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

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November 2024

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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- 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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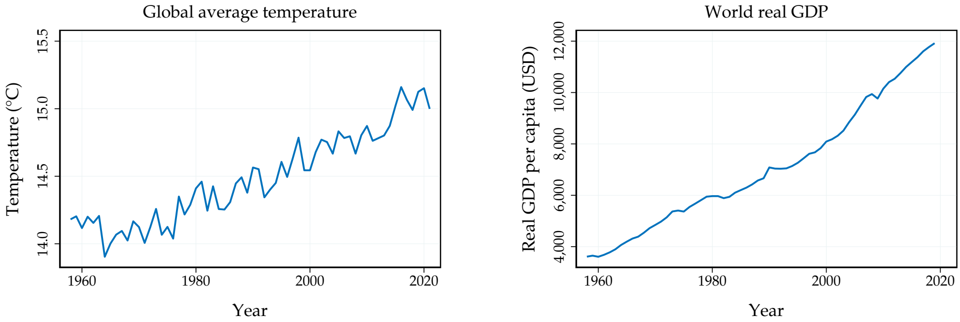
- Quantify the **Social Cost of Carbon** & the **welfare cost** of climate change
  - Use reduced-form impacts to estimate damage functions in NGM (=DICE)
  - **SCC = $1,367/tCO2** for global temperature vs. **$178/tCO2** for local temperature
  - Adding 2°C to 2024 temperature by 2100 implies a **25% 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)

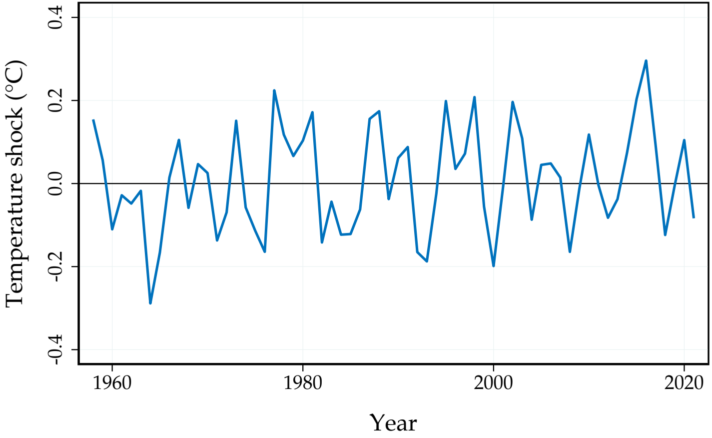
- Estimate **transient component** in temperature as forecast error

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

- 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 global temperature shocks

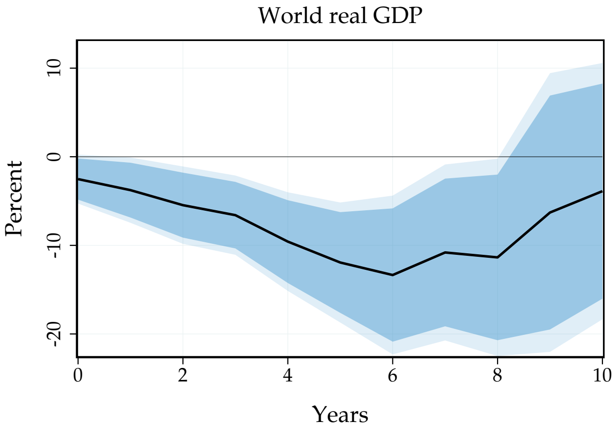
- Estimate dynamic causal effects to global temperature shocks using local projections (Jordà 2005)

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

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: 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**

▸ 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

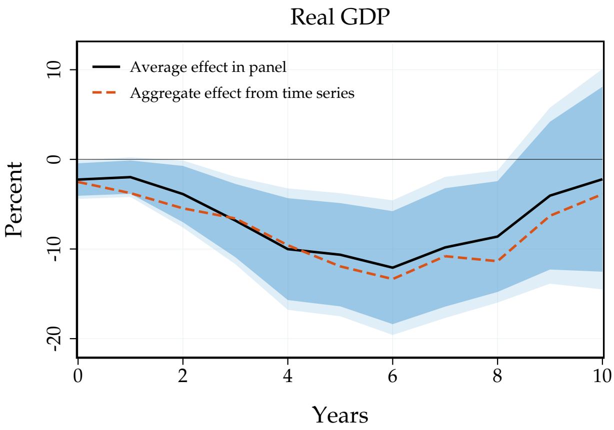
- Use panel local projections (Jordà et al 2020)

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

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

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

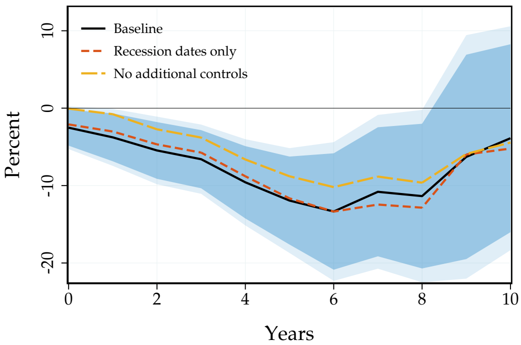
▸ Bootstrap

Four identification concerns

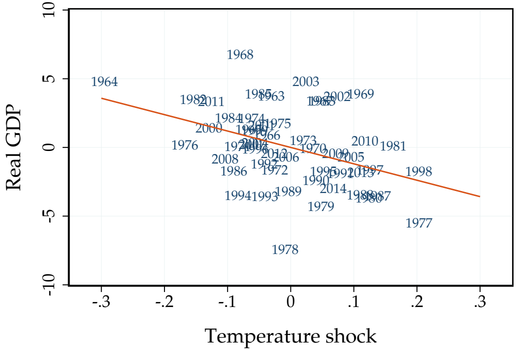
1. **Omitted variable bias (global)**
   - Temperature shocks may happen to coincide with adverse *global* economic shocks
2. **Reverse causality**
   - Economic activity may lead to emissions and changes in temperature
3. **External validity**
   - Estimates may change over time and by source of global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

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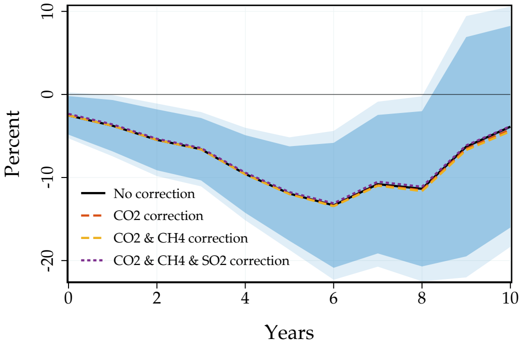
Accounting for concern #2: Reverse causality



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

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

Four identification concerns

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3. **External validity**
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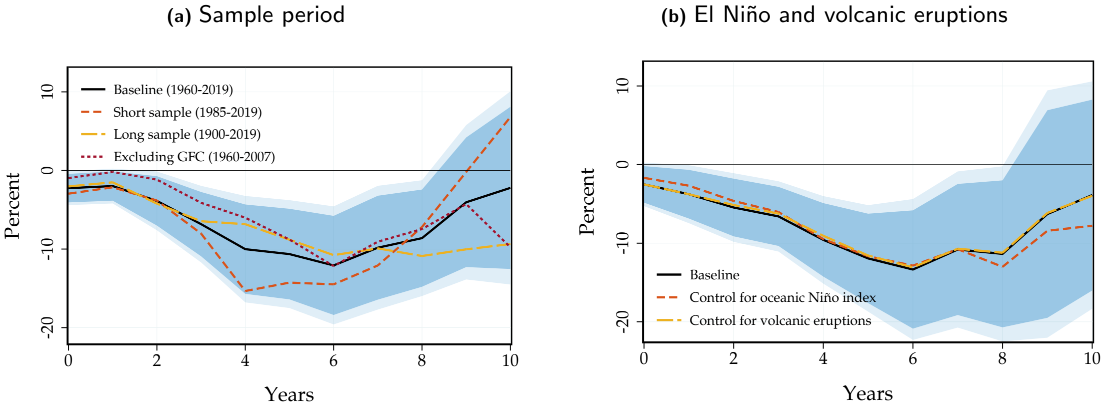
Accounting for concern #3: External validity



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

Four identification concerns

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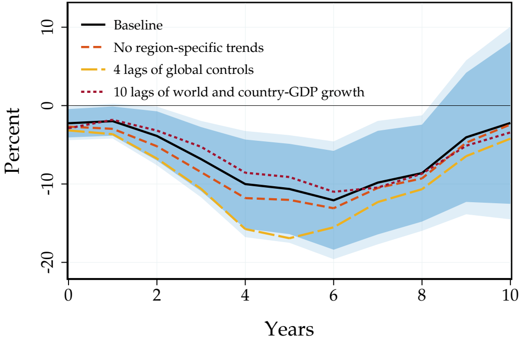
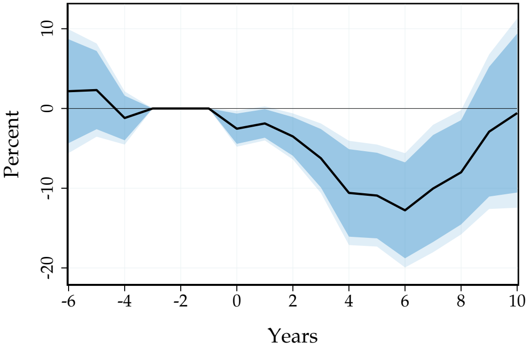
Accounting for concern #4: Omitted variable bias (regional)

(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**

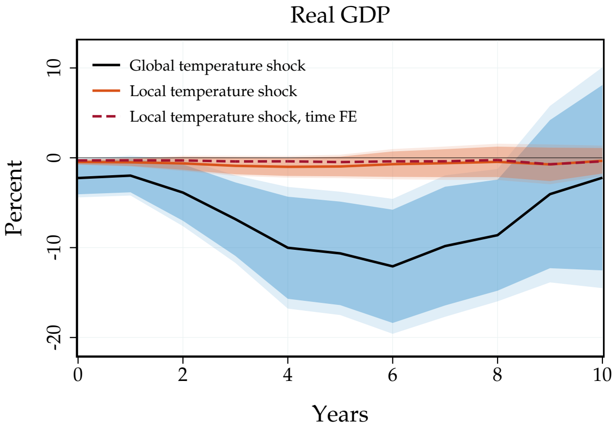
- Just replace global shock with **local temperature shock**

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

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

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

Impact of global vs. local temperature shocks



Notes: Point estimate with 68 and 90% 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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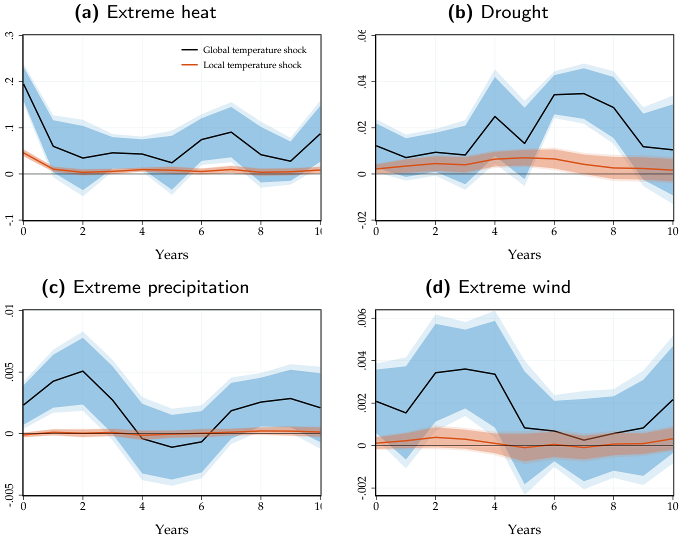
2. **Economic spillovers** due to trade linkages and spatially correlated local temperature?
   - Omitted variable in standard panel regression
   - Test with **external, trade-weighted temperature** Details
   - **Rule out spillovers**: external temperature has **small** effects on country GDP
     - Under moderate openness cannot expect to get much more than direct local temperature effect

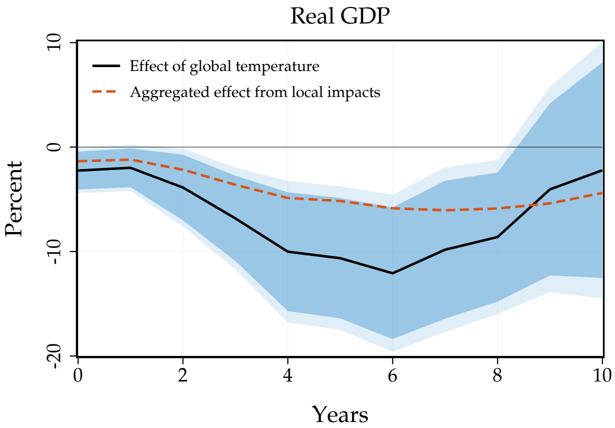
Extreme events help rationalize the GDP impact of global temperature



- 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

▸ Economic spillovers ▸ Extreme events damages ▸ Local temperature

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

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

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

- Firms solve

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

- 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

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

Estimating damage function

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

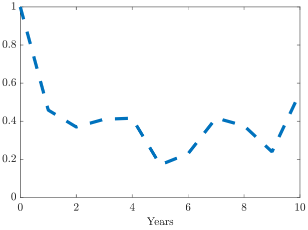
$$\hat{y}_t = \underbrace{\hat{\boldsymbol{z}}_t}_{\text{direct effect}} + \underbrace{\alpha \int_0^\infty \mathcal{K}_{t,s} \hat{\boldsymbol{z}}_s ds}_{\text{indirect effect through capital}}$$

- 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**

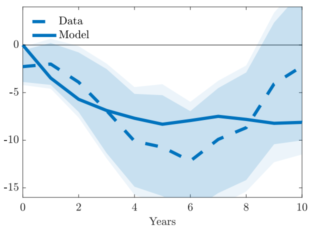
Target transitory shocks

Damage functions from global temperature shocks

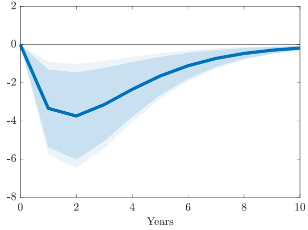
(a) Temperature



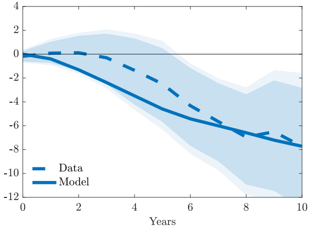
(b) Output



(c) Damage function $\{\zeta_s\}_s$



(d) Capital



Damage functions from temperature shocks

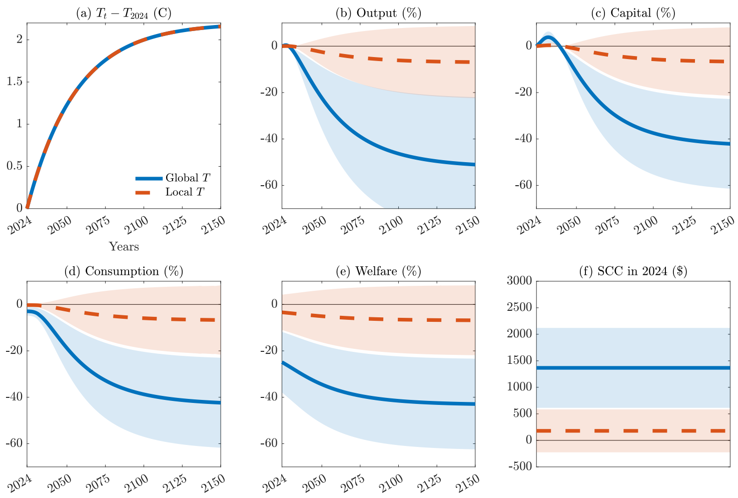
- Model matches output and capital responses reasonably well
- **Global** temperature implies **large productivity** and **capital depreciation** damages
  - -4% productivity
  - **Persistent** effects on productivity even when shock is transitory
- **Local** temperature implies **small productivity** 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

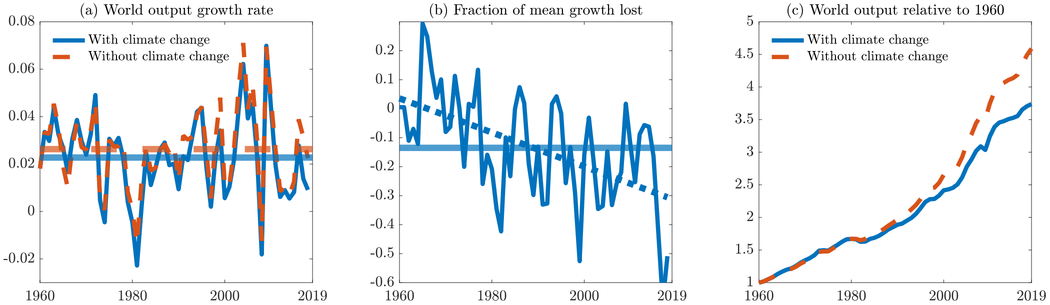
The Welfare Impact of Climate Change

The impact of climate change



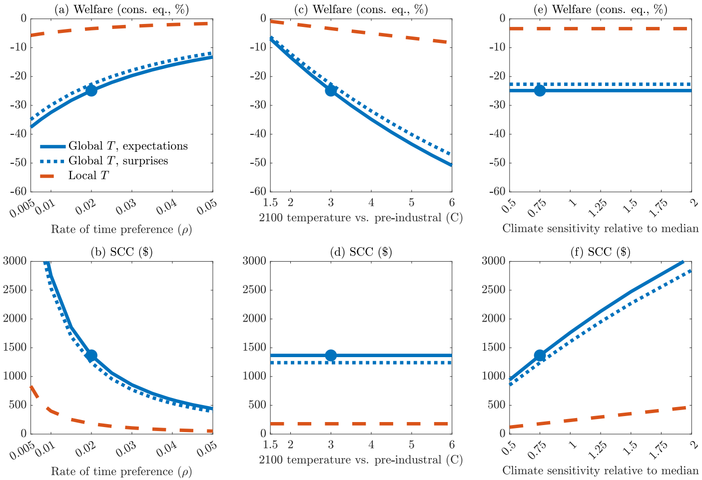
- **Global** shocks ⇒ large impacts
  - 2100 $C, Y \downarrow$ **40%**
  - **25% welfare loss**
  - **SCC = $1,367/tCO2**
- **Local** shocks ⇒ small impacts
  - 2100 $C, Y \downarrow$ **6%**
  - **3% welfare loss**
  - **SCC = $178/tCO2**
  - In line with previous findings

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

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

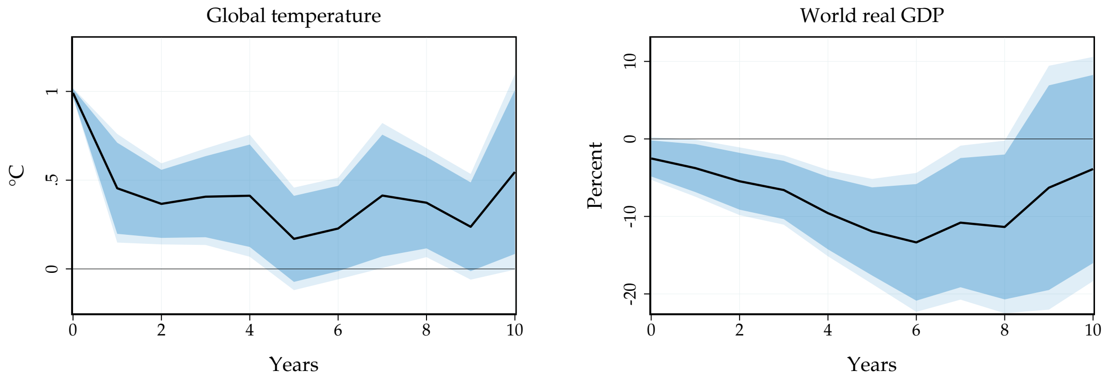
- Link global temperature shocks to extreme events

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

Back

Persistence of output response reflects persistence of temperature shock

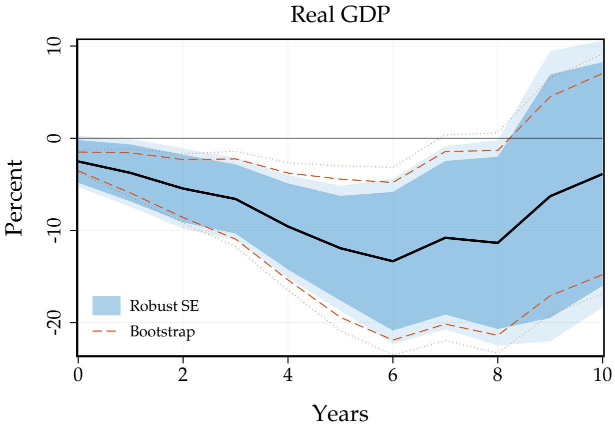


Notes: Point estimate with 68 and 90% confidence bands based on robust standard errors

▸ Back

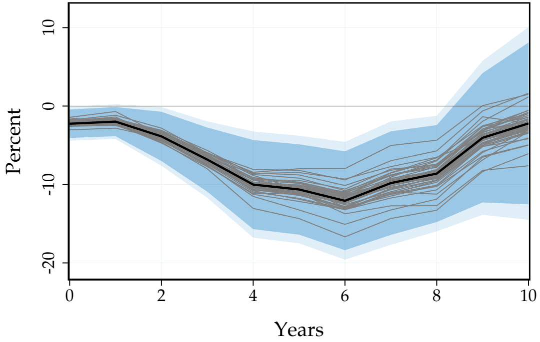
Bootstrapped confidence bands

- Taking estimation uncertainty in temperature shocks into account:

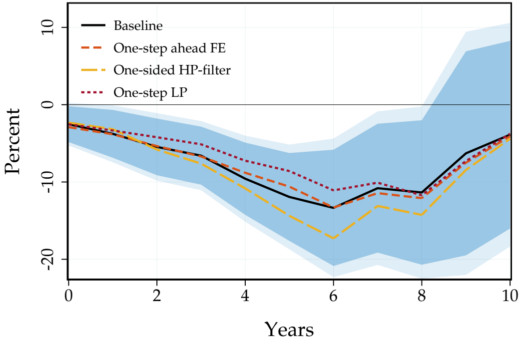


Accounting for concern #1: Omitted variable bias (global)

(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.

Forecastablity

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

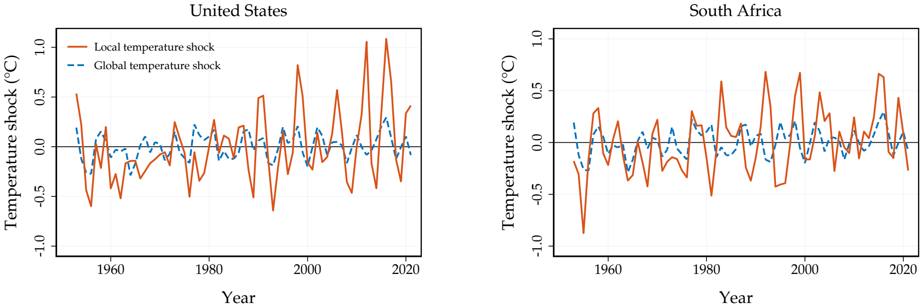
Table: Granger-causality tests

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

Back

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

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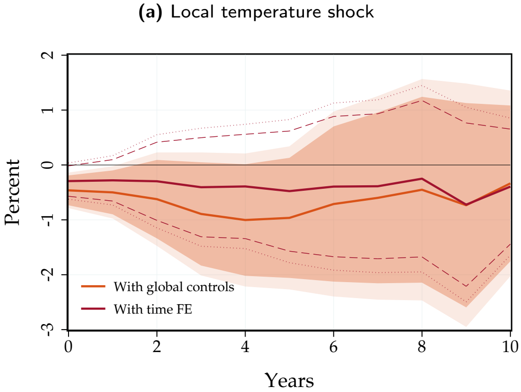
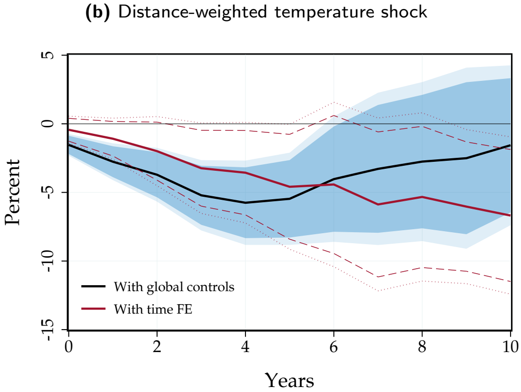
Time fixed effects





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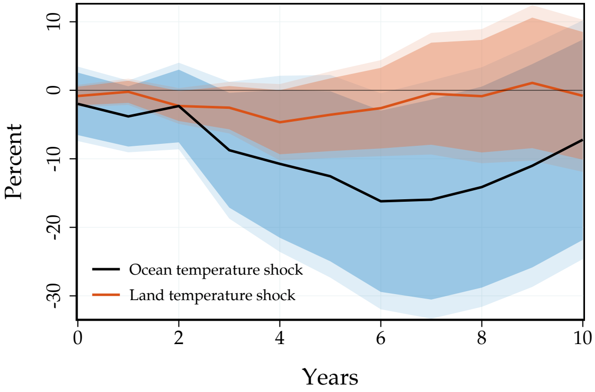
Ocean vs. land temperature shocks

- Ocean surface temperature drives our aggregate effects



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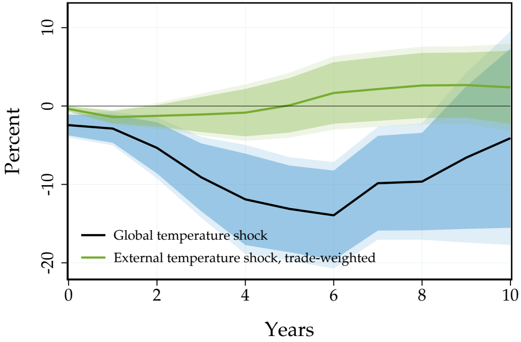
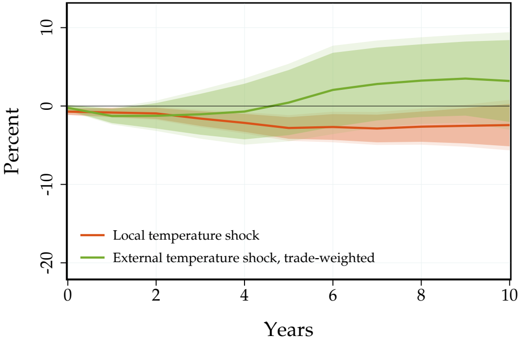
The role of economic spillovers

(a) Global temperature vs. trade-weighted



(b) Local temperature vs. trade-weighted



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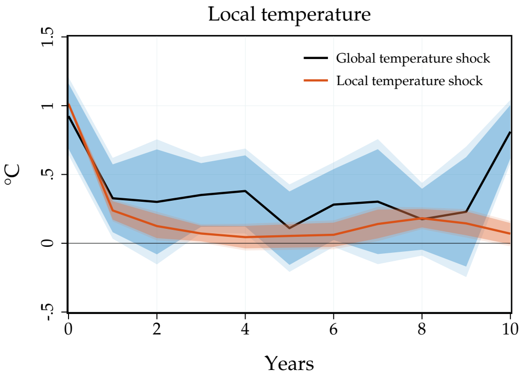
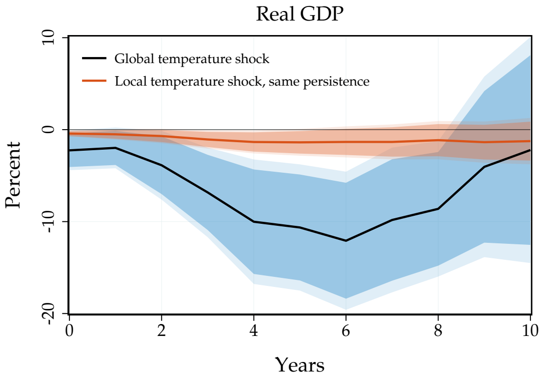
The local temperature response

(a) Local temperature response



(b) Imposing same persistence



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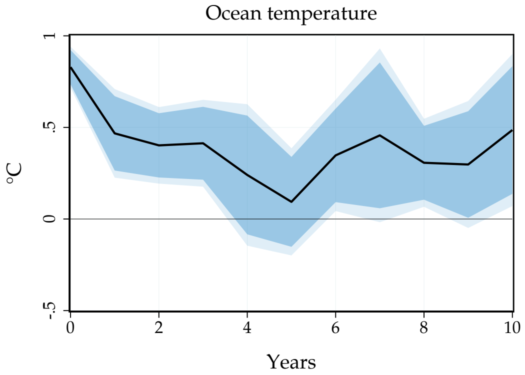
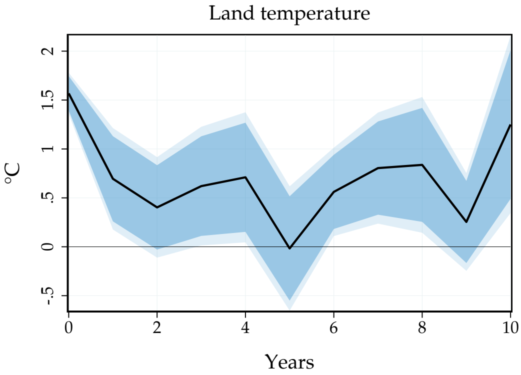
The effect on ocean vs. land temperature





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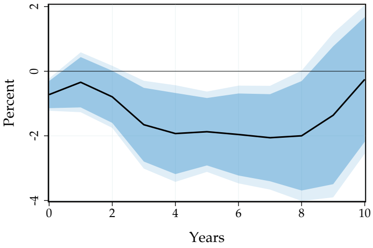
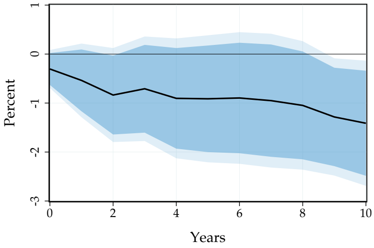
The impact of extreme events on GDP

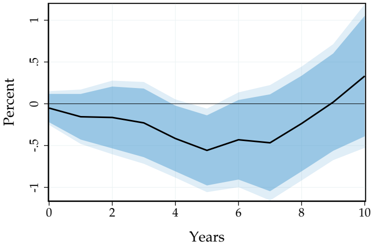
(a) Extreme heat



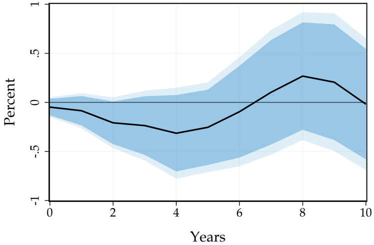
(b) Drought



(c) Extreme precipitation



(d) Extreme wind



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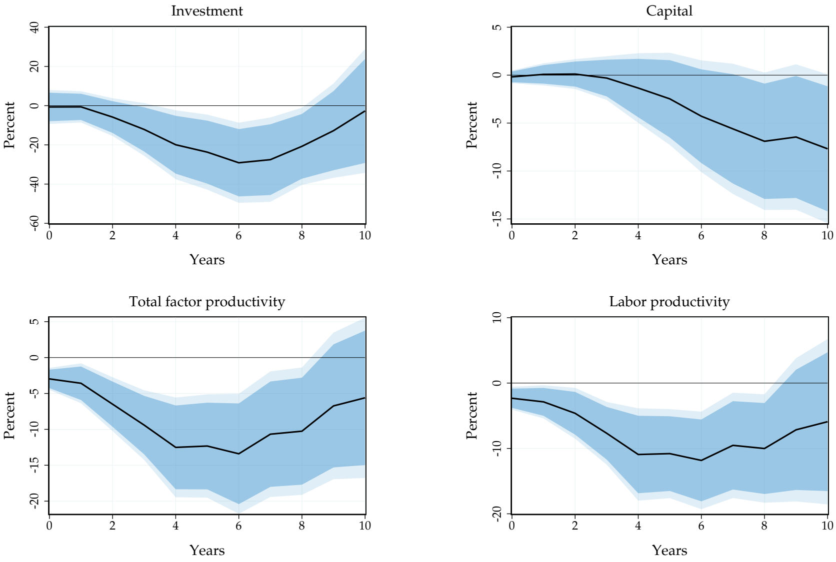
Mechanisms



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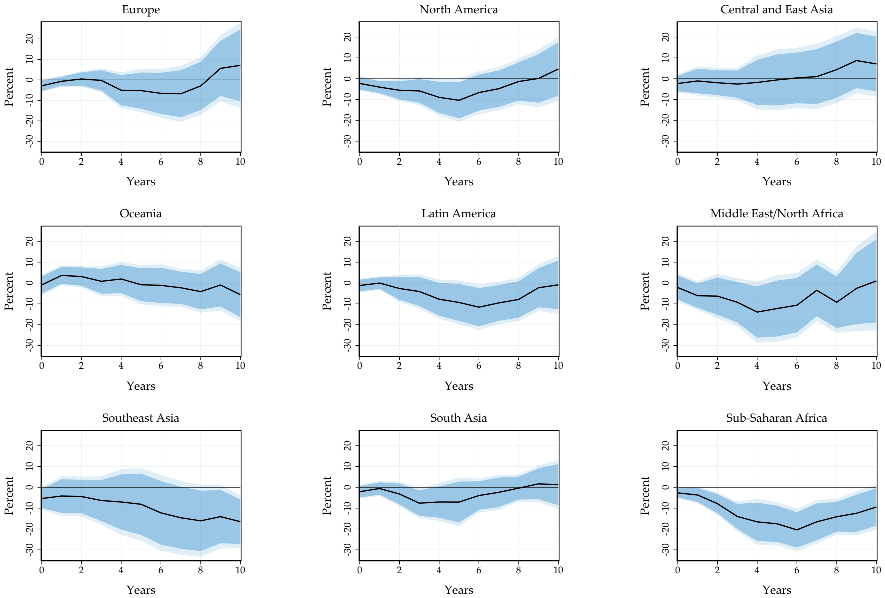
Heterogeneity



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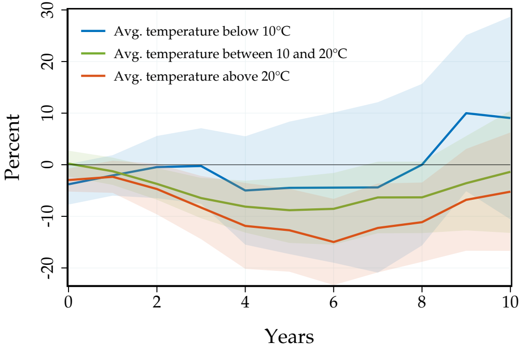
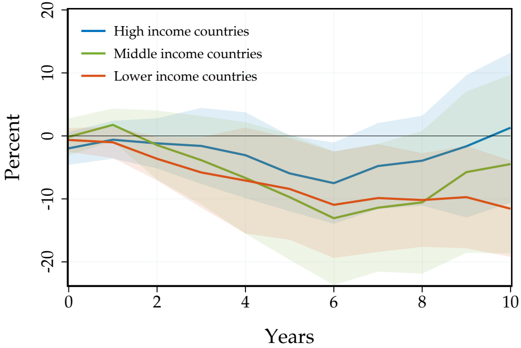
Heterogeneity

(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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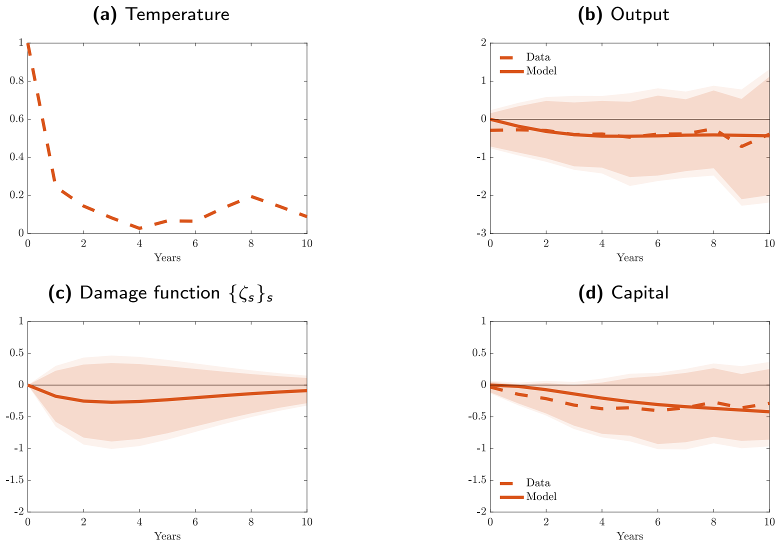
Damage functions from local temperature shocks



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