

Climate Damages and Decarbonization: An Updated Perspective on Benefits and Costs

IBRN Climate workshop

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The state of climate-macro

The state of climate-macro

- The dominant approach to **climate-macro** has been structural
- Write down **integrated assessment/computable general equilibrium** models to study climate change and policy
 - Extremely important research agenda $\Rightarrow$ how to jointly model climate & economy
 - Culminated in Nordhaus' Nobel Prize
- **Key challenge:** have to discipline key model parameters/objects
 - Climate damage function
 - Abatement cost function
 - Elasticity of substitution between inputs (different energy inputs, capital, labor)
 - ...

The state of climate-macro

- Influential literature has exploited variation at the micro level
 - Facilities, firms, regions, countries, ...
 - Credible identification, absorbing potential endogeneity using fixed effects
 - Great to study heterogeneity / speak to certain mechanisms
- **But** estimates micro-elasticities/relative effects $\neq$ macro-elasticities/aggregate effects
 - ⇒ **Missing intercept problem**, abstracts from GE effects and spillovers
- In macro: Key object of interest are **macro-elasticities**
- How do we arrive at these?

Bridging climate-micro and macro

- In short: need more structure...
- **Dominant approach:** write down structural model to map micro to macro effects
 - Either fully specified model or with sufficient statistics estimable from the data
 - But relies on stringent structural assumptions
- **Alternative:** exploit time-series variation to estimate aggregate effect
 - This approach has a lot of promise, especially in the **climate/environment** context
 - Why? Identifying macro shocks is difficult since policy and economy interact endogenously
 - Climate shocks are often more exogenous, making them easier to identify
 - Relies on much weaker structural assumptions
- **This talk:** showcase time-series approach to revisit **cost-benefit analysis**

Outline of this talk

1. Estimating climate damages
2. Estimating abatement costs
3. Updating cost-benefit analyses

Estimating climate damages

Estimating climate damages: Bilal & Känzig (2025)

- Climate change is often portrayed as having **major economic consequences**
- Yet empirical estimates imply **moderate** 1-3% GDP loss per 1°C
(Nordhaus 1992, Dell et al. 2012, Burke et al. 2015, Nath et al. 2023, Kotz et al. 2024)
- All focus on within-country, local temperature panel variation

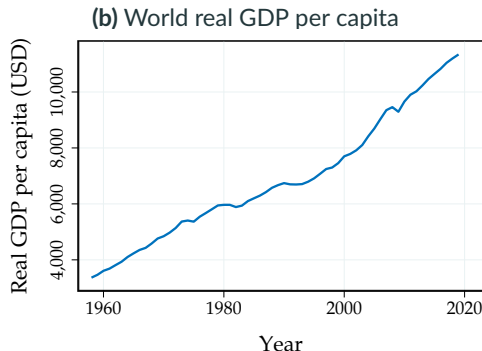
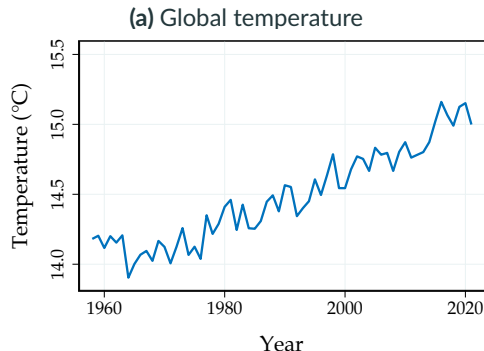
Questions

- Are the economic consequences of climate change truly so small?
- Or is local temperature a partial representation of climate change?

Estimating climate damages: Bilal & Känzig (2025)

- We propose new focus on **global temperature**
- Key **summary statistic** of climate change, used by the IPCC
- Includes **ocean** surface temperature!
- Lots of time-series variation in global temperature unrelated to economic activity
 - Natural climate variability: El Niño, solar cycles, volcanic eruptions, ...
- What do we get from this approach?

Global temperature and economic growth



Notes: Global average temperature (including sea surface) from Berkeley earth, 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 and tracing their effects

- Use approach by Hamilton (2018) as in Nath et al. (2024) for local temperature
- Estimate **innovation** in global temperature process as forecast error

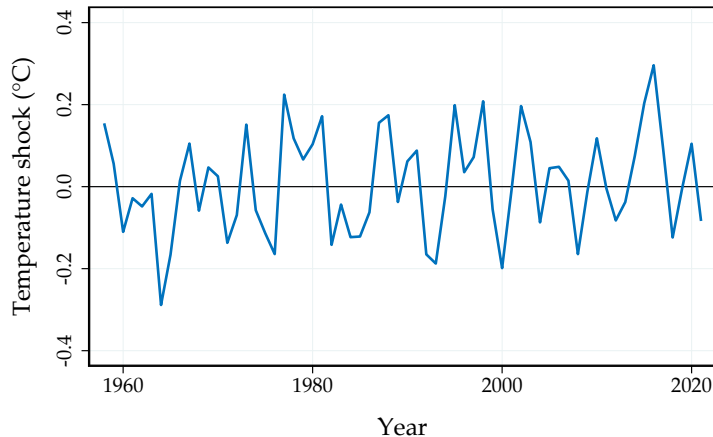
$$T_t^{\text{shock}} = T_t - (\hat{\beta}_0 + \hat{\beta}_1 T_{t-q} + \dots + \hat{\beta}_{p+1} T_{t-q-p}),$$

- Driven by solar cycles, volcanic eruptions, and internal climate variability (e.g. El Niño)
 - Virtually identical results if use HP filter, etc.
- Estimate effects of global temperature shocks using local projections (Jordà et al. 2020)

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

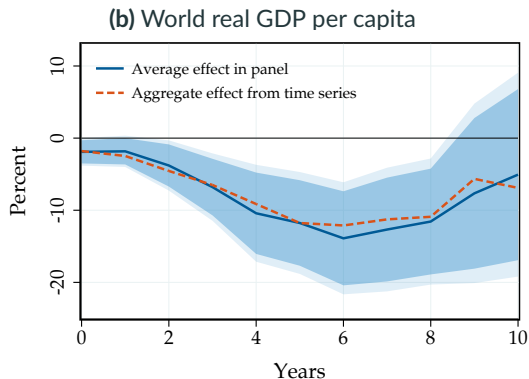
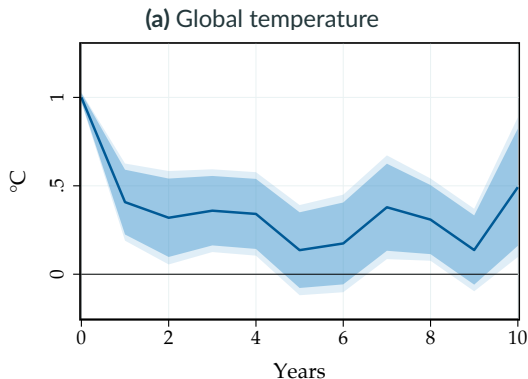
- $y_{i,t}$ is real GDP per capita of country i
 - $\mathbf{x}_t, \mathbf{x}_{i,t}$ are vectors of global and country-level controls

Global temperature shocks



Notes: Global temperature shocks, computed using Hamilton filter with $q = 2$, $p = 2$.

The impact of a 1°C global temperature shock



Notes: 90 and 95% confidence bands. GDP per capita data: Penn World Tables for 173 countries, 1960-2019.

- Estimate effect of **permanent** 1°C rise as cumulative response ratio
- Corresponds to a **20% long-run reduction** in world GDP per capita

Four identification concerns

1. Omitted variable bias

- 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

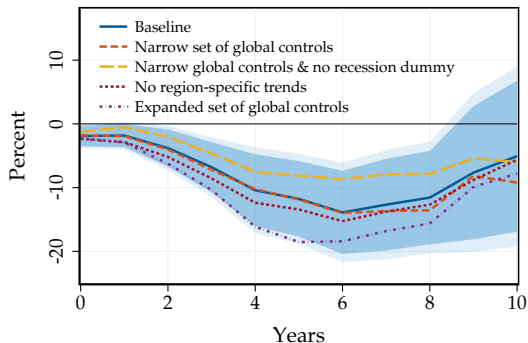
- Estimates stable over time and by source of global temperature variation

4. Regional omitted variables

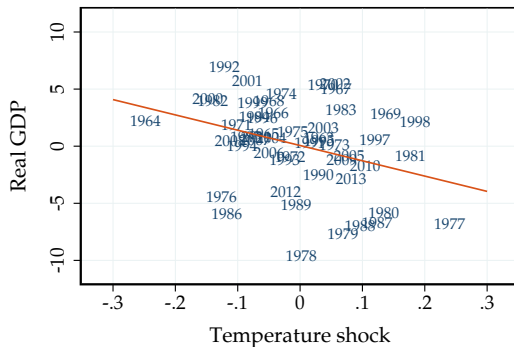
- Stable regardless of regional & country controls and weighting, no discernable pre-trends

Accounting for concern #1: Omitted variable bias

(a) Sensitivity with respect to controls



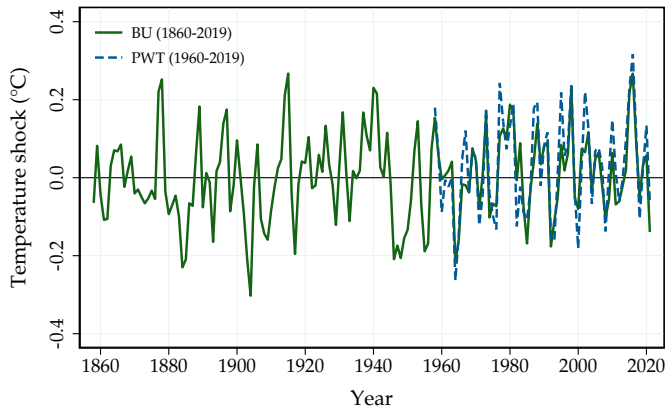
(b) Scatter plot at $h = 6$



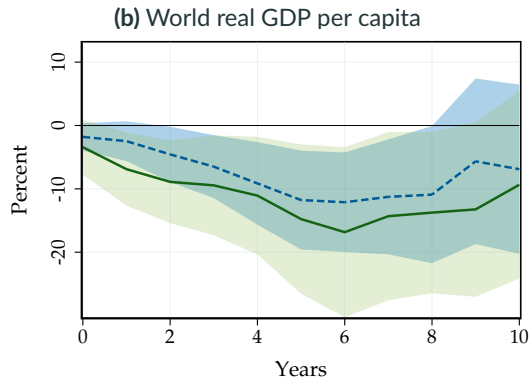
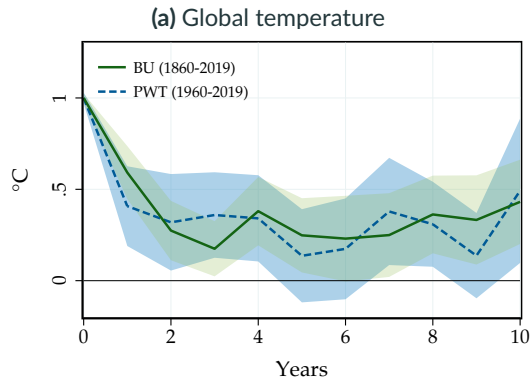
Notes: 90 and 95% confidence bands based on Driscoll-Kraay SE. Baseline: two lags of global temperature shock, GDP, global oil prices and the US treasury yield, indicators for global economic recessions, region-specific trends.

Accounting for concern #1: Omitted variable bias

- Omitted variable bias more acute in shorter sample
- Revisit evidence in longer sample: 43 countries, 1860-2019



Accounting for concern #1: Omitted variable bias



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

Four identification concerns

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2. Reverse causality

- Economic activity may lead to emissions and changes in temperature

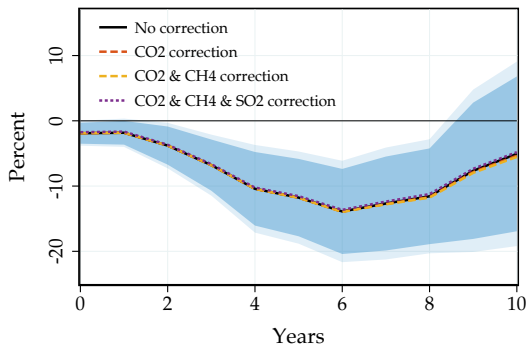
3. External validity

- Estimates stable over time and by source of global temperature variation

4. Regional omitted variables

- Stable regardless of regional & country controls and weighting, no discernable pre-trends

Accounting for concern #2: Reverse causality



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

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

Four identification concerns

1. Omitted variable bias

- 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 stable over time and by source of global temperature variation

4. Regional omitted variables

- Stable regardless of regional & country controls and weighting, no discernable pre-trends

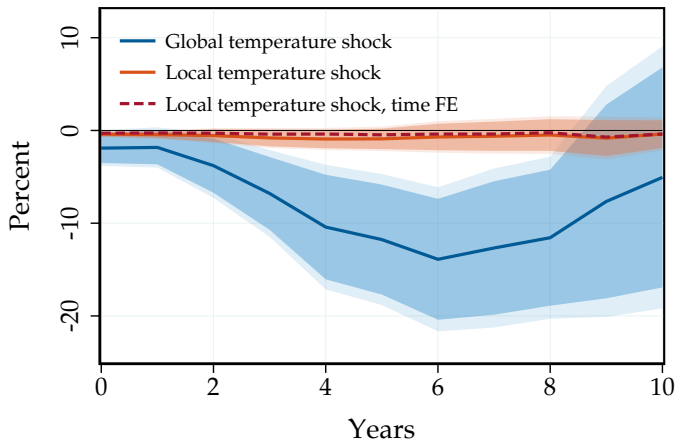
Global vs. local temperature shocks

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

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

- Without and with time fixed effects

Impact of global vs. local temperature shocks

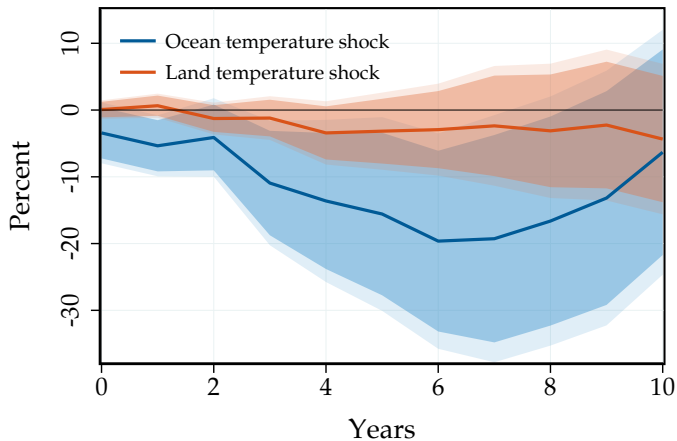


Notes: Point estimate with 90 and 95% confidence bands based on Driscoll-Kraay SE

Why is global temperature different?

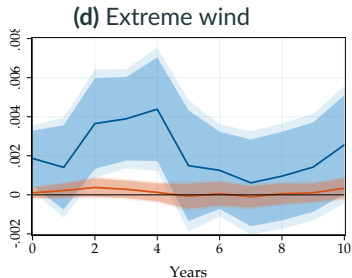
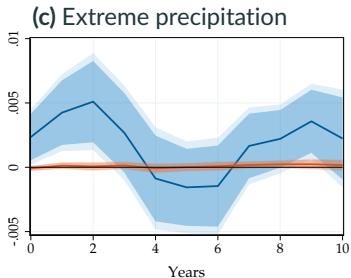
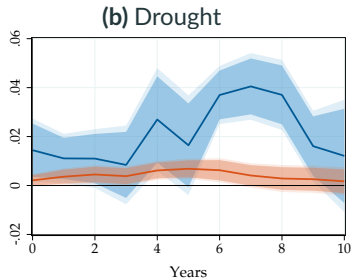
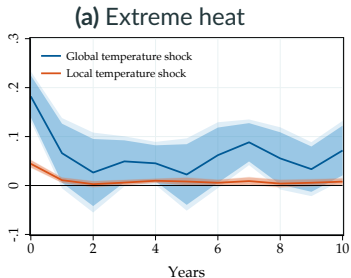
- Global temperature is a better **summary statistic** of state of climate system
- Integrates land and **ocean surface temperatures**, reflecting global energy balance
- Better captures the frequency, intensity, and distribution of extreme weather events
- Captures correlated nature of local shocks and spillovers

Oceans drive global temperature effects

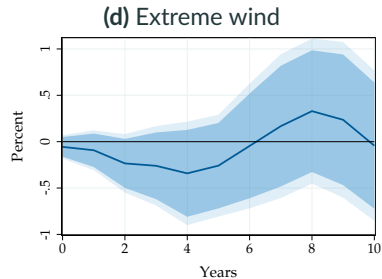
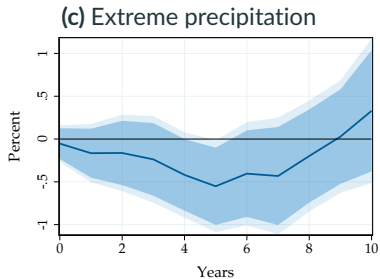
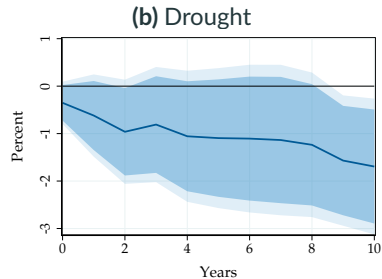
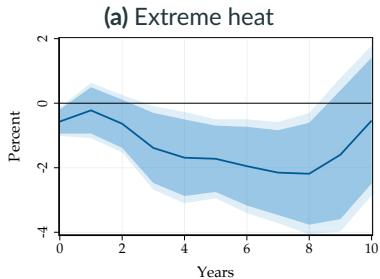


Notes: joint estimation of the impact of ocean and land temperatures. 90 and 95% confidence intervals.

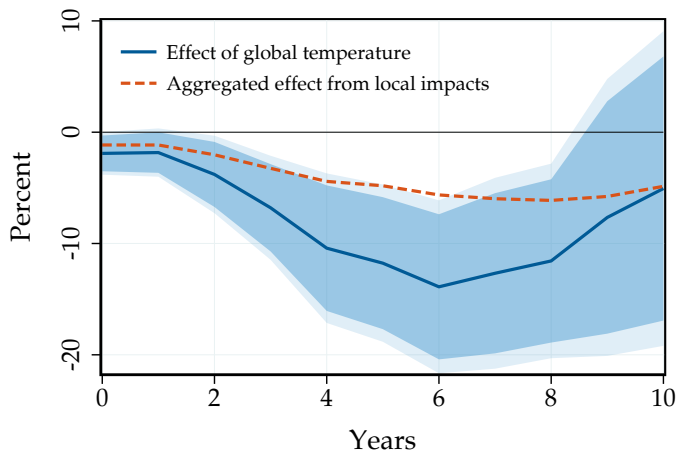
Damaging extreme events correlate strongly with global temperature



Extreme events lead to GDP damages



Local extremes help close gap between global and local temperature

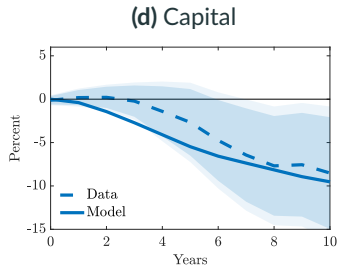
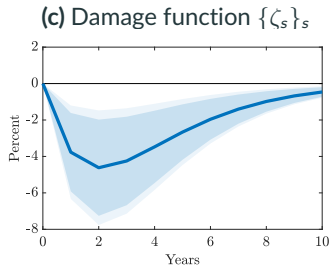
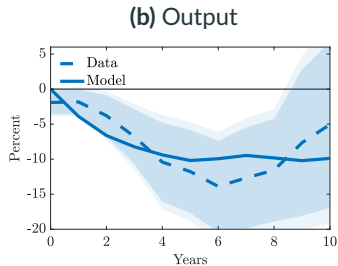
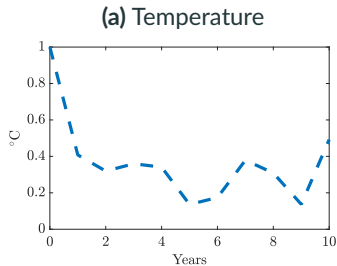


Notes: predicted effect on GDP based on aggregating local impacts. Interact frequency response of extremes to global temperature with estimated damages of extremes. 90 and 95% confidence intervals.

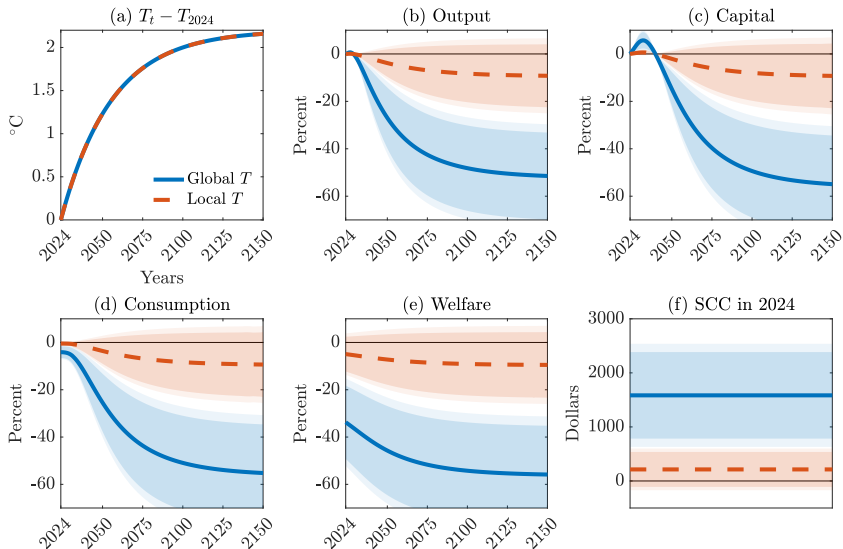
A simple climate-economy model

- Use the **neoclassical growth model**
 - Damage function: temperature reduces aggregate productivity: $Z_t = Z_0 \exp \left(\int_0^t \zeta_s \hat{T}_{t-s} ds \right)$
 - Includes lagged effects
- **Estimate damage function** by matching estimated output responses in the data
 - Characterize **identification in model**
 - Estimation accounts for internal persistence of temperature
- Use estimated model to perform **counterfactual** analyses and estimate **SCC**
 - Consider business-as-usual scenario with additional 2°C warming by 2100
 - Use climate sensitivity from state-of-the-art climate models

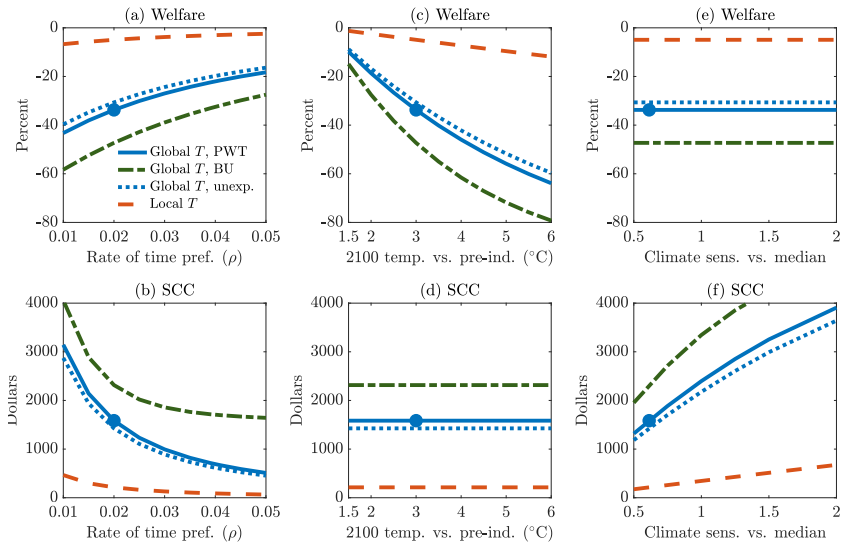
Damage functions from global temperature shocks



The impact of climate change



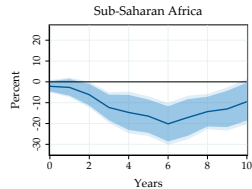
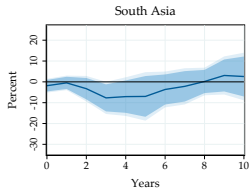
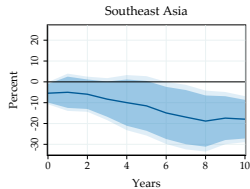
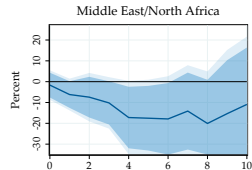
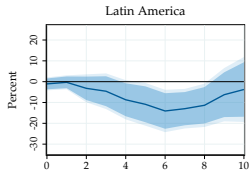
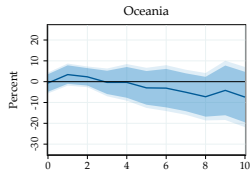
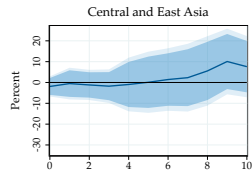
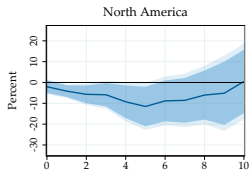
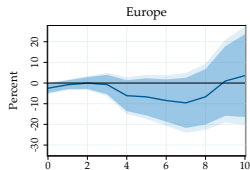
Sensitivity



Updating damage estimates

- Global temperature shocks have large economic effects
 - 1°C global temperature rise implies a **20%** decline in world GDP vs. **3%** for local temperature
- Why? **Geophysical** explanation:
 - **Global** temperature estimates driven by **ocean temperature**, not **land temperature**
 - **Global** temp shocks predict damaging **extreme events**: explain 1/2 of direct estimate
 - **Local** temperature shocks do not
- Global temperature shocks imply large **SCC** and **welfare costs** of climate change
 - Use reduced-form impacts to estimate damage functions in IAM and infer long-run effects
 - **SCC** $\geq$ **\$1,500/tCO₂** for global temperature vs. $\approx$ **\$200/tCO₂** for local temperature
 - Adding 2°C to 2024 temperature by 2100 implies a **30% welfare loss**

Regional heterogeneity



Estimating abatement costs

Carbon pricing across the globe

- Looming **climate crisis** put climate change at **top** of the **global policy agenda**
- **Carbon pricing** increasingly used as a tool to mitigate climate change **but:**
- **Little known** about effects on **emissions** and the **economy** in practice
 - Effectiveness?
 - Short-term economic costs?
 - Distributional consequences?
- With >20 years of practical experience in carbon pricing, what does the data say?

Estimating the impacts of carbon pricing: Känzig (2025)

- **Challenge:** carbon prices are not set in a vacuum
 - Policymakers respond to macroeconomic developments when deciding on climate policy
 - Cap-and-trade prices are market prices driven by demand & supply
- Identification challenge more **acute** for cap-and-trade prices
- But: **institutional** features allow for credible identification of carbon price impacts
 - Cap-and-trade regulates quantity, establishes **market price** for carbon
 - Liquid **futures markets** on allowances
 - Regulations in the market **changed** considerably over time
 - Isolate **exogenous** variation by measuring carbon price change in **tight window** around **policy events**

EU carbon price



Regulatory events

- Collected **comprehensive list** of **regulatory update** events
 - Decisions of European Commission
 - Votes of European Parliament
 - Judgments of European courts
- Of interest in this paper: regulatory news on the **supply of allowances**
 - National **allocation plans**
 - **Auctions**: timing and quantities
 - Use of international credits
- **Identified 114 relevant events** from 2005-2019

High-frequency identification

- **Idea:** Identify carbon policy surprises from changes in EUA futures price in tight window around regulatory event

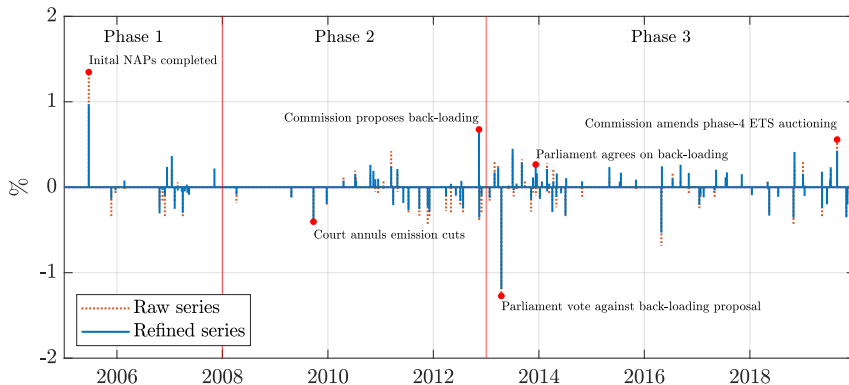
$$CPSurprise_d = \frac{F_d^{\text{carbon}} - F_{d-1}^{\text{carbon}}}{P_{d-1}^{\text{elec}}}$$

where $F_{t,d}$ is log settlement price of the EUA front contract on event day d in month t

- Purge from potential predictability from macro- & financial variables, $CPSurprise_d^\perp$
- Aggregate surprises to **monthly** series

$$CPSurprise_t^\perp = \begin{cases} CPSurprise_{t,d}^\perp & \text{if one event} \\ \sum_i CPSurprise_{t,d_i}^\perp & \text{if multiple events} \\ 0 & \text{if no event} \end{cases}$$

Carbon policy surprises



Econometric framework

- Carbon policy surprise series has **good properties** but still imperfect measure
⇒ Use it as an **instrument** to estimate dynamic causal effects on variables of interest
- For estimation I rely on VAR techniques given the short sample
- Identifying assumptions:

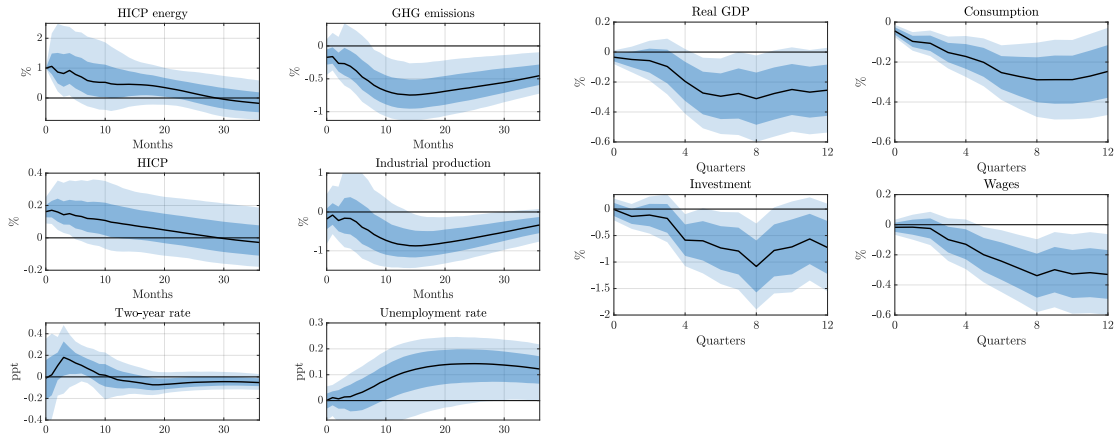
$$\mathbb{E}[z_t \varepsilon_{1,t}] = \alpha \neq 0 \quad (\text{Relevance})$$

$$\mathbb{E}[z_t \varepsilon_{2:n,t}] = \mathbf{0}, \quad (\text{Exogeneity})$$

$$\mathbf{u}_t = \mathbf{S} \varepsilon_t \quad (\text{Invertibility})$$

- Use carbon policy surprise series as *external instrument* for energy price

The aggregate effects of carbon pricing



Notes: The solid line is the point estimate and the dark and light shaded areas are 68 and 90% confidence bands

Revisiting marginal abatement cost

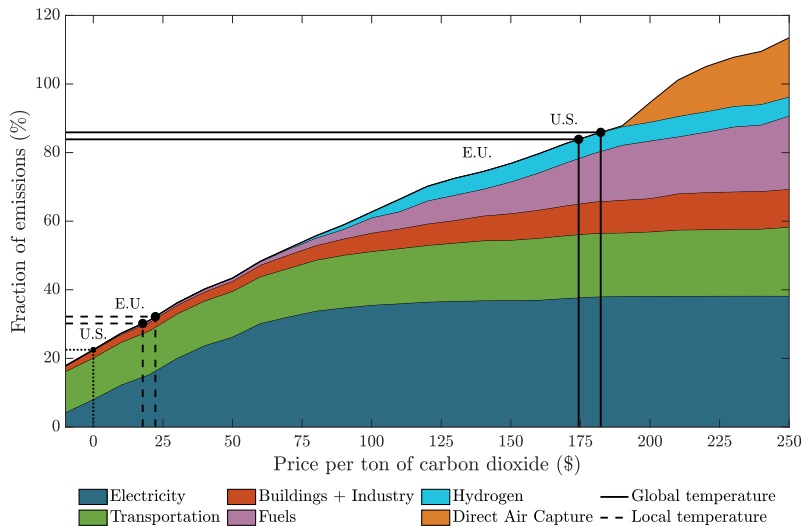
- Back-of-the-envelope estimate based on impulse responses gives **MAC** of $\approx \text{€}107/\text{tCO}_2$
- Higher than many engineering estimates & avg. ETS price over the sample $\approx \text{€}12/\text{tCO}_2$
 - Market prices do **not internalize** GE effects via prices, consumption, employment
 - Higher economy-wide costs of decarbonization
- Important implications for **cost-benefit analyses**

Updating cost-benefit analyses

Updating cost-benefit analyses: Bilal & Känzig (AEAPP, 2025)

- Most large-scale decarbonization policies in IRA cost $\approx \$80/\text{tCO}_2$ (Bistline et al. 2023)
 - Below traditional **worldwide** SCC estimates, e.g. $\$200/\text{tCO}_2$ with **local temperature**
 - But higher than **US-only** Domestic Cost of Carbon, e.g. $\$30/\text{tCO}_2$ 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 $\geq \$200/\text{tCO}_2$
 - Higher than the cost of decarbonization
 - So **unilateral, non-cooperative** decarbonization policy becomes **cost-effective**
 - Under standard abatement cost curves implies $\geq 80\%$ **unilateral decarbonization** in US and EU

Updating cost-benefit analyses: Bilal & Känzig (AEAPP, 2025)



Conclusion

- Accounting for market-wide impacts, decarbonizing the economy is **costly**
- But inaction is **way costlier**
- SCC based on global temperature is $\geq \$1,500/\text{tCO}_2$ and welfare cost is **30%**
- Magnitudes are comparable to a permanent 1929 Great Depression
- Imply that **unilateral** decarbonization policy is optimal

Thank you!