The Macroeconomic Impact of Climate Change: Global vs. Local Temperature

Adrien Bilal

Harvard University

Diego Känzig

Northwestern University

August 2024

Introduction

- Climate change is often portrayed as an **existential threat**

- Yet empirical estimates imply **small**, 1-3% GDP loss per 1°C
  (Nordhaus 1992, Dell et al. 2012, Burke et al. 2015, Nath et al. 2023)

- All focus on within-country, local temperature panel variation

Questions

- Are the economic consequences of climate change truly so small?

- Or is local temperature an incomplete representation of climate change?

This paper

- Provide new **macroeconomic** estimates of the impact of temperature
  - Novel focus on **global temperature** rather than **local temperature**
  - Use natural climate variability and time series variation
  - 1°C global temperature implies a **12%** decline in world GDP vs. **1.5%** for local temperature

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- Reconcile **global** and **local** temperature estimates
  - ▸ **Global** temperature shocks predict strong rise in damaging **extreme events**
  - ▸ **Local** temperature shocks do not

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- Quantify the **Social Cost of Carbon** & the **welfare cost** of climate change
  - ▶ Use reduced-form impacts to estimate damage functions in NGM (=DICE)
  - ▶ for global temperature vs. **$223/tCO2** for local temperature
  - ▶ Adding 2°C to 2024 temperature by 2100 implies a   in permanent consumption
  - ▶ Imply that **unilateral** decarbonization policy is optimal

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- Quantify the **Social Cost of Carbon** & the **welfare cost** of climate change
  - Use reduced-form impacts to estimate damage functions in NGM (=DICE)
  - **SCC = $1,065/tCO2** for global temperature vs. **$223/tCO2** for local temperature
  - Adding 2°C to 2024 temperature by 2100 implies a **29% welfare loss** in permanent consumption
  - Imply that **unilateral** decarbonization policy is optimal

Global Temperature and Economic Growth

Global temperature and economic growth
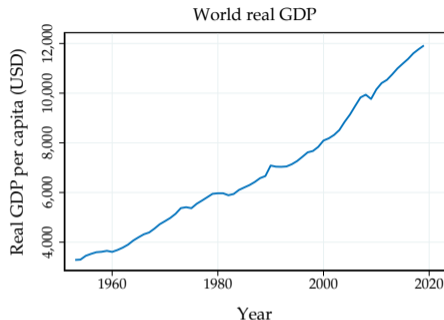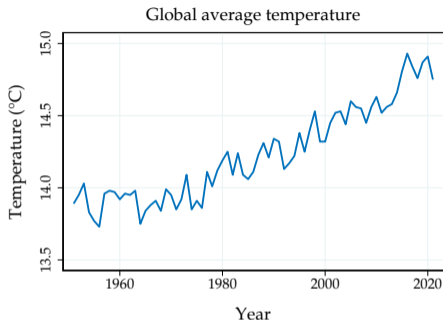
Notes: Global average temperature (including sea surface) from NOAA, world real GDP from PWT

- **Global temperature** and **world GDP** both trending up over our sample

- May bias estimated effects of temperature on output
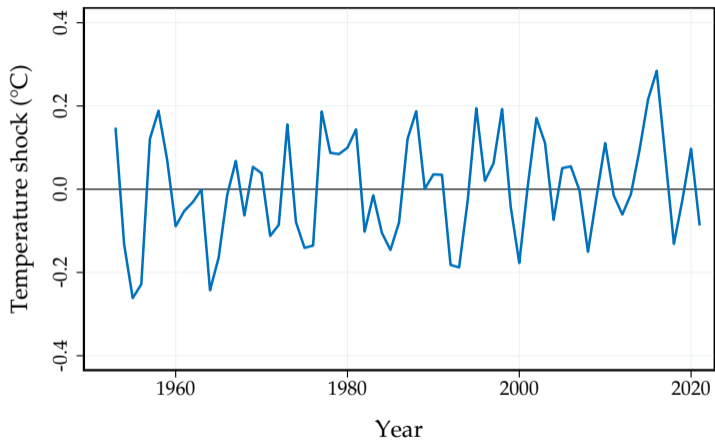
- Focus on **temperature shocks**

Measuring temperature shocks

- Use approach by Hamilton (2018)

- Estimate **transient component** in temperature as forecast error

$$\widehat{T_{t+h}^{\text{shock}}} = T_{t+h} - (\hat{\beta}_0 + \hat{\beta}_1 T_t + \ldots + \hat{\beta}_{p+1} T_{t-p}),$$

- What drives variation around **temperature** trend?
    - Solar cycles & volcanic eruptions
    - Internal climate variability

- Choose $h = 2$ (and p=2) to allow for **persistent** climatic phenomena
    - e.g. El Niño events
    - Results robust to alternative choices

Global temperature shocks

Estimating the effects of global temperature shocks

- Estimate dynamic causal effects to global temperature shocks using local projections (Jordà 2005)

$$y_{t+h} - y_{t-1} = \alpha_h + \theta_h \, T_t^{\text{shock}} + \mathbf{x}_t' \boldsymbol{\beta}_h + \varepsilon_{t+h},$$

where

- y_t is (log) world real GDP per capita
- T_t^{shock} is the temperature shock
- θ_h is the dynamic causal effect at horizon h
- $\mathbf{x}_t$ is a vector of controls

The effects of global temperature shocks
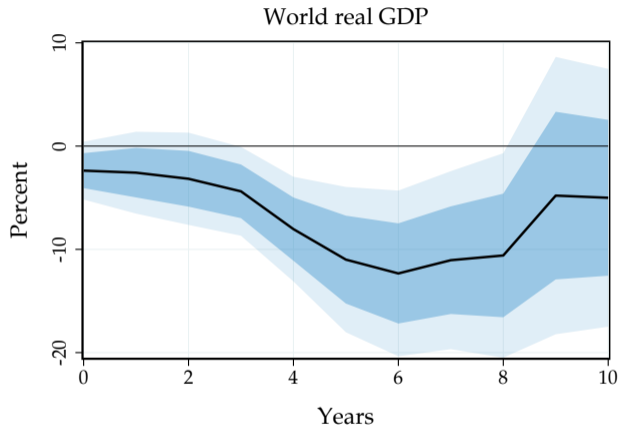
World real GDP

Notes: 68 and 90% confidence bands based on robust standard errors

- **Global temperature shocks**
  - ▸ Significant & persistent impact

- After a 1°C shock
  - ▸ GDP per capita falls by 2% on impact
  - ▸ Effect builds up to >**10%** after 6 years
  - ▸ Impact persists even 10 years out
  - ▸ B/c **internal temperature persistence**

Four identification concerns

1. **Omitted variable bias (global)**
   - ▸ Temperature shocks may happen to coincide with adverse *global* economic shocks

2. **Reverse causality**
   - ▸ Economic activity may lead to emissions and changes in temperature

3. **External validity**
   - ▸ Estimates may change over time and by source of global temperature variation

4. **Omitted variable bias (regional)**
   - ▸ Temperature shocks may happen to coincide with adverse *regional* economic shocks

Four identification concerns

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- Address **1 and 2** in the **time series** and **3 and 4** in the **panel**

Accounting for concern #1: Omitted variable bias (global)

(a) Sensitivity with respect to controls
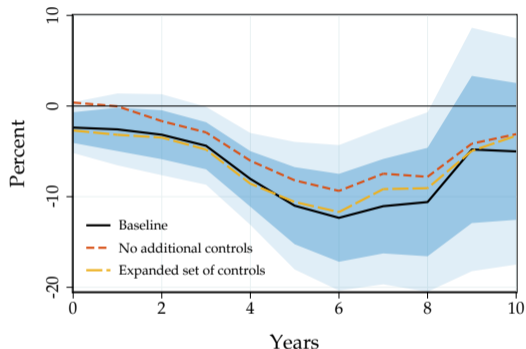
(b) Scatter plot at $h = 5$
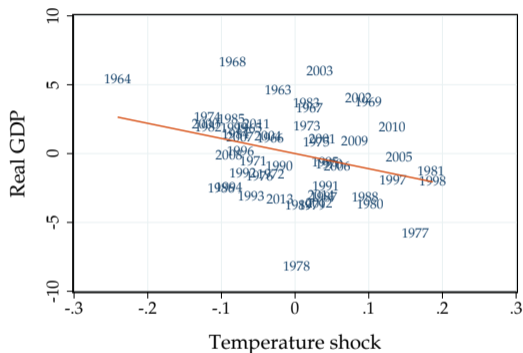
Notes: 68 and 90% confidence bands based on robust standard errors. No additional controls: two lags of GDP and global temperature. Baseline: add indicators for global economic recessions. Expanded set of controls: add global oil prices and the US treasury yield.

Accounting for concern #2: Reverse causality
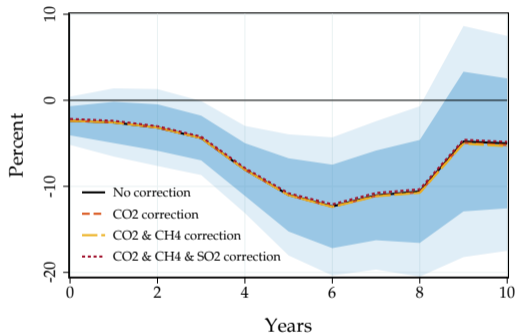
- Control for reverse causality
  - ▸ Feedback of GDP on T via emissions
  - ▸ Climate models: CO2, CH4 and SO2
- Results virtually unchanged
  - ▸ Emissions fluctuations too small

Notes: 68 and 90% confidence bands based on robust standard errors.

Global Temperature Shocks in the Panel of Countries

A new climate-economy panel

- New climate-economy panel dataset covering 173 countries
  - Main sample starts in 1960; for some countries we can go back until 1900

- Economic data from PWT & JST Macrohistory database
  - Real GDP pc, population, capital, investment, productivity

- Temperature data from NOAA and Berkeley earth
  - Allows for timely updates

- Extreme weather data from ISIMIP
  - Use gridded data from to construct country-level measures

Estimating the effects of global temperature shocks in the panel

- Estimate the dynamic causal effects to **global temperature shocks** in the panel

- Use panel local projections (Jordà et al 2020)

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \theta_h \boldsymbol{T_t^{\text{shock}}} + \mathbf{x}_t' \boldsymbol{\beta}_h + \mathbf{x}_{i,t}' \boldsymbol{\gamma}_h + \varepsilon_{i,t+h},$$

where

  - $y_{i,t}$ is (log) real GDP per capita in country i
  - T_t^{shock} is the temperature shock
  - θ_h is the dynamic causal effect at horizon h
  - $\mathbf{x}_t$ is a vector of global controls, $\mathbf{x}_{i,t}$ are country controls

- Can estimate responses to **global** and **local** temperature shocks

Global temperature shocks in the panel

Real GDP
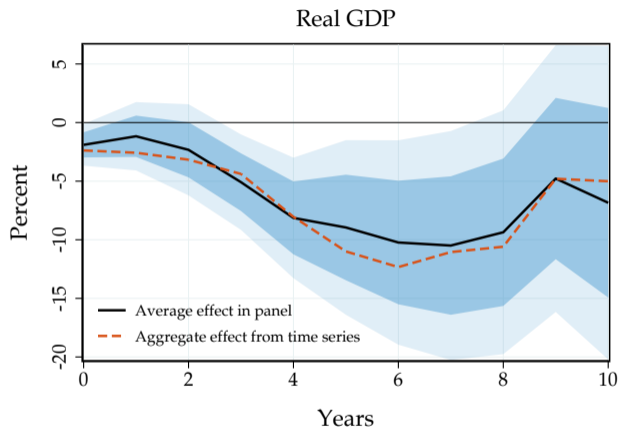
- **Global temperature shocks**
  - ▸ **Substantial** impact in panel
  - ▸ GDP per capita falls by **over 10%**

- **Effect in panel ≈ effect in time series**

Notes: Point estimate with 68 and 90% confidence bands based on Driscoll-Kraay SE

Accounting for concern #3: External validity

(a) Sample period
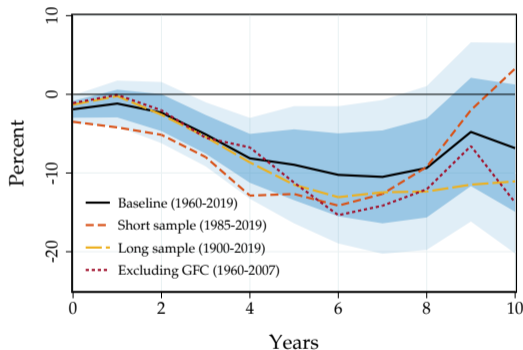
(b) El Niño and volcanic eruptions
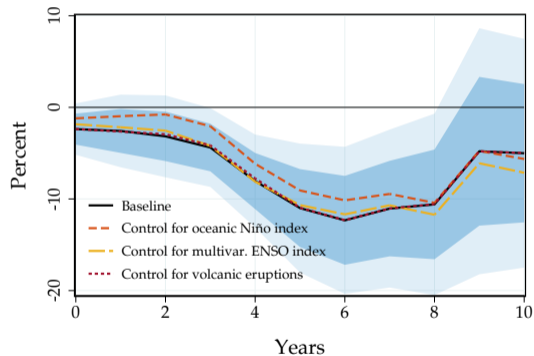
Notes: Point estimate with 68 and 90% confidence bands based on Driscoll-Kraay SE

Accounting for concern #4: Omitted variable bias (regional)

(a) Regional controls
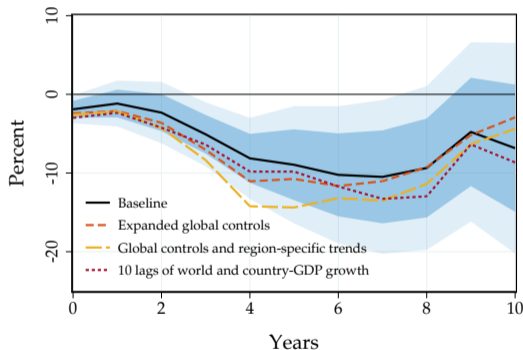
(b) Pre-trends
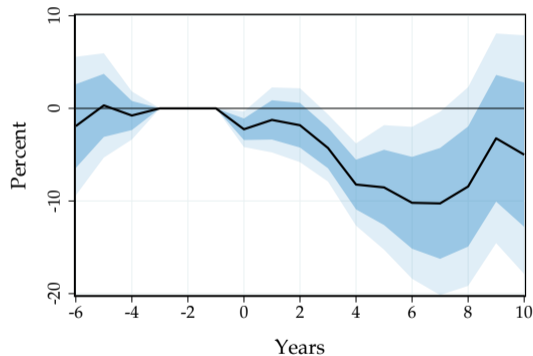
Notes: Point estimate with 68 and 90% confidence bands based on Driscoll-Kraay SE

Global vs. Local Temperature in the Panel of Countries

Global vs. local temperature shocks

- How do **global** temperature shocks compare to **local**, country-level temperature shocks?
  - ▸ Virtually **all previous work** uses **local** temperature shocks

- To maximize comparability, estimate responses using **same specification**

- Just replace global shock with **local temperature shock**

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \quad \theta_h \, \boldsymbol{T}^{\text{shock}}_{\boldsymbol{i,t}} + \mathbf{x}'_t \boldsymbol{\beta}_h + \mathbf{x}'_{i,t} \boldsymbol{\gamma}_h + \varepsilon_{i,t+h}$$

- Alternatively, can also control for **time FE**

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \boldsymbol{\delta_{t,h}} + \theta_h \, \boldsymbol{T}^{\text{shock}}_{\boldsymbol{i,t}} + \quad \mathbf{x}'_{i,t} \boldsymbol{\gamma}_h + \varepsilon_{i,t+h}$$

▸ Local temperature variation

Impact of global vs. local temperature shocks

Real GDP
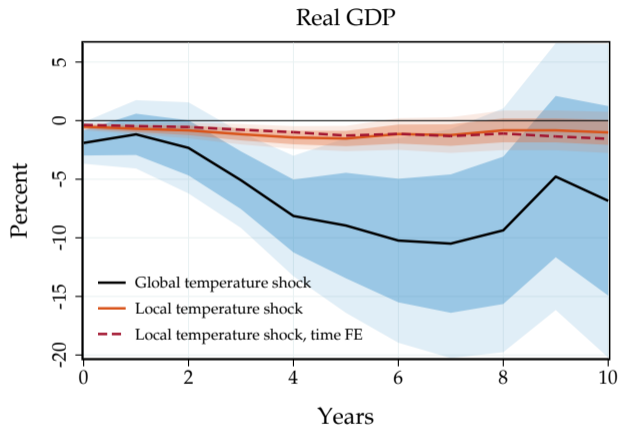
- Effect of **local temperature shocks**
  - ▶ Is in line with previous literature
  - ▶ Much smaller than **global T shocks**

- With time FE: no difference ▸ More
  - ▶ Nature of T shock rather than controls

- For **global temperature shocks** ▸ More
  - ▶ Similar for corr. T shocks + time FE

Notes: Point estimate with 68 and 90% confidence bands based on Driscoll-Kraay SE

Reconciling cross-sectional & time-series evidence

- What can explain the large difference between **local** and **global** shocks?

1. **Economic spillovers** due to trade linkages and spatially correlated local temperature?
    - ▶ Omitted variable in standard panel regression
    - ▶ Test with **external temperature** ▸ Details
        - ★ Trade-weighted average of local temperature shocks of trade partners
    - ▶ **Rule out spillovers**: external temperature has **tiny** effects on country GDP
        - ★ Under moderate openness cannot expect to get much more than direct local temperature effect

2. **Global temperature fundamentally different** from local temperature?
    - ▶ Global temperature: better **summary statistic** of state of climate system
    - ▶ Better captures the frequency, intensity, and distribution of extreme weather events

Extreme events help rationalize the GDP impact of global temperature

(a) Extreme heat

(b) Drought

(c) Extreme precipitation

(d) Extreme wind

Real GDP
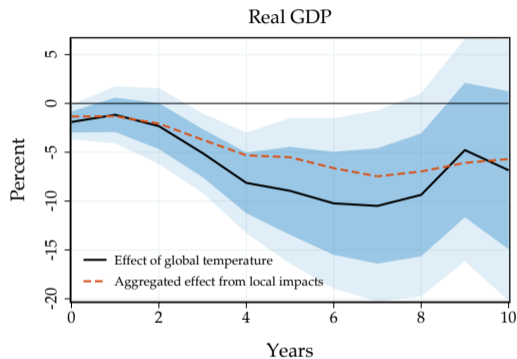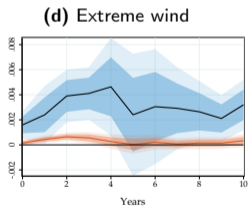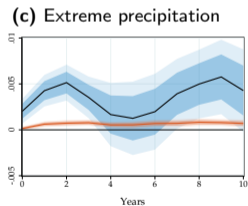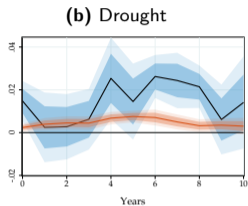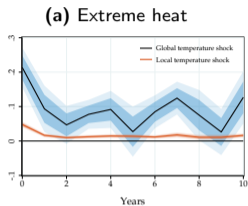
Notes: Predicted effect on GDP based on aggregating local impacts. Interact frequency response of extremes to global temperature with estimated damages of extremes.

A Model of Climate Change

A Neoclassical growth model

- Households solve

$$V_0(K_0) = \max_{\{C_t, K_t\}_t} \int_0^\infty e^{-\rho t} U(C_t) dt \quad \text{subject to} \quad C_t + \dot{K}_t = w_t + r_t K_t$$

$$K_0 \text{ given}$$

- Firms solve

$$\max_{K_t^D, L_t^D} Z_t (K_t^D)^\alpha (L_t^D)^{1-\alpha} - (r_t + \Delta_t) K_t^D - w_t L_t^D$$

- Prices r_t, w_t clear markets: $K_t = K_t^D$ and $1 = L_t^D$

- Temperature shocks $\hat{T}_t$ affect productivity and depreciation with a lag

$$Z_t = Z_0 \exp\left(\int_0^t \zeta_s \hat{T}_{t-s} ds\right) \qquad \qquad \Delta_t = \Delta_0 \exp\left(\int_0^t \delta_s \hat{T}_{t-s} ds\right)$$

Damage functions from temperature shocks

- Estimate $\{\zeta_s, \delta_s\}_{s \geq 0}$ by matching output and capital responses in the data
  - ▸ Characterize **identification in model** ▸ Details
  - ▸ Estimation **accounts for internal persistence of temperature**

- **Global** temperature implies **large productivity** and **capital depreciation** damages ▸ Details
  - ▸ -3% productivity and +1p.p. capital depreciation at peak
  - ▸ **Persistent** effects on productivity even when shock is transitory

- **Local** temperature implies **small productivity** and **capital depreciation** damages ▸ Details
  - ▸ -0.5% productivity and 0.5p.p. capital depreciation
  - ▸ Consistent with smaller economic impact estimated in data and literature

- For both shocks we include capital depreciation damages
  - ▸ Previous literature focuses on productivity damages

Climate change and the Social Cost of Carbon

- With estimated damage functions can evaluate climate change and SCC counterfactuals

- **Climate change**
  - Specify excess global temperature path $\{\hat{T}_t\}_{t\geq 0}$
  - Use 2024 as $t = 0$ and add 2°C by 2100 so 3°C above pre-industrial levels
  - Conservative relative to business-as-usual (IPCC)

- **SCC:** \$ losses associated with emitting 1 ton of CO2
  - Consider excess global temperature $\{\hat{T}_t^{\text{SCC}}\}_{t\geq 0}$ induced by a 1 ton of CO2 pulse (Dietz et al. 2021)
  - SCC = equivalent variation to make households indifferent between steady-state and the CO2 pulse

The Welfare Impact of Climate Change

The impact of climate change

(a) $T_t - T_{2024}$ (C)

(b) Output (%)

(c) Capital (%)

(d) Consumption (%)

(e) Welfare (%)

(f) SCC in 2024 ($)

Legend: Global T, prod. and dep. — Global T, prod. only (dotted) — Local T, prod. only (dashed)
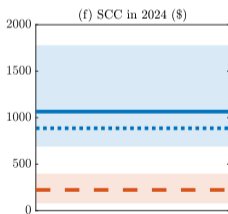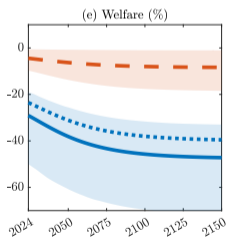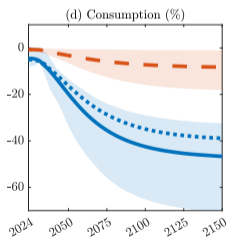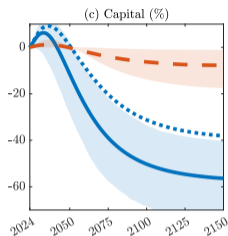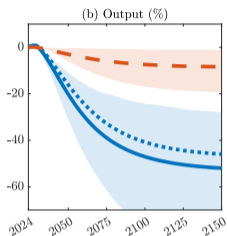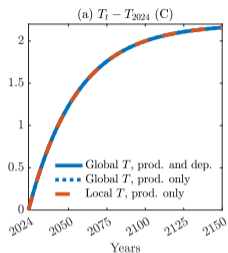
- **Global** shocks $\Rightarrow$ large impacts
  - ▸ 2100 **C, Y ↓ 47%**
  - ▸ **29% welfare loss**
  - ▸ **SCC = $1,065/tCO2**

- **Local** shocks $\Rightarrow$ small impacts
  - ▸ 2100 **C, Y ↓ 7%**
  - ▸ **4% welfare loss**
  - ▸ **SCC = $223/tCO2**
  - ▸ In line with previous findings

- Difference driven by
  - ▸ Global vs. local shocks
  - ▸ Not cap. dep. damages

Policy Implications

Policy implications

- Most large-scale decarbonization policies in the IRA cost **$80/tCO2** (Bistline et al. 2023)
    - ▸ Below typical **worldwide** traditional SCC estimates, e.g. **$223/tCO2** with **local temperature**
    - ▸ But higher than **US-only** Domestic Cost of Carbon, e.g. **$45/tCO2** with **local temperature**
    - ▸ So **unilateral, non-cooperative** policy is **not cost-effective**

- Our estimates with **global temperature** entirely **reverse this trade-off**
    - ▸ Even the **US-only** Domestic Cost of Carbon is **$213/tCO2**
    - ▸ Higher than the cost of decarbonization
    - ▸ So **unilateral, non-cooperative** decarbonization policy becomes **cost-effective**

Thank you!

Appendix

Literature

Temperature and economic growth: Dell et al. 2012, 2014; Burke et al. 2015; Newell et al., 2021; Nath et al. 2023; Bansal and Ochoa 2011; Berg et al. 2023

- ▶ Empirical impact of **global temperature** on world GDP + structural model + SCC and welfare

Economic impact of storms and heatwaves: Deschênes and Greenstone 2011; Deryugina 2013; Hsiang and Jina 2014; Bilal and Rossi-Hansberg 2023; Phan and Schwartzman 2023; Tran and Wilson 2023

- ▶ Link global temperature shocks to extreme events

Integrated assessment modeling/cost of climate change: Nordhaus 2013; Desmet and Rossi-Hansberg 2015; Desmet et al. 2021; Cruz and Rossi-Hansberg 2023; Rudik et al. 2022; Conte et al. 2022; Krusell and Smith 2022; Bilal and Rossi-Hansberg 2023; Stern et al. 2022

- ▶ Find large SCC in a NGM/IAM once use global temperature impact in estimation

Persistence of output response reflects persistence of temperature shock
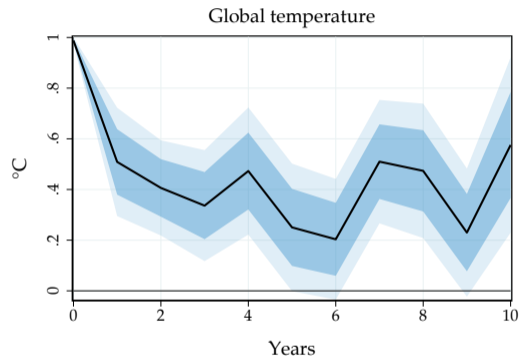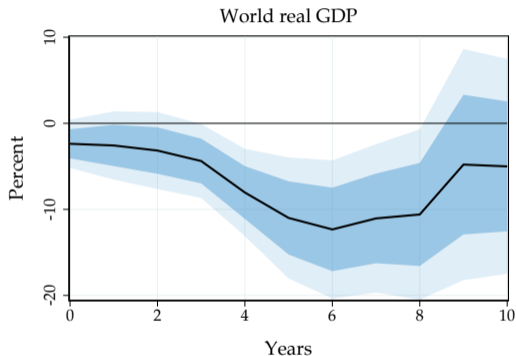
Notes: Point estimate with 68 and 90% confidence bands based on robust standard errors

Accounting for concern #1: Omitted variable bias (global)

(a) Jackknife/leave-one-out
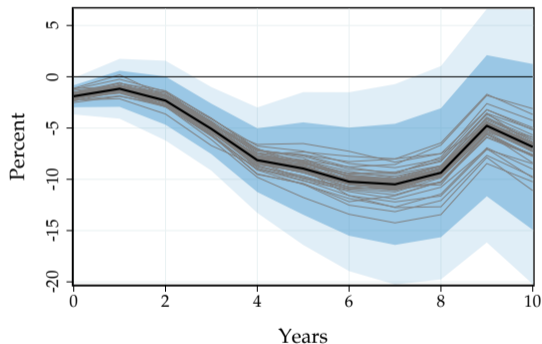
(b) Construction of temperature shock
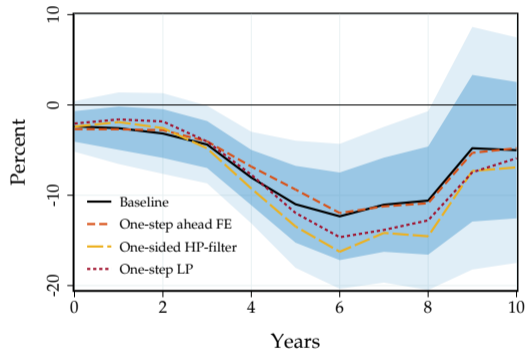
Notes: 68 and 90% confidence bands based on robust standard errors. Jackknife: censor one shock value at the time to zero.

▸ Back

Forecastablity

- Temperature shocks **not forecastable** by past macro and financial variables
  - even true when allowing for long lags

Table: Granger-causality tests

Variable	p-value
Real GDP	0.494
Population	0.801
Brent price	0.756
Commodity price index	0.664
Treasury 1Y	0.830
Overall	0.825

Bootstrapped confidence bands

- Taking estimation uncertainty in temperature shocks into account:

Real GDP

Legend:
- Robust SE
- Bootstrap
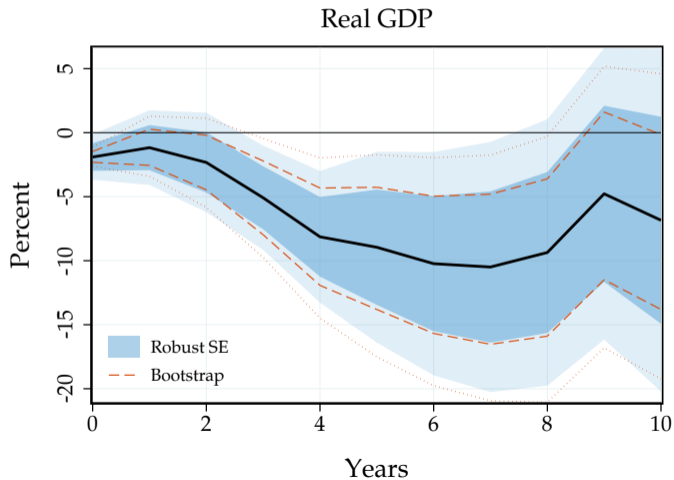
Global vs. local temperature shocks

- Construct temperature shocks using same Hamilton filter

- Use population-weighted country-level temperature
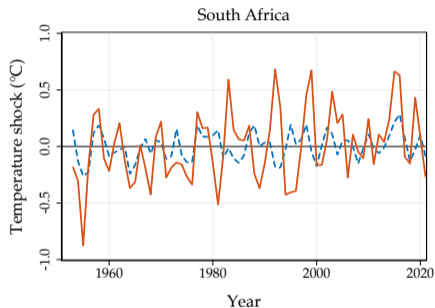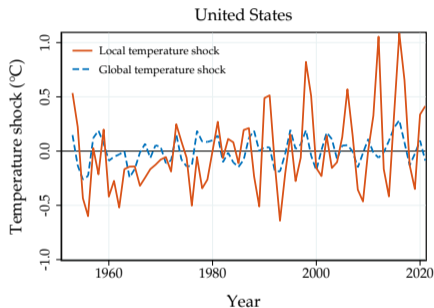
- Local temperature shocks more volatile
- Only weakly correlated with global temperature shocks

Time fixed effects

Real GDP
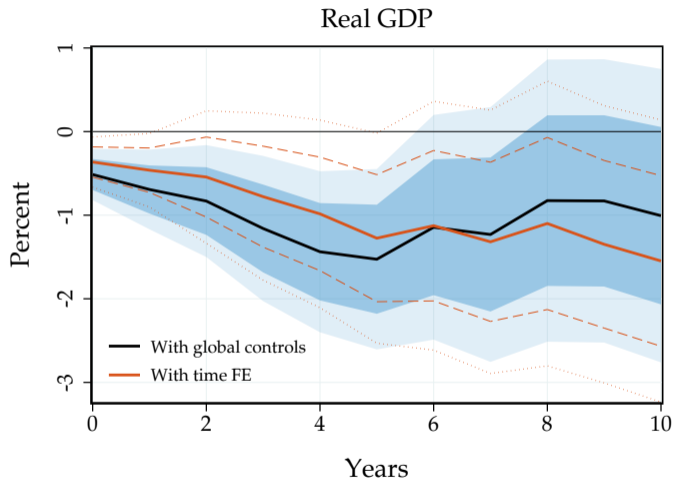
Correlated temperature shocks

Real GDP
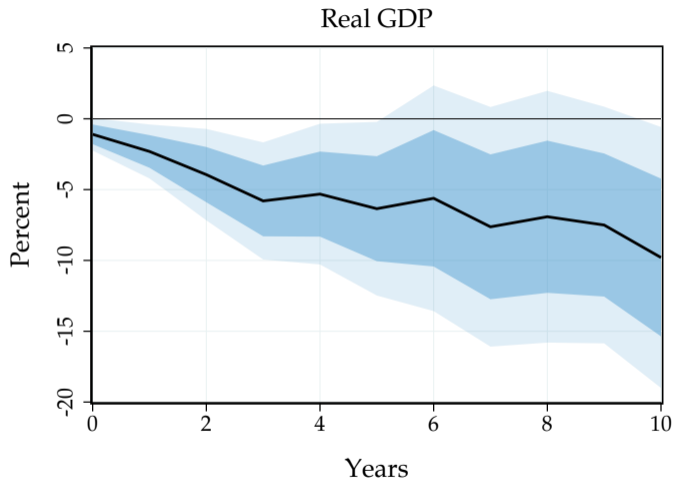
The role of economic spillovers

(a) Global temperature vs. trade-weighted
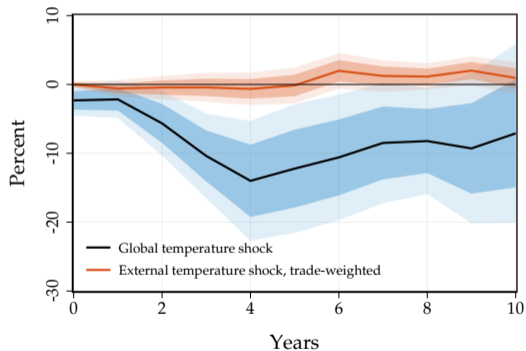
(b) Distance- vs. trade-weighted
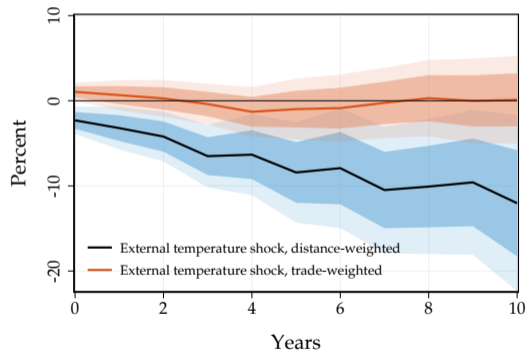
The local temperature response

(a) Local temperature response
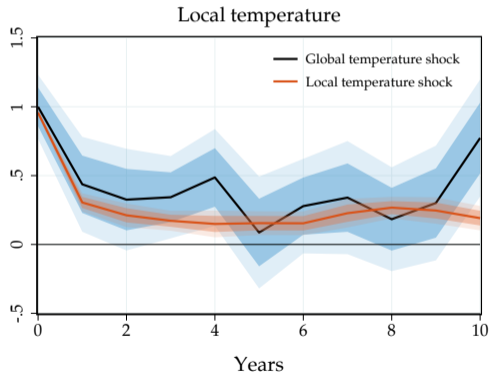
(b) Imposing same persistence
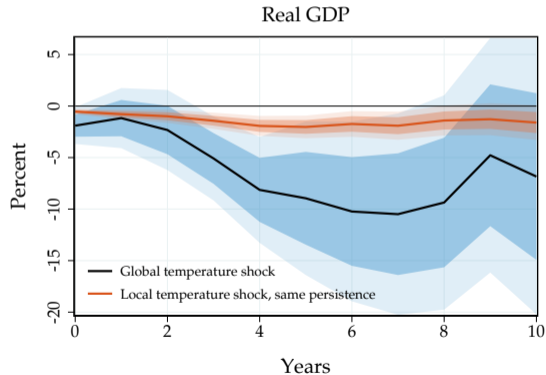
The impact of extreme events on GDP

(a) Extreme heat
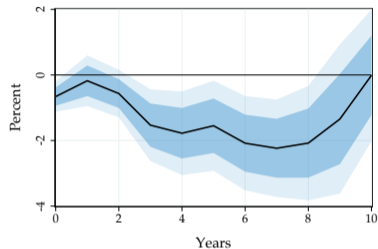
(b) Drought
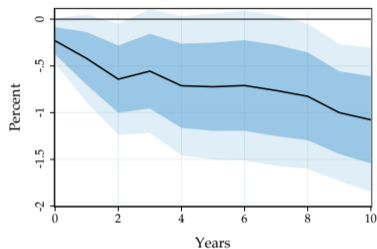
(c) Extreme precipitation
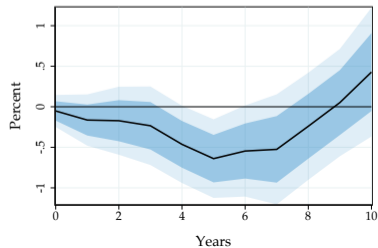
(d) Extreme wind
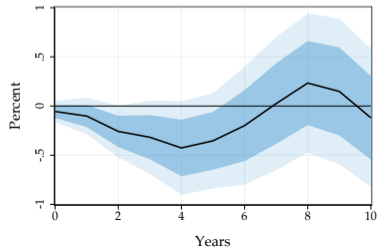
Mechanisms

- Which elements of GDP respond? ▸ More
    - **Capital stock** and investment fall substantially with some lag
    - **Productivity** falls immediately and persistently

- Consistent with both capital and productivity damages

Heterogeneity

- So far focus on aggregate/average effect of **global temperature shocks**

- How are effects distributed **across countries**?

- Run local projections by country characteristics/different regions ▸ More
  - ▸ Southeast Asia and Sub-Saharan Africa most adversely affected
  - ▸ But substantial negative effects even in Europe & North America
  - ▸ Positive effects in Central & East Asia
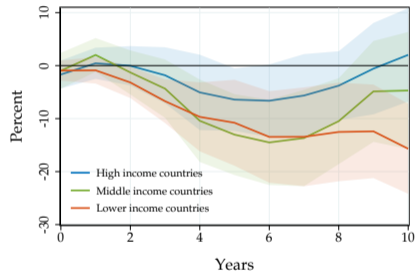 - ▸ Warmer countries are more adversely affected

Mechanisms
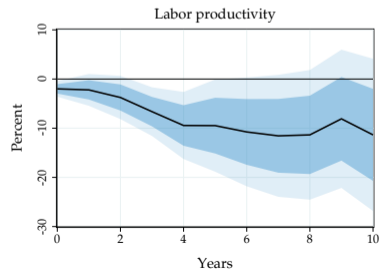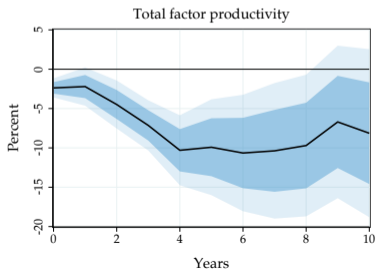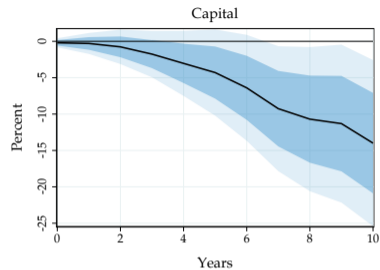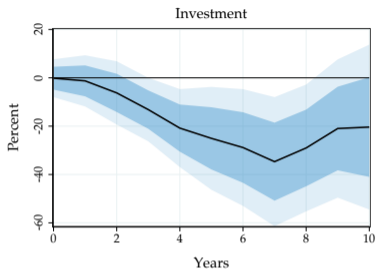
Heterogeneity
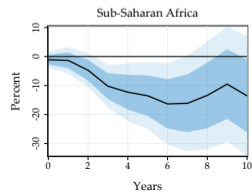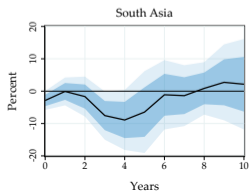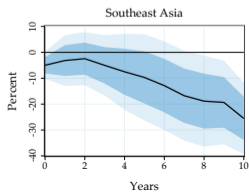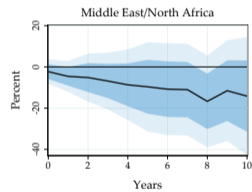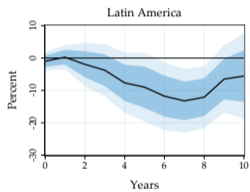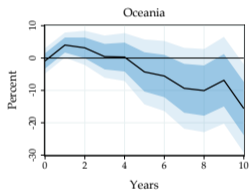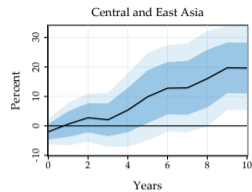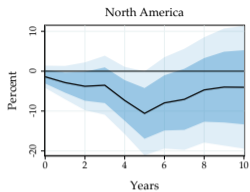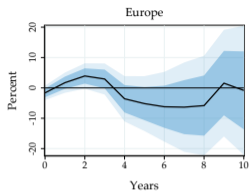
Heterogeneity

(a) By average temperature
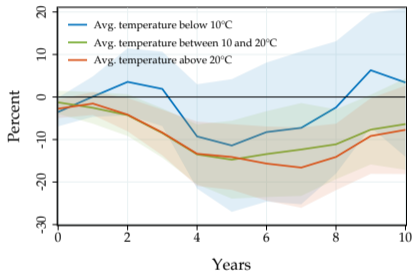
(b) By income per capita

Estimating damage functions

- Use reduced-form GDP and capital IRFs to identify **damage functions δ_s, ζ_s**

- Leverage **identification result**: for small temperature shocks

$$\hat{y}_t = \hat{z}_t + \alpha \hat{k}_t \qquad\qquad \hat{k}_t = \mathcal{K}_t(\hat{z}) + \int_0^\infty \mathcal{J}_{t,s} \hat{\Delta}_s ds$$

  for known $\mathcal{J}_{t,s}, \mathcal{K}_t(\hat{z})$

- Recover sequence of **prod.** and **dep.** shocks $\hat{z}_t, \hat{\Delta}_t$ following temperature shock in data

- Then estimate δ_s, ζ_s as innovations to $\hat{z}_t, \hat{\Delta}_t$

- As temperature shock is persistent, **account for internal persistence of realized temperature**

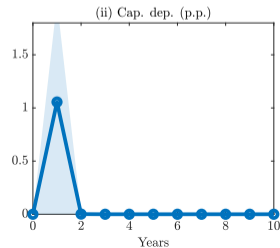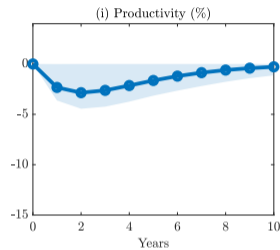# Damage functions from global temperature shocks

(a) Underlying temperature $\hat{T}_t$
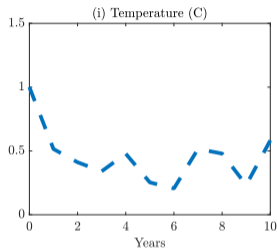
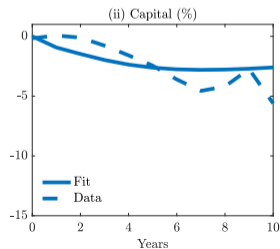**(b)** Output and capital
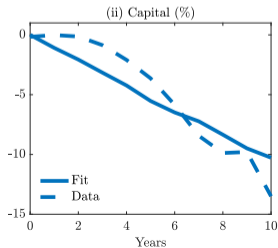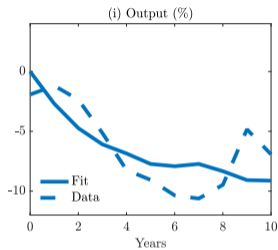
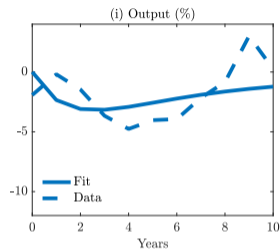**(c)** Damage Functions δ, ζ

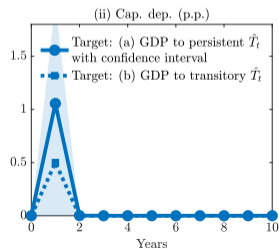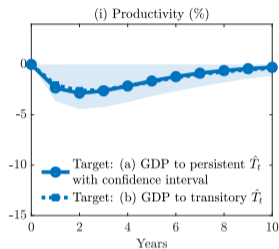# Targeting response to persistent vs. transitory shocks

- Can target GDP/capital IRFs after either **persistent** or **transitory** temperature shock

- When targeting IRFs after persistent shocks
  - Assumes that households **expect** future temperature impacts
  - Baseline estimation

- Alternative: target IRFs after transitory temperature shock (Sims 1986)
  - Assumes that households are **surprised** every period
  - Only affects estimation of capital depreciation shocks

- **Both cases account for internal persistence of realized temperature**

- Only differ in expectations of future temperature
  - Productivity shocks unaffected since read off data directly
  - Capital depreciation shocks potentially affected

Damage functions from transitory global temperature shocks
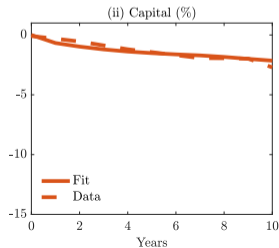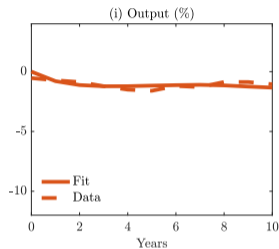
(a) Transitory $\hat{T}_t$

(i) Output (%)

(b) Damage Functions δ, ζ

(i) Productivity (%)

Target: (a) GDP to persistent $\hat{T}_t$ with confidence interval
Target: (b) GDP to transitory $\hat{T}_t$

(ii) Capital (%)

(ii) Cap. dep. (p.p.)

Target: (a) GDP to persistent $\hat{T}_t$ with confidence interval
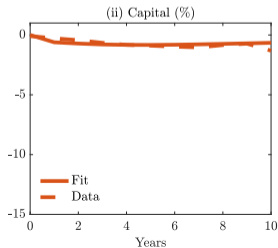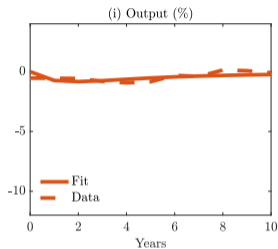Target: (b) GDP to transitory $\hat{T}_t$

- Results very similar to persistent target estimates

- Only differs in expectations of future temperature

- Only affects estimation of capital depreciation shocks

  ▸ Effect on productivity due to constrained optimization

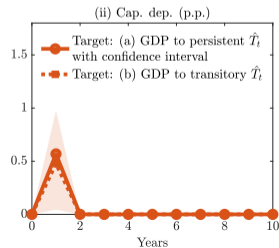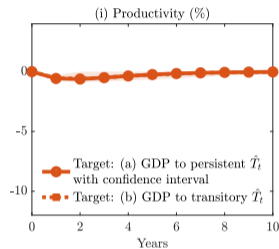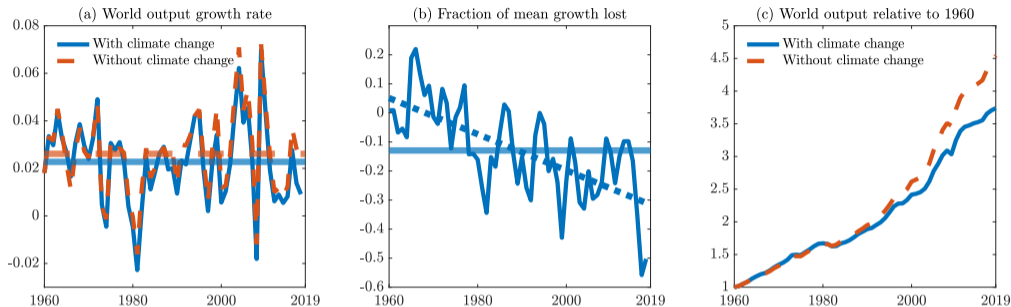# Damage functions from local temperature shocks

(a) Persistent $\hat{T}_t$ **(b)** Transitory $\hat{T}_t$ **(c)** Damage Functions δ, ζ
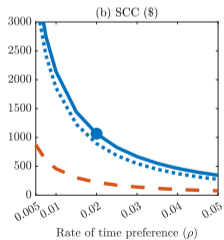
The impact of past climate change under global temperature estimates

(a) World output growth rate   (b) Fraction of mean growth lost   (c) World output relative to 1960

- Use 1960 as $t = 0$ and **realized** excess global temperature path $\{\hat{T}_t\}_{t \geq 0}$ up to 2019

- **Output would be 17% higher today** had historical climate change not occurred

- **Welfare would be 46% higher today** without past and future climate change

Sensitivity

(a) Welfare (cons. eq., %)

Global T, expectations
Global T, surprises
Local T, prod. and exp.

Rate of time preference (ρ)

(c) Welfare (cons. eq., %)

2100 temperature vs. pre-industral (C)

(e) Welfare (cons. eq., %)

Climate sensitivity relative to median

(b) SCC ($)

Rate of time preference (ρ)

(d) SCC ($)

2100 temperature vs. pre-industral (C)

(f) SCC ($)

Climate sensitivity relative to median
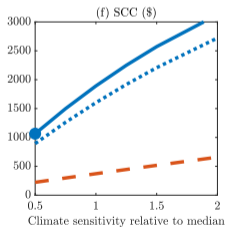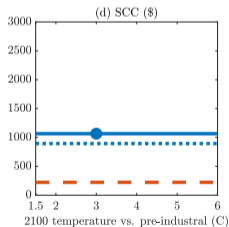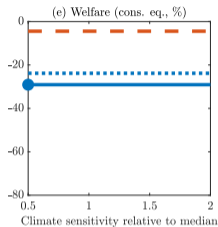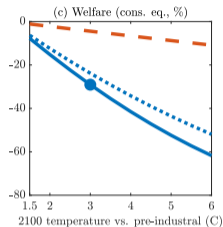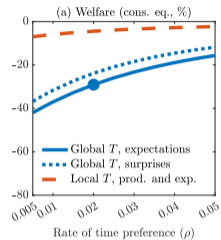
- Magnitudes **robust** w.r.t.
  - ▸ Discount rate
  - ▸ Warming scenario
  - ▸ Climate sensitivity

- Still **large effects** under
  - ▸ Moderate warming of 2°C
  - ▸ Large discount rate of 4%

- In **plausible pessimistic** cases
  - ▸ **Welfare loss $\geq$ 40%**
  - ▸ **SCC $\geq$ \$3,000/tCO2**