Heterogeneity and market adaptation to climate change in dynamic spatial equilibrium

Ivan Rudik
Cornell

Gary Lyn
Iowa State

Weiliang Tan
Cornell

Ariel Ortiz-Bobea
Cornell

Virtual Seminar on Climate Economics

What is the effect of climate change in the US?

We will look at welfare, employment, and migration

What's the effect of weather and climate change on the US (and the globe)?

What are the roles of different adaptation mechanisms?

- → Trade of goods
- → Migration across regions
- → Specialization / workers switching into different industries

What about the climate-economy matters for welfare?

- → Input-output linkages?
- → Non-market impacts on amenities?
- → Industrial heterogeneity in sensitivity to climate shocks?
- → Temperature variability?

We take a dynamic spatial model to the data

Eaton and Kortum (2002) multi-industry Ricardian model

Artuc et al. (2010) dynamic labor adjustment model

- Moving costs are important for quantifying welfare effects of environmental change (Bayer et al., 2009)

Burke et al. (2015) and Moore and Diaz (2015) temperature impacts to growth

- Capture full within-year temperature distribution because temperature variability is costly (Calel et al., 2020; Alem and Colmer, 2021; Linsenmeier, 2021)

Temperature directly affects utility via local amenities (Sterner and Persson, 2008; Drupp and Hänsel, 2021)

We take a dynamic spatial model to the data

We use the structure of the model to:

1. Estimate the effect of climate change on productivity growth
   - Extreme temperatures and variability reduce growth
2. Estimate the effect of climate change on local amenities
   - Extreme temperatures and variability directly reduce utility
3. Decompose the value of adaptation
   - Trade, migration, and industry switching all matter
4. Understand the importance of how we represent the climate-economy
   - Input-output linkages amplify climate impacts
   - Industrial heterogeneity dampens climate impacts
   - Temperature variability worsens climate impacts

How should you think about this paper?

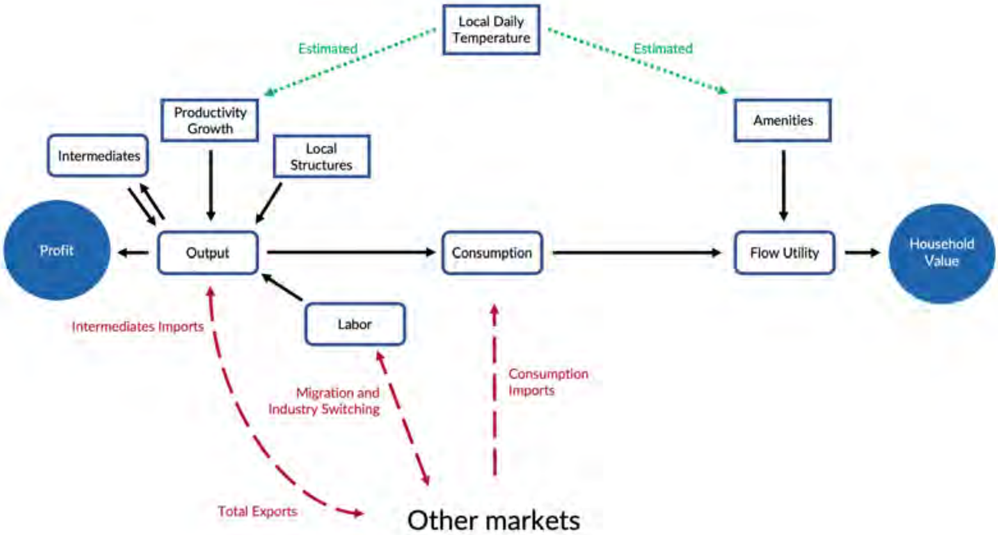
We add to two climate economics literatures

1. Climate econometrics (Hsiang, 2016; Deryugina and Hsiang, 2017; Mérel and Gammans, 2018; Carleton et al., 2020; Lemoine, 2021)
    - Derive estimating equations for weather impacts in dynamic-spatial equilibrium that can be used in quantitative simulations of climate change
    - Derive reduced-form dynamic climate change impact estimates with almost zero production assumptions and one additional assumption on costs of migration

2. Dynamic/spatial GE models of climate change (Nath, 2020; Cruz and Rossi-Hansberg, 2021; Bakkensen and Barrage, 2021; Fried, 2021)
    - Full labor-side dynamics + space together
    - Detailed representation of industrial heterogeneity, labor adjustment costs, and climatic variability
    - Climate impacts are estimated using the GE model structure

How the model works

Multi-industry Ricardian model + a dynamic discrete choice household problem



How the model works: firm side

Cobb-Douglas, trade costs, immobile capital, mobile labor, intermediates, growth rate effects

Perfectly competitive firms with Cobb-Douglas technology operating in different industries k, s and locations n, i

Factor productivity $Z^k_{n,t}$ grows at rate: $\underbrace{(1+\bar{r}^k_{n,t})}_{\text{base growth}} \overbrace{\exp(g(\boldsymbol{T}_{n,t}; \zeta_{\mathbf{Z}}))}^{\text{temperature's effect}}$

$\rightarrow$ We will estimate $\zeta_{\mathbf{Z}}$

Industry k goods can be shipped from i to n with iceberg trade costs τ^k_{ni}

How the model works: household side

Dynamic discrete choice, migration costs, nonemployment option, temperature in utility

Households inelastically supply labor and receive a competitive wage $w_{n,t}^{k}$, or are nonemployed with payoff $b_{n,t}$

Locations have heterogeneous amenities $B_{n,t} = \bar{B}_{n,t} \underbrace{\exp(h(\boldsymbol{T}_{n,t}; \zeta_{\mathbf{B}}))}_{\text{impact on amenities}}$

$\rightarrow$ We will estimate $\zeta_{\mathbf{B}}$

Households receive utility from consumption $C_{n,t}^{k}$ and amenities $B_{n,t}$: $\log(C_{n,t}^{k} B_{n,t})$

End of year: households choose a location i to live, industry s to work (including nonemployment), subject to moving costs μ_{ni}^{ks}, and idiosyncratic T1EV shock

Key variables in the model for estimation and simulation

The data tell us about unobservables

The key data/variables for estimation are:

1. Total expenditures by n X_n^k
2. Bilateral expenditures by n on i's goods X_{ni}^k
3. Migration flows from (n, k) to (i, s) (only have US data) π_{ni}^{ks}

They also act as sufficient statistics in the simulations for (Caliendo et al., 2019):

1. Productivity $Z_{n,t}^k$
2. Trade costs τ_{ni}^k
3. Moving costs μ_{ni}^{ks}

Next steps

We will estimate the climate-relevant relationships using equilibrium conditions

We need to recover the $\zeta_{\mathbf{Z}}$ and $\zeta_{\mathbf{B}}$ terms that govern how temperature affects growth and amenities

We use the equilibrium conditions of the model to guide estimation of these coefficient vectors

Two key benefits to estimating impacts using the model structure:

1. Estimates are internally consistent with our quantitative simulations
2. Estimates account for dynamics (amenities) and spatial linkages (amenities and growth)

Estimating the effect of climate change on growth

Growth in trade flows tells us how productivity is growing

In equilibrium, n's imports from i at time t $X^k_{ni,t}$ are governed by:

$$\underbrace{\log\left(\frac{X^k_{ni,t}/X^k_{nn,t}}{X^k_{ni,t-1}/X^k_{nn,t-1}}\right)}_{\text{growth in expenditures on } i \text{ relative to } n} = \underbrace{\left[h(\mathbf{T}_{i,t};\zeta^k_{\mathbf{z}}) - h(\mathbf{T}_{n,t};\zeta^k_{\mathbf{z}})\right]}_{\text{difference in temperature}} + \underbrace{\log\left(\frac{1+\bar{r}^k_{i,t}}{1+\bar{r}^k_{n,t}}\right)}_{\text{non-climate productivity growth}}$$

$$- \underbrace{\theta^k \log\left(\frac{\tau^k_{ni,t}}{\tau^k_{ni,t-1}}\right)}_{\text{growth in trade costs}} - \underbrace{\theta^k \log\left(\frac{x^k_{i,t}}{x^k_{i,t-1}} \Big/ \frac{x^k_{n,t}}{x^k_{n,t-1}}\right)}_{\text{growth in input cost differences}}$$

Intuition: country n imports more from country i relative to itself if:

- → *i* is relatively more productive
- → Trade costs with *i* are low
- → *i* has relatively lower input costs

Estimating the effect of climate change on growth

Growth in trade flows tells us how productivity is growing

$$\overbrace{\log\left(\frac{X^k_{ni,t}/X^k_{nn,t}}{X^k_{ni,t-1}/X^k_{nn,t-1}}\right)}^{\substack{\text{growth in expenditures} \\ \text{on } i \text{ relative to } n}} = \overbrace{\left[h(\mathbf{T}_{i,t};\zeta^k_{\mathbf{Z}}) - h(\mathbf{T}_{n,t};\zeta^k_{\mathbf{Z}})\right]}^{\text{difference in temperature}} - \overbrace{\theta^k \log\left(\frac{\tau^k_{ni,t}}{\tau^k_{ni,t-1}}\right)}^{\text{growth in trade costs}}$$

$$- \underbrace{\theta^k \log\left(\frac{x^k_{i,t}}{x^k_{i,t-1}} \middle/ \frac{x^k_{n,t}}{x^k_{n,t-1}}\right)}_{\substack{\text{growth in input} \\ \text{cost differences}}} + \underbrace{\delta^k_t + \varphi^k_{ni}}_{\text{fixed effects}} + \varepsilon^k_{ni,t}$$

Use FEs for origin, destination, industry, year to address non-climate growth factors

Estimating the effect of climate change on local amenities

Migration flows (conditional on wages) tells us about local amenities

In equilibrium, households in n migrate to i relative to staying in n according to:

$$\frac{\nu}{\beta}\overbrace{\log\left(\frac{\pi^{ks}_{ni,t}}{\pi^{kk}_{nn,t}}\right)}^{\text{current flows}} = \overbrace{[h(\mathbf{T_{i,t+1}};\zeta_{\mathbf{B}}) - h(\mathbf{T_{n,t+1}};\zeta_{\mathbf{B}})]}^{\text{difference in climate amenities}} + \overbrace{\log\left(\frac{\bar{B}_{i,t+1}}{\bar{B}_{n,t+1}}\right)}^{\text{difference in non-climate amenities}}$$

$$+ \underbrace{\frac{\beta-1}{\beta}\mu^{ks}_{ni}}_{\text{moving costs}} + \underbrace{\log\left(\frac{\omega^{s}_{i,t+1}}{\omega^{k}_{n,t+1}}\right)}_{\text{difference in wages}} + \nu\underbrace{\log\left(\frac{\pi^{ks}_{ni,t+1}}{\pi^{ss}_{ii,t+1}}\right)}_{\text{future flows}} + \varepsilon^{k}_{i,t}$$

Intuition?

LHS is effectively difference in expected welfare in i relative to n at time $t+1$

RHS breaks it down into its component parts

Estimating the effect of climate change on local amenities

Migration flows (conditional on wages) tells us about local amenities

$$\frac{\nu}{\beta}\overbrace{\log\left(\frac{\pi^{ks}_{ni,t}}{\pi^{kk}_{nn,t}}\right)}^{\text{current flows}} = \overbrace{\left[h(\mathbf{T_{i,t+1}};\zeta_{\mathbf{B}}) - h(\mathbf{T_{n,t+1}};\zeta_{\mathbf{B}})\right]}^{\text{difference in climate amenities}} + \overbrace{\log\left(\frac{\bar{B}_{i,t+1}}{\bar{B}_{n,t+1}}\right)}^{\substack{\text{difference in}\\ \text{non-climate amenities}}}$$

$$+ \underbrace{\frac{\beta-1}{\beta}\mu^{ks}_{ni}}_{\text{moving costs}} + \underbrace{\log\left(\frac{\omega^{s}_{i,t+1}}{\omega^{k}_{n,t+1}}\right)}_{\substack{\text{difference}\\ \text{in wages}}} + \underbrace{\nu\log\left(\frac{\pi^{ks}_{ni,t+1}}{\pi^{ss}_{ii,t+1}}\right)}_{\text{future flows}} + \varepsilon^{k}_{i,t}$$

Intuition: More people in *n* move to *i* rather than stay in *n* if:

→ *i* has relatively better amenities next year

→ Migration costs to *i* are low

→ *i* has relatively higher real wages next year

→ *i* has relatively higher future welfare after next year

Causal effects of climate change?

We identify growth and amenities effects using variation in flows of goods and people across space/time (alternatively: GDP, housing prices, etc)

These are causal effects of changes in temperature distributions in a world with:

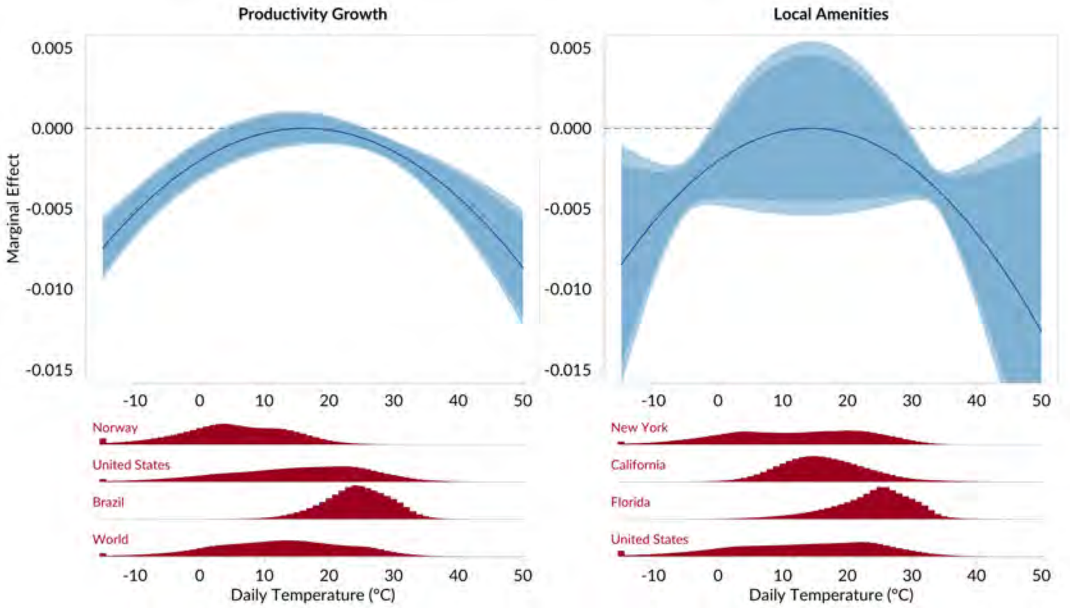
- Forward-looking, dynamically optimizing households & statically profit-maximizing firms

We get to effects of climate change by simulating the full model

Later we validate our structural results with a reduced form/envelope theorem approach consistent with our model (Hsiang, 2016; Deryugina and Hsiang, 2017)

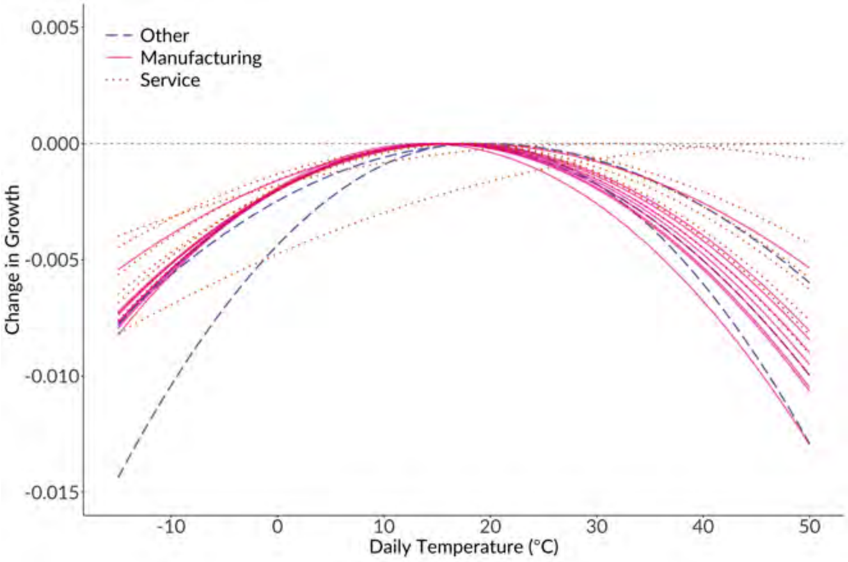
Growth and amenity response functions

Peak productivity growth: 16°C; Peak amenities: 14°C



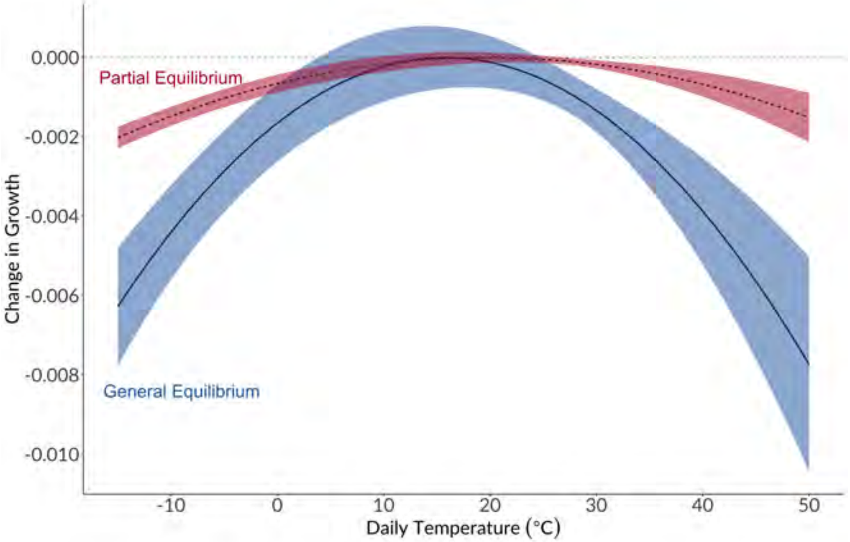
Industry-specific productivity effects

Manufacturing + construction is more sensitive than services



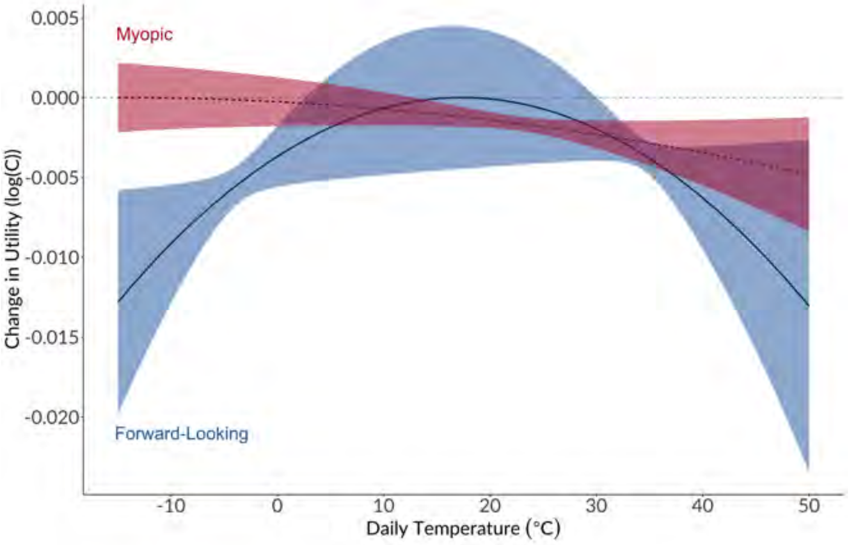
Spatial general equilibrium linkages matter for productivity effects

Correlated shocks raise market access & GDP → partial equilibrium models biased toward zero



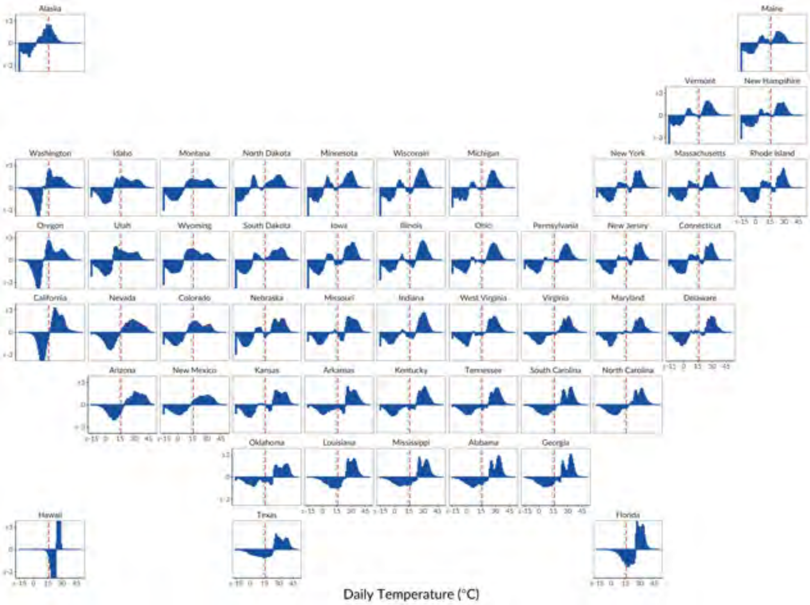
Dynamics and forward-looking behavior matter for amenities impacts

Dynamics and forward-looking behavior matter for amenities



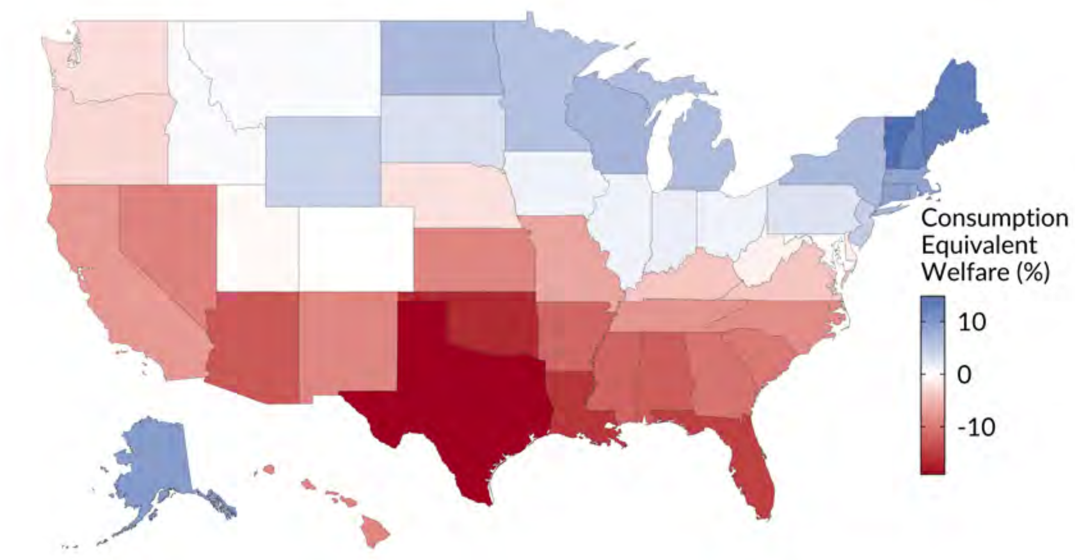
Change in within-year temperature by end of century

General shift toward hotter days, good amount of heterogeneity across states



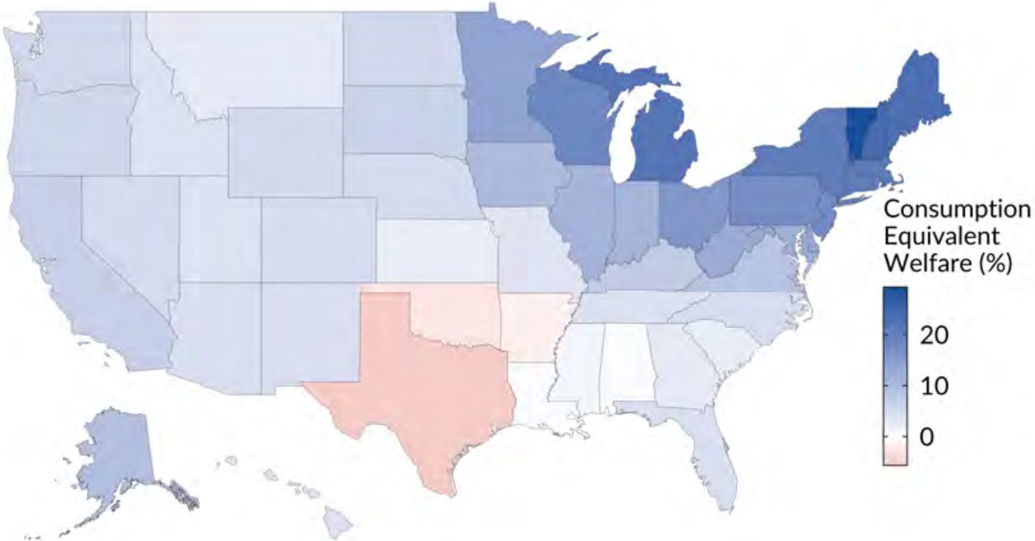
Present value US welfare impacts through 2100: -4.6% total

Baseline simulation: no input-output linkages, amenities, heterogeneity, nor adaptation



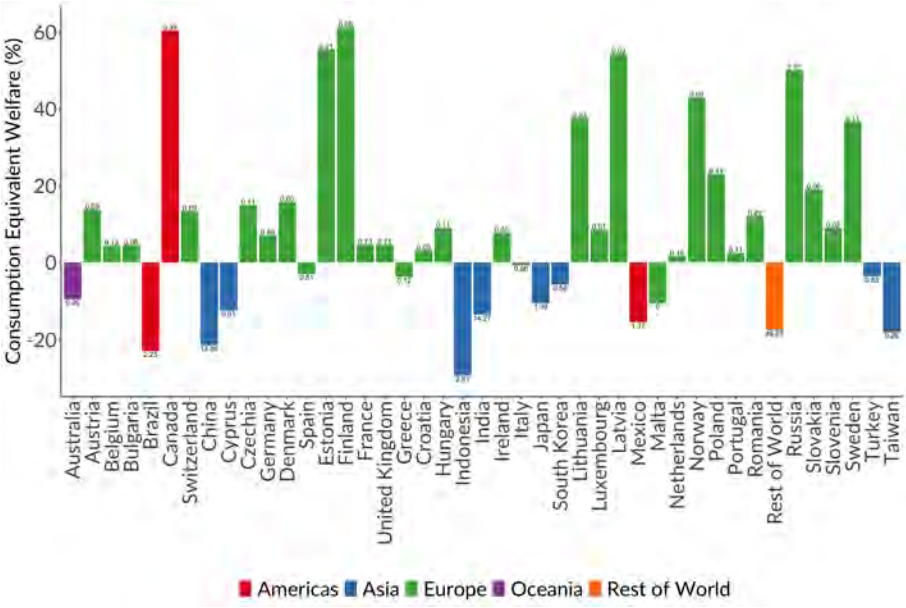
Present value US welfare impacts through 2100: +8.5% total

Full model: input-output linkages, amenities, industry heterogeneity, and labor adaptation



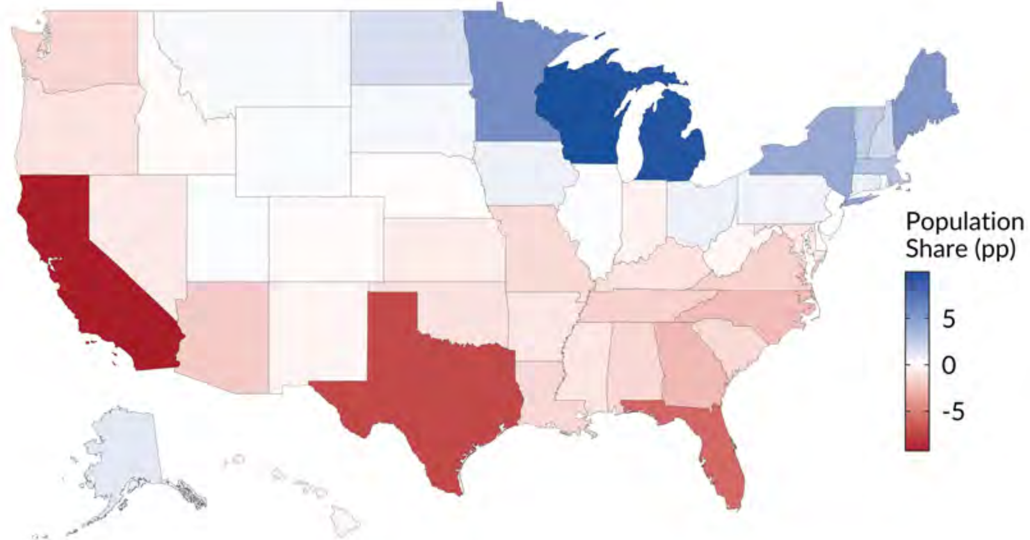
Present value global welfare impacts through 2100: -14.6% total

Europe gains, almost everyone else loses



Change in US population with climate change relative to without

People migrate north toward the Great Lakes



Relative change in US industry employment

Labor supply increases, shift from manufacturing to services

Does all of this modeling structure matter?

How much does the structure of the model matter for measuring climate impacts?

Are there first-order effects of:

→ Production networks / input-output structure?

→ Amenities?

→ Industrial heterogeneity in climate effects?

→ Within-year temperature variability?

Model structure matters for welfare

	US	Global
Welfare	**8.5%**	**-14.6%**
Value of Input-Output Linkages	+4.9pp	-4.4pp
Value of Amenities	-1.0pp	-2.4pp
Value of Industry Heterogeneity	+5.7pp	+6.5pp
Value of All Temperature Variability	-11pp	-9.3pp

1. Input-output linkages amplify climate shocks
2. Productivity effects matter more than amenities
3. Ignoring industrial heterogeneity overstates costs of climate change
4. Ignoring temperature variability understates costs of climate change

Why does capturing these features of the climate-economy matter?

1. Input-output linkages amplify climate shocks
   - Negative shocks to producers propagate and raise costs for downstream buyers of output, reduce demand for upstream sellers of inputs (Carvalho and Tahbaz-Salehi, 2019; Baqaee and Farhi, 2019)
2. Productivity effects matter more than amenities
   - Growth shocks have permanent effects and are amplified by the input-output network
3. Ignoring industrial heterogeneity overstates costs of climate change
   - Heterogeneity is required for adaptation, the aggregate response function abstracts it away
4. Ignoring temperature variability understates costs of climate change
   - Second-order changes in climate have first-order economic effects with non-linear responses: mean-preserving spreads reduce welfare (Burke et al., 2015)

The value of adaptation in the US: 2015-2100

Welfare impact of climate change with adaptation versus without

How much does adaptation contribute to the 8.5% welfare gain in the US?

Value of Trade Adjustments	Value of Migration	Value of Industry Switching	Value of Migration and Industry Switching	Value of Trade, Migration, and Industry Switching
11.3pp	6.6pp	1.6pp	8.2pp	13pp

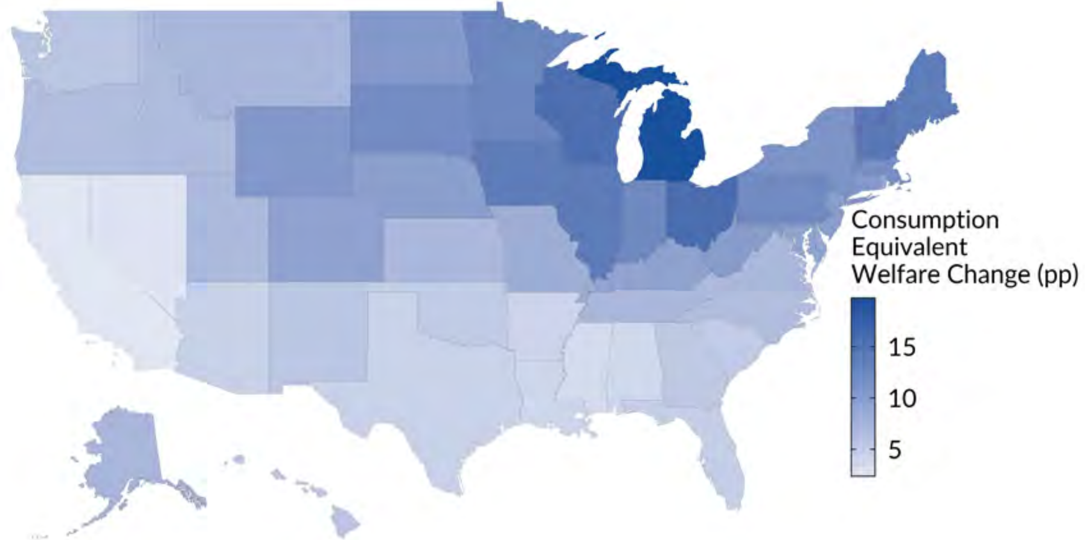
Trade improves welfare significantly, without trade welfare declines by 3%

Mobility across space is more important than across jobs

Trade and labor adaptation display some substitutability: 11.3 + 6.6 + 1.6 > 13

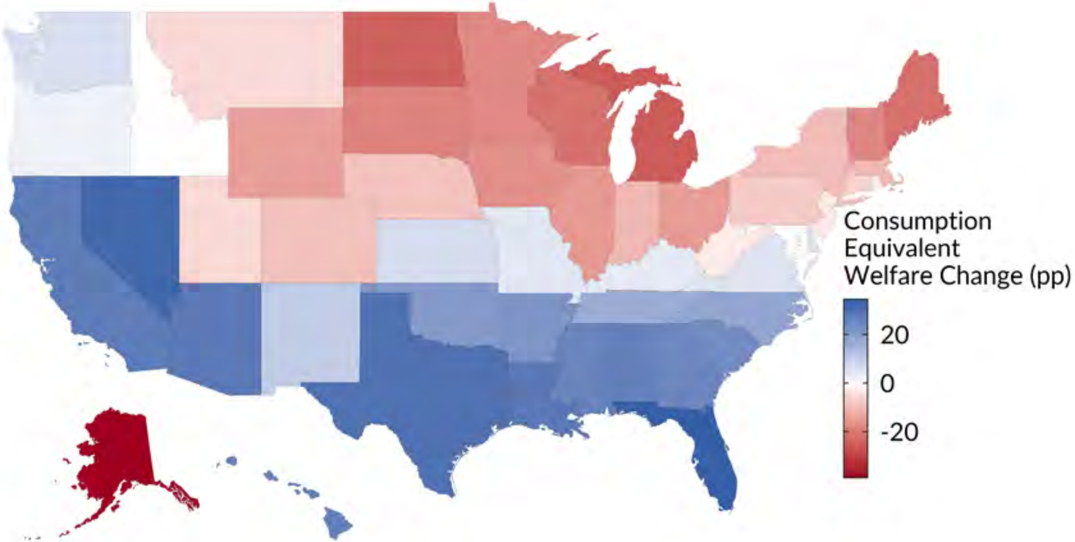
The adaptation value of trade

All US states benefit from trade



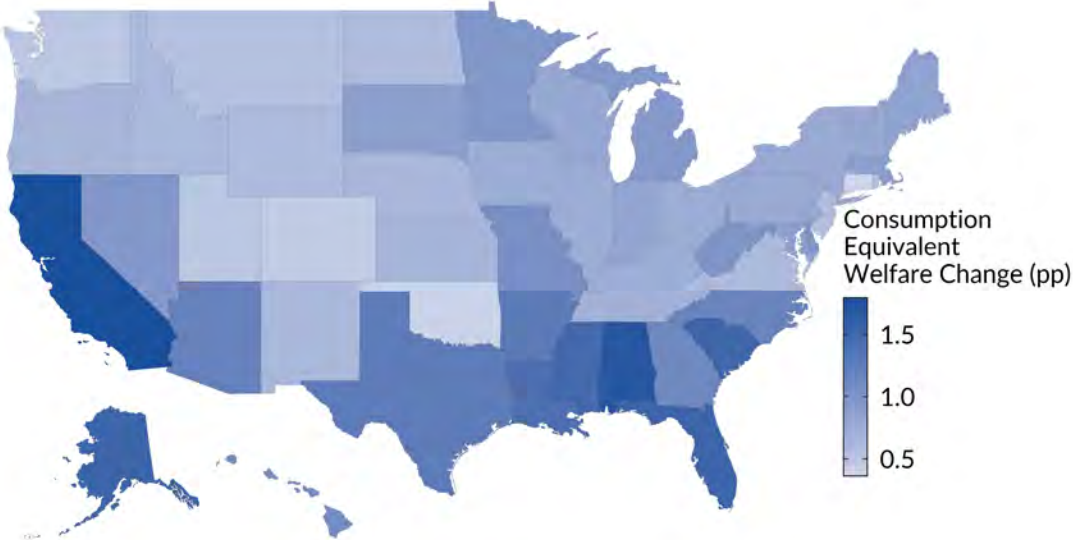
The adaptation value of migration

South benefits by moving North (at the North's expense)



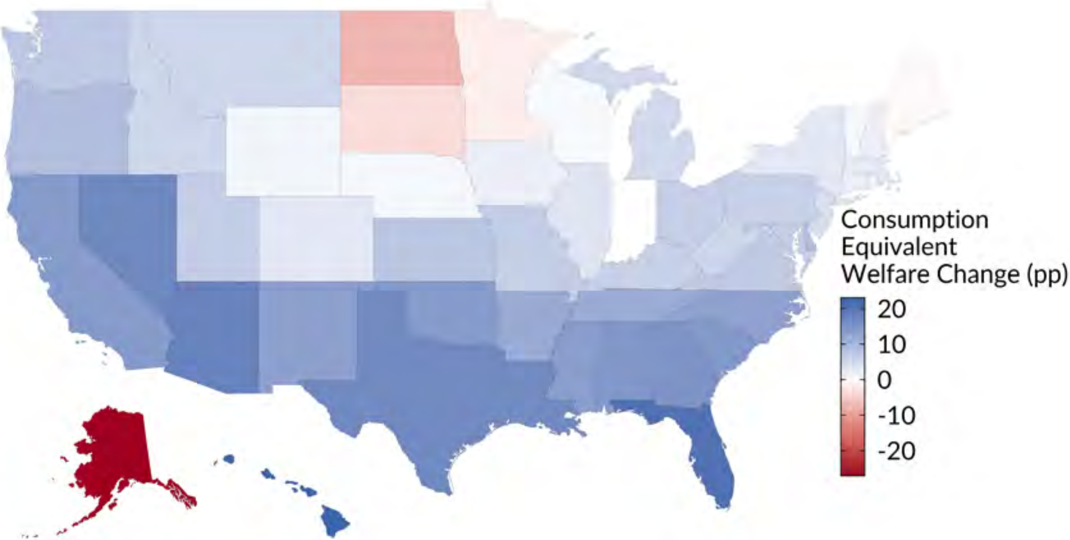
The adaptation value of industry reallocation

All US states benefit from being able to reallocate across industries



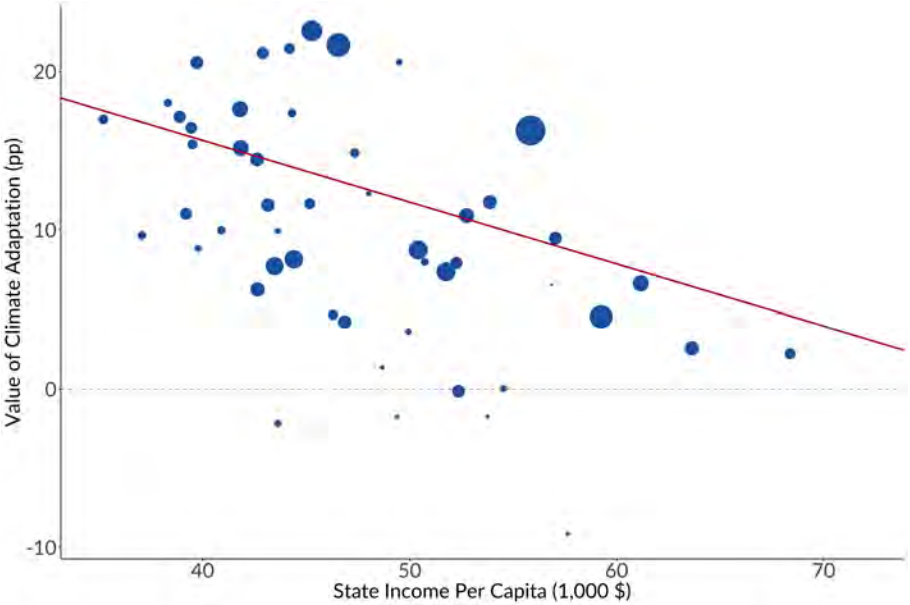
The total value of adaptation

Virtually every state benefits



Adaptation has progressive effects on the US

Migration and job switching help poorer states the most



Reduced form for dynamic value

"Structure-light" approach to getting marginal effects of climate change

Thus far: we used well-identified estimates of impacts of temperature on growth and amenities

We got to effects of climate change by simulating a relatively complicated structural model

How reasonable are the assumptions of the model? Can we validate this against something reduced form/data-driven?

Dynamic envelope theorem tells us if we can recover a maximized objective, regressing it on weather identifies marginal changes in climate

Reduced form for dynamic value

"Structure-light" approach to getting marginal effects of climate change

We can obtain household's expected continuation value given the labor structure of our model, and that firms make zero profits

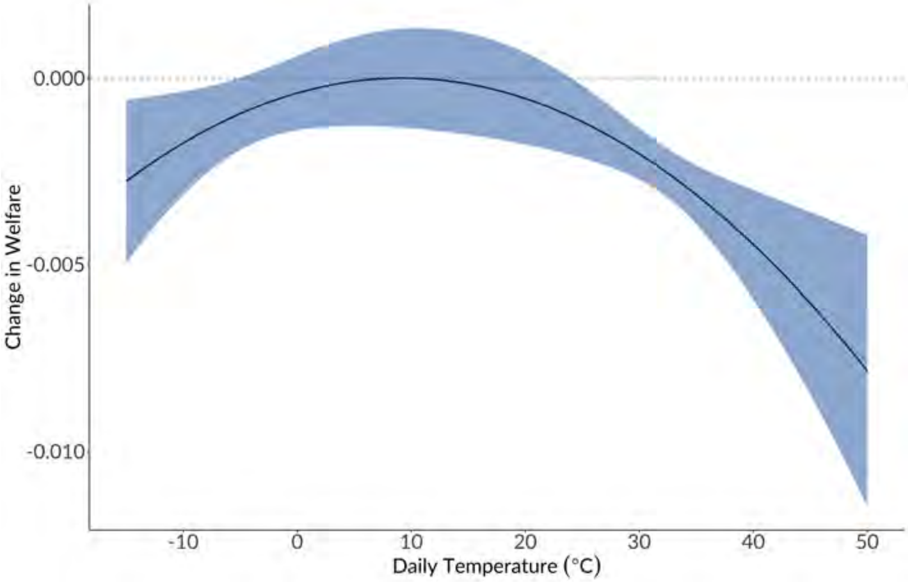
Critical assumption: origin and destination components of migration costs are separable (Conte et al., 2020; Cruz and Rossi-Hansberg, 2021)

Under this assumption: expected value for households in a particular market (n, k) are fully captured by:

1. In-migration flows
2. A market fixed effect
3. A year effect common to all markets

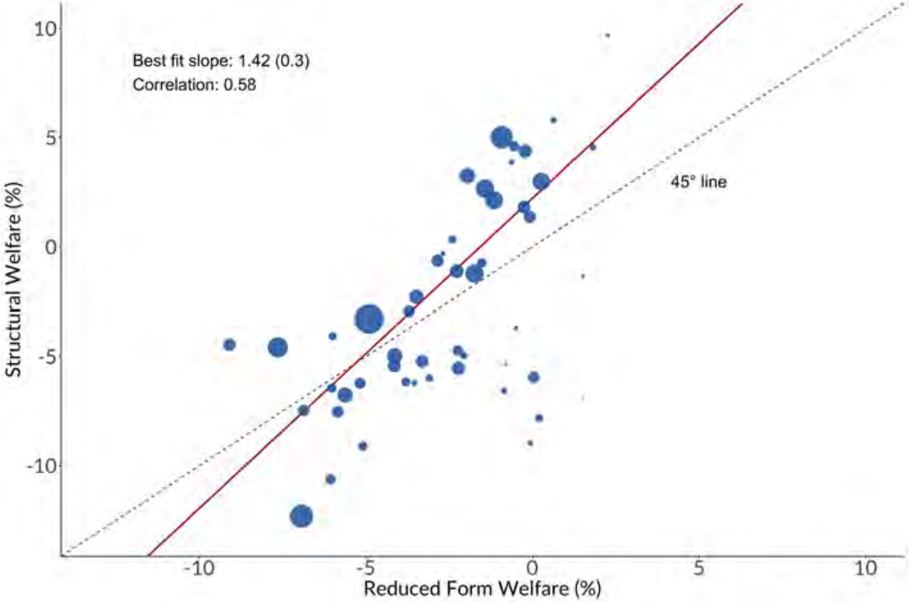
The climate change response function

Agnostic about production side except zero profit



Reduced form versus structural welfare

Welfare outcomes are highly consistent



Wrap up

We build a dynamic spatial model to understand the costs of climate change, the role of adaptation, and the representation of the climate-economy

Use the model to estimate effects of local daily temperature

→ Accounting for dynamics and space in estimation matters

Climate change is costly globally, but beneficial to the US

→ Does **not** account for all climate impacts

Adaptation has first-order effects, can flip the sign of climate change's effect

Static production structure seems to match results from agnostic reduced-form valuation approach