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**, 1-2% 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

▸ Literature

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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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  - **Local** temperature shocks do not
- 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. **$178/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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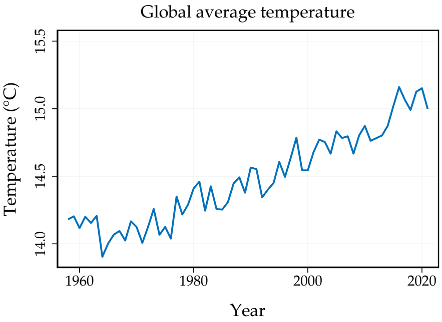
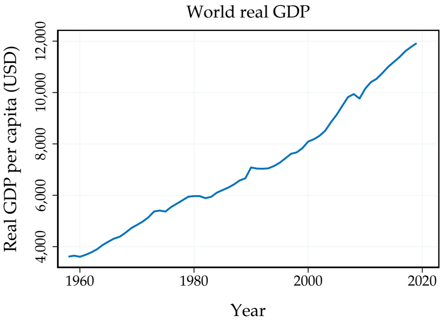
- Quantify the **Social Cost of Carbon** & the **welfare cost** of climate change
  - Use reduced-form impacts to estimate damage functions in NGM (=DICE)
  - **SCC = $1,367/tCO2** for global temperature vs. **$178/tCO2** for local temperature
  - Adding 2°C to 2024 temperature by 2100 implies a **25% welfare loss** in permanent consumption
  - Imply that **unilateral** decarbonization policy is optimal

▸ Literature

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)

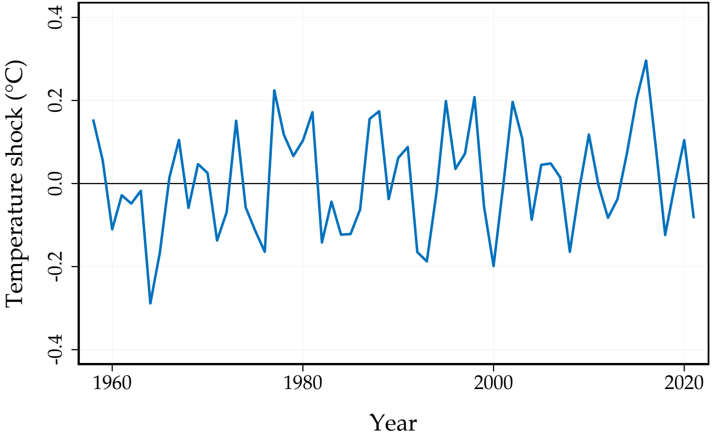
- Estimate **transient component** in temperature as forecast error

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

- 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

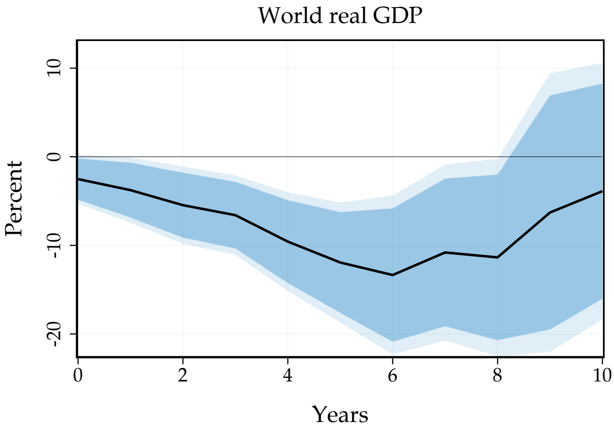
- Estimate dynamic causal effects to global temperature shocks using local projections (Jordà 2005)

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

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: 90 and 95% 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**

‣ Internal persistence of temperature

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 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

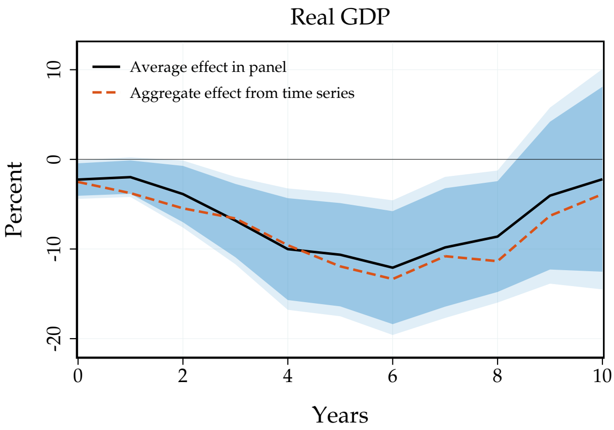
- Use panel local projections (Jordà et al 2020)

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

  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 90 and 95% confidence bands based on Driscoll-Kraay SE

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

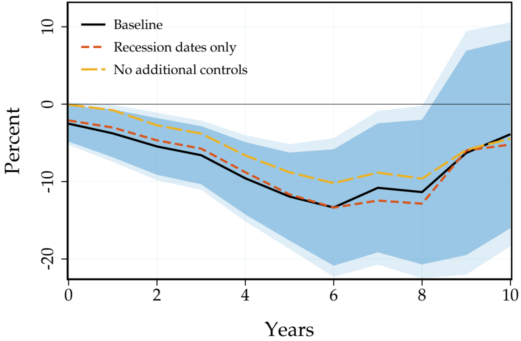
▸ Bootstrap

Four identification concerns

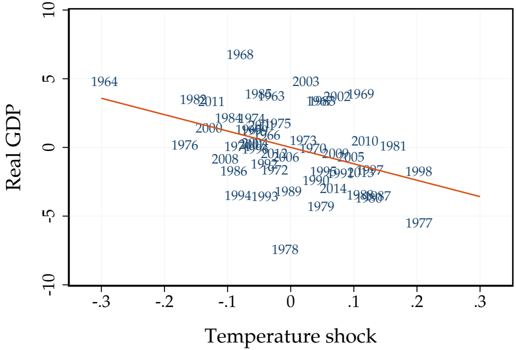
1. **Omitted variable bias (global)**
   - Temperature shocks may happen to coincide with adverse *global* economic shocks
2. **Reverse causality**
   - Economic activity may lead to emissions and changes in temperature
3. **External validity**
   - Estimates may change over time and by source of global temperature variation
4. **Omitted variable bias (regional)**
   - Temperature shocks may happen to coincide with adverse *regional* economic shocks

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

(a) Sensitivity with respect to controls



(b) Scatter plot at $h = 5$



Notes: 90 and 95% 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.

‣ Construction of T shock and jackknife

Four identification concerns

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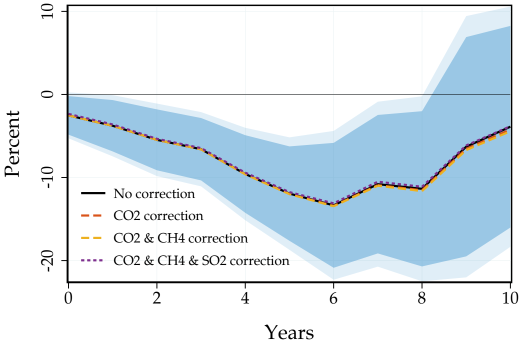
Accounting for concern #2: Reverse causality



Notes: 90 and 95% confidence bands based on robust standard errors.

- Control for reverse causality
  - Feedback of GDP on T via emissions
  - Climate models: CO_2, CH_4 and SO_2
- Results virtually unchanged
  - Emissions fluctuations too small

Four identification concerns

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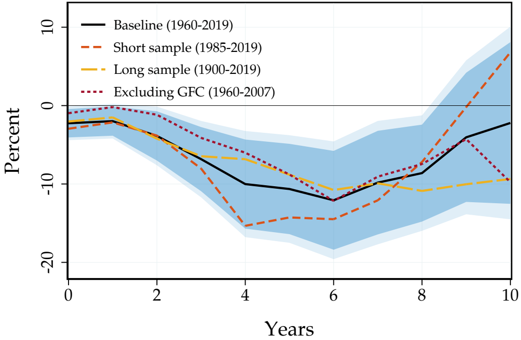
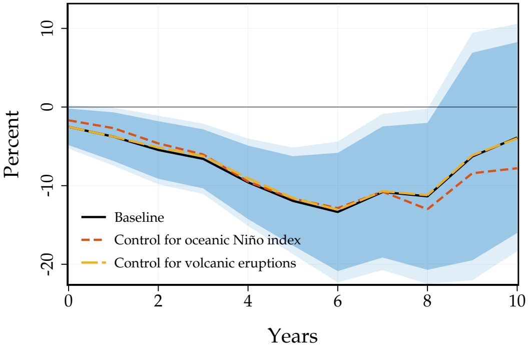
Accounting for concern #3: External validity

(a) Sample period



(b) El Niño and volcanic eruptions



Notes: Point estimate with 90 and 95% confidence bands based on Driscoll-Kraay SE

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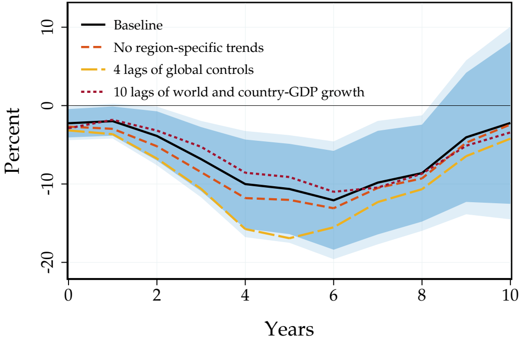
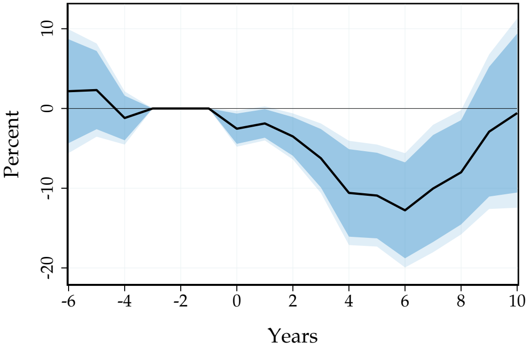
Accounting for concern #4: Omitted variable bias (regional)

(a) Regional controls



(b) Pre-trends



Notes: Point estimate with 90 and 95% 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**

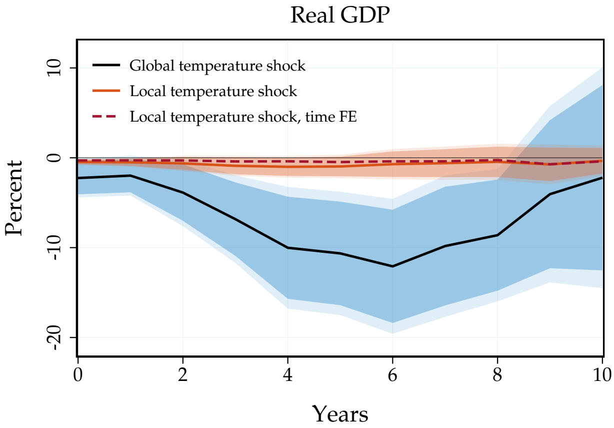
$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \theta_h \boldsymbol{T_{i,t}^{\text{shock}}} + \mathbf{x}_t'\boldsymbol{\beta}_h + \mathbf{x}_{i,t}'\gamma_h + \varepsilon_{i,t+h}$$

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

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

▸ Local temperature variation

Impact of global vs. local temperature shocks



Notes: Point estimate with 90 and 95% confidence bands based on Driscoll-Kraay SE

- 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

Reconciling cross-sectional & time-series evidence

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

1. **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

2. **Economic spillovers** due to trade linkages and spatially correlated local temperature?
   - Omitted variable in standard panel regression
   - Test with **external, trade-weighted temperature** Details

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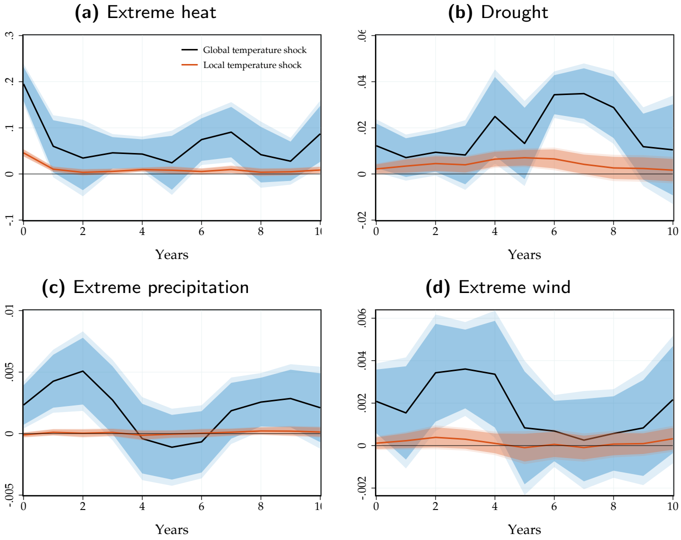
2. **Economic spillovers** due to trade linkages and spatially correlated local temperature?
   - Omitted variable in standard panel regression
   - Test with **external, trade-weighted temperature** Details
   - **Rule out spillovers**: external temperature has **small** effects on country GDP
     - Under moderate openness cannot expect to get much more than direct local temperature effect

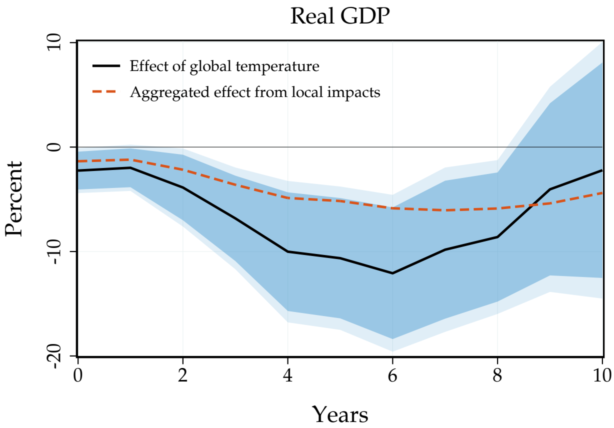
Extreme events help rationalize the GDP impact of global temperature



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

Local temperature · Extreme events damages · Economic spillovers

Extreme events help rationalize the GDP impact of global temperature



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

- Aggregating local impacts
  - implies large damages
  - up to 2/3 of **global T** effect
  - persistent rise in extremes key
- Challenging to capture all local margins
  - key advantage of **global T** approach

Extreme events damages · Ocean temperature · Economic spillovers · Spatial correlation

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

A Model of Climate Change

A Neoclassical growth model

- Households solve

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

- Firms solve

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

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

- Excess temperature relative to baseline $\hat{T}_t$ affects productivity

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

Estimating damage function

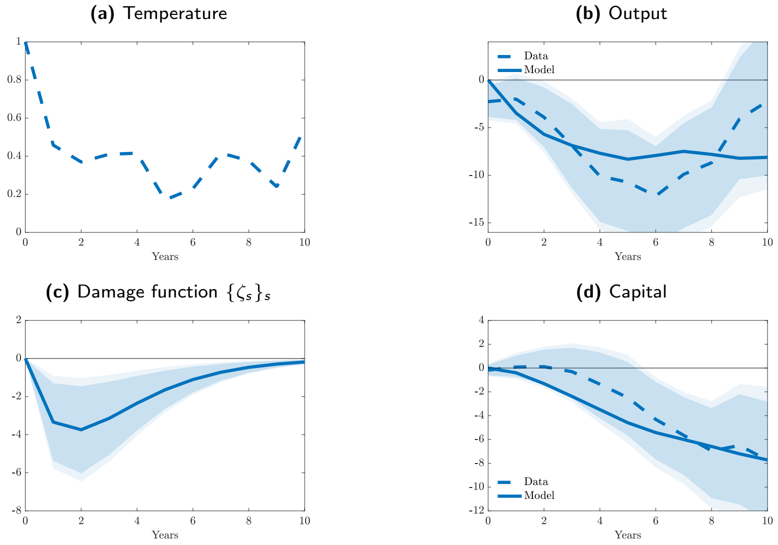
- Use reduced-form GDP and capital IRFs to identify **damage function ζ_s**
- Leverage **identification result**: for small temperature shocks

$$\hat{y}_t = \underbrace{\hat{\boldsymbol{z}}_t}_{\text{direct effect}} + \underbrace{\alpha \int_0^{\infty} \mathcal{K}_{t,s} \hat{\boldsymbol{z}}_s ds}_{\text{indirect effect through capital}}$$

- Recover sequence of **productivity** following a temperature shock in data
- Then obtain ζ_s as innovations to $\hat{\boldsymbol{z}}_t$ using estimated temperature reponse to temperature shock
  - **Accounts for internal persistence of realized temperature**

▸ Target transitory shocks

Damage functions from global temperature shocks



Damage functions from temperature shocks

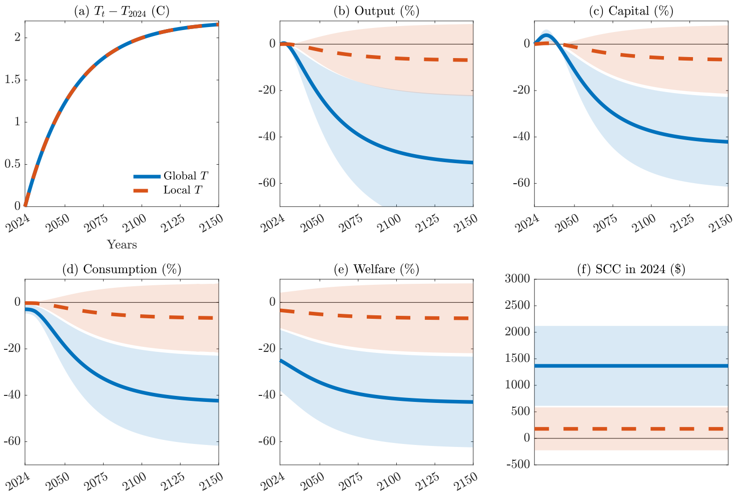
- Model matches output and capital responses reasonably well
- **Global** temperature implies **large productivity** and **capital depreciation** damages
  - -4% productivity
  - **Persistent** effects on productivity even when shock is transitory
- **Local** temperature implies **small productivity** and **capital depreciation** damages ▸ Details
  - -0.25% productivity
  - Consistent with smaller economic impact estimated in data and literature

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

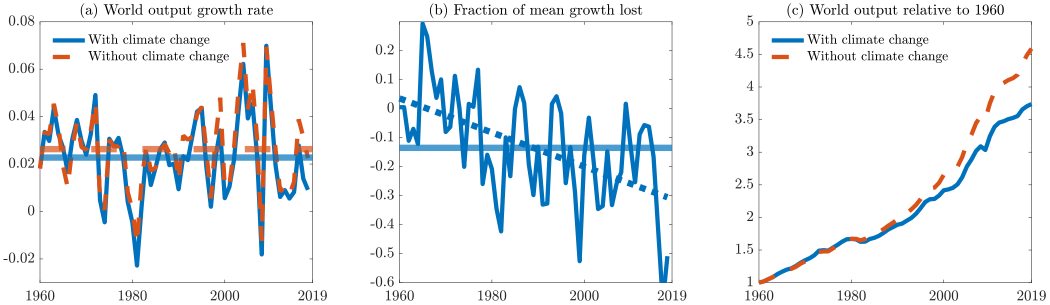
The Welfare Impact of Climate Change

The impact of climate change



- **Global** shocks ⇒ large impacts
  - 2100 $C, Y \downarrow$ **40%**
  - **25% welfare loss**
  - **SCC = $1,367/tCO2**
- **Local** shocks ⇒ small impacts
  - 2100 $C, Y \downarrow$ **6%**
  - **3% welfare loss**
  - **SCC = $178/tCO2**
  - In line with previous findings

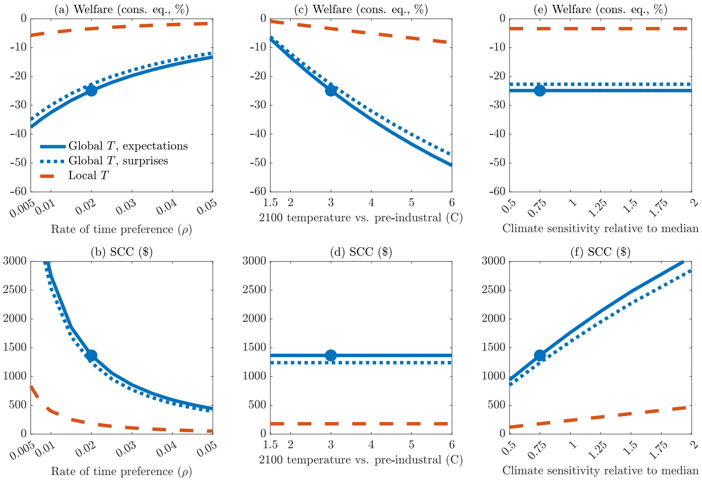
The impact of past climate change under global temperature estimates



- Use 1960 as $t = 0$ and **realized** excess global temperature path $\{\hat{T}_t\}_{t \geq 0}$ up to 2019
- **Output would be 19% higher today** had historical climate change not occurred
- Damages rise to 25% by 2040 due to delayed impacts

Back

Sensitivity



- 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 $\geq$ 30%**
  - **SCC $\geq$ \$2,000/tCO2**

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. **$178/tCO2** with **local temperature**
  - But higher than **US-only** Domestic Cost of Carbon, e.g. **$36/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 **$273/tCO2**
  - Higher than the cost of decarbonization
  - So **unilateral, non-cooperative** decarbonization policy becomes **cost-effective**

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 **$1,367/tCO2** and welfare cost of **25%**
  - 5-6 times larger than previous estimates
  - Magnitudes are comparable to a permanent 1929 Great Depression
  - Imply that **unilateral** decarbonization policy is optimal

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

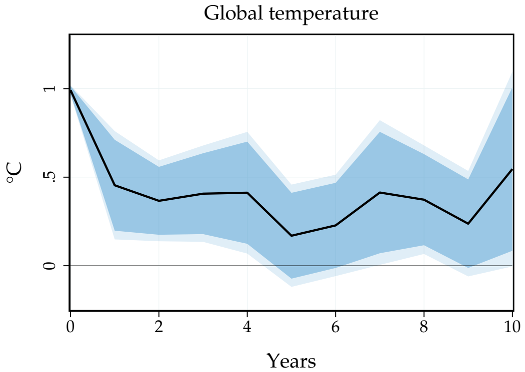
Economic impact of storms and heatwaves: Deschênes and Greenstone 2011; Deryugina 2013; Hsiang and Jina 2014; Bilal and Rossi-Hansberg 2023; Phan and Schwartzman 2023; Tran and Wilson 2023

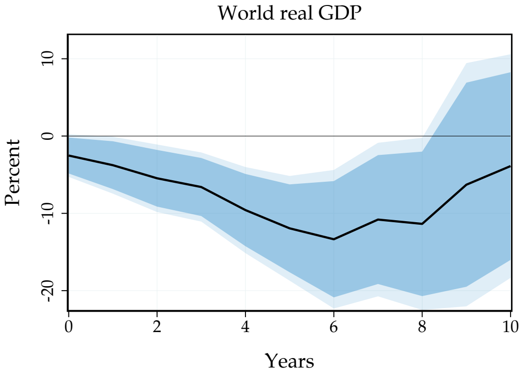
- Link global temperature shocks to extreme events

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



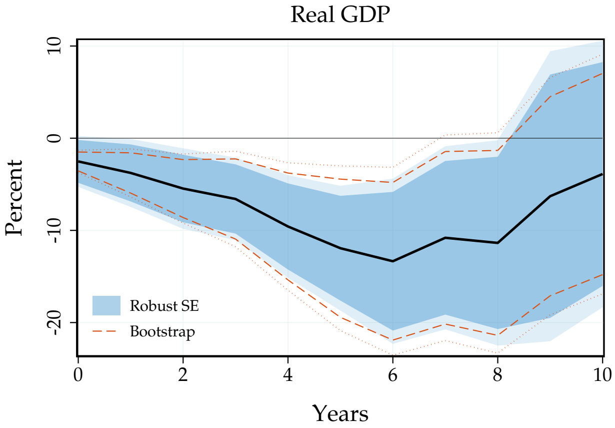


Notes: Point estimate with 90 and 95% confidence bands based on robust standard errors

▸ Back

Bootstrapped confidence bands

- Taking estimation uncertainty in temperature shocks into account:



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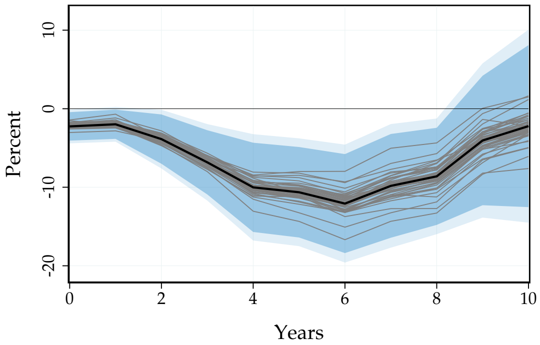
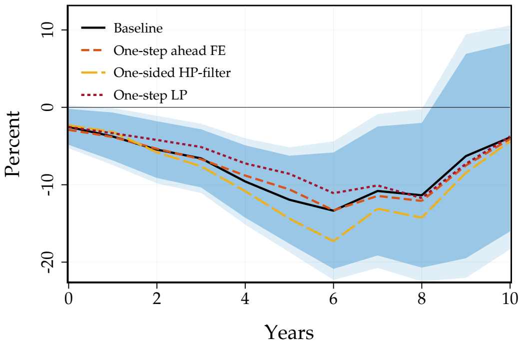
Accounting for concern #1: Omitted variable bias (global)

(a) Jackknife/leave-one-out



(b) Construction of temperature shock



Notes: 90 and 95% confidence bands based on robust standard errors. Jackknife: censor one shock value at the time to zero.

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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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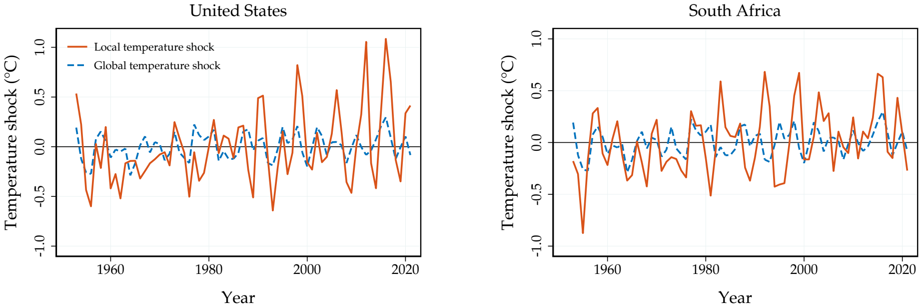
Global vs. local temperature shocks

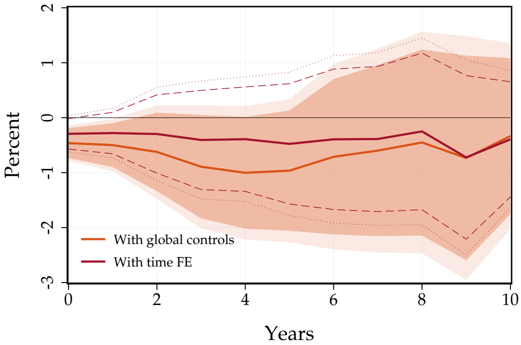
- Construct temperature shocks using same Hamilton filter
- Use population-weighted country-level temperature



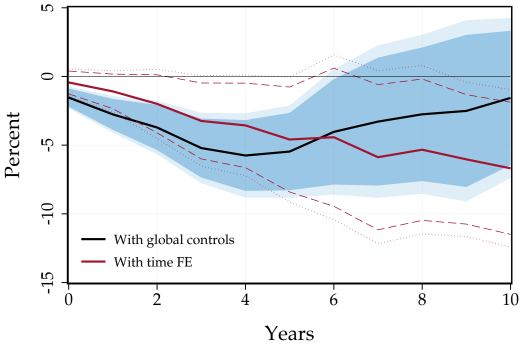
- Local temperature shocks more volatile
- Only weakly correlated with global temperature shocks

Time fixed effects

(a) Local temperature shock



(b) Distance-weighted temperature shock



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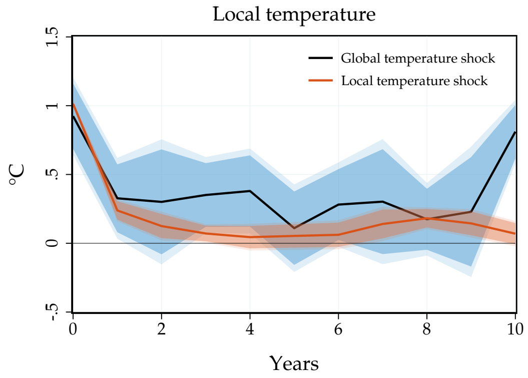
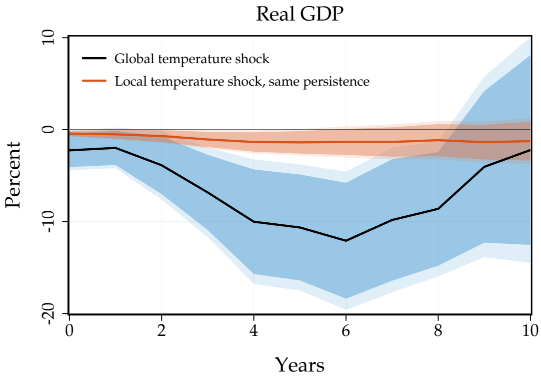
The local temperature response

(a) Local temperature response

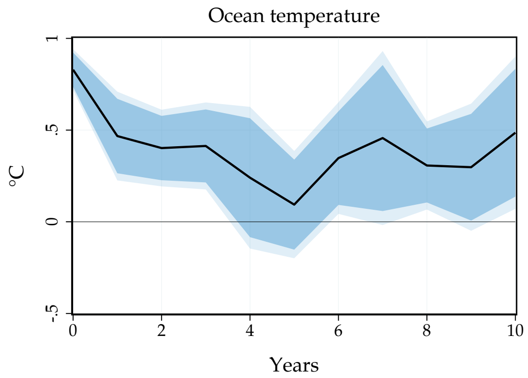


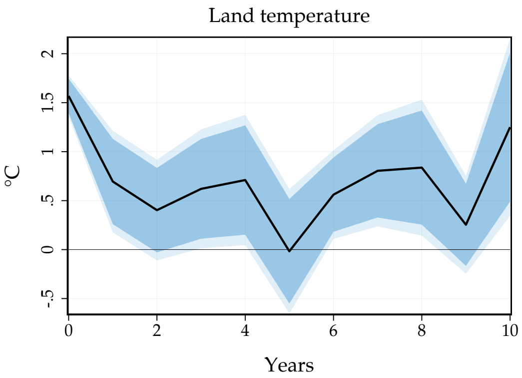
(b) Imposing same persistence



Back to extreme events

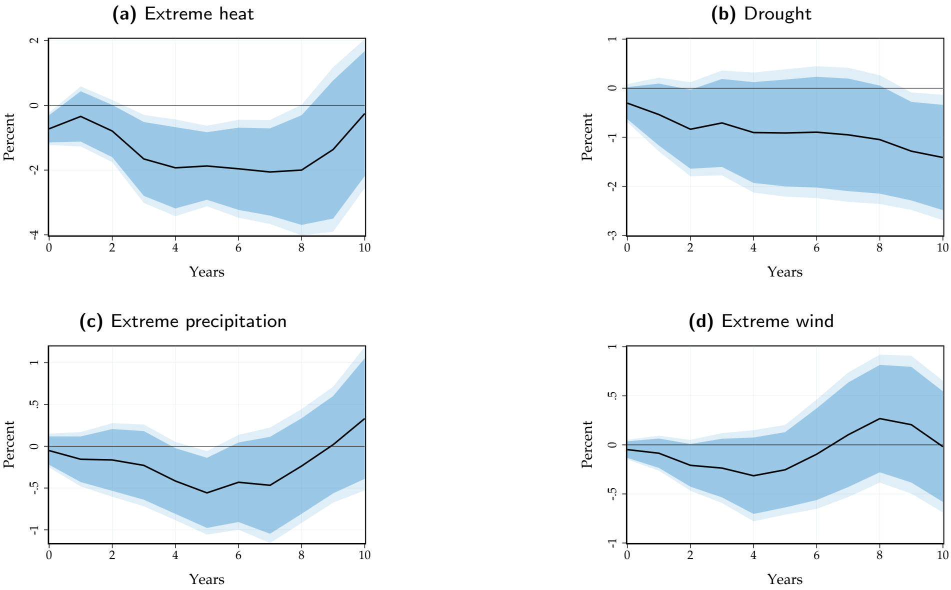
The effect on ocean vs. land temperature





Back to extreme events

The impact of extreme events on GDP



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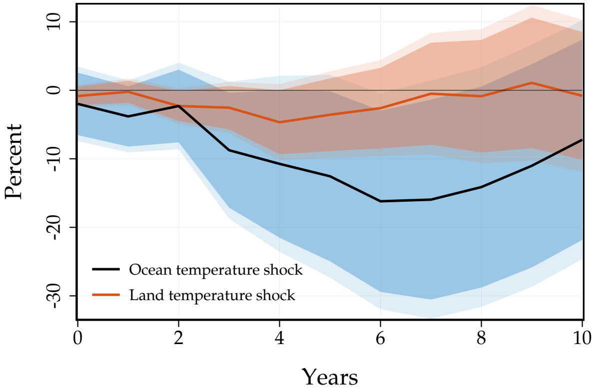
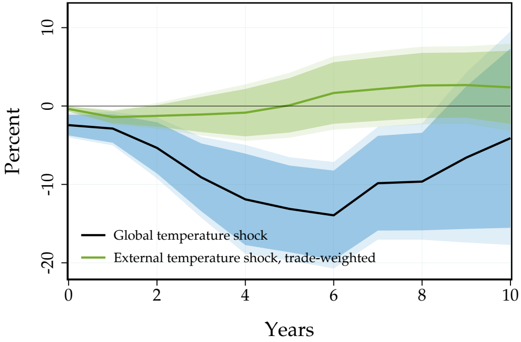
Ocean vs. land temperature shocks

- Ocean surface temperature drives our aggregate effects

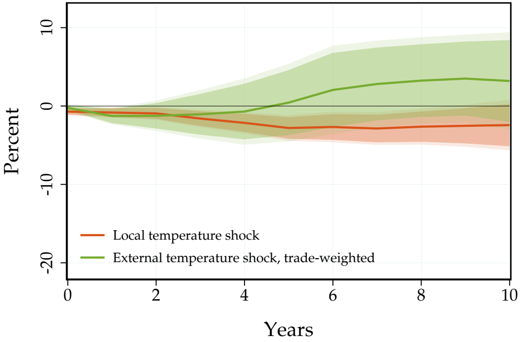


Back to extreme events

The role of economic spillovers



(a) Global temperature vs. trade-weighted

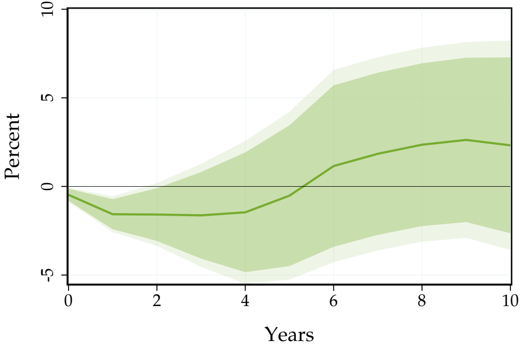


(b) Local temperature vs. trade-weighted

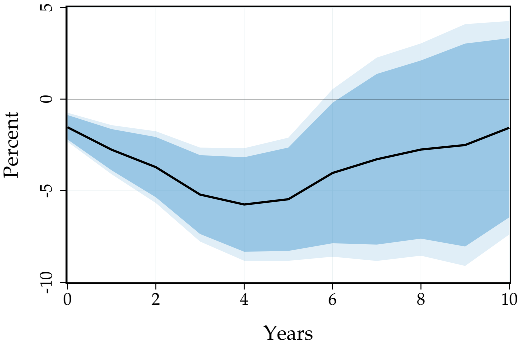
Back to two explanations   Back to extreme events

Economic vs. spatial spillovers

(a) Trade-weighted shock



(b) Distance-weighted shock



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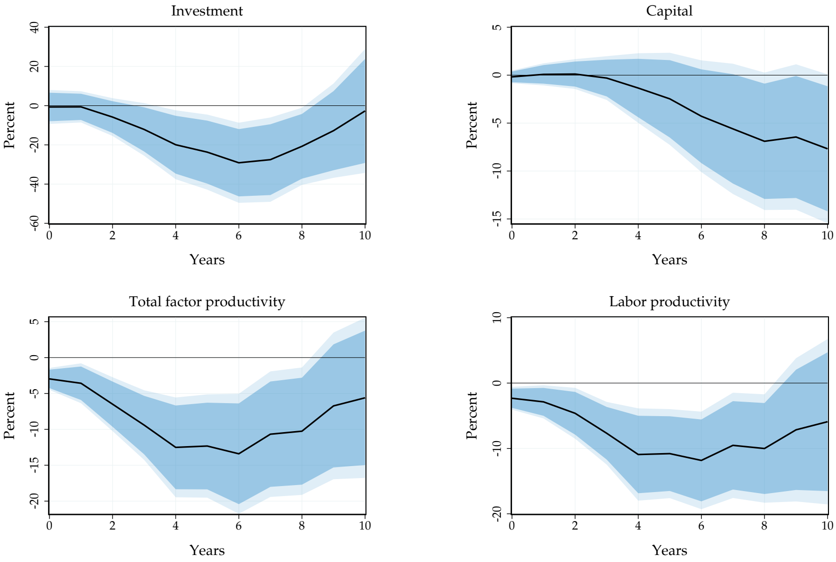
Mechanisms



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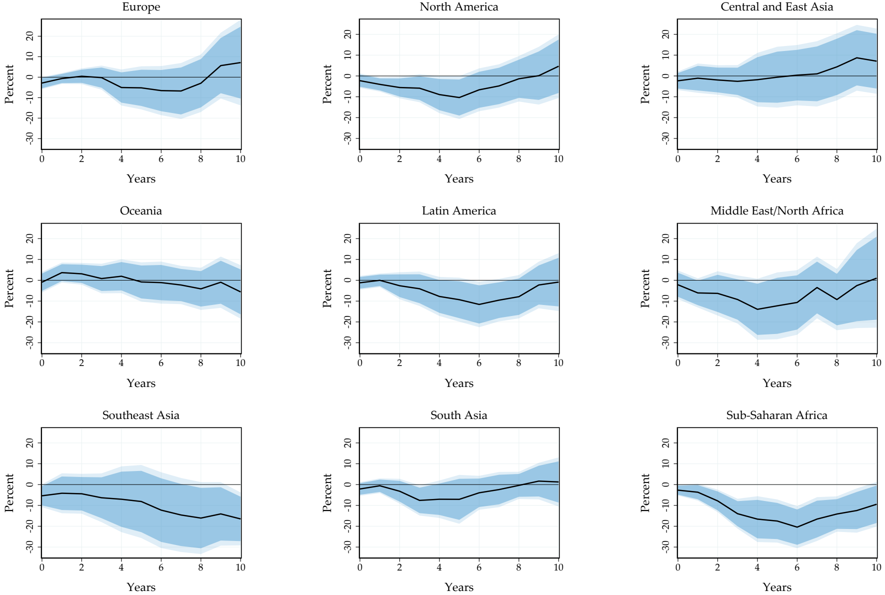
Heterogeneity



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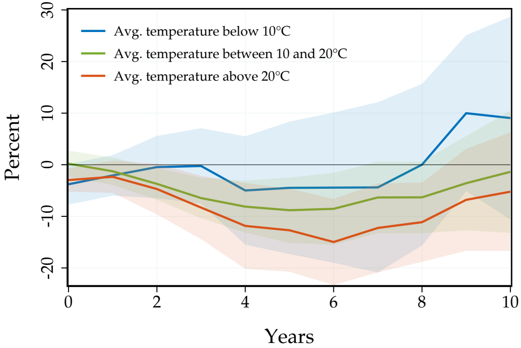
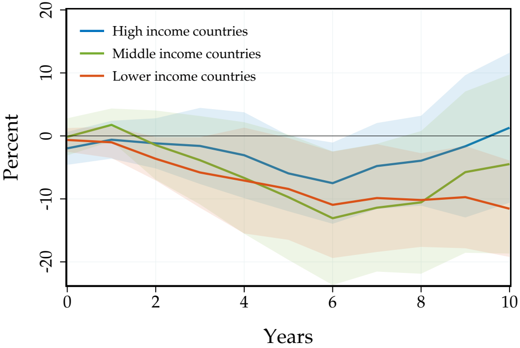
Heterogeneity

(a) By average temperature



(b) By income per capita



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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

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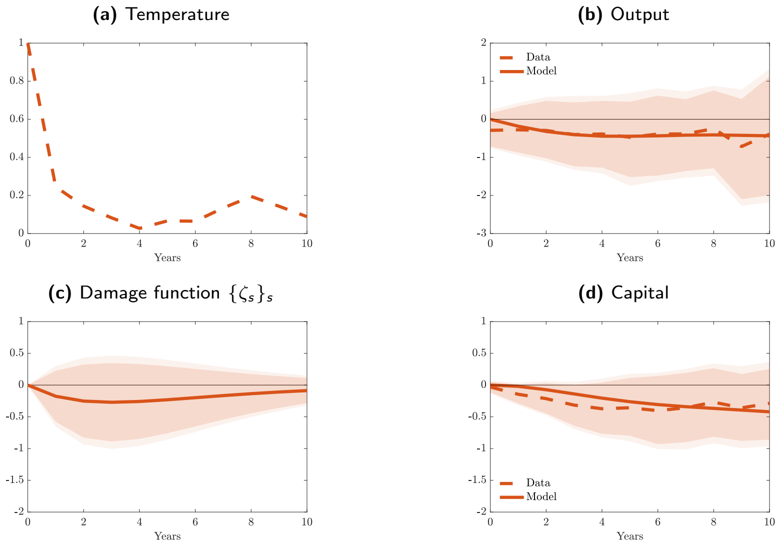
Damage functions from local temperature shocks



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