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

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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%** 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. **$151/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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  - **SCC = $1,056/tCO2** for global temperature vs. **$151/tCO2** for local temperature
  - Adding 2°C to 2024 temperature by 2100 implies a **31% welfare loss** in permanent consumption
  - Imply that **unilateral** decarbonization policy is optimal

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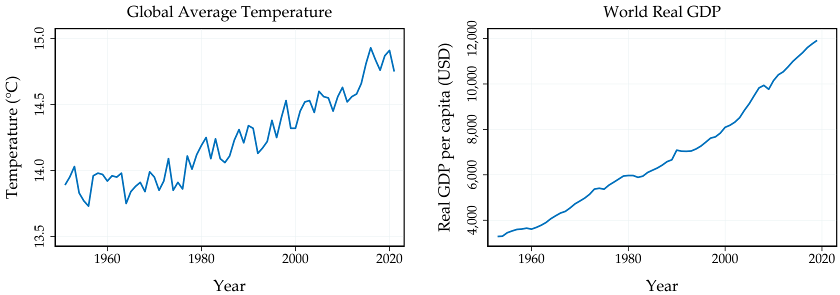
Global Temperature and Economic Growth

Global temperature and economic growth



Notes: Global avg temperature (incl. 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)

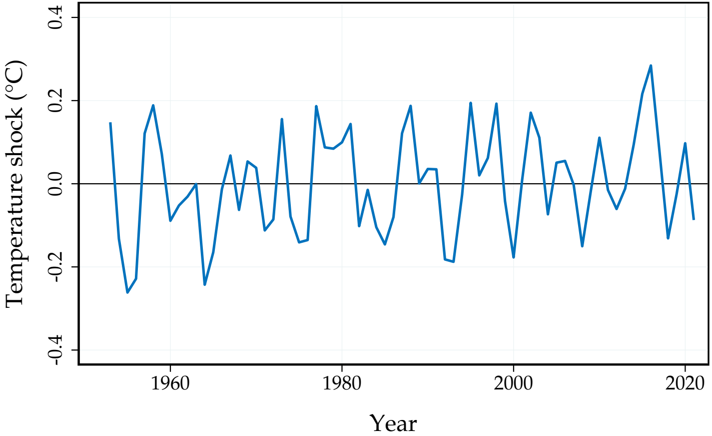
- Estimate **transient component** in temperature as forecast error

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

- 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 temperature shocks

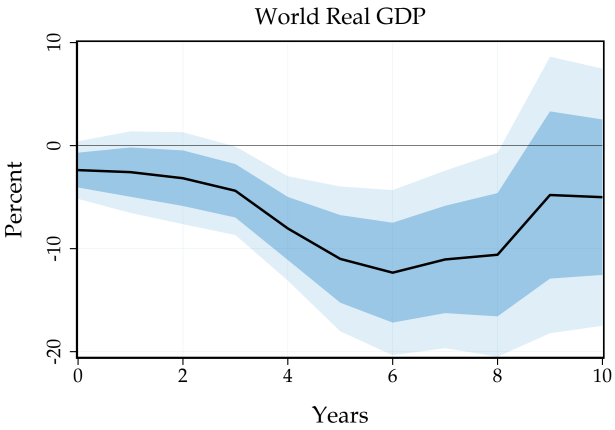
- Estimate dynamic causal effects to global T shocks using local projections (Jordà 2005)

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

  where

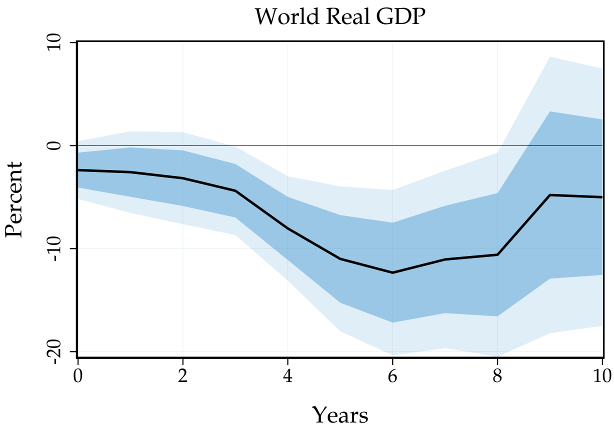
  - y_t is (log) world real GDP per capita
  - T_t^{shock} is the temperature shock
  - θ_h is the dynamic causal effect at horizon h
  - $\mathbf{x}_t$ is a vector of controls

The effects of global temperature shocks



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

The effects of global temperature shocks



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

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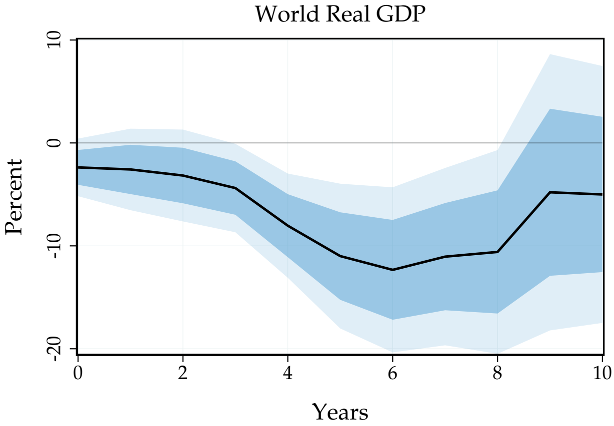

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- **Global temperature shocks**
  - Significant & persistent impact
- After a 1°C shock
  - GDP per capita falls by 2% on impact
  - Effect builds up to >**10%** after 6 years
  - Impact persists even 10 years out

Threats to identification

- **Confounders**: **temperature shocks** coincide with adverse **economic shocks**

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  - Control for global economic and financial variables
  - Control for large global shocks using dummies (e.g. oil price shocks in 70s or Great Recession)
  - Results survive in panel where we can do much more ...

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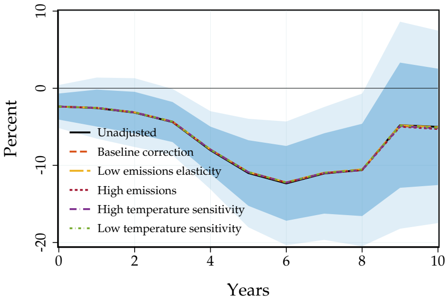
  - Results survive in panel where we can do much more . . .
- **Reverse causality**: **economic activity** leads to emissions and changes in **temperature**
  - Reverse causality concerns attenuate economic effects of temperature shocks
  - Emissions translate into temperature with a substantial lag (max warming after 10 years)
  - Annual emissions fluctuations imply negligible temperature variations vs. typical temperature shocks
  - Temperature shocks not forecastable by past macro variables

▸ Granger causality tests

Reverse causality



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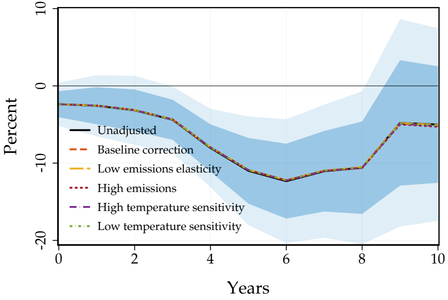
- Formally accounting for reverse causality produces virtually identical results

Reverse causality



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- Formally accounting for reverse causality produces virtually identical results
- Robust to
  - Temperature sensitivity
  - Emissions elasticity
  - Level of emissions

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 temperature shocks in the panel

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

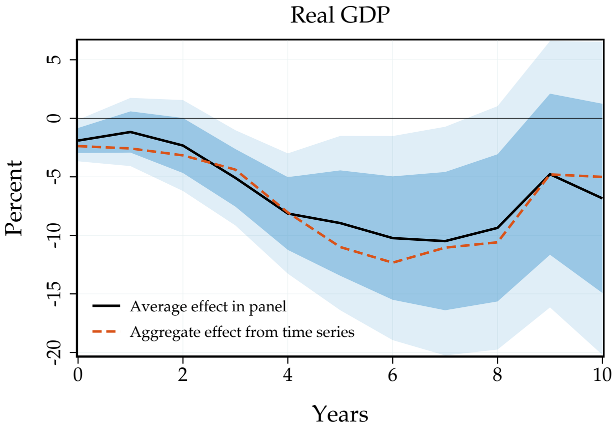
- Use panel local projections (Jordà et al 2020)

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

  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



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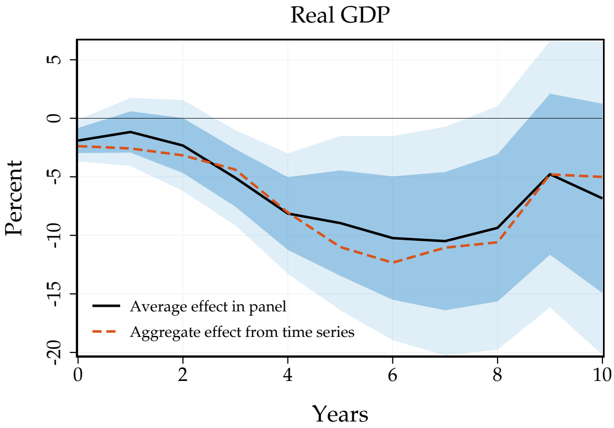

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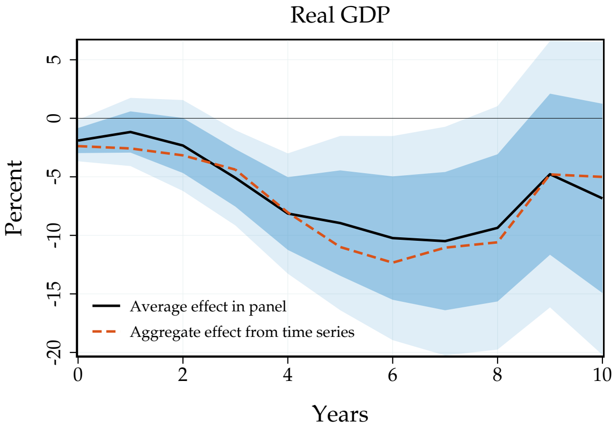
- **Global temperature shocks**
  - **Substantial** impact in panel
  - GDP per capita falls by **over 10%**

Global temperature shocks in the panel



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- **Global temperature shocks**
  - **Substantial** impact in panel
  - GDP per capita falls by **over 10%**
- **Effect in panel ≈ effect in time series**

Robustness

- Power of **panel** allows us to do a lot of sensitivity
- Results **robust** to
  1. Construction of temperature shock More
  2. Selection of controls More
  3. Sample period More
  4. No evidence for pre-trends More

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**

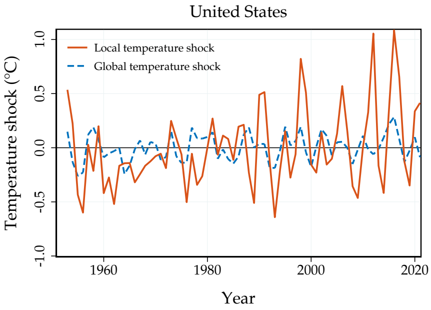
- Just replace global shock with **local temperature shock**

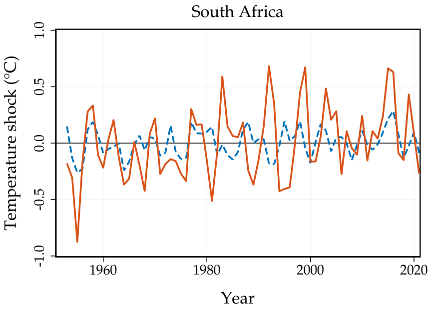
- Alternatively, can also control for time FE

$$y_{i,t+h} - y_{i,t-1} = \alpha_i + \delta_t + \theta_h T^{\text{shock}}_{i,t} + \mathbf{x}'_{i,t}\gamma + \varepsilon_{i,t+h},$$

Global vs. local temperature shocks

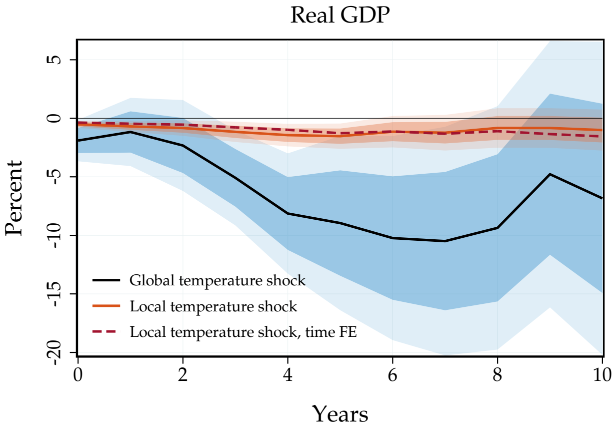
- Construct temperature shocks using same Hamilton filter
- Use population-weighted country-level temperature





- Local temperature shocks more volatile
- Only weakly correlated with global temperature shocks

Impact of global vs. local temperature shocks



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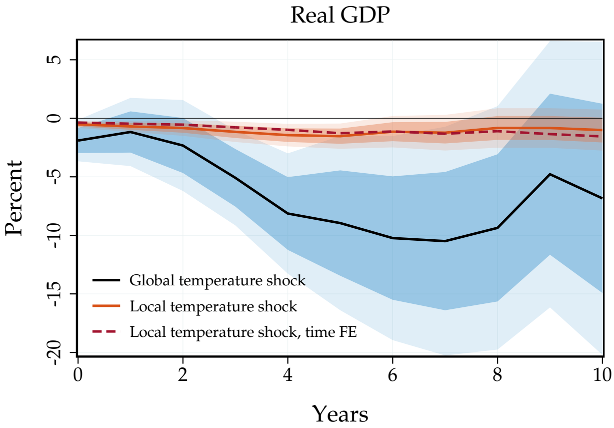

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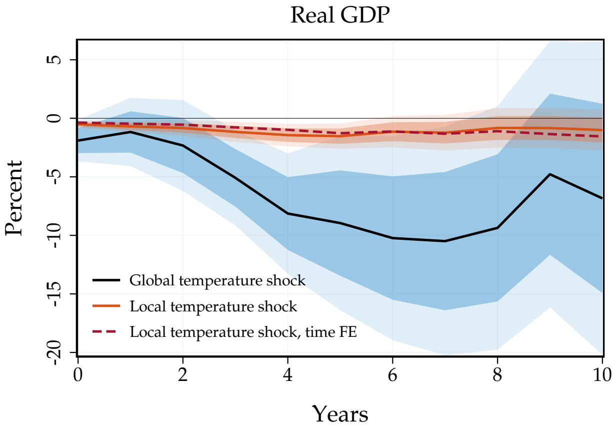
- Effect of **local T shocks**
  - Is in line with previous literature
  - Much smaller than **global T shocks**
- With time FE: no difference More
  - Nature of T shock rather than controls

Impact of global vs. local temperature shocks



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- Effect of **local T shocks**
  - Is in line with previous literature
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- With time FE: no difference More
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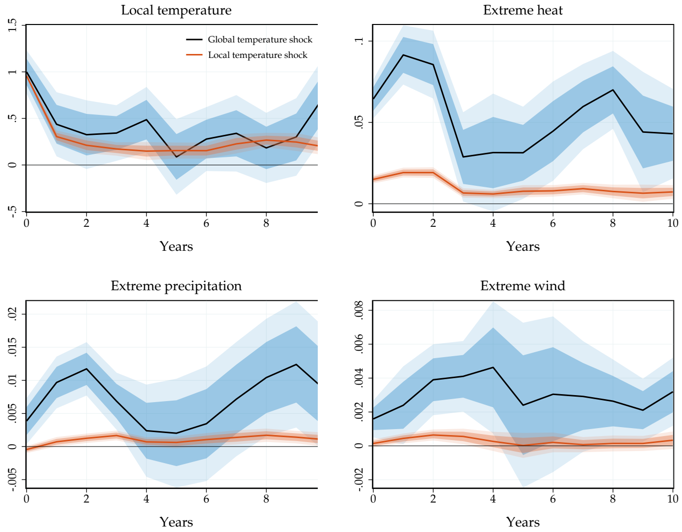
- For **global T shocks** More
  - Similar results for correlated T shocks even with time FE

Reconciling cross-sectional & time-series evidence

- What can explain the large difference between **local** and **global** shocks?
- **Conjecture:** global average temperature better proxy of **climate change**
  - Climate change materializes as a rise in global mean temperature
  - Change in global temperature affects the Earth's climate system as a whole
  - Influences the frequency, intensity, and distribution of extreme weather events
- Is this borne out in the data?
  - Study responses on extreme climatic events from ISIMIP

Reconciling cross-sectional & time-series evidence



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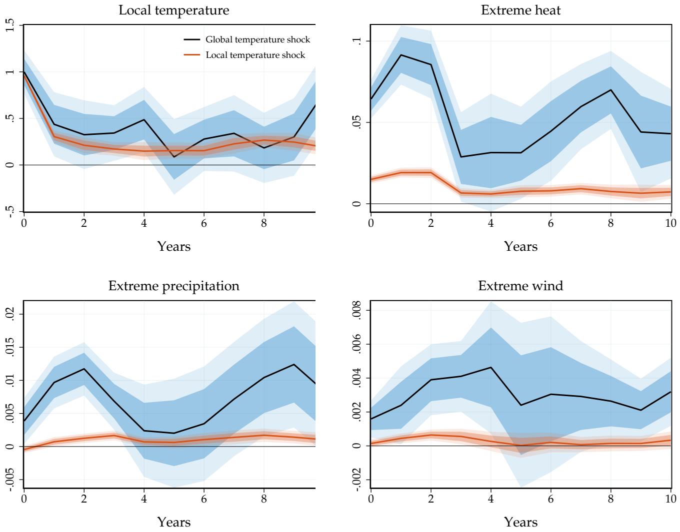


- **Temperature** response after shock
  - Similar for local & global shocks
  - Persistent increase
- Response of climatic **extremes**
  - **Much larger under global shocks**
  - Rise in
    - Extreme heat
    - Extreme precipitation
    - Extreme wind
  - **Local** shocks: barely significant

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 T 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

A Global 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

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

- 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

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

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

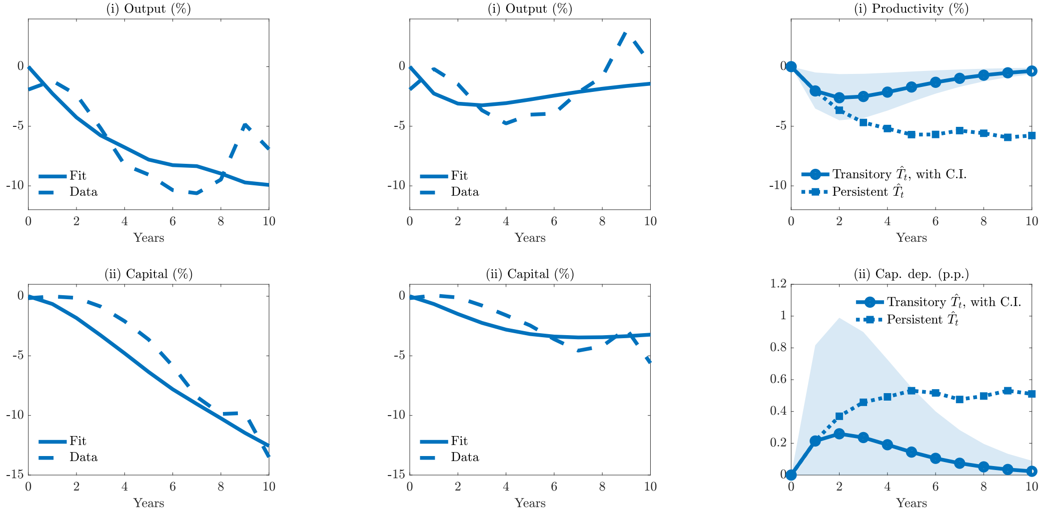
$$\hat{y}_t = \hat{z}_t + \alpha \hat{k}_t \qquad \hat{k}_t = \mathcal{K}_t(\hat{z}) + \int_0^\infty \mathcal{J}_{t,s} \hat{\boldsymbol{\Delta}}_s ds$$

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

- Recover sequence of **prod.** and **dep.** shocks $\hat{z}_t, \hat{\boldsymbol{\Delta}}_t$ following T shock in data
- Then estimate δ_s, ζ_s as innovations to $\hat{z}_t, \hat{\boldsymbol{\Delta}}_t$

Damage functions from global temperature shocks

(a) Persistent $\hat{T}_t$ **(b)** Transitory $\hat{T}_t$ **(c)** Damage Functions δ, ζ



Damage functions from global temperature shocks

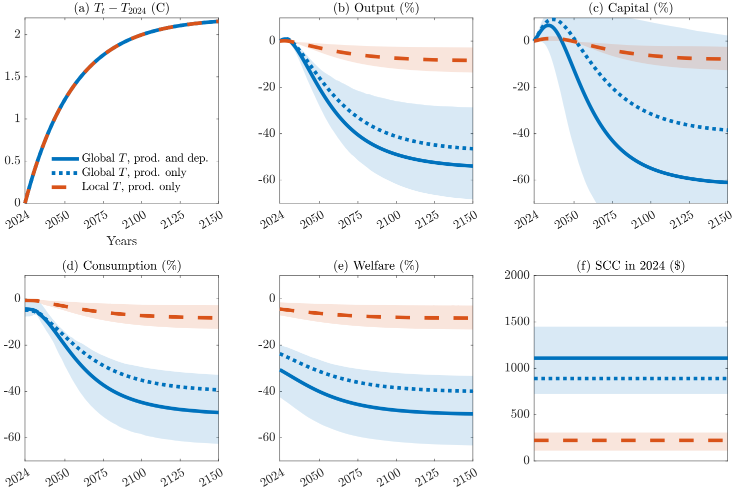
- Model matches output and capital responses reasonably well
- **Global** transitory temperature shocks imply **large productivity** and **capital depreciation** damages
  - -2.5% productivity and +0.3p.p. capital depreciation at peak
  - **Persistent** effects on productivity and capital depreciation despite shock being transitory
- Then repeat estimation with **local** temperature shocks More
  - Find **much smaller** productivity and capital depreciation damages
  - -0.5% productivity and only short-lived capital depreciation
  - Consistent with smaller economic impact estimated in data
- 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:** excess global temperature $\{\hat{T}_t\}_{t\geq 0}$
  - 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 (Joos et al. 2013)
  - 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



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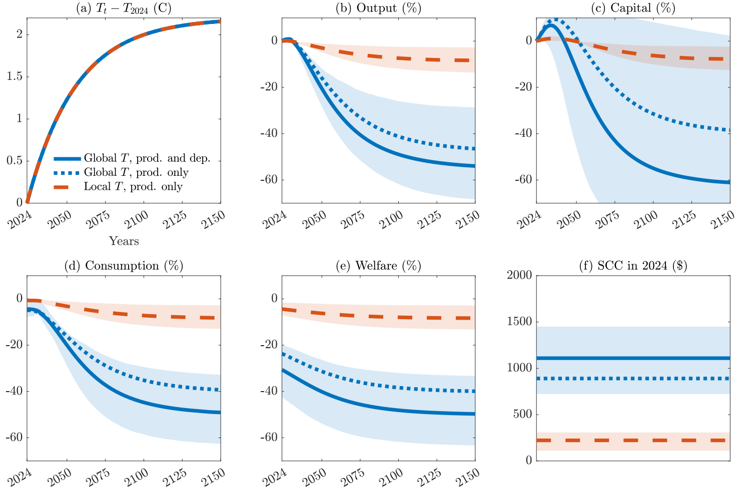
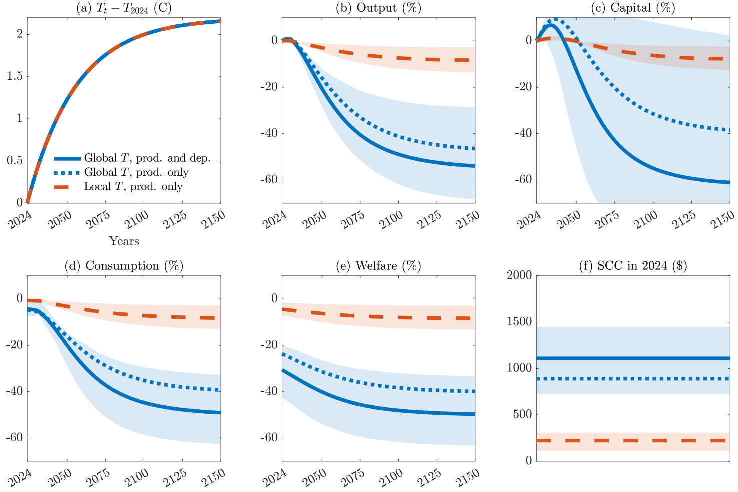


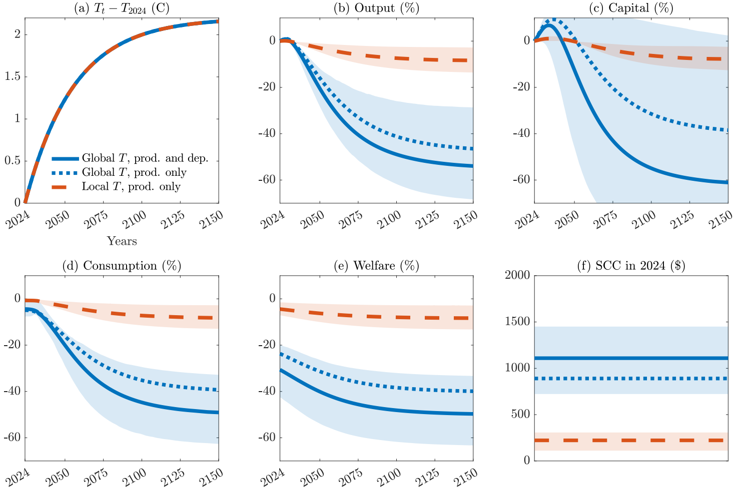
- **Global** shocks $\Rightarrow$ large impacts
  - BAU 2050 $C, Y \downarrow$ **30%**
  - **31% welfare loss**
  - **SCC = $1,056/tCO2**

The impact of climate change



- **Global** shocks ⇒ large impacts
  - BAU 2050 **C, Y ↓ 30%**
  - **31% welfare loss**
  - **SCC = $1,056/tCO2**
- **Local** shocks ⇒ small impacts
  - **4% welfare loss**
  - **SCC = $151/tCO2**
  - In line with previous findings

The impact of climate change



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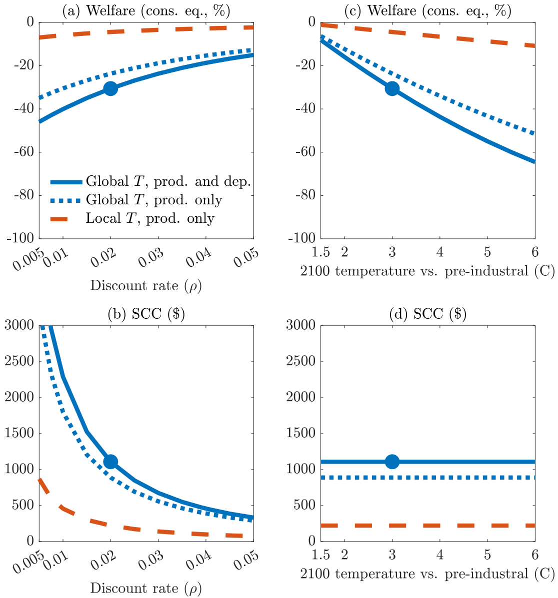
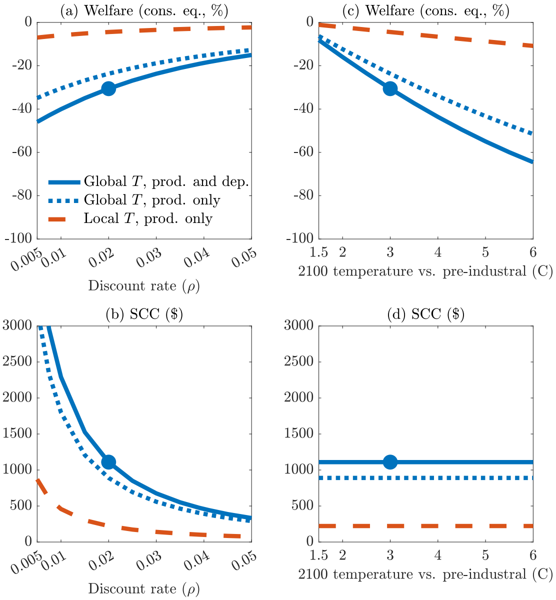
- Difference driven by
  - Global vs. local shocks
  - Not cap. dep. damages

Sensitivity



Sensitivity



- Overall magnitudes **robust** w.r.t.
  - Warming scenario
  - Discount rate
- Still **substantial effects** under
  - Moderate warming of 2°C
  - Large discount rate of 4%
- For **plausible pessimistic** cases
  - **Welfare loss $\geq$ 40%**
  - **SCC $\geq$ \$3,000/tCO2**

Policy Implications

Policy Implications

- Most large-scale decarbonization policies in the IRA cost **\$27-95/tCO2**
  - Below typical **global** traditional SCC estimates, e.g. **\$151/tCO2** with local temperature shocks
  - But higher than **US-only** Domestic Cost of Carbon (DCC), e.g. **\$30/tCO2** with local T shocks
  - So **unilateral** policy likely to face substantial opposition in long-run
- Our estimates with **global** temperature shocks entirely **reverse this trade-off**
  - Even the **US-only** DCC is **\$211/tCO2**
  - Much higher than the cost of decarbonization
  - So **unilateral** decarbonization policy is actually **optimal**
  - Makes widespread decarbonization much more likely and sustainable

Conclusion

Conclusion

- We evaluate the **macroeconomic** impact of climate change
- Propose focus on more **direct** proxy of climate change: **global temperature**
- **Global temperature** shocks have much larger effects than **local temperature** shocks
  - Because they lead to substantial increase in **extreme climatic events**
- Use evidence to discipline simple NGM at core of IAMs
- Implied SCC of **\$1,056/tCO2** and welfare cost of **31%**
  - Six times larger than previous estimates
  - Magnitudes are comparable to damages from fighting a war permanently
  - Imply that **unilateral** decarbonization policy is optimal

Thank you!

For questions or comments: dkaenzig@northwestern.edu

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

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

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

▸ 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

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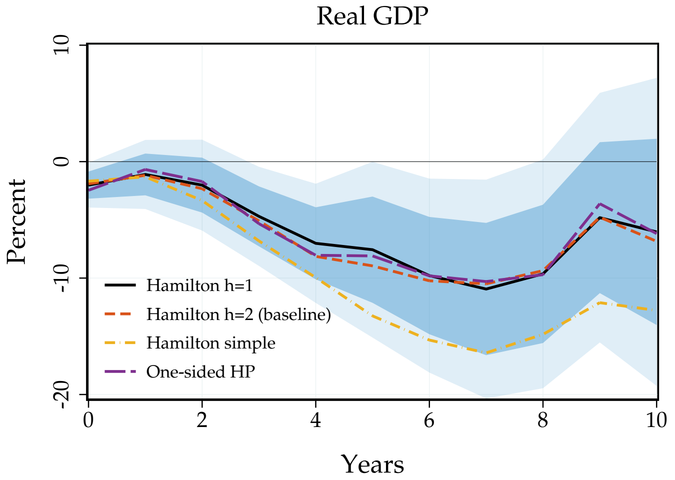
Construction of temperature shock



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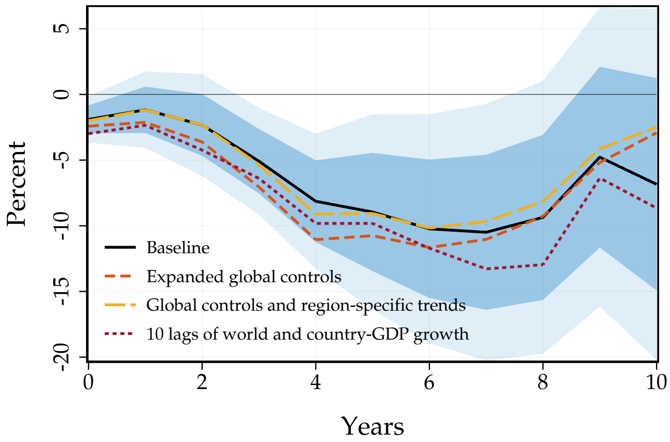
Selection of controls



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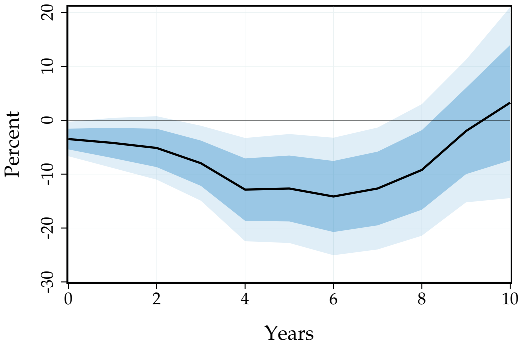
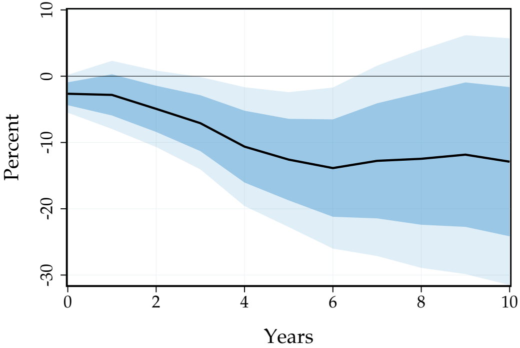
Sample period

(a) Short sample: 1985-2019



(b) Long sample: 1900-2019



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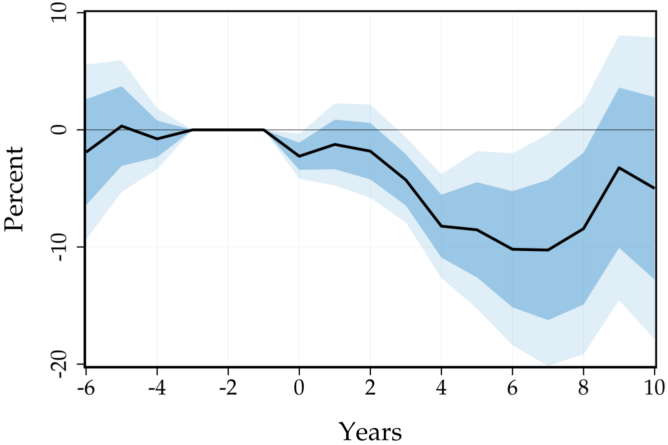
Pre-trends



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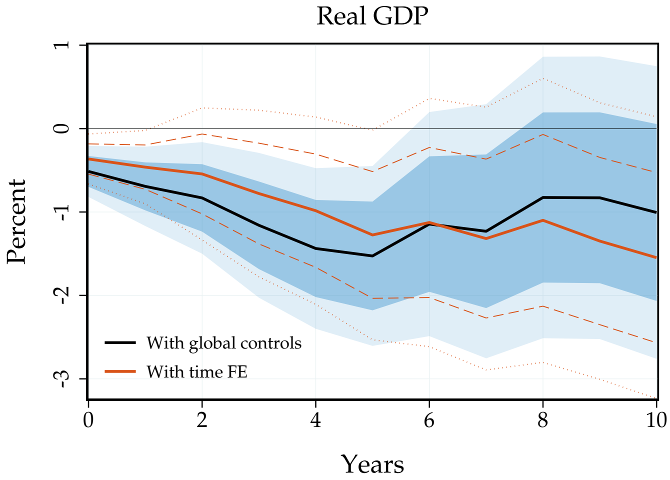
Time fixed effects



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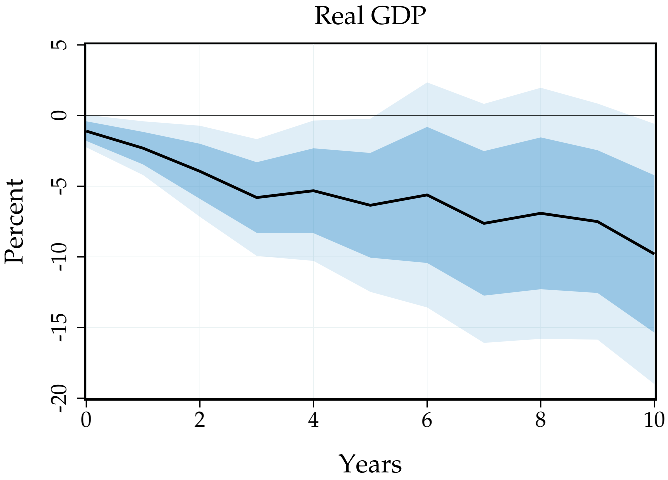
Correlated temperature shocks



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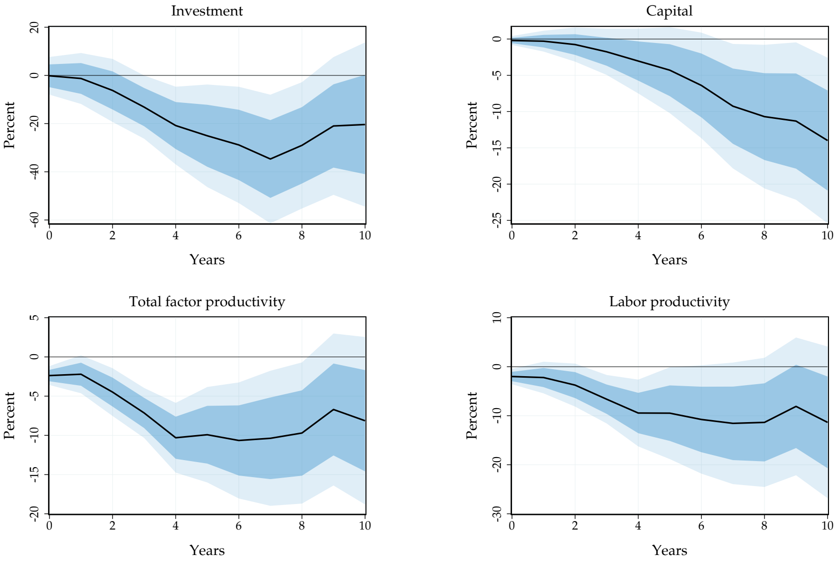
Mechanisms



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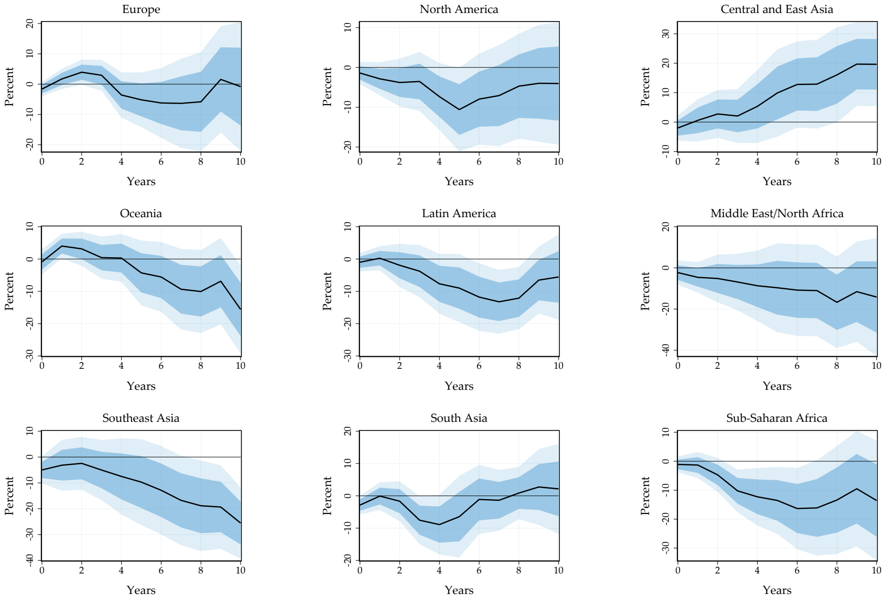
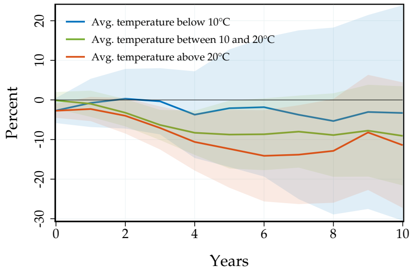
Heterogeneity

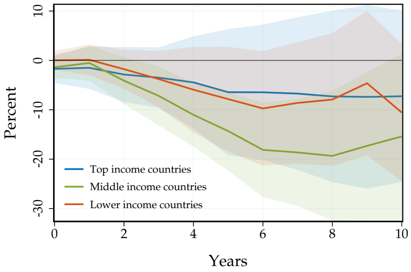


Heterogeneity

(a) By average temperature



(b) By income per capita



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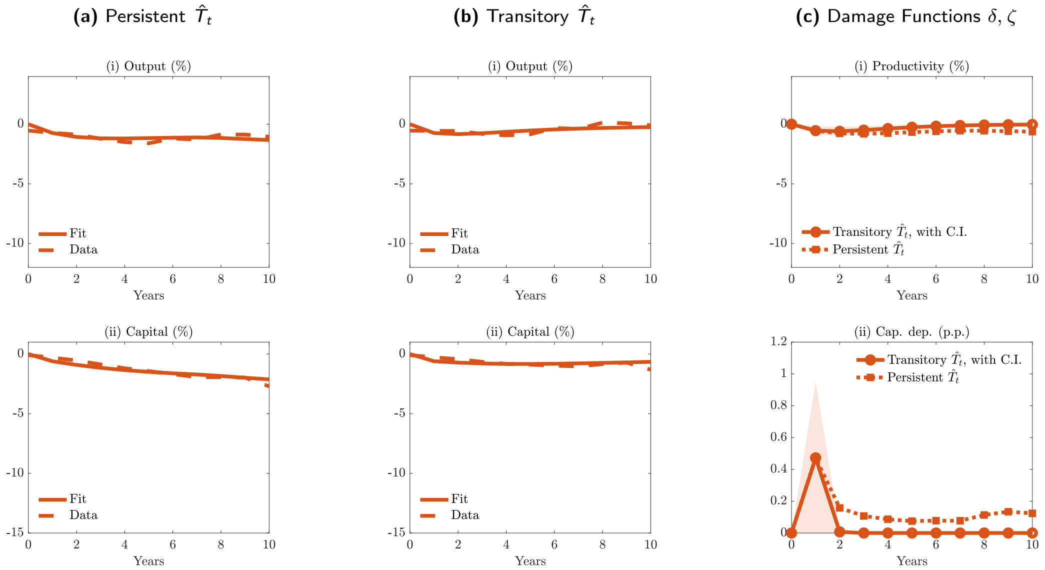
Damage functions from local temperature shocks



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