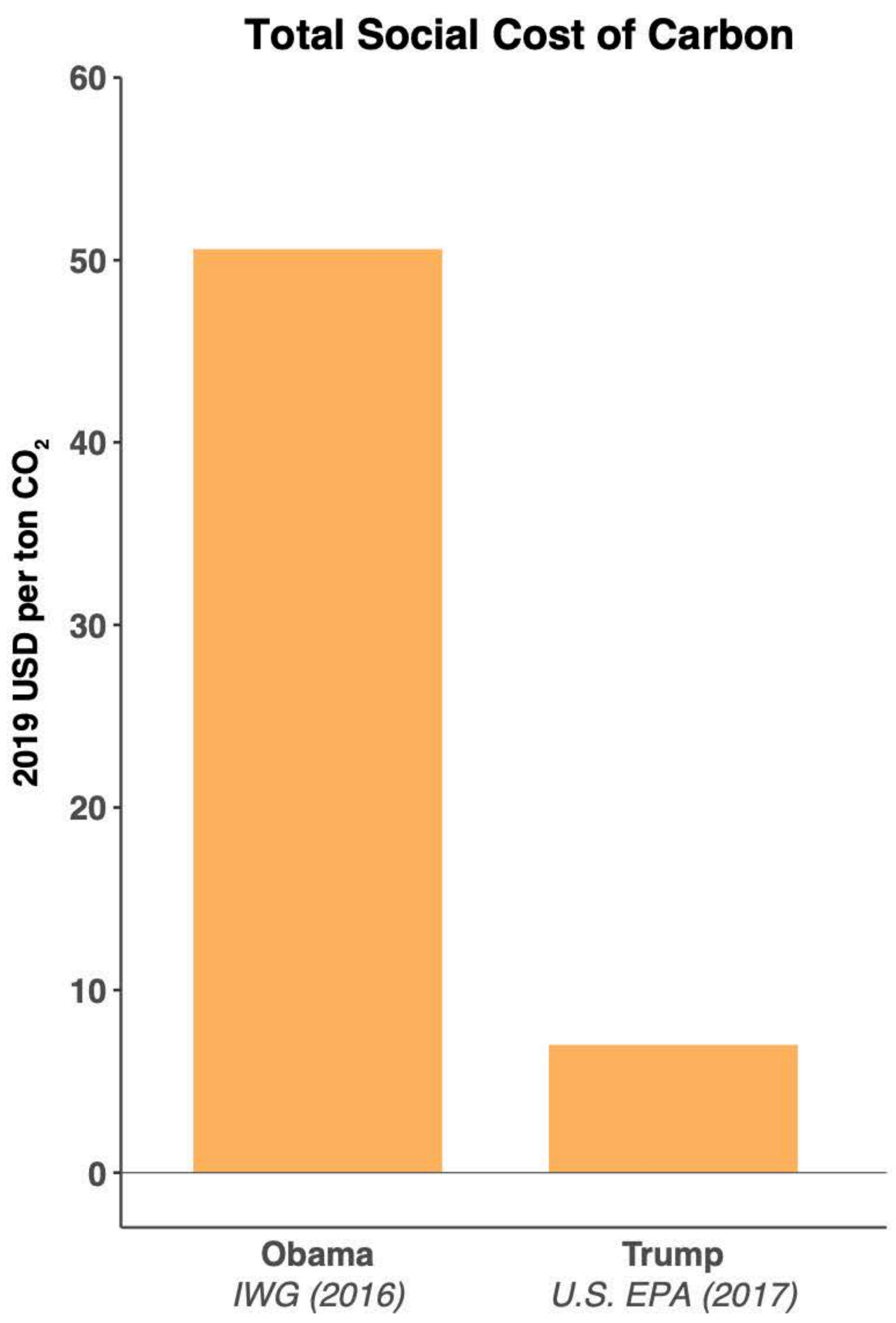
- “Shared Socioeconomic Pathways” are standardized inputs to climate models.
- They were not designed to be realistic or for use in economic analyses.
- We need projections that are.



Financialization of Carbon

(New Directions)

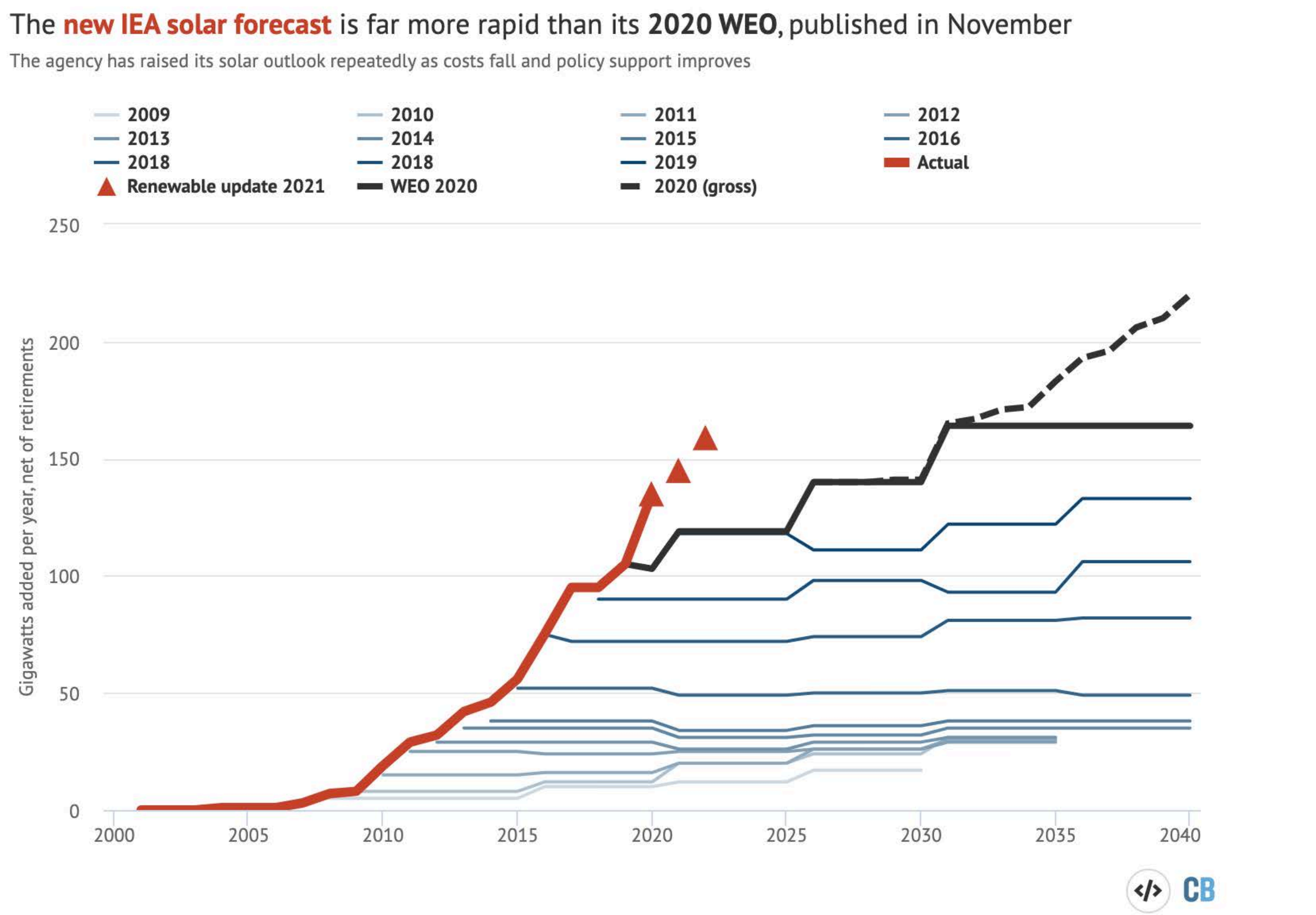
- Global CO2 emissions = 40 billion tons
- Suppose SCC = $60 / ton (Obama, 2.5% discount rate)
- Annual emissions valued at $2.4T (Global GDP = $96T)
- Explicit or implicit carbon pricing creates a new major asset class “out of thin air”.
- What are the implications for non-carbon markets (e.g. inflation)?
- How should control of the price be structured?



Innovation forecasting

(New Directions)

- Technological innovation is the weakest link is many analyses.
- How can we project it better?
- What do current markets indicate about the future?
- What policies accelerate changes in relative prices via innovation?

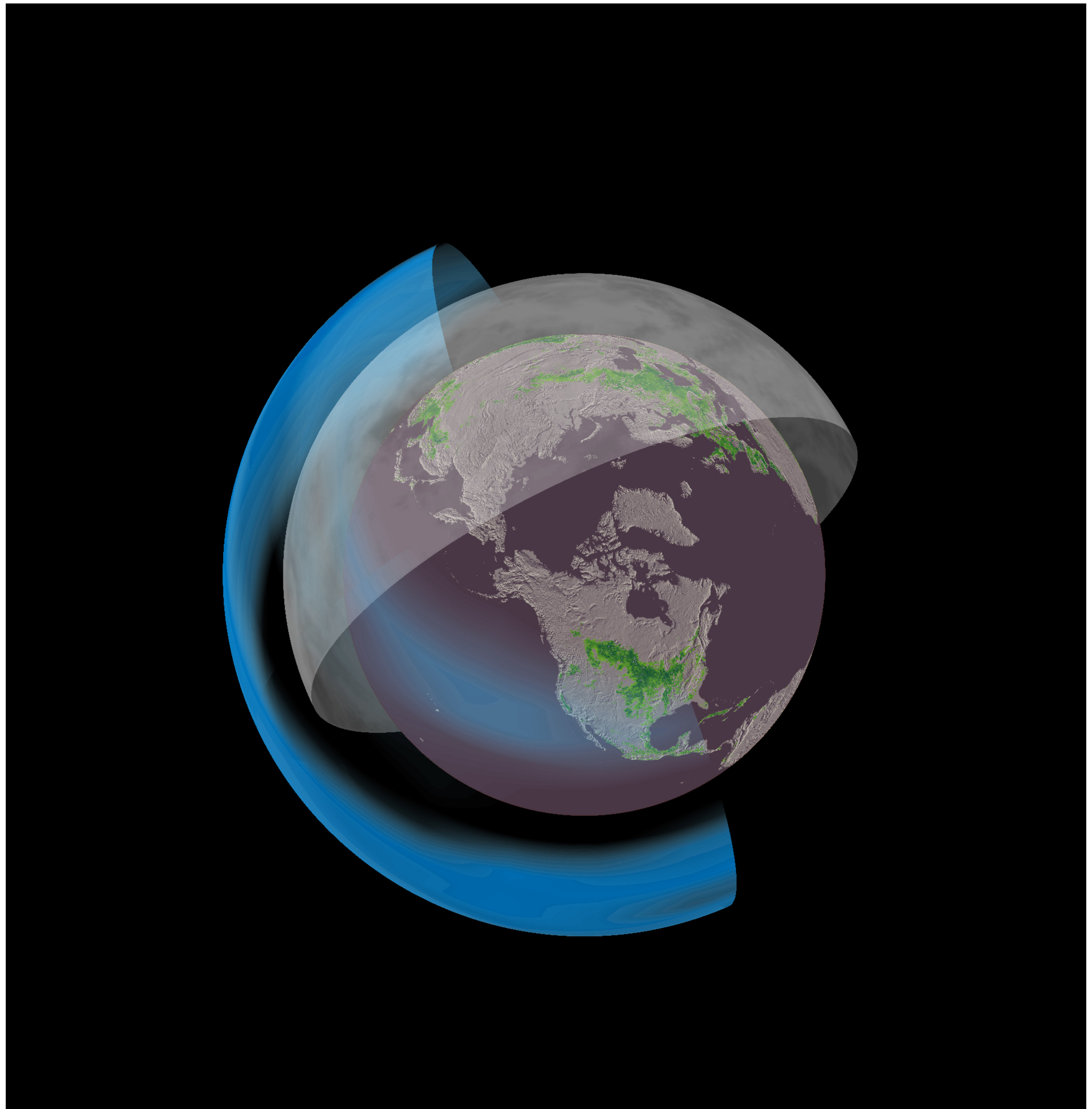


Gigawatts of solar capacity added around the world each year (red line) and the IEA renewable market update 2021 (red triangles), as well as IEA World Energy Outlooks published between 2009-2020. Source: Carbon Brief analysis of IEA reports. Chart by Carbon Brief using Highcharts.

Geoengineering

(New Directions)

- Incentives to geoengineer are enormous
- What is the scale/scope of externalities?
- Local, national, and global regulatory regimes are almost non-existant
- Geoengineering changes the SCC. How to design a consistent management system?
- What is a reasonable and tractable liability regime?

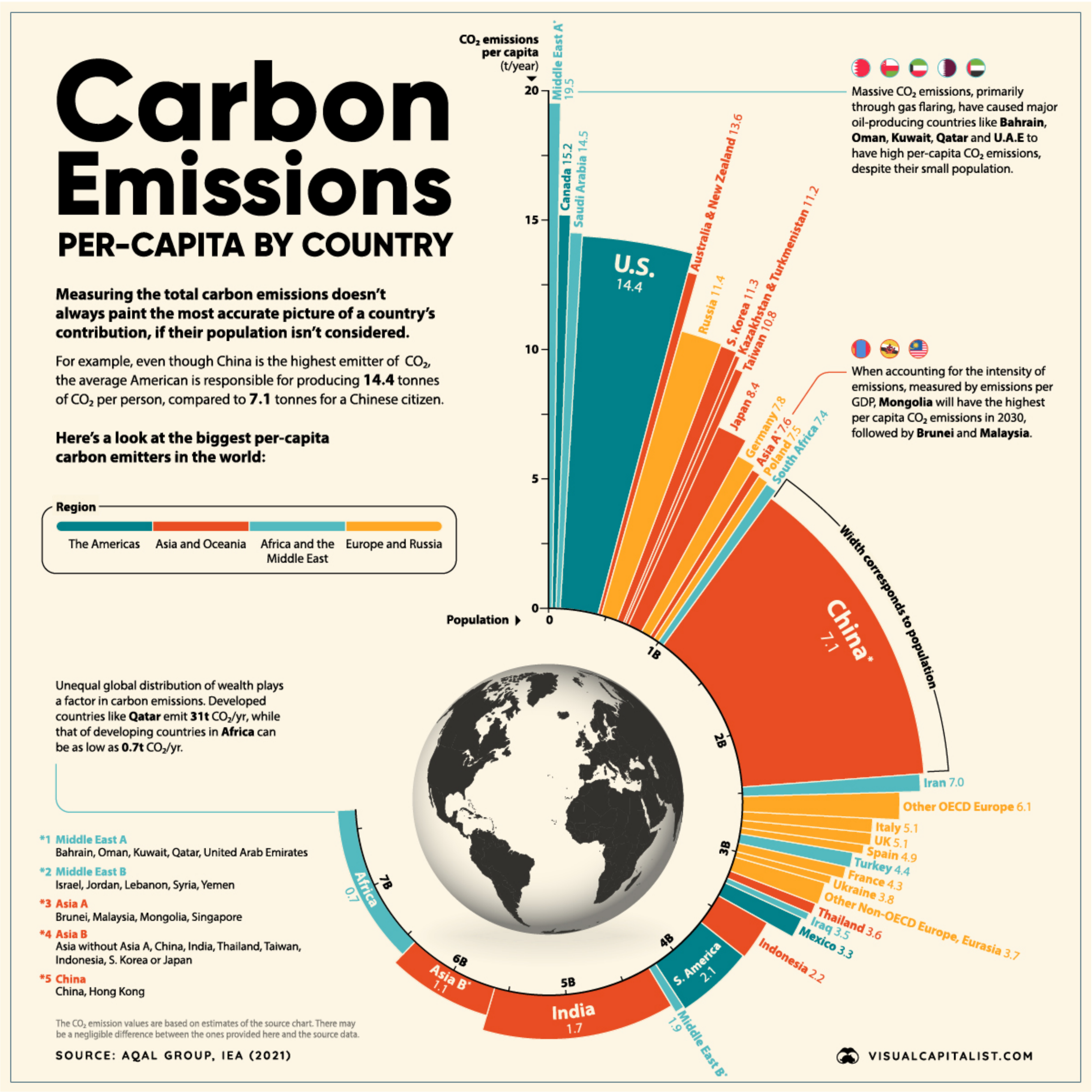


Proctor et al. (Nature, 2018)

Practical energy strategies for developing economies

(New Directions)

- Energy access must scale.
- Emissions probably shouldn't.
- What is a practical plan?
- Integrated global welfare analysis of proposals?
- How is intragenerational and intergenerational equity achieved?



Treaty design in the presence of “adversaries”
(New Directions)

- The global treaty system is experimental
- Kyoto and Paris did not “work”
- Treaty design literature focuses on incentive-compatible & self-enforcing systems among sovereigns that are regulators.
- Actual treaties are pulled apart by strategic agents that are not sovereigns and not bound by the same game.
- We need treaties that are robust to external adversarial strategies, not just self-interest of participants.

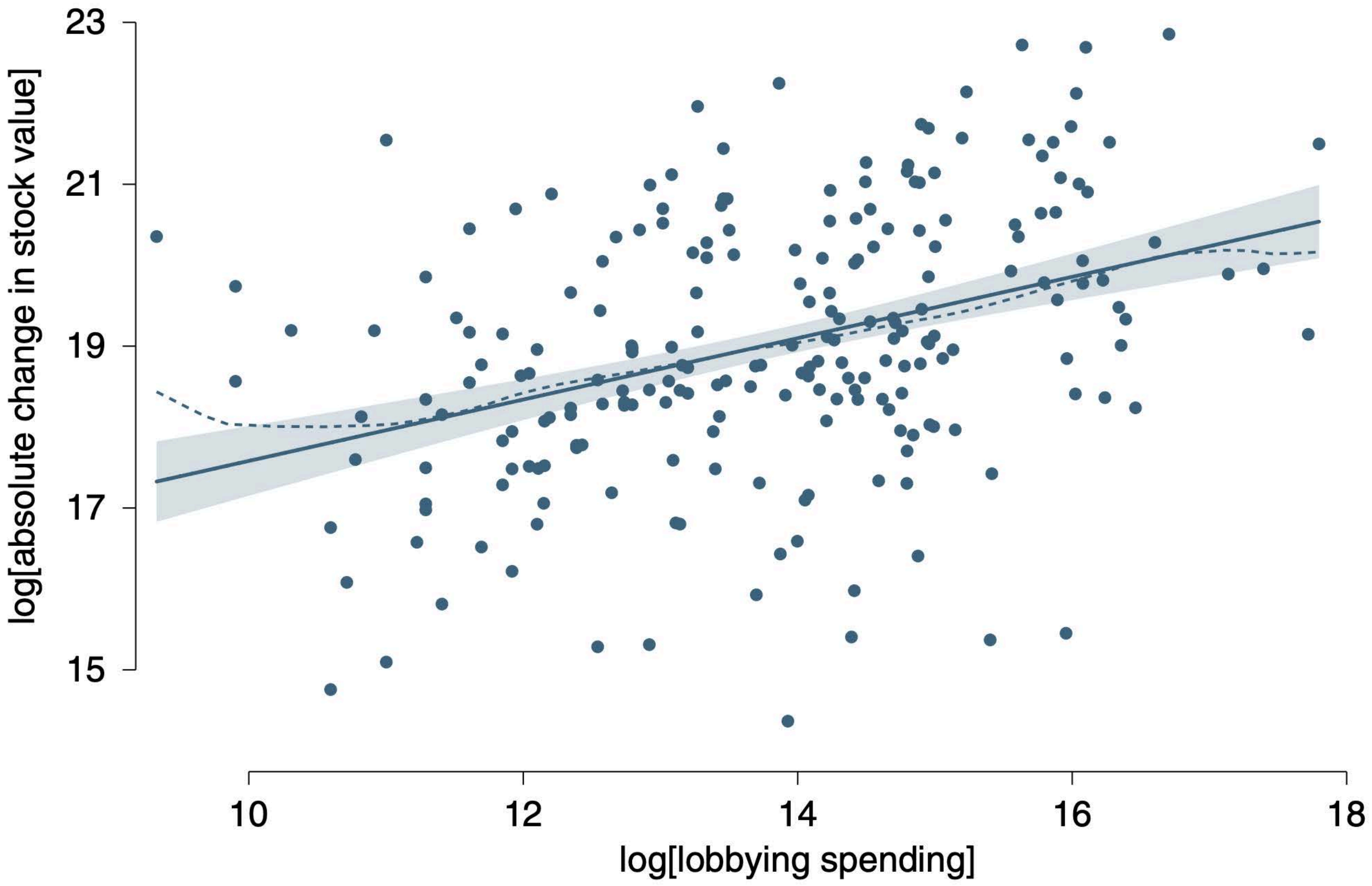


Fig. 1 | Waxman-Markey lobbying spending and change in firm value.

Meng & Rode (Nature Climate Change, 2019)

Institutions for adaptation

(New Directions)

- There are / will be massive efforts to minimize economic damages from climate change.
- There are no institutions to ensure policies / technologies are “safe and effective”
- We must design institutions for third-party verification (think: RCTs) to protect consumers (e.g. cities).
- What is the structure / design of these institutions?

World Health Organization

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

DEPARTMENT OF HEALTH & HUMAN SERVICES · USA
FDA

We do not have comparable institutions for climate-related policies or technologies

One view of the research outlook

What might happen by 2030?

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