Carbon Taxes in Spatial Equilibrium

🦆 John M. Morehouse 🦆

Federal Reserve Board

$\mathrm{CO_2}$ creates well recognized global externalities

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The public:

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Insight: Need to know *who* individuals are, and *where* they are for a Pareto improvement from efficiency-enhancing policy

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This paper: Who bears the burden from carbon pricing? **Where** are they?

Motivation

Welfare effects from a carbon tax are hard to capture

- Heterogeneity creates differences in initial burden of the tax
- Households can respond to these differences by moving, changing consumption,etc...
- These responses affect wages, rents, goods prices, causing further changes!

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Non-College-educated households:

- Spend larger share of income on energy (estimates)
- Work in more carbon-intensive sectors (Känzig, 2021)
- Are less mobile across occupations and locations (this paper + others)

What I do

Build a general equilibrium model of US local labor markets

- Multiple locations and sectors: emissions, wages, and rents are endogenous
- Imperfectly mobile households choose location and sector as a static discrete choice
- Model captures: household emissions and firm emissions from electricity and nat. gas

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- American Community Survey
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Simulate a national, uniform carbon tax

- Decompose results and demonstrate considerable heterogeneity
- Simulate carbon tax with transfer payments

Literature

I am not the first to recognize the **distributional impacts of carbon pricing**:

- CGE model w/ 15k HHs to recover incidence (Rausch et al., 2011)
- Employment impacts from BC carbon tax (Yamazaki, 2018)
- Employment effects in general eq. (Hafstead & Williams, 2018)
- Intergenerational Distributional Impacts (Fried, Novan, Peterman, 2018)
- CGE model with two cases: perfect mobility and perfect immobility (Castellanos & Heutel, 2019)

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Quantitative Spatial Equilibrium (QSE) Models:

- Endogeneous amenities and college wage premia (Diamond, 2015)
- Impacts of immigration on wages (Piyapromdee, 2019)
- Origins and determinants of urban gentrification (Su, 2021)
- Land Use regs and HH carbon emissions (Colas & Morehouse, 2021)

Road map

Intro: ✅

Model

Data + Estimation

Carbon Taxes

Model

Model Overview

Households

- Static; discrete choice: locations & sectors
- Consume numeraire, housing, and energy

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- Change in energy prices $\implies$ **change in wages**
  - This change varies by city + sector (due to **differences in prod. params**)

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  - This change varies by city + sector (due to differences in prod. params)
- Change in wages $\implies$ **sorting!** New location-sector choices further change prices.

Road map: progress

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Model:

- Overview: ✅
- Labor Supply
- Labor (and Energy) demand
- Fuel Supply and Rents

Data + Estimation

Carbon Taxes

Model: Labor Supply

Indirect utility for HH i of educ. level e in city j, sector n:

$$V_{ijn} = \beta_e^w \log(W_{ejn}) - \beta_e^r \log R_j - \sum_m \alpha_{ej}^m \log P_j^m + f(j, \mathcal{B}_i) + \hat{\lambda}_{ijn}$$

where

- W_{ejn} is income, R_j is rents
- P_j^m is price of energy type $m \in \{\text{elec,gas,oil}\}$
- $f(j, \mathcal{B}_i)$ moving cost as a function of euclidean distance from j to i's birthstate

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- $f(\cdot) = \gamma_e^{div} \mathbb{I}\left(j \in \mathcal{B}_i^{div}\right) + \gamma_e^{\text{dist}} \phi\left(j, \mathcal{B}_i^{st}\right) + \gamma_e^{\text{dist2}} \phi^2\left(j, \mathcal{B}_i^{st}\right)$

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- $\hat{\lambda}_{ijn} = \xi_{ejn} + \sigma_e \epsilon_{ijn}$ amenities:
  - ξ_{ejn} unobserved (to me), shared by all agents in educ. group/city/sector
  - ϵ_{ijn} iid pref shock, dispersion parameter σ_e

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Model: Firms

Firms in perfectly competitive markets produce with tech:

$$Y_{jn} = A_{jn} K_{jn}^{\eta} \mathcal{I}_{jn}^{1-\eta}$$

where

$$\mathcal{I}_{jn} = \left(\alpha_{jn} \mathcal{E}_{jn}^{\rho_{el}^{n}} + (1 - \alpha_{jn}) \mathcal{L}_{jn}^{\rho_{el}^{n}} \right)^{\frac{1}{\rho_{el}^{n}}}$$

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ζ : Electricity intensity

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[Input Demand Curves]

Road map: progress

Intro: ✅

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Data + Estimation

Carbon Taxes

Electricity and Emissions

Electricity is supplied in one of 9 NERC regions, $\mathcal{R}$. LR supply curve is:

$$P_j^{\text{elec}} = a_{kj} Q_{\mathcal{R}(j)}^{\mu}$$

where

- a_{kj} is an intercept that varies across $k \in \{\textbf{residential}, \textbf{industrial}\}$ and cities within a region, reflecting different costs of delivery
- $Q_{\mathcal{R}(j)}$ is the quantity of electricity supplied in NERC region $\mathcal{R}$

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- Emissions factor for fuel-type m in city j

$$\delta_j^m = \begin{cases} \delta_{\mathcal{R}(j)}^{elec} & \text{if } m \in \{\text{elec}\} \\ \delta_m & \text{if } m \in \{\text{gas}, \text{oil}\} \end{cases}$$

[NERC Regions]

Rents

I posit a long-run upward sloping rental supply curve:

$$R_j = \beta_j H_j^{\kappa_j}$$

Differences in:

- β_j: reflect differences in construction/materials costs across cities
- κ_j: reflect differences in amount of land for dev. and land-use regs

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Data

Data comes from multiple sources:

1) Census and ACS: HH level data with:

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3) EIA: Emissions data + Aggregate Firm Energy Consumption

- Impute city-sector firm energy consumption as proportional to each city-sectors' employment share
- Implies constant energy/labor ratios across cities (but not sectors)

Estimation

The model has a *ton* of parameters and “market-level” indices.

- Wage and rent indices: [Details]
- Household Energy Consumption: [Details]
- Firm Production Parameters: [Details]
- Energy Supply Curve Parameters: [Details]
- Rental Supply Curve Parameters: [Details]

Labor Supply: Most important component, gets a whole slide 😁

Labor Supply

I use a **two-step** estimation procedure

1) Recover moving cost parameters using "**micro-BLP**" (BLP, 2004). [Details]

- Treat locations-sectors as "products" with characteristics by educ. group
- Use repeated cross-sections of census. Estimate parameters and corresponding mean utilities for 4 sample years

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2) Estimate β_e^w and β_e^r in **first-differences with IV**. [Details]

- Bartik labor demand shocks identifies β_w^e
- Bartik labor demand shocks $\times$ city housing supply elasticity identifies β_r^e

- [Parameter Estimates]
- [Model Fit]

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Data + Estimation ✅

- Overview and Data: ✅
- Labor supply estimates: ✅

Carbon Taxes

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Carbon taxes

A carbon tax (of τ) impacts the price of energy. New energy supply curves are:

$$\begin{aligned}
\tilde{P}_j^m &= P_j^m + \tau \times \delta^m \quad \text{for } m \in \{\text{gas}, \text{oil}\} \\
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Use the estimated model to solve for counterfactual **equilibrium**[1] with a $31 per ton (SCC à la Nordhaus, 2017)

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Compensating Variation: Dollar amount HH would need (yearly) to be indifferent between tax and no tax:

$$CV_i = \underbrace{\left(\mathbb{E}[V(\tau > 0)] - \mathbb{E}[V(\tau = 0)]\right)}_{\%\Delta\text{Expected Utility}} \times \underbrace{\frac{w_i}{\beta^w}}_{\text{Wage conversion}}$$

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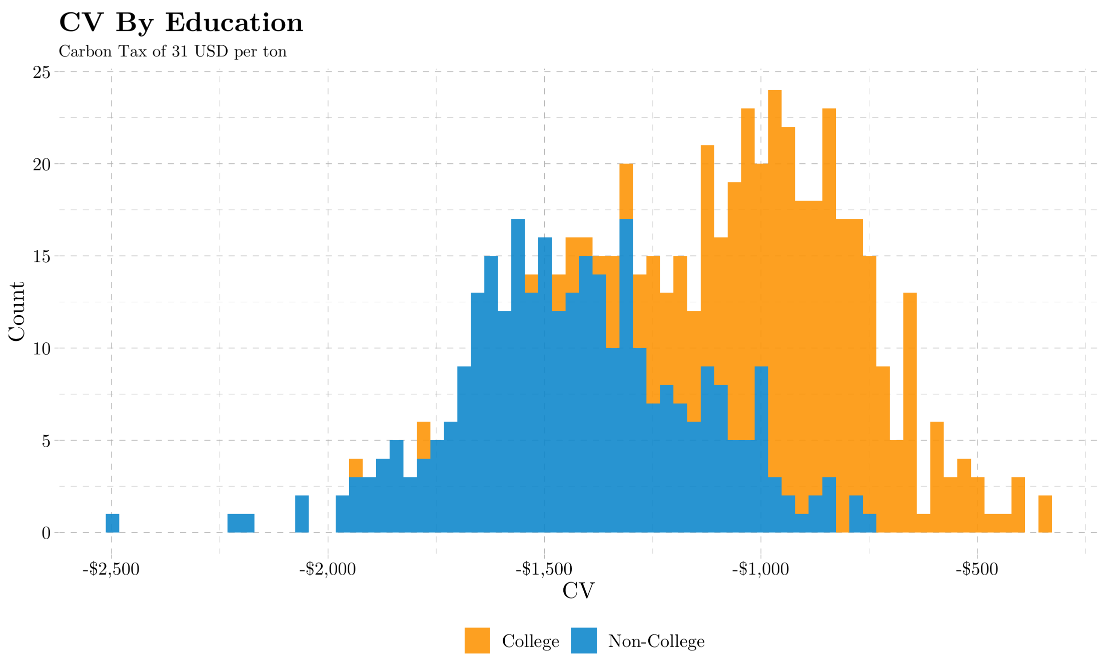
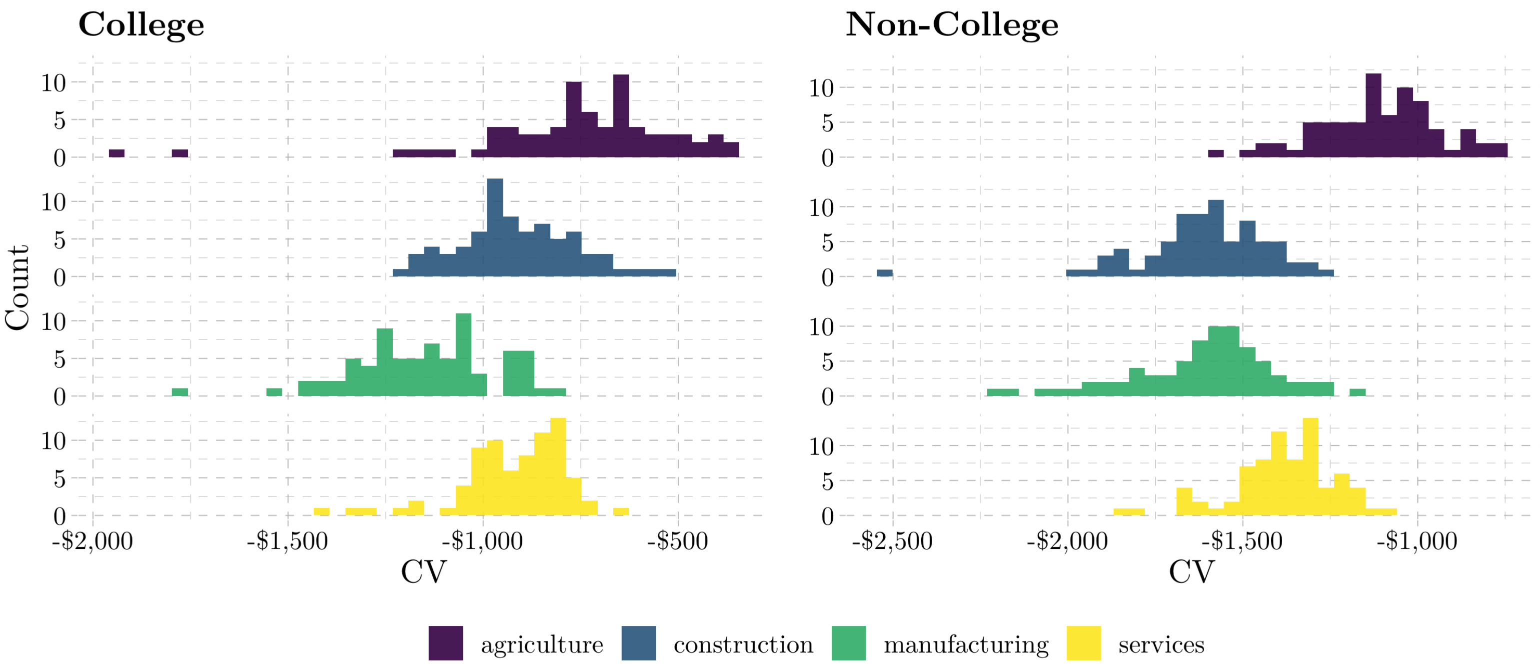
Results



τ = \$31/ton:	%Δ Emissions: −19.8			
No Transfers	Mean CV (\$)	Mean/st.dev CV	%Δ Man. Emp	%Δ Ser. Emp
Total	−1,221	−3.14	−11.1	2.01
College	−926	−3.55	−12.7	1.78
Non-College	−1,417	−4.16	−10.4	2.34

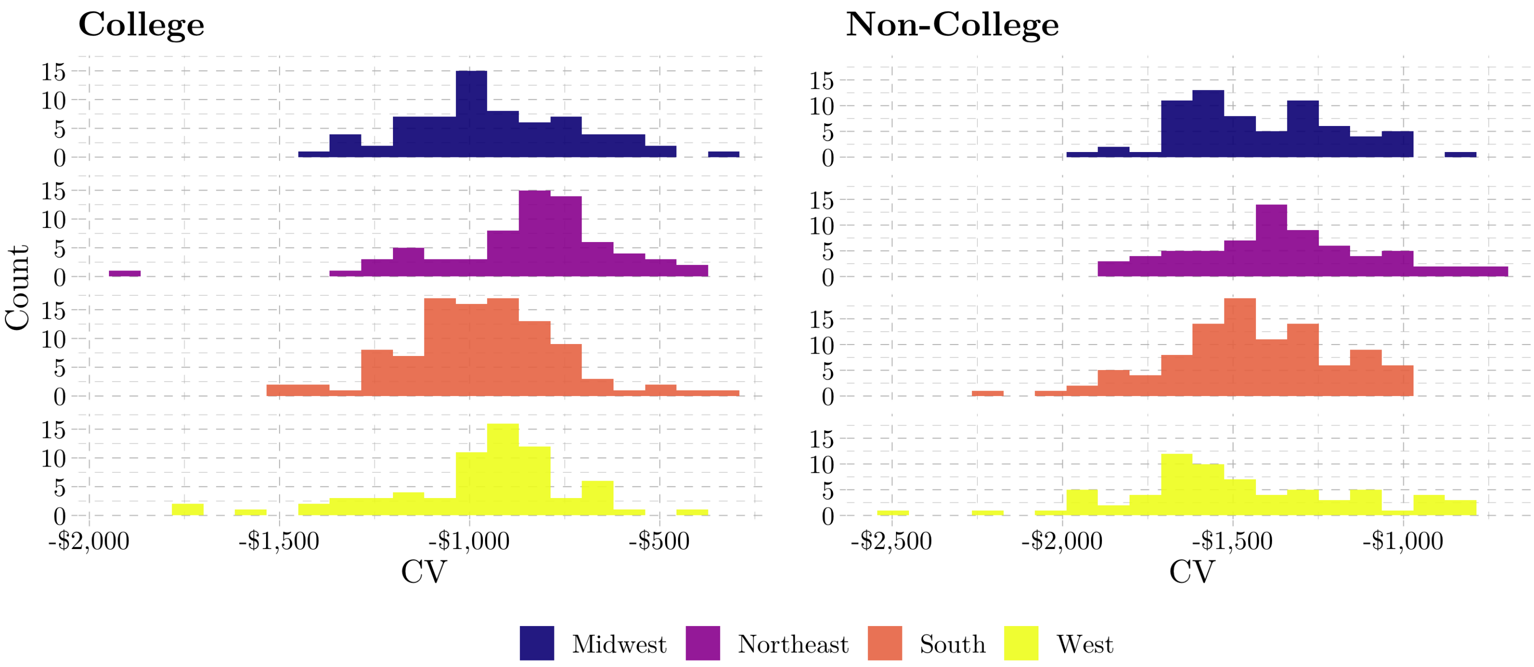
Results

Compensating variation across cities by **industry**

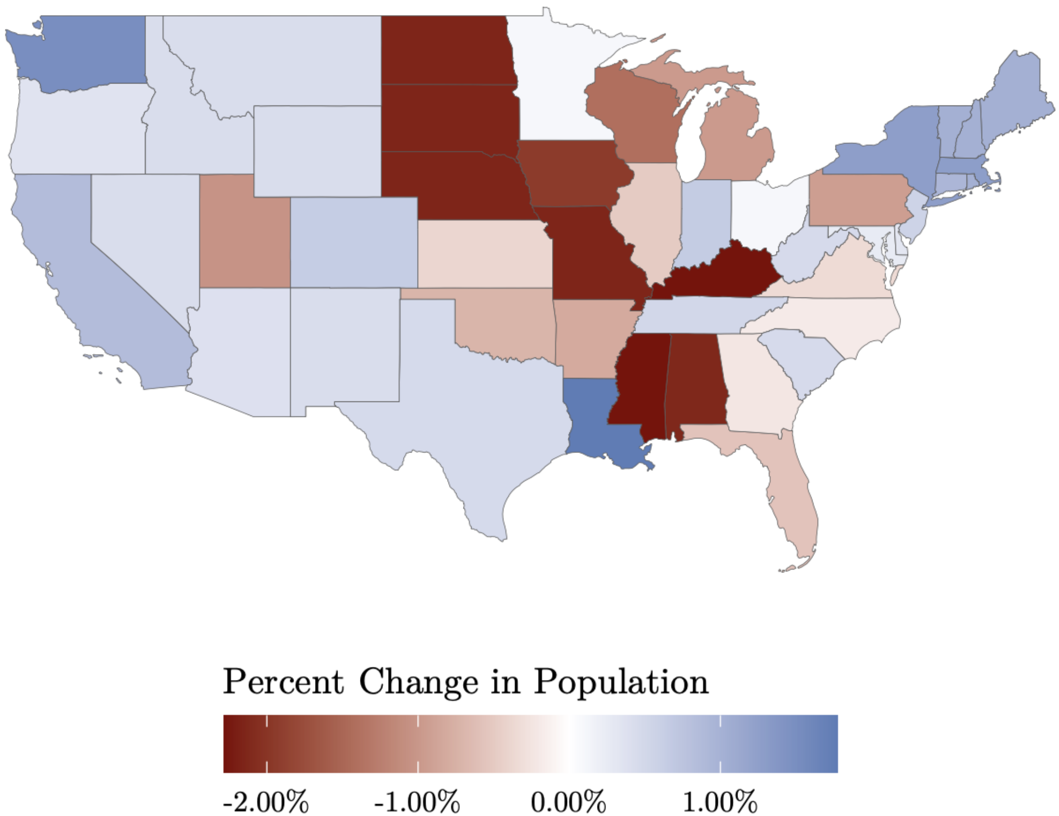


Results

Compensating variation across city-industries by **Census Region**



Migration Results



By education

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Data + Estimation

- Overview and Data: ✅
- Labor supply estimates: ✅

Carbon Taxes

- Compensating Variation: ✅
- Welfare Metrics
- Transfers

Welfare Metrics

Next: map out non-monetized tax incidence ("incidence")

- Due to variation in wages, incidence may be different than CV ("monetized" incidence)

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Example: Avg. compensating variation for a non-college household in:

- San Francisco: $1,876
- Detroit: $1,619

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Might naively conclude that worker in SF has higher tax burden than Detroit

- Wages mask important underlying heterogeneity in incidence!
- Look at incidence in percent terms rather than levels

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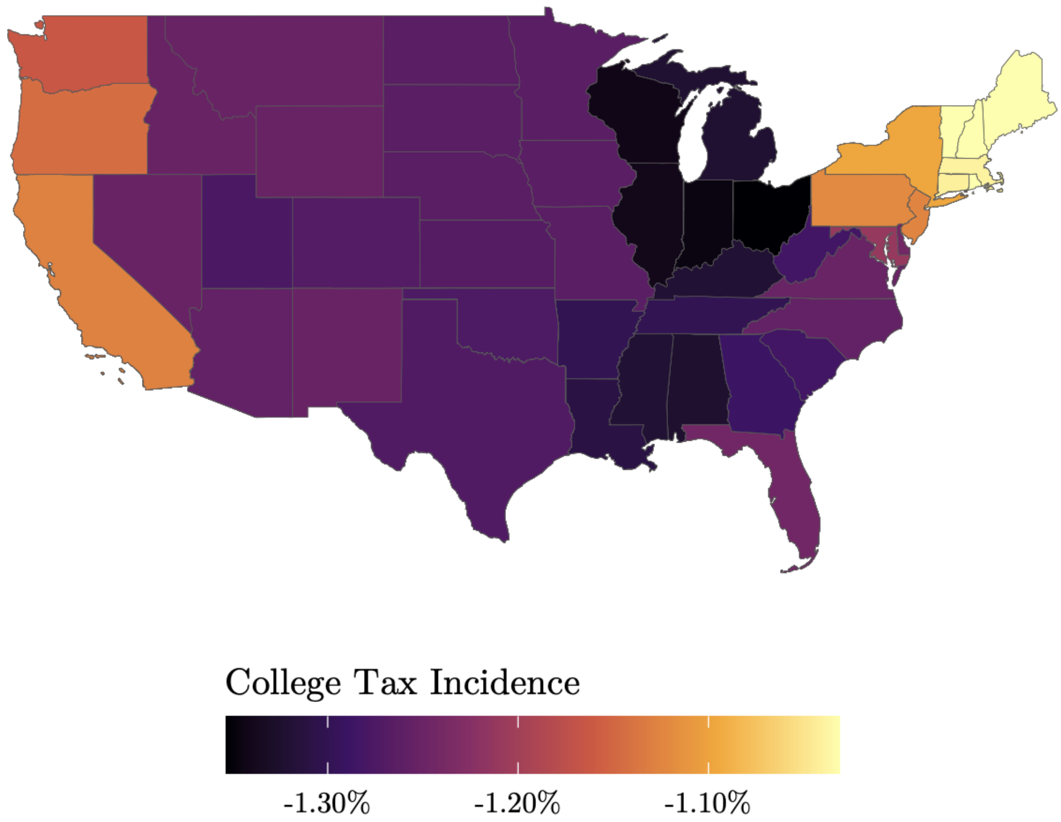

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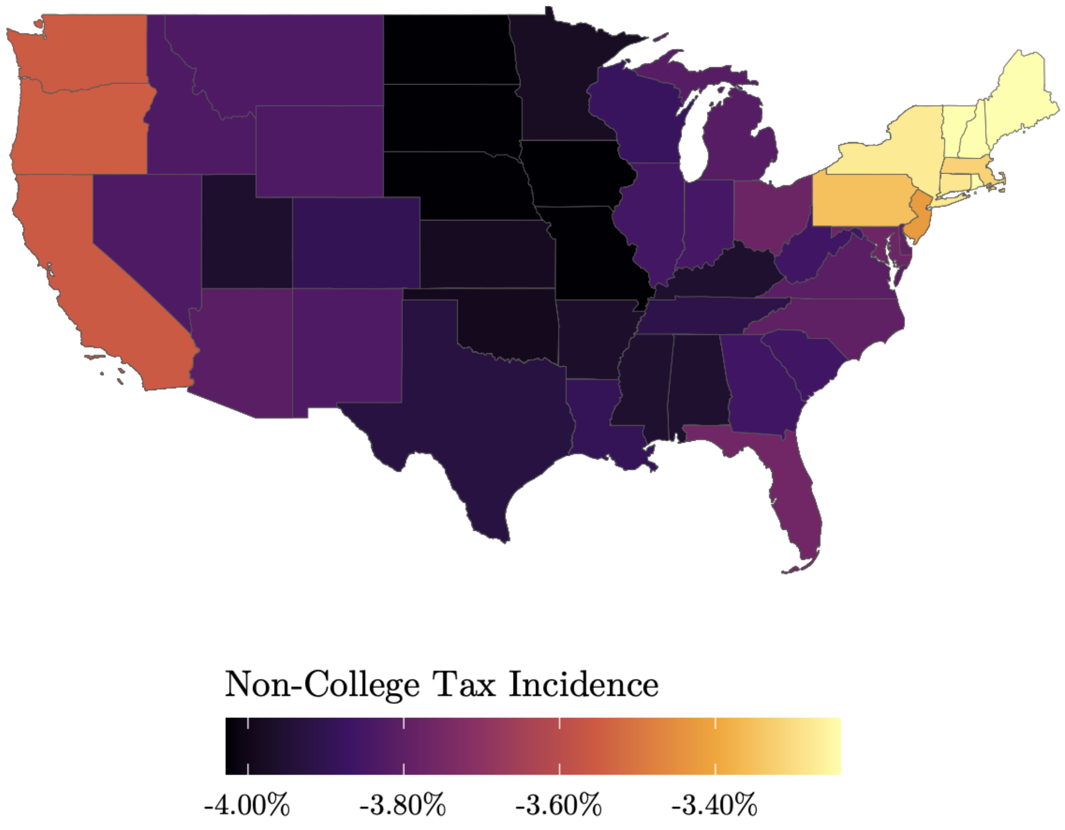

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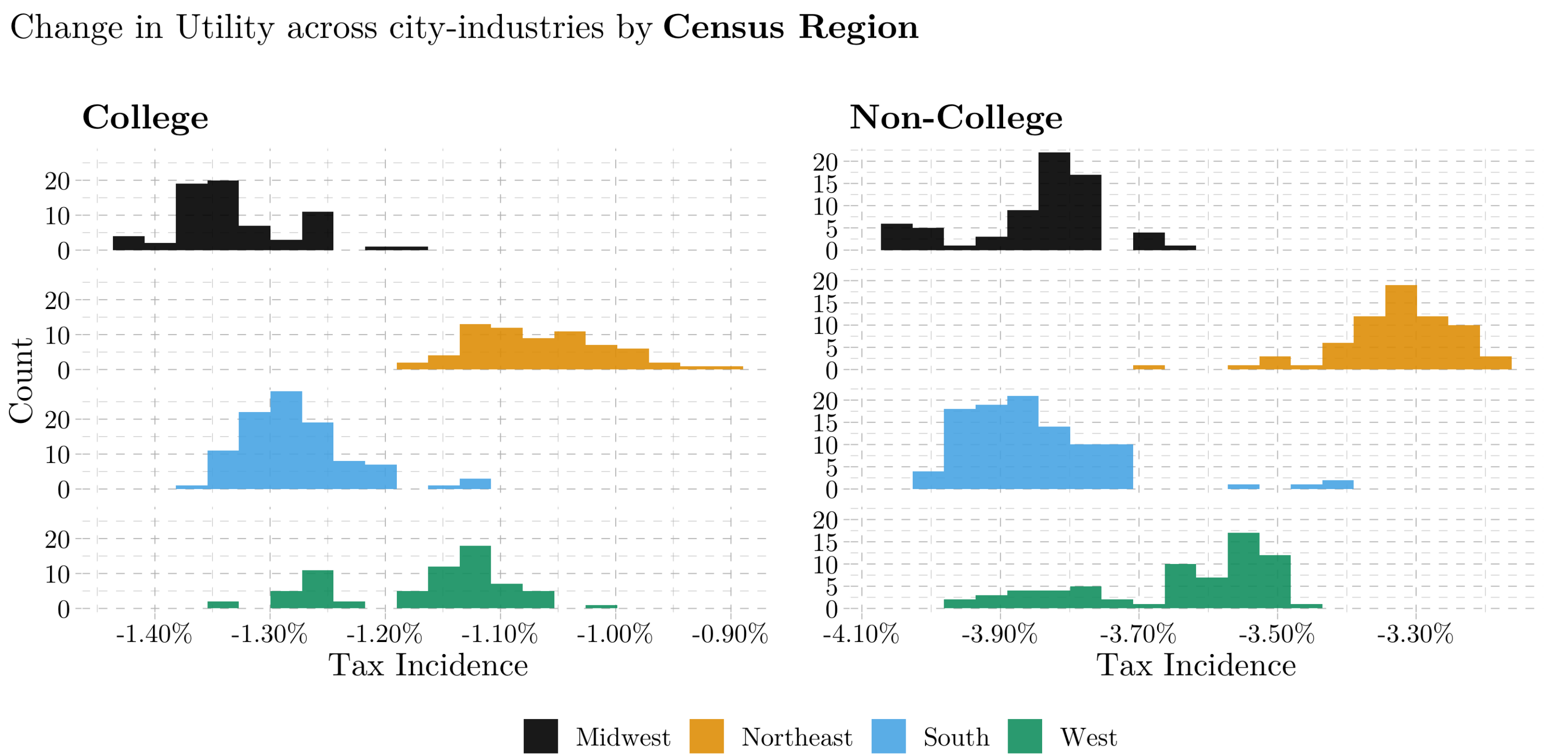

[Correlation with Voting Patterns]

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Data + Estimation: ✅

- Overview and Data: ✅
- Labor supply estimates: ✅

Carbon Taxes

- Compensating Variation: ✅
- Welfare Metrics: ✅
- Transfers

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    - $\lambda > 0$: level of reimbursement. Determined endogenously. [Details]
    - $\gamma \geq 1$: progressivity of the transfers

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Counterfactuals: Use model to examine how aggregate emissions depend on transfers [Mechanism]

Results

I find that a **1%** increase in the progressivity of transfers leads to a **-0.001%** decrease in aggregate emissions

- **Note:** This is *relative* to an equilibrium with lump-sum transfers
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Takeaways?

- Progressive transfers *may* reduce emissions relative to flat transfers
- More conservatively: progressive transfers don't cause agg. emissions to increase

Road map: progress

Intro: ✅

Model:

- Overview: ✅
- Labor Supply: ✅
- Labor (and Energy) demand: ✅
- Fuel Supply and Rents: ✅

Data + Estimation: ✅

- Overview and Data: ✅
- Labor supply estimates: ✅

Carbon Taxes

- Compensating Variation: ✅
- Welfare Metrics: ✅
- Transfers:✅

Conclusions

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- Driven by differences in wages across cities

3) Progressivity of transfers and aggregate emissions go hand-in-hand

- Point estimate is small, however
- Progressive transfers do not undo emissions reductions

Thank You!!

John Morehouse

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Current papers:

- The Environmental Cost of Land-Use Restrictions
    - **Forthcoming:** Quantitative Economics (*with Mark Colas*)
- In Search of Peace and Quiet: The Heterogeneous Effects of Short-Term Rentals on Housing Prices
    - **R&R:** Regional Science and Urban Economics (*with Brett Garcia and Keaton Miller*)
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  - **Under Review** (*with Ed Rubin*)

Works in progress include:

- Studying the effects of coal stack-heights on health and attribution
- Heterogeneity in response to climate change across demographic groups
- Labor market power and the college wage premium

Land-Use Regulations

The Environmental Cost of Land-Use Restrictions (with Mark Colas)

Research Question: How do stringent land-use regs impact national carbon emissions?

Methods:

- Strucutral estimation of HH sorting model
- Semi-parametric estimation of causal effect of location on HH energy consumption
- Integrate InMAP polltion transport model with sorting model

Main Finding: Relaxing CA land-use regs to level faced by median urban HH reduces carbon emissions by 0.6%

Power Plants: Strategic Siting

Downwind and Out: The Strategic Dispersion of Power Plants and their Pollution (with Ed Rubin)

Research Questions: Have power plants been strategically sited to export their emissions? How far do their emissions travel and where?

Methods:

- Descriptive statistics on geography of US power plants
- Non-parametric test of strategic siting for coal plants. Strategic Identified off of upwind/downwind areas
- HYSPLIT model for estimating dispersion of coal-based particulates

Main Findings:

- Coal plants have been sited strategically to reduce downwind emissions
- Emissions travel far and fast. 90% of coal-based pm leaves **state** of origin within 48 hours

Short-Term Rentals

In Search of Peace and Quiet: The Heterogeneous Effects of Short-Term Rentals on Housing Prices (with Brett Garcia and Keaton Miller)

Research Question: Can short-term rentals (STRs) reduce housing prices? If so, how?

Methods:

- Theoretical model of housing demand with externalities
- Instrumental variables + difference-in-differences
- Difference-in-Discontinuities

Main Findings:

- Relationship between housing prices and STRs is an ambiguous function of the relationship between STRs and amenities
- Empirical estimates suggest in some cities the effect is negative, contrary to the literature

Appendix

Energy Expenditures

Expenditure Share on:	College	Non-College
Electricity		
Mean (SD)	0.025 (0.013)	0.046 (0.018)
Range	[0.005, 0.084]	[0.014, 0.133]
Natural Gas		
Mean (SD)	0.03 (0.03)	0.04 (0.05)
Range	[0.00, 0.39]	[0.00, 0.36]
Fuel-Oil		
Mean (SD)	0.001 (0.003)	0.003 (0.005)
Range	[0.000, 0.021]	[0.000, 0.025]

[Return]

Model: Firms

Energy Demand

$$P^E_{jn} = \mathcal{A}_{jn}\mathcal{I}^{1-\rho^n_{el}}_{jn}\mathcal{E}^{(\rho^n_{el}-\rho^n_e)}_{jn}\alpha_{jn}\zeta_n E^{\rho^n_e-1}_{jn}$$
$$P^G_{jn} = \mathcal{A}_{jn}\mathcal{I}^{1-\rho^n_{el}}_{jn}\mathcal{E}^{(\rho^n_{el}-\rho^n_e)}_{jn}\alpha_{jn}(1-\zeta_n)G^{\rho^n_e-1}_{jn}$$

Labor Demand

$$W^C_{jn} = \mathcal{A}_{jn}\mathcal{I}^{1-\rho^n_{el}}_{jn}\mathcal{L}^{(\rho^n_{el}-\rho_l)}_{jn}(1-\alpha_{jn})(\theta_{jn})C^{\rho_l-1}_{jn}$$
$$W^L_{jn} = \mathcal{A}_{jn}\mathcal{I}^{1-\rho^n_{el}}_{jn}\mathcal{L}^{(\rho^n_{el}-\rho_l)}_{jn}(1-\alpha_{jn})(1-\theta_{jn})L^{\rho_l-1}_{jn}$$

Model: Firms

Energy Demand

$$P_{jn}^{E} = \mathcal{A}_{jn}\mathcal{I}_{jn}^{1-\rho_{el}^{n}}\mathcal{E}_{jn}^{(\rho_{el}^{n}-\rho_{e}^{n})}\alpha_{jn}\zeta_{n}E_{jn}^{\rho_{e}^{n}-1}$$
$$P_{jn}^{G} = \mathcal{A}_{jn}\mathcal{I}_{jn}^{1-\rho_{el}^{n}}\mathcal{E}_{jn}^{(\rho_{el}^{n}-\rho_{e}^{n})}\alpha_{jn}(1-\zeta_{n})G_{jn}^{\rho_{e}^{n}-1}$$

Labor Demand

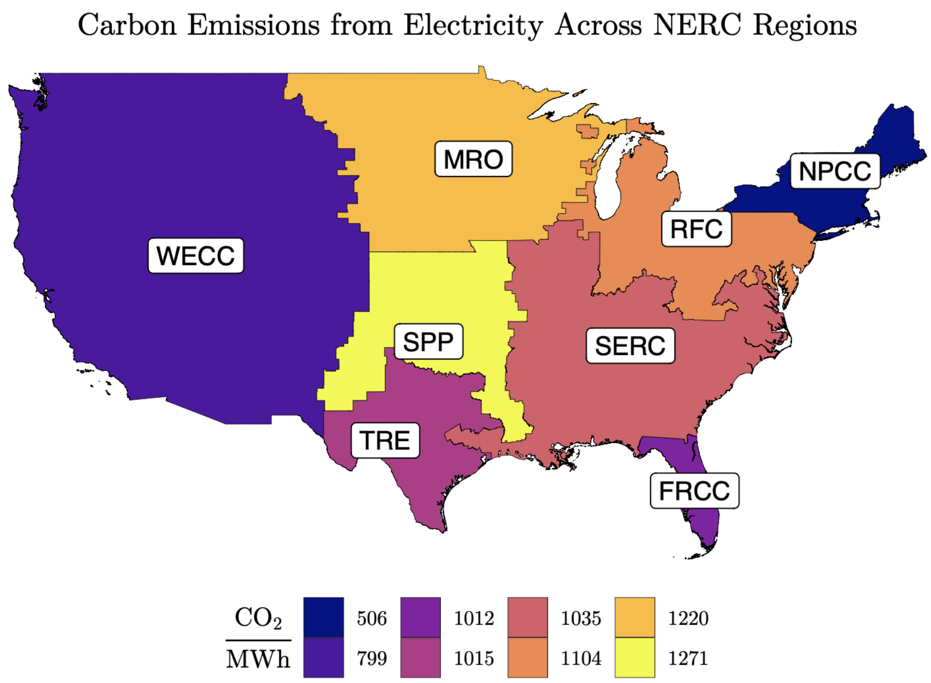
$$W_{jn}^{C} = \mathcal{A}_{jn}\mathcal{I}_{jn}^{1-\rho_{el}^{n}}\mathcal{L}_{jn}^{(\rho_{el}^{n}-\rho_{l})}(1-\alpha_{jn})(\theta_{jn})C_{jn}^{\rho_{l}-1}$$
$$W_{jn}^{L} = \mathcal{A}_{jn}\mathcal{I}_{jn}^{1-\rho_{el}^{n}}\mathcal{L}_{jn}^{(\rho_{el}^{n}-\rho_{l})}(1-\alpha_{jn})(1-\theta_{jn})L_{jn}^{\rho_{l}-1}$$

where

$$\mathcal{A}_{jn} = P_{n}A_{jn}\left(\frac{A_{jn}\eta}{\bar{r}}\right)^{\frac{\eta}{1-\eta}}(1-\eta).$$

[Return]

NERC Map



Return

Wage and Rent Series

Estimating equation for wages given by:

$$\log(W_{ejn}) = \nu_{ejn} + \beta_1^e \log(\text{white}_i) + \beta_2^e \log(\text{over35}_i) + \varepsilon_{ijn}$$

where ν_{ejn} is a fixed effect that estimates the city-sector-education group wage.

Estimating equation for rents:

$$\log(R_i) = \beta_{CBSA(i)} + \beta_1 \text{Units}_i + \beta_2 \text{Bedrooms}_i + \beta_3 \left(\frac{\text{members}_i}{\text{rooms}_i} \right) + \varepsilon_i$$

City-level rents are given estimated off of the cbsa fixed effect, holding the covariates constant across all cities at their median level

[Return]

Household Energy

Follow Glaeser & Kahn (2010) and estimate:

$$x_i^m = \gamma_{\mathrm{CBSA(i)}} + \beta_1 \log(\mathrm{Income}_i) + \beta_2 \mathrm{HHsize}_i + \beta_2 \mathrm{Agehead}_i + \varepsilon_i$$

where:

- x_i^m is household i's consumption of fuel type $m \in \{\mathrm{gas, elec, oil}\}$,
- $\gamma_{\mathrm{CBSA(i)}}$ is a fixed effect for the household's CBSA

Take estimates of HH energy and adjust by city composition of single unit/multi-unit and owned/rented homes.

Return

Production Parameters

Calibrate elasticities of substitution (multiple sources)

Factor intensities are solved for in two steps:

1) Recover labor and energy intensities using relative labor and energy demand curves:

$$\underbrace{\log\left(\frac{I^C_{jn}}{I^L_{jn}}\right)}_{\text{Estimated}} = \underbrace{-\frac{1}{\sigma_l}}_{\text{Calibrated}} \underbrace{\log\left(\frac{C_{jn}}{L_{jn}}\right)}_{\text{Data}} + \underbrace{\log\left(\frac{\theta_{jn}}{1-\theta_{jn}}\right)}_{\text{Unknown}}$$

$$\underbrace{\log\left(\frac{P^E_{jn}}{P^G_{jn}}\right)}_{\text{data}} = \underbrace{-\frac{1}{\sigma_e}}_{\text{Calibrated}} \underbrace{\log\left(\frac{E_{jn}}{G_{jn}}\right)}_{\text{Data}} + \underbrace{\log\left(\frac{\zeta_{jn}}{1-\zeta_{jn}}\right)}_{\text{Unknown}}$$

Production Parameters

2) Use ratio of energy prices to wages and estimates from step 1 to recover input intensities:

$$\underbrace{\log\left(\frac{P_{jn}^{E}}{W_{jn}^{C}}\right)}_{\text{data}} = \underbrace{\log\left(\frac{E_{jn}^{\rho_e^n-1}}{C_{jn}^{\rho_l-1}}\right)}_{\text{Data}} + \underbrace{\log\left(\frac{\mathcal{E}_{jn}^{\rho_e l^n-\rho_e^n}}{\mathcal{L}_{jn}^{\rho_{el}^n-\rho_l}}\right)}_{\text{data}} + \underbrace{\log\left(\frac{\zeta_{jn}}{\theta_{jn}}\right)}_{\text{Solved above}} + \underbrace{\log\left(\frac{\alpha_{jn}}{1-\alpha_{jn}}\right)}_{\text{Unknown}}$$

[Return]

Energy Parameters

First, I calibrate inverse supply elasticity, μ (Dahl & Duggan, 1996).

Residential Energy Supply Curve.

Cobb-Douglas demand function for energy:

$$x_{ejn}^{m\star} = \frac{\alpha_{ejn}^{m} w_{ejn}}{\boldsymbol{\alpha}_{ejn} P_j^m} \quad \forall m \in \{\text{elec}, \text{gas}, \text{oil}\}$$

Aggregating to the city-level and plugging into the supply curve yields:

$$\log(P_{kj}^{elec}) = \frac{\mu}{1+\mu} \log\left(\sum_e \sum_n N_{ejn} \frac{\left(\alpha_{ejn}^{\text{elec}} \times w_{ejn}\right)}{\boldsymbol{\alpha}_{ejn}} \right) + a_{kj}$$

[Return]

Energy Parameters

Industry Energy Supply Curve

In this case, I simply set

$$a_{kj} = \log(P_{kj}^{\text{elec}}) - \mu \times \log(E_j)$$

where $E_j = \sum_n E_{jn}$ is firm energy consumption in city j (aggregated over sectors).

Return

Rent Parameters

Calibrate inverse supply elasticities (Saiz (2010)). Cobb-Douglas demand for housing:

$$H^{\star}_{ejn} = \frac{\alpha^H_e w_{ejn}}{\boldsymbol{\alpha}_{ejn} R_j}$$

Aggregating to the city level and plugging this into the supply curve yields:

$$\log(R_j) = \frac{\beta_j}{1+\beta_j} \log\left(\sum_e \sum_n N_{ejn} \frac{(\alpha^H_e \times w_{ejn}))}{\boldsymbol{\alpha}_{ejn}} \right) + \eta_j$$

[Return]

Estimation: Step 1

With EV1 assumption on error term, choice probabilities are:

$$Pr_i(\mathbf{\Theta}^{\gamma_{et}}) = \frac{\exp\left(\delta_{ejnt} + \mathit{\Theta}_{et}^{div}\mathbb{I}\left(j \in \mathcal{B}_i^{div}\right) + \mathit{\Theta}_{et}^{\text{dist}}\phi\left(j, \mathcal{B}_i^{st}\right) + \mathit{\Theta}_{et}^{\text{dist2}}\phi^2\left(j, \mathcal{B}_i^{st}\right)\right)}{\sum\limits_{j' \in J}\sum\limits_{n' \in N}\exp\left(\delta_{ej'n't} + \mathit{\Theta}_{et}^{div}\mathbb{I}\left(j' \in \mathcal{B}_i^{div}\right) + \mathit{\Theta}_{et}^{\text{dist}}\phi\left(j', \mathcal{B}_i^{st}\right) + \mathit{\Theta}_{et}^{\text{dist2}}\phi^2\left(j', \mathcal{B}_i^{st}\right)\right)}$$

where

- $\delta_{ejnt} = \beta_e^w \log(W_{ejnt}) + \beta_e^r \log(R_{jt}) + \sum_m \beta_{ej}^m \log P_{jt}^m + \xi_{ejnt}$ is the mean utility

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Given this, the LL function is:

$$\mathbf{L}_{et}(\boldsymbol{\Theta}^{\gamma_{et}}) = \sum_{i=1}^{N^d}\sum_{n \in N}\sum_{j \in J}\mathbb{I}_i(j, n)\log(Pr_i(\boldsymbol{\Theta}^{\gamma_{et}}))$$

[Return]

Estimation: MLE

Outer loop:

- Guess parameter vector, $\vec{\theta}_e$

Inner Loop:

- Guess arbitrary vector of mean utilities $\vec{\delta}_0$
- Use Nevo (2000) contraction to recover "true" mean utilities given $\vec{\theta}_e$:

$$\exp(\vec{\delta}_1) = \exp(\vec{\delta}_0) \times \left(\frac{S_{\text{data}}}{S_0(\vec{\delta}_0, \vec{\theta}_e)} \right)$$

- Check the value of the likelihood function. If not maximized, go back to step one.
    - Estimates robust to different maximization algorithms

[Return]

Estimation: Step 2

With $\mathbf{\Theta}^{\gamma_{et}}$, can recover the “true” mean utilities. Estimating eqn is:

$$\Delta\delta_{ejn} = \beta_e^w \Delta \log(W_{ejn}^{EA}) + \beta_e^r \Delta \log(R_j) + \Delta\epsilon_{ejn}$$

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Need instruments:

- Consider a school built in j (unobservable amenity increase) $\implies \delta_{ejn} \uparrow \implies$ workers in, wages down and rents up (mechanically)
- **Wages:** Bartik-Style instrument: $\Delta Z_{ejnt} = \sum_{\iota\in n} \omega_{ej\iota}^{1990} \times \left(\Delta\text{Hours}_{e,-j,\iota}\right)$
    - $\omega_{ej\iota}^{1990}$: share of total hrs by and ι in city j by education group e in 1990 as a fraction of the total hours worked in city j by education group e in 1990
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  - $\Delta \text{Hours}_{e,-j,\iota}$ is the change in national hours worked in all cities except city j
- **Rents:** $\Delta Z_{ejnt} \times \kappa_j$ where κ_j is the housing supply elasticity of city j
  - Two cities with identical labor demand shocks but different supply elasticities $\implies$ different change in rental prices

[Return]

Energy Adjusted Income

Mean utility estimating equation:

Note that $\tilde{\alpha}^m_{ejnt} = \frac{\alpha^m_{ejnt}}{\boldsymbol{\alpha_{ejnt}}}$ implies that $\sum_{m'} \tilde{\alpha}^{m'}_{ejt} = \frac{\sum_{m'} \tilde{\alpha}^{m'}_{ejt}(1+\alpha^h_e)}{1-\sum_{m'} \tilde{\alpha}^{m'}_{ejt}}$ and thus $\boldsymbol{\alpha}^m_{ejt} = \frac{\tilde{\alpha}^m_{ejt}(1+\alpha^h_e)}{1-\sum_{m'} \tilde{\alpha_{ejt}}^{m'}}$. I can plug these into the mean utility equation to get:

$$\delta_{ejnt} = \left(\frac{1 + \alpha^h_e + \frac{\tilde{\alpha}^m_{ejt}(1+\alpha^h_e)}{1-\sum_{m'} \tilde{\alpha_{ejt}}^{m'}}}{\sigma_e} \right) \log(w_{ejnt}) - \frac{\alpha^h_e}{\sigma_e} \log(R_{jt}) - \frac{(1+\alpha^h_e)}{1 - 1 - \sum_{m'} \tilde{\alpha_{ejt}}^{m'}} \sum_m \frac{\tilde{\alpha}^m_{ej}}{\sigma_e} \log P^m_{jt} + \xi_{ejnt}.$$

Rearranging yields: $\delta_{ejnt} = \beta^w_e \log(W^{EA}_{ejnt}) + \beta^r_e \log(R_j) + \epsilon_{ejn}$.

where: $W^{EA}_{ejnt} = \dfrac{\log(W_{ejnt}) - \sum_m \left(\tilde{\alpha}^m_{ejnt} \log(P_{jt}) \right)}{1 - \sum_m \tilde{\alpha}^m_{ejnt}}$

- $\beta^w_e = \frac{1+\alpha^h_e}{\sigma_e}$
- $\beta^r_e = \frac{\alpha^h_e}{\sigma_e}$.

[Return]

Labor Supply

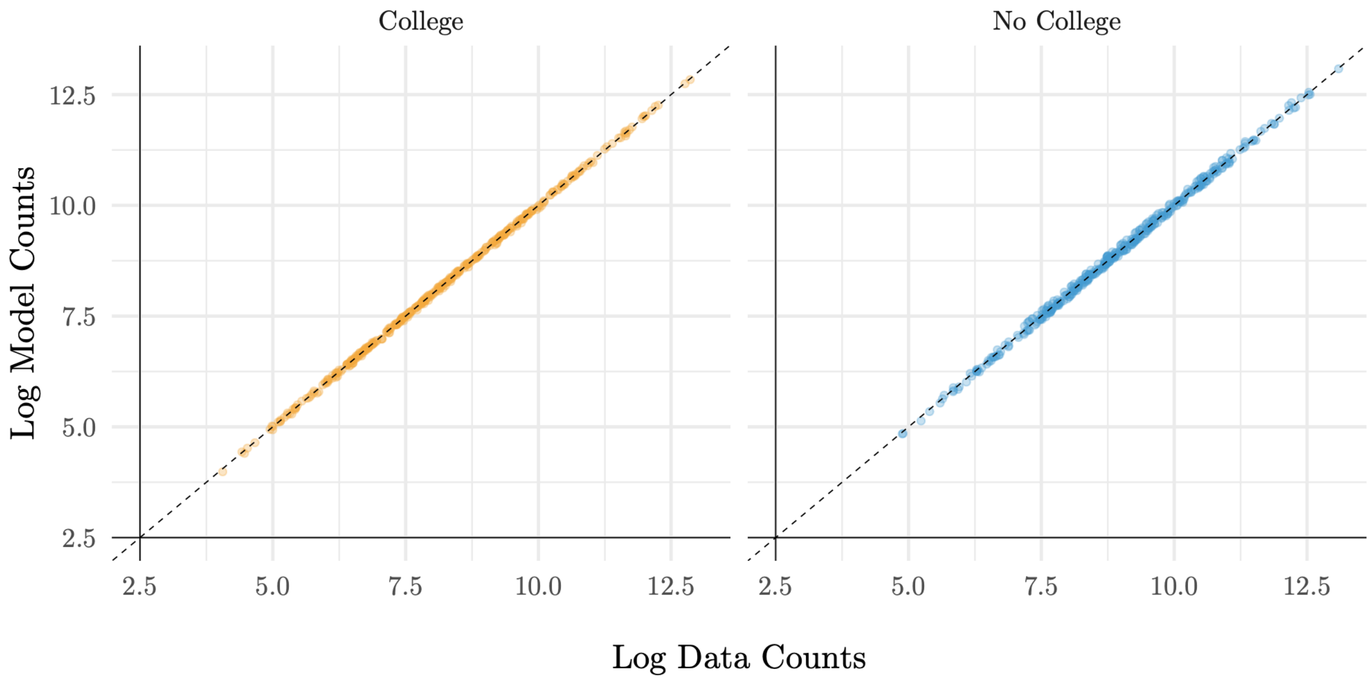
	No College			College		
	Θ_{ut}^{div}	Θ_{ut}^{dist}	Θ_{ut}^{dist2}	Θ_{st}^{div}	Θ_{st}^{dist}	Θ_{st}^{dist2}
2017	1.698	-3.218	0.696	1.489	-2.609	0.644
	(0.004)	(0.005)	(0.004)	(0.012)	(0.006)	(0.003)

Income and Rents	No College	College
Θ_e^w	3.558***	7.0362***
	(0.591)	(0.815)
Θ_e^r	-2.160***	-3.731***
	(0.372)	(0.348)
Cragg-Donald F-Stat: 14.63		

Table 2: Standard errors are in parentheses. Maximum likelihood standard errors are estimated numerically. Stars indicate statistical significance: *p<0.05; **p<0.01; ***p<0.001.

[Return]

Model Fit



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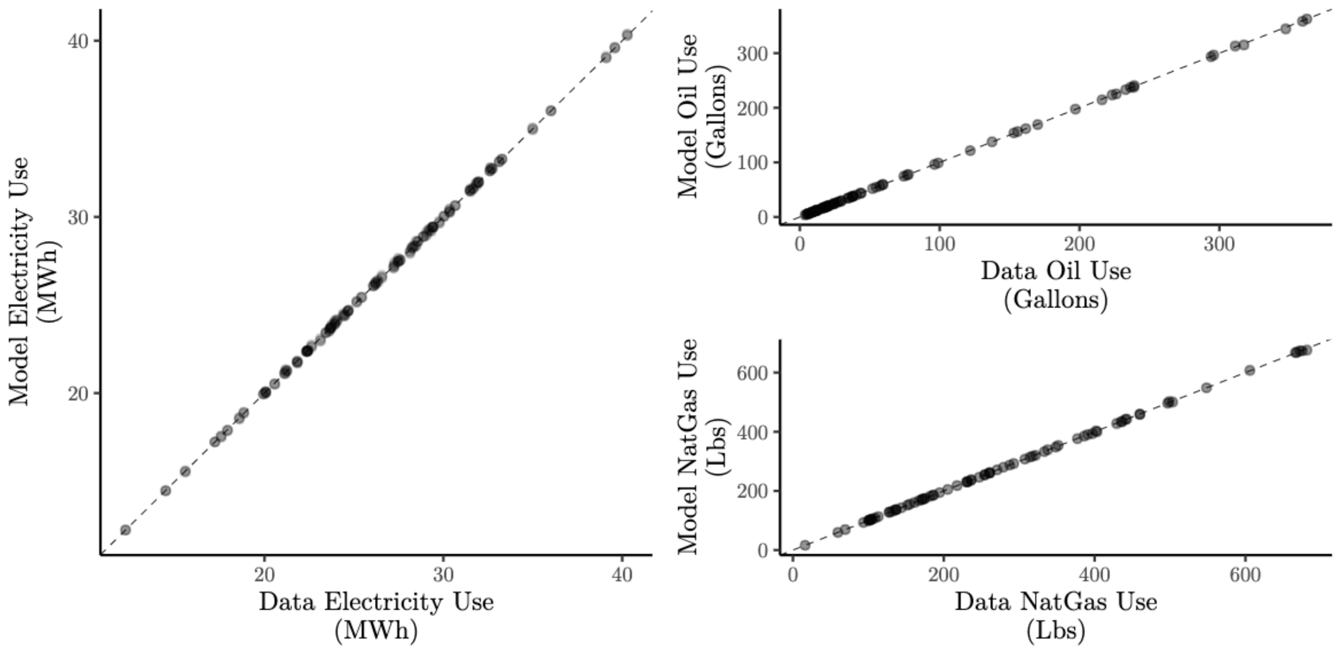
Model Fit



[Return]

Equilibrium Sketch

An equilibrium requires utility maximization, profit maximization, and all-markets need to clear.

Solving the equilibrium:

1) Guess a vector of choice-shares for each education group. Also guess vectors of firm energy demands

- Use guess to calculate implied population levels

2) Use the pop. levels from step 1 to calculate city level prices (wages, rents, energy)

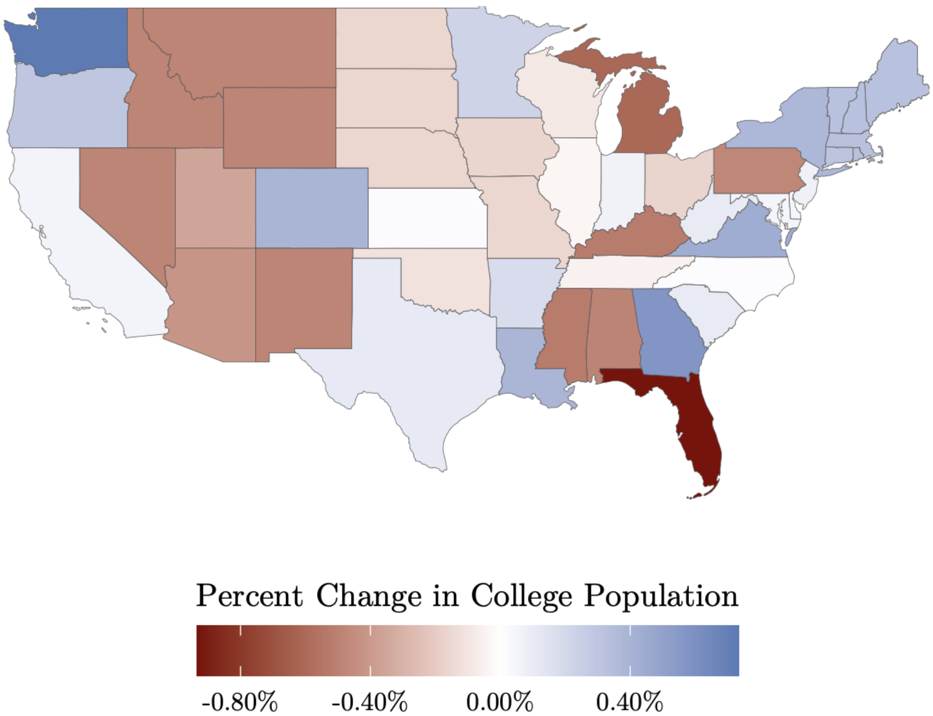
3) Calc utility-maximizing shares using the logit probabilities from the agents problem and the output from step 2

3) Check if firm's WTP for energy given guess in step 1 and energy demand curve consistent with supply

4) If no to either of step 3, update guess of shares/energy and return to step 1

[Return]

Migration Results



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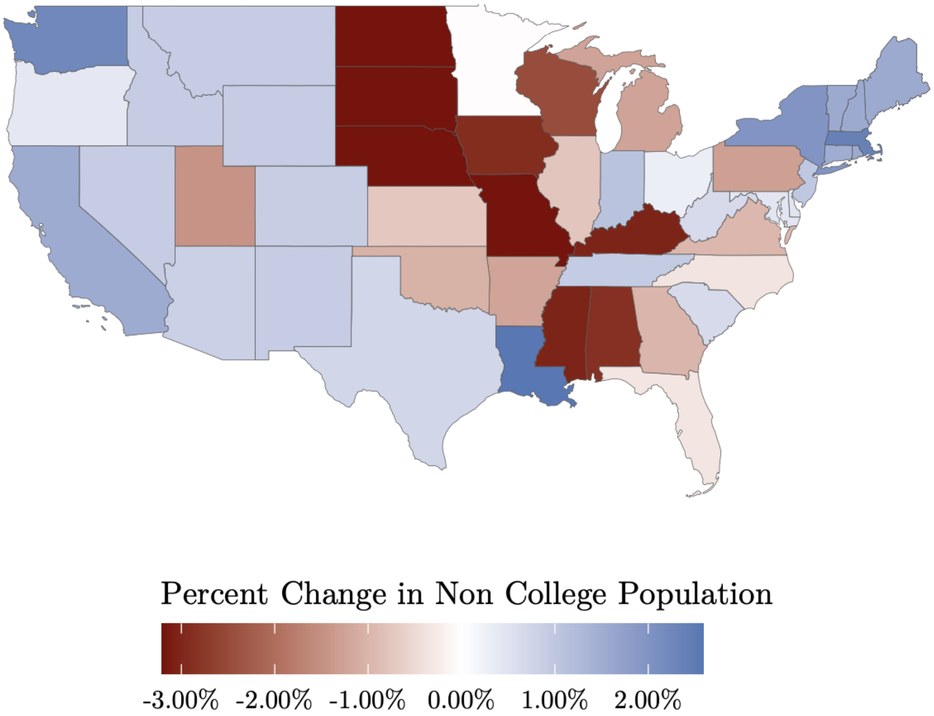

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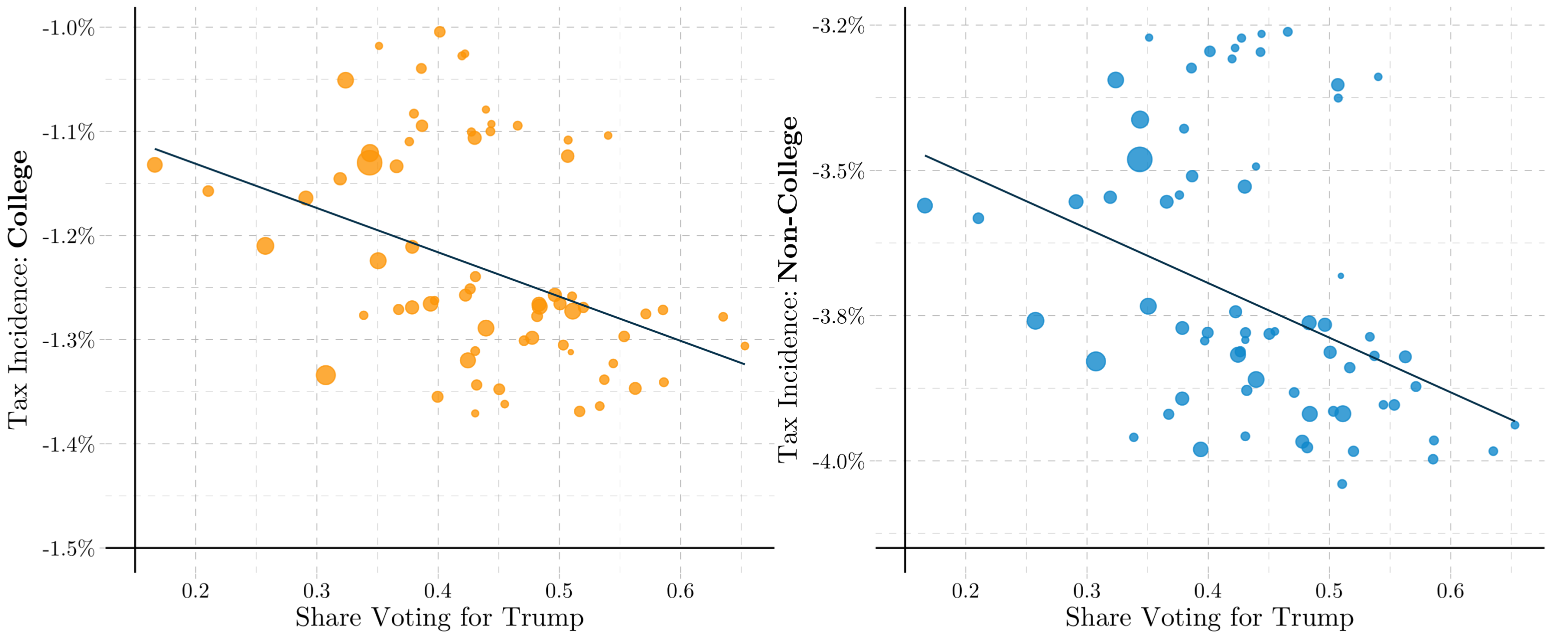
Voting Results



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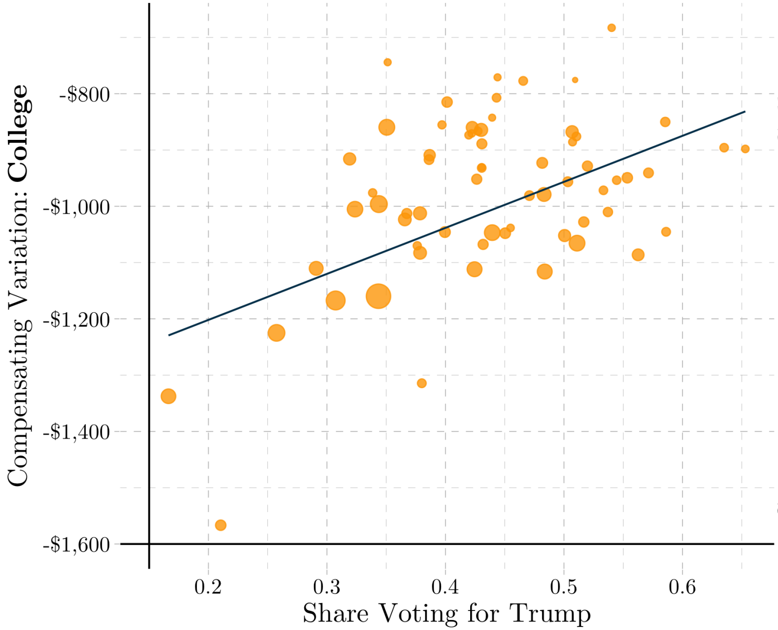

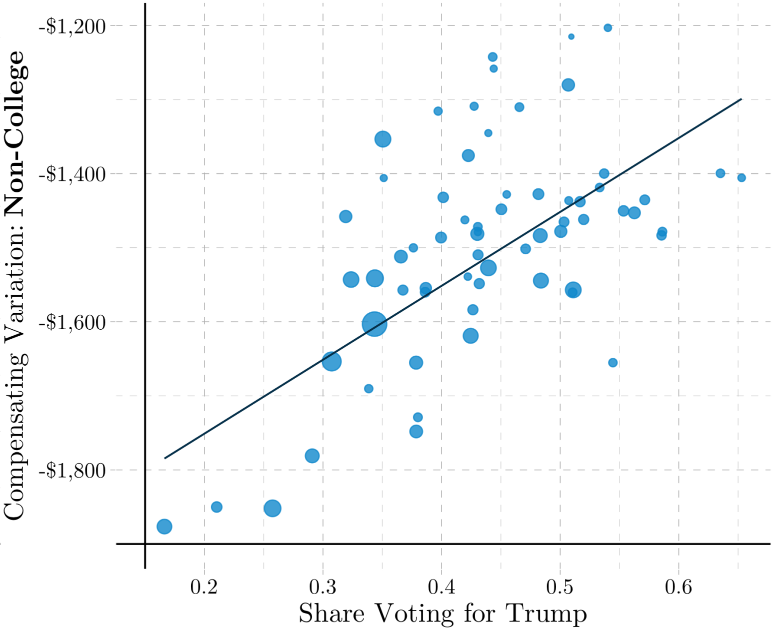

[Return]

Endogenous Transfers

The transfer function is: $\mathcal{T}(w) = \lambda w^{1-\gamma}$

- Paramter γ is exogenous. Parameter λ is determined by gov't budget clearing
- **Sum of revenue:** $\mathbb{T} = \tau \sum_n \sum_j \sum_m \delta_j^m \hat{f}_{jn}^m$
  - where $\hat{f}_{jn}$ is total energy use in jn of fuel type m
- **Sum of payments:** $\mathbb{G} = \sum_i \lambda^\star w_{ij}^{1-\gamma}$

Balanced budget implies:

$$\lambda^\star \sum_e \sum_j N_{ejn}^\star w_{ejn}^{1-\gamma} = \tau \sum_n \sum_j \sum_m \delta_j^m \hat{f}_{jn}^m$$

$$\lambda^\star = \frac{\tau \sum_n \sum_j \sum_m \delta_j^m \hat{f}_{jn}^m}{\sum_e \sum_j N_{ejn}^\star w_{ejn}^{1-\gamma}}$$

[Return]

Relationship between equity-of-transfers and aggregate emis depends on:

1) City-sector level relationship between wages and emissions

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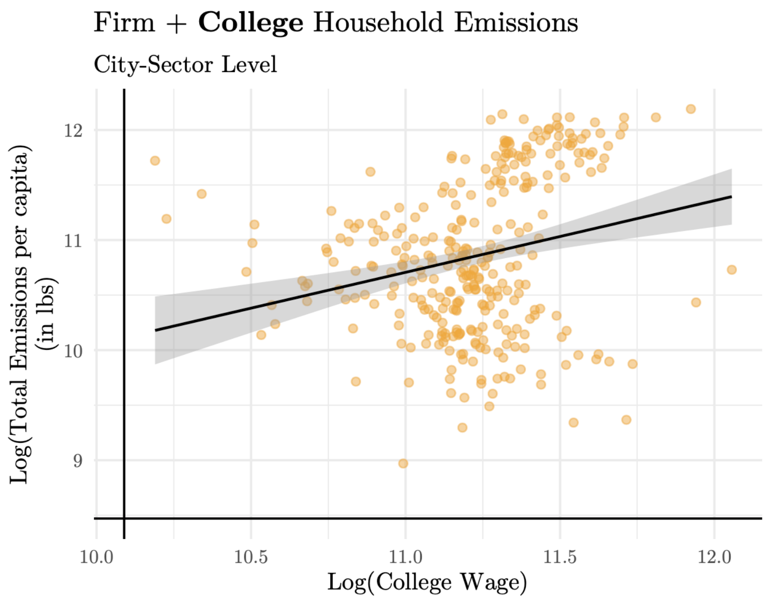
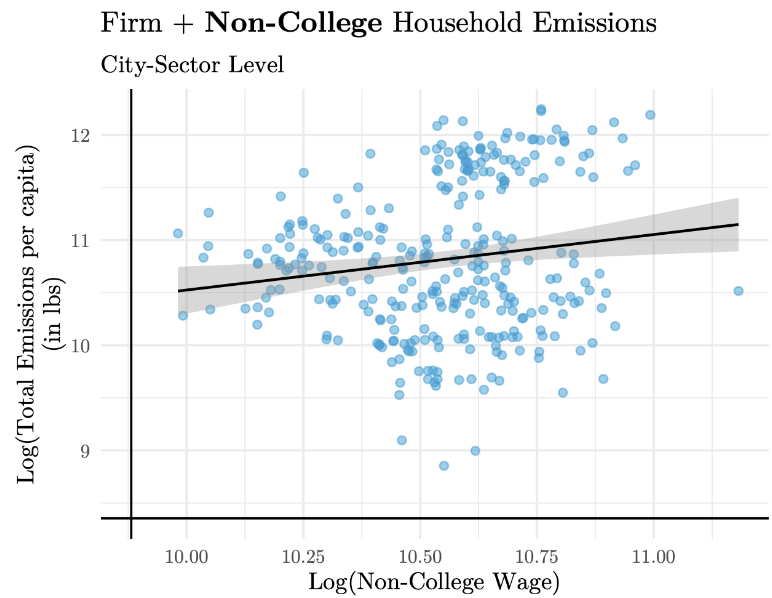
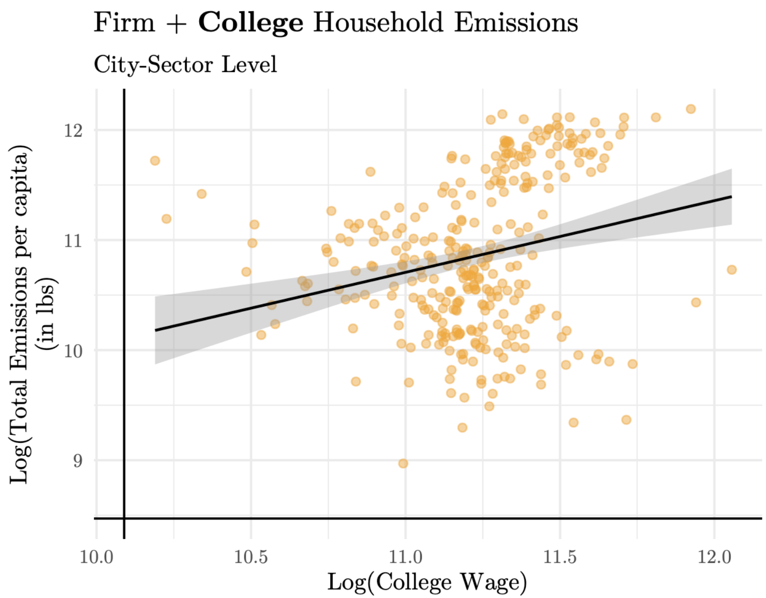


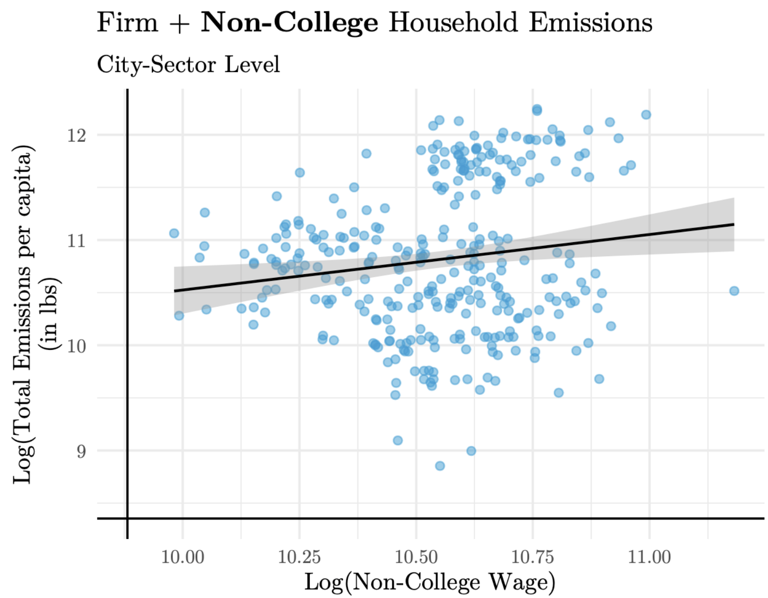


Relationship between equity-of-transfers and aggregate emis depends on:

1) City-sector level relationship between wages and emissions

2) Substitution patterns across lower wage (and thus higher transfer) cities





I use the model to simulate the general equilibrium elasticity of aggregate emissions with respect to the relative progressivity of transfers:

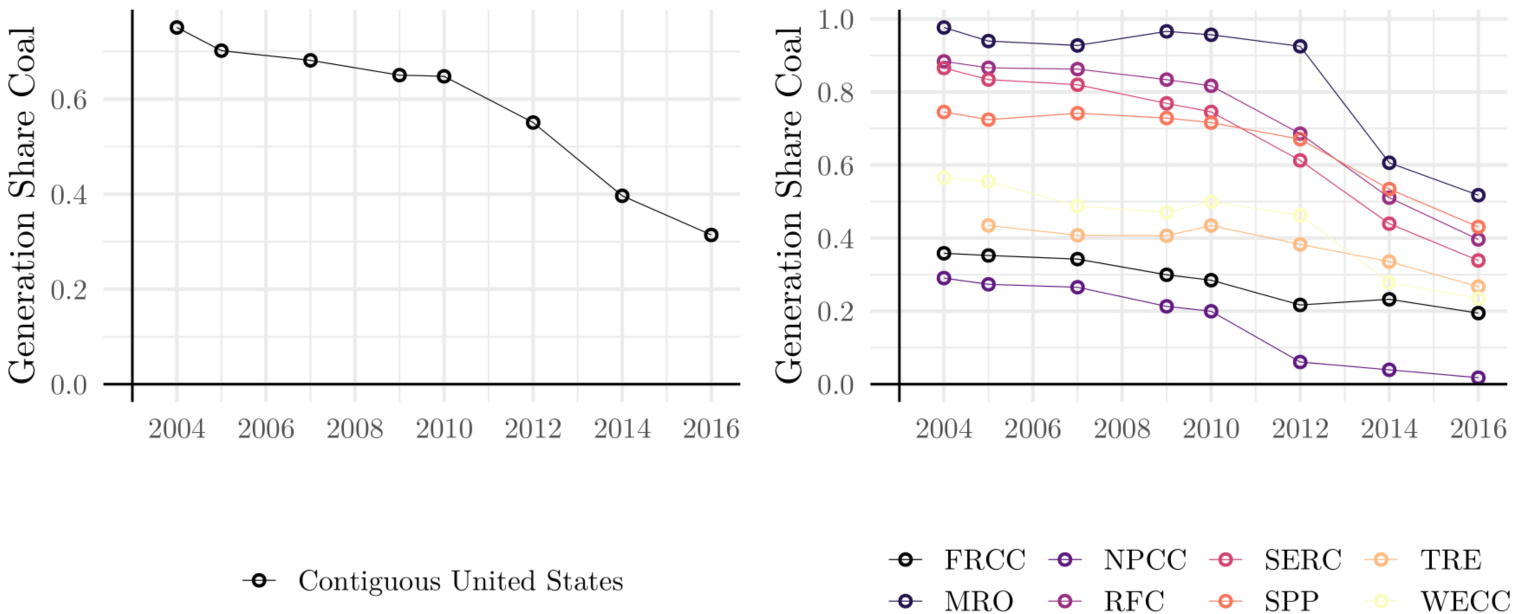
$$\epsilon_{\texttt{Emissions},\gamma} = \frac{\partial \texttt{Emissions}}{\partial \gamma} \frac{\gamma}{\texttt{Emissions}}.$$

[Return]

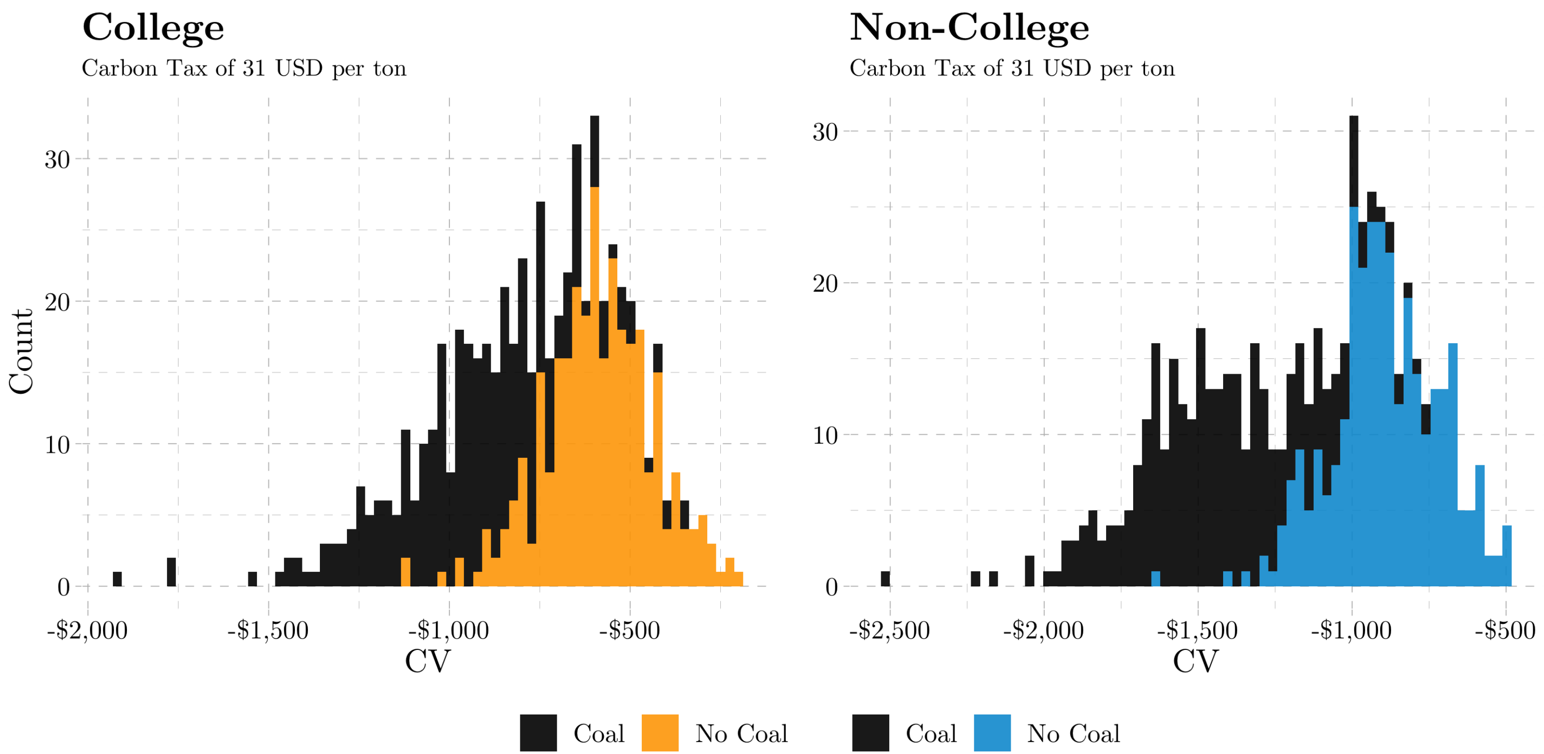
Coal

I use the model to simulate tax incidence without coal-fired electricity.

Motivation:



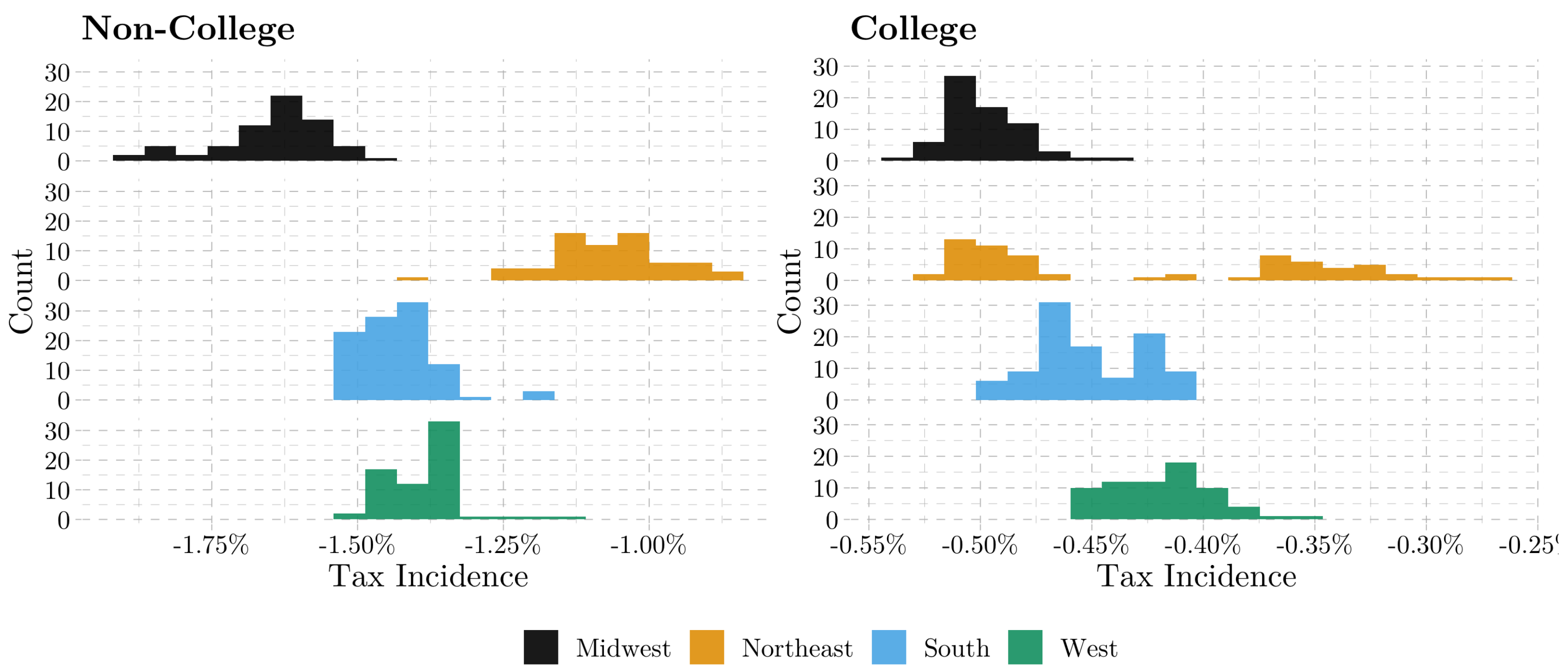
Results



College
Carbon Tax of 31 USD per ton
Non-College
Carbon Tax of 31 USD per ton
Count
30
20
10
0
-$2,000
-$1,500
-$1,000
-$500
CV
30
20
10
0
-$2,500
-$2,000
-$1,500
-$1,000
-$500
CV
Coal
No Coal
Coal
No Coal

Results

No-coal change in Tax Incidence across **Census Regions**



[Return]

Transfers: Sectoral Changes

$\gamma = \mathbf{1}$	$\%\Delta$ Man. Emp	$\%\Delta$ Ser. Emp	$\%\Delta$ Con. Emp	$\%\Delta$ Ag. Emp
Total	-11.8	2.42	1.57	-2.78
College	-13.7	1.99	0.07	-3.51
Non-College	-10.9	2.80	1.7	-2.62
$\gamma = \mathbf{1.2}$				
Total	-11.9	2.49	1.36	-1.86
College	-13.8	2.03	0.05	-2.78
Non-College	-11.1	2.91	1.5	-1.65

Return