

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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 - ▶ Use natural climate variability and time series variation
 - ▶ 1°C global temperature implies a **12%** decline in world GDP vs. **1%** for local temperature
- Reconcile **global** and **local** temperature estimates
 - ▶ **Global** temperature shocks predict strong rise in damaging **extreme events**
 - ▶ **Local** temperature shocks do not

This paper

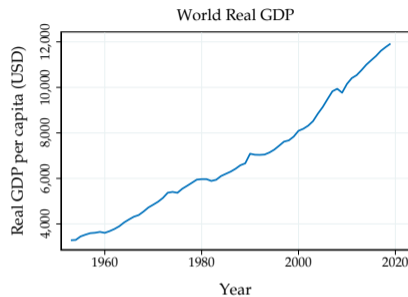
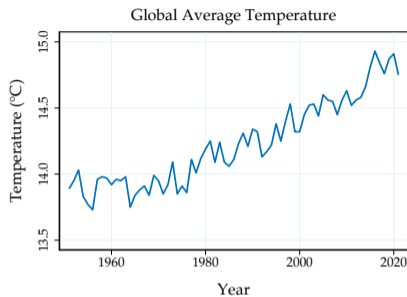
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- Quantify the **Social Cost of Carbon** & the **welfare cost** of climate change
 - ▶ Use reduced-form impacts to estimate damage functions in NGM (=DICE)
 - ▶ **\$151/tCO₂** for global temperature vs. **\$151/tCO₂** for local temperature
 - ▶ Adding 2°C to 2024 temperature by 2100 implies a **12% decline in world GDP** 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 = \$1,056/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

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**

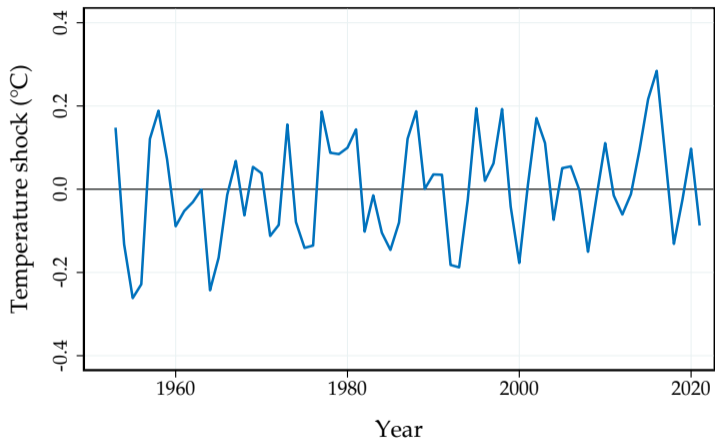
Measuring temperature shocks

- Use approach by Hamilton (2018)
- Estimate **transient component** in temperature as forecast error

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

- 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

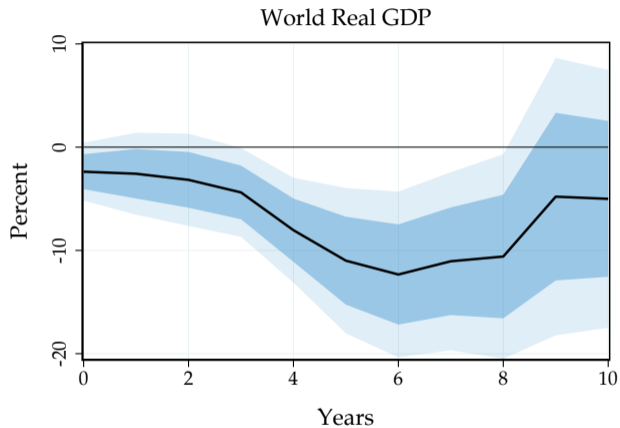
- Estimate dynamic causal effects to global T shocks using local projections (Jordà 2005)

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

where

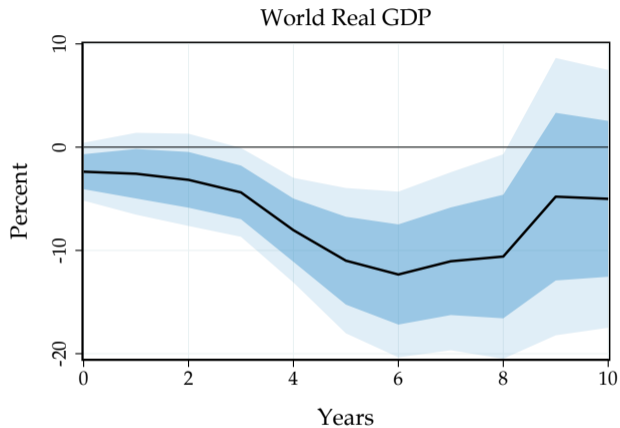
- ▶ y_t is (log) world real GDP per capita
- ▶ T_t^{shock} is the temperature shock
- ▶ θ_h is the dynamic causal effect at horizon h
- ▶ \mathbf{x}_t is a vector of controls

The effects of global temperature shocks



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

The effects of global temperature shocks

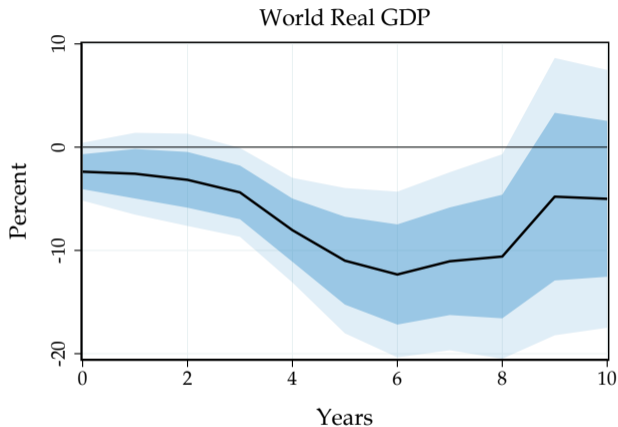


- **Global temperature shocks**

- ▶ Significant & persistent impact

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The effects of global temperature shocks



- **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

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

Threats to identification

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

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 - ▶ 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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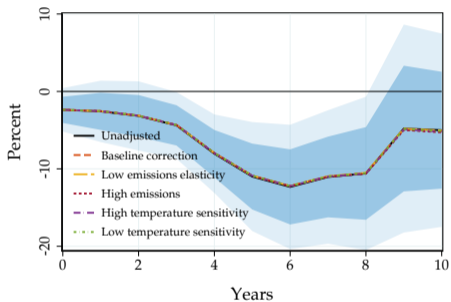
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- **Reverse causality:** **economic activity** leads to emissions and changes in **temperature**
 - ▶ Reverse causality concerns attenuate economic effects of temperature shocks
 - ▶ Emissions translate into temperature with a substantial lag (max 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

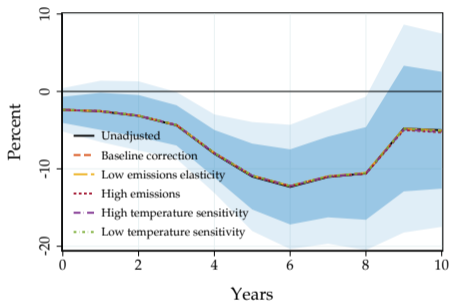
Reverse causality



- Formally accounting for reverse causality produces virtually identical results

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

Reverse causality



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

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

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

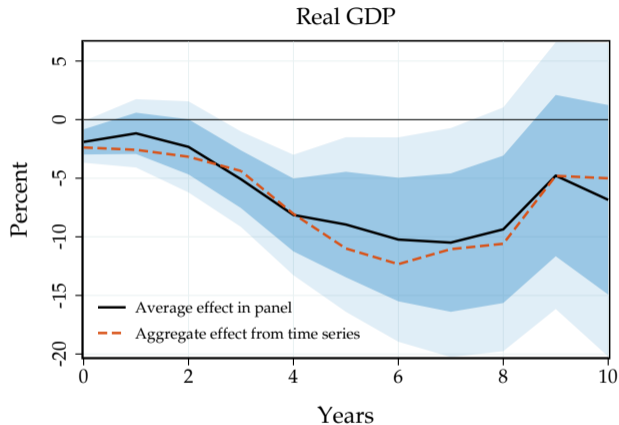
- Estimate the dynamic causal effects to **temperature shocks** in the panel
- Use panel local projections (Jordà et al 2020)

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

where

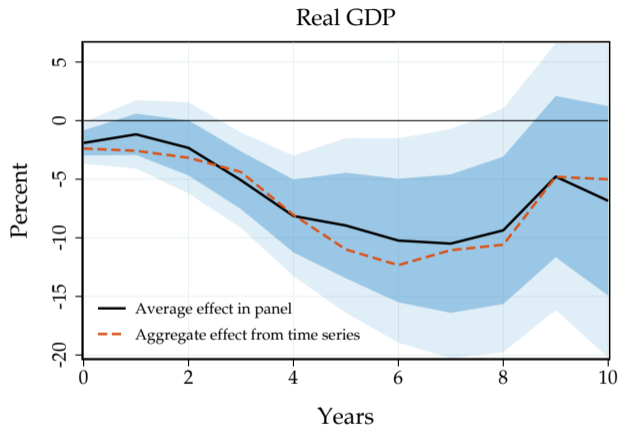
- ▶ $y_{i,t}$ is (log) real GDP per capita in country i
 - ▶ T_t^{shock} is the temperature shock
 - ▶ θ_h is the dynamic causal effect at horizon h
 - ▶ \mathbf{x}_t is a vector of global controls, $\mathbf{x}_{i,t}$ are country controls
- Can estimate responses to **global** and **local** temperature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

Global temperature shocks in the panel



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

Global temperature shocks in the panel

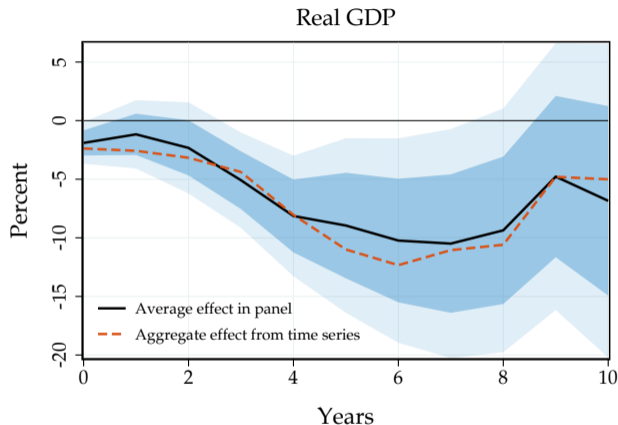


- **Global temperature shocks**

- ▶ **Substantial** impact in panel
- ▶ GDP per capita falls by **over 10%**

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Global temperature shocks in the panel



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

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

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](#)

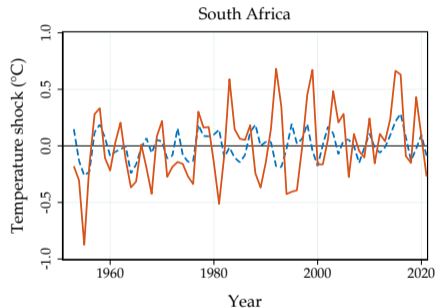
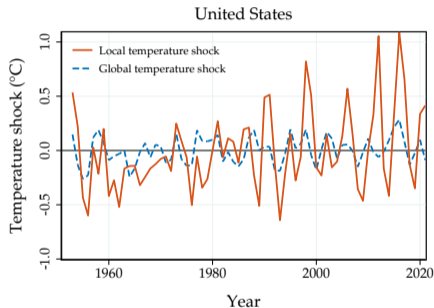
Global vs. local temperature shocks

- 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**

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

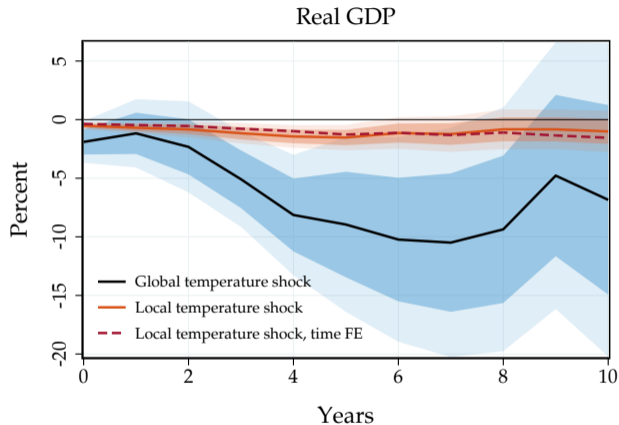
Global vs. local temperature shocks

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



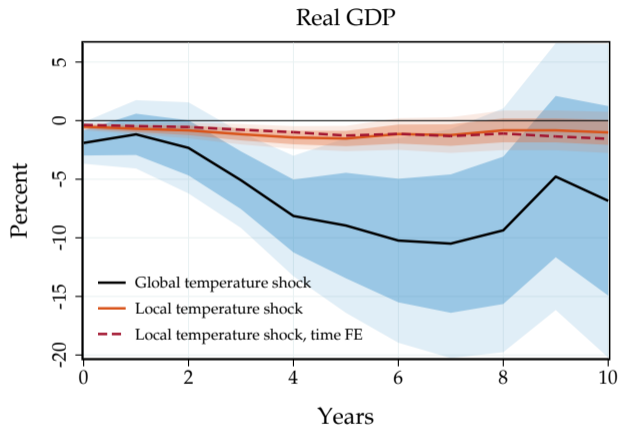
- Local temperature shocks more volatile
- Only weakly correlated with global temperature shocks

Impact of global vs. local temperature shocks



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

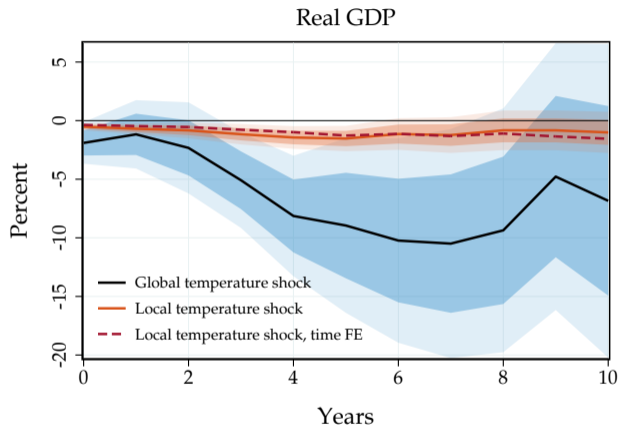
Impact of global vs. local temperature shocks



- 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

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Impact of global vs. local temperature shocks



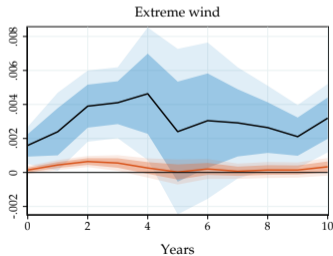
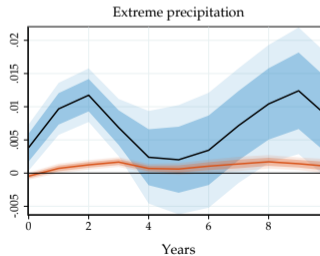
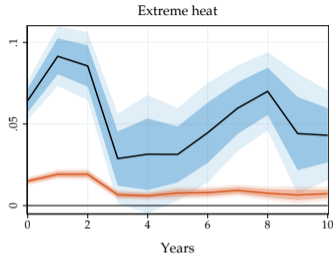
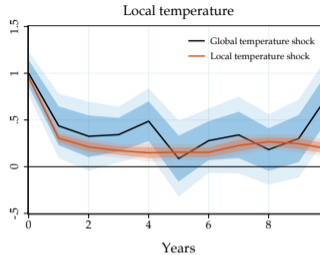
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 - ▶ Nature of T shock rather than controls
- For **global T shocks** ▶ More
 - ▶ Similar results for correlated T shocks even with time FE

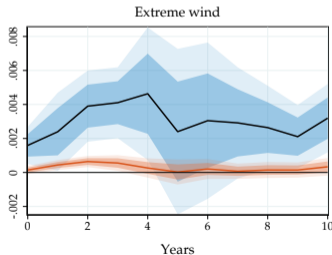
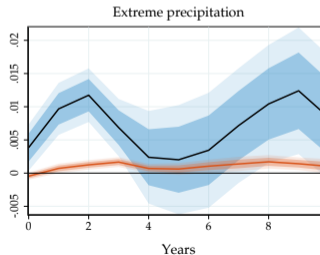
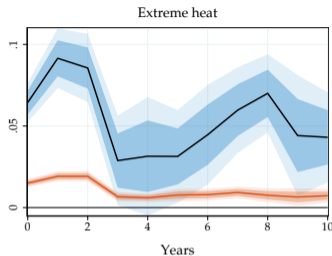
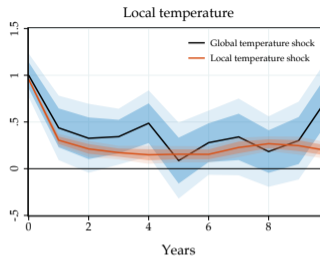
Reconciling cross-sectional & time-series evidence

- 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



Reconciling cross-sectional & time-series evidence



- **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 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

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

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

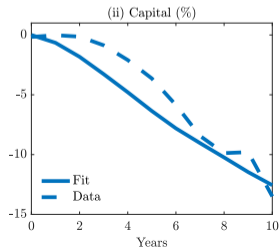
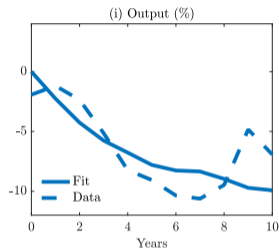
$$\hat{y}_t = \hat{z}_t + \alpha \hat{k}_t \qquad \hat{k}_t = \mathcal{K}_t(\hat{z}) + \int_0^\infty \mathcal{J}_{t,s} \hat{\Delta}_s ds$$

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

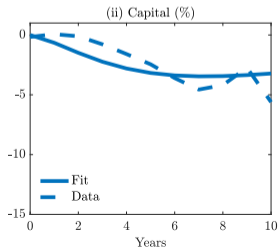
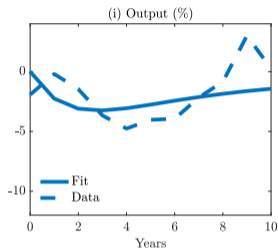
- Recover sequence of **prod.** and **dep.** shocks $\hat{z}_t, \hat{\Delta}_t$ following T shock in data
- Then estimate δ_s, ζ_s as innovations to $\hat{z}_t, \hat{\Delta}_t$

Damage functions from global temperature shocks

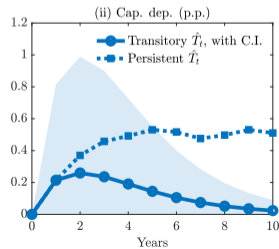
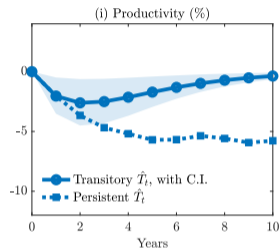
(a) Persistent \hat{T}_t



(b) Transitory \hat{T}_t



(c) Damage Functions δ, ζ



Damage functions from global temperature shocks

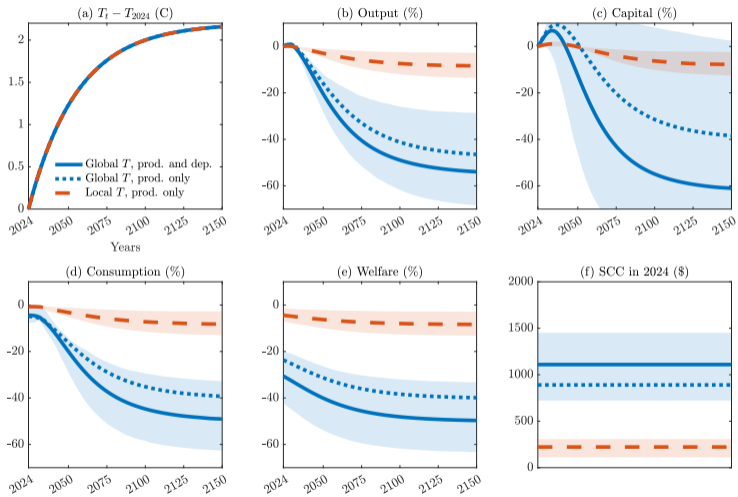
- Model matches output and capital responses reasonably well
- **Global** transitory temperature shocks imply **large productivity** and **capital depreciation** damages
 - ▶ -2.5% productivity and +0.3p.p. capital depreciation at peak
 - ▶ **Persistent** effects on productivity and capital depreciation 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

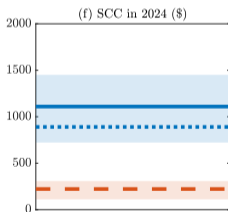
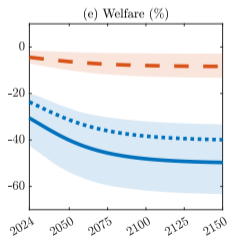
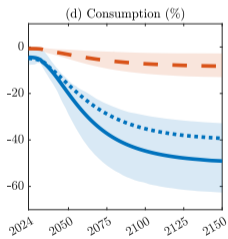
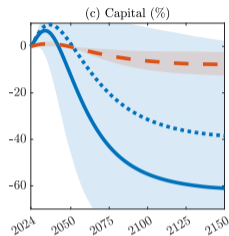
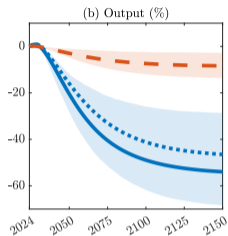
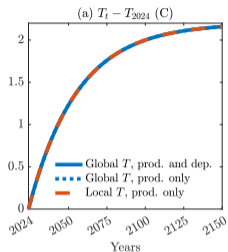
- With estimated damage functions can evaluate climate change and SCC counterfactuals
- **Climate change:** excess global temperature $\{\hat{T}_t\}_{t \geq 0}$
 - ▶ Use 2024 as $t = 0$ and add 2°C by 2100 so 3°C above pre-industrial levels
 - ▶ Conservative relative to business-as-usual (IPCC)
- **SCC:** \$ 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



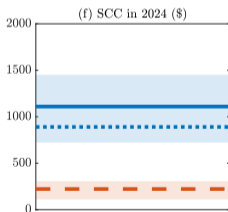
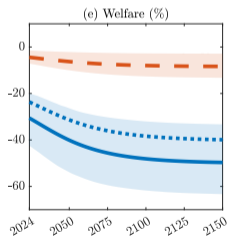
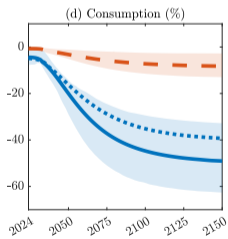
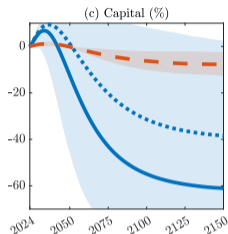
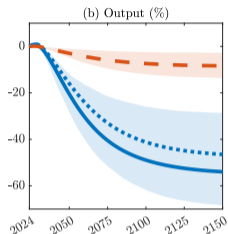
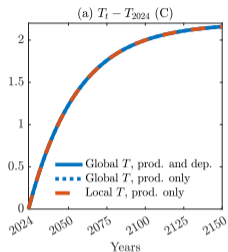
The impact of climate change



- **Global** shocks \Rightarrow large impacts

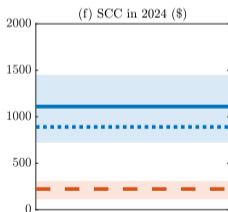
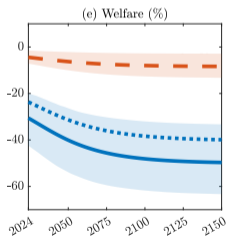
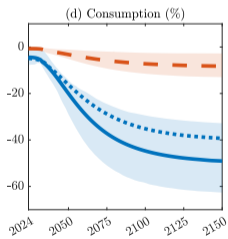
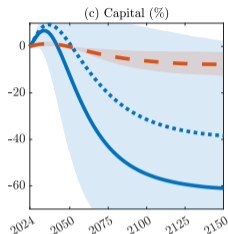
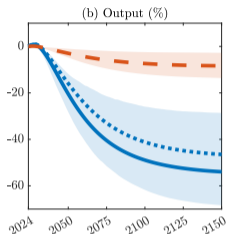
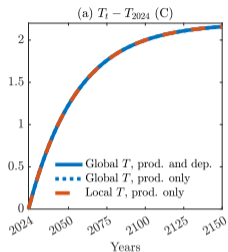
- ▶ BAU 2050 $C, Y \downarrow 30\%$
- ▶ **31% welfare loss**
- ▶ **SCC = \$1,056/tCO₂**

The impact of climate change



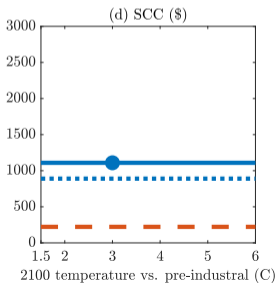
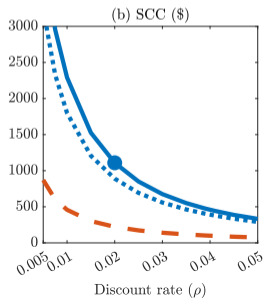
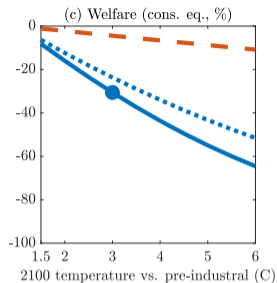
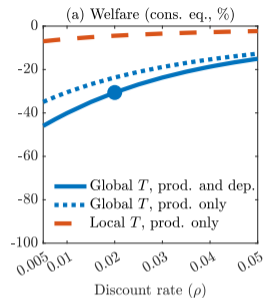
- **Global** shocks \Rightarrow large impacts
 - ▶ BAU 2050 C , $Y \downarrow 30\%$
 - ▶ **31% welfare loss**
 - ▶ **SCC = \$1,056/tCO₂**
- **Local** shocks \Rightarrow small impacts
 - ▶ **4% welfare loss**
 - ▶ **SCC = \$151/tCO₂**
 - ▶ In line with previous findings

The impact of climate change

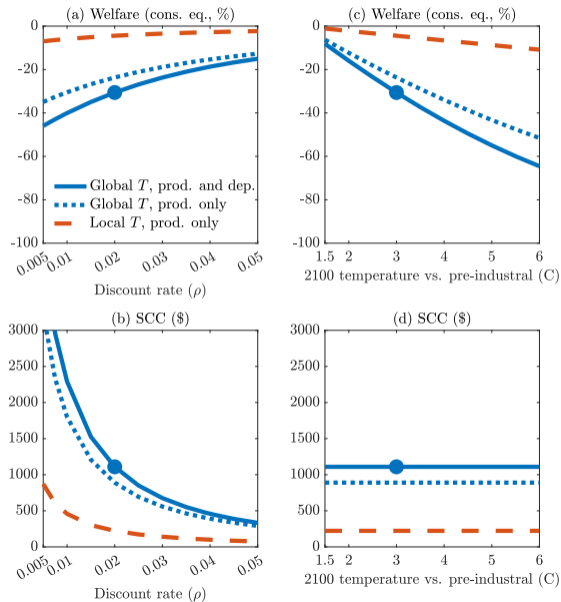


- **Global** shocks \Rightarrow large impacts
 - ▶ BAU 2050 $C, Y \downarrow 30\%$
 - ▶ **31% welfare loss**
 - ▶ **SCC = \$1,056/tCO₂**
- **Local** shocks \Rightarrow small impacts
 - ▶ **4% welfare loss**
 - ▶ **SCC = \$151/tCO₂**
 - ▶ In line with previous findings
- Difference driven by
 - ▶ Global 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 $\geq \$3,000/\text{tCO}_2$**

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

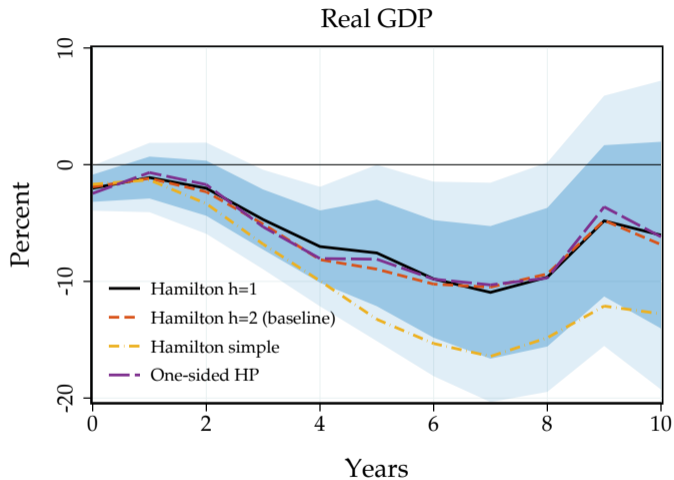
Forecastability

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

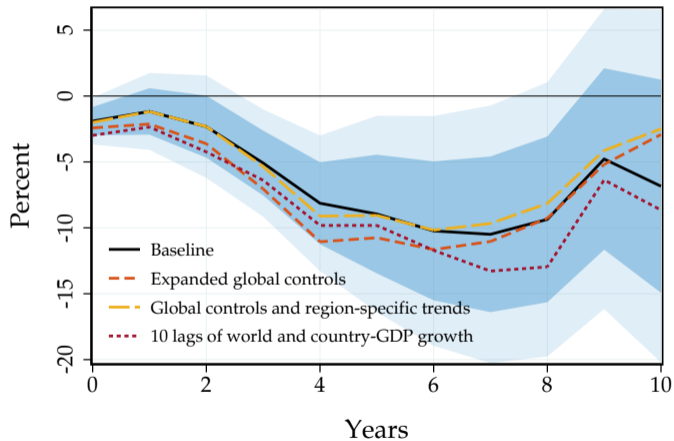
Table: Granger-causality tests

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

Construction of temperature shock

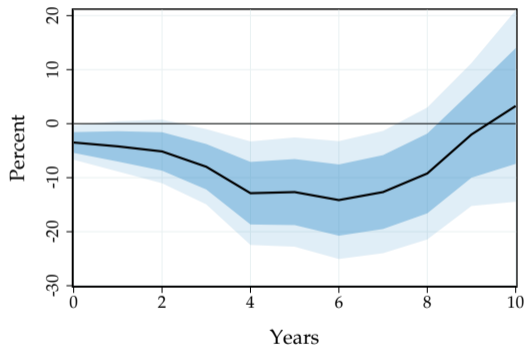


Selection of controls

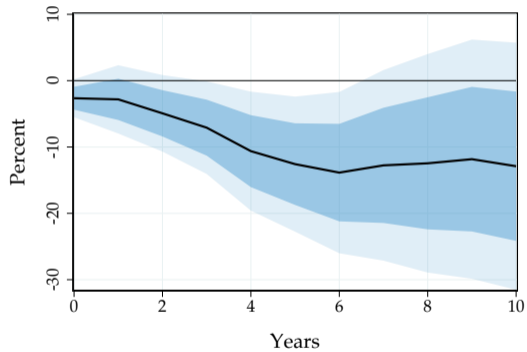


Sample period

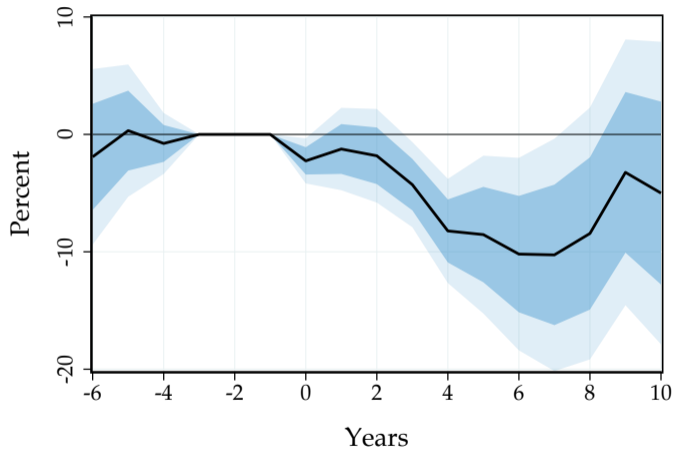
(a) Short sample: 1985-2019



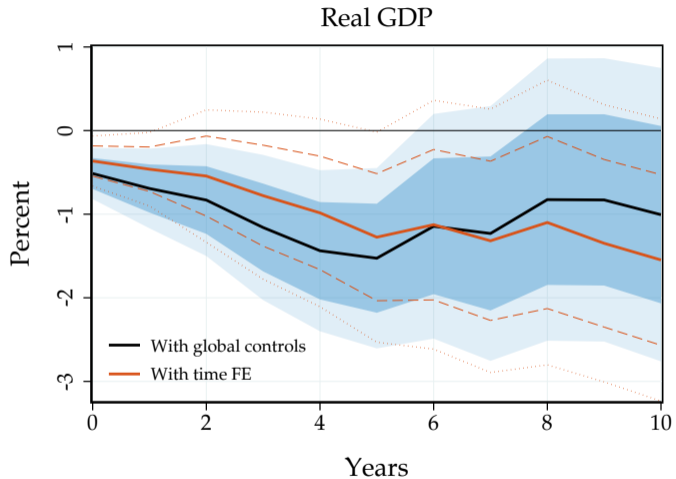
(b) Long sample: 1900-2019



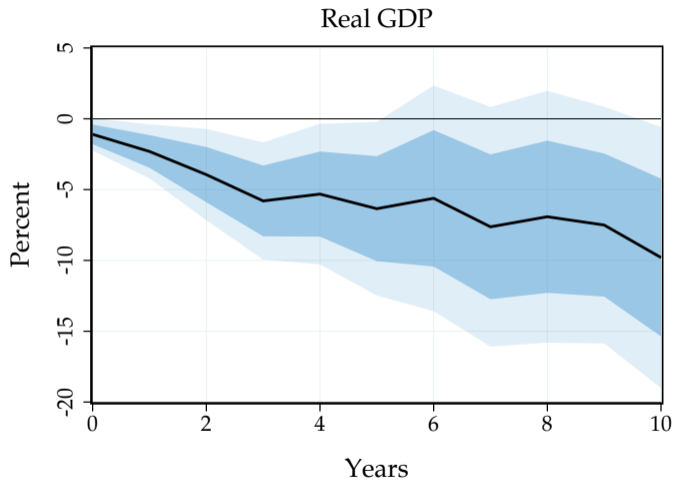
Pre-trends



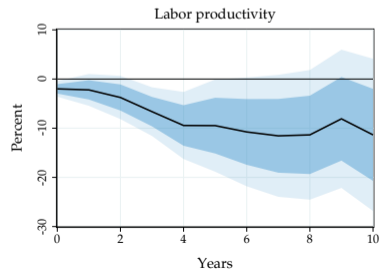
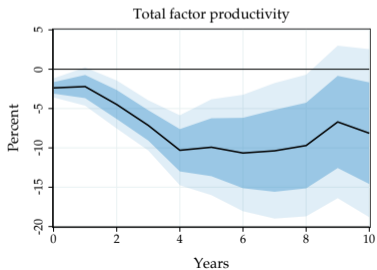
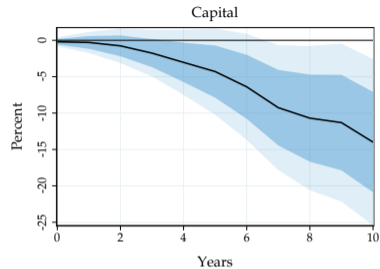
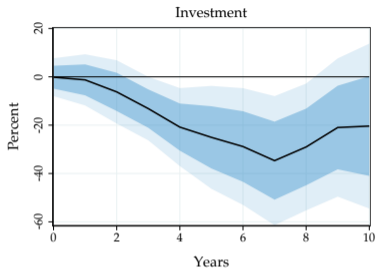
Time fixed effects



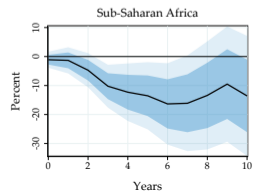
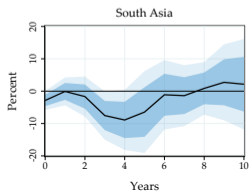
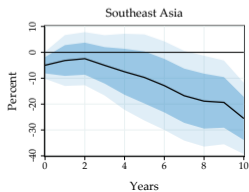
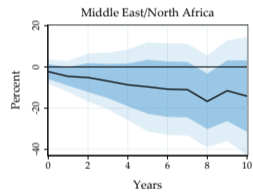
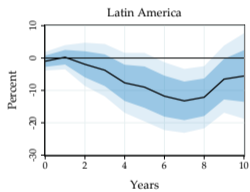
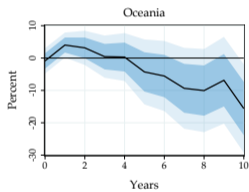
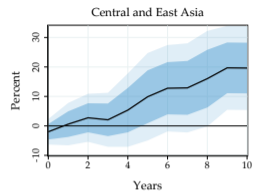
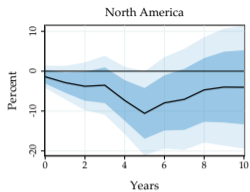
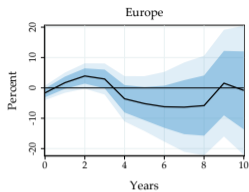
Correlated temperature shocks



Mechanisms

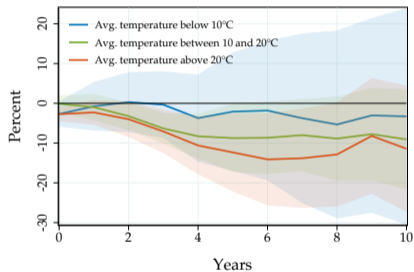


Heterogeneity

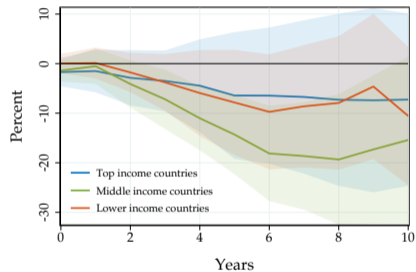


Heterogeneity

(a) By average temperature

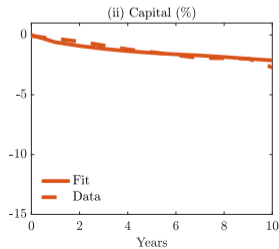
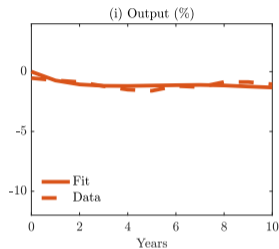


(b) By income per capita

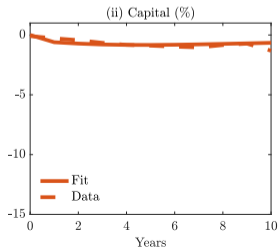
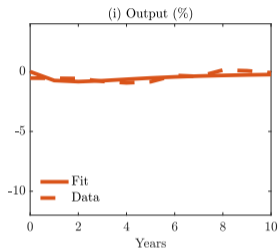


Damage functions from local temperature shocks

(a) Persistent \hat{T}_t



(b) Transitory \hat{T}_t



(c) Damage Functions δ, ζ

