Carbon Taxes in Spatial Equilibrium

🌉 SF Fed Brown Bag, August 2021 🌉

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Research Overview

Carbon emissions create well-recognized negative externalities

- Despite popular support, success of global policy efforts has been fairly limited
- Sallee (2019): designing pareto improving pigouvian taxes is hard!

Research Qs: How would a carbon tax impact US labor markets?

- How does incidence from carbon pricing vary by education level? City and Sector?
- Does the tax-regressivity vary across locations/sectors?
- How much of the tax incidence is driven by coal?
- How much of the tax burden comes from HH energy expenditures? Changes in wages?

Literature

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

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

Quantitative Spatial Equilibrium (QSE) Models:

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

Contributions

I make **three** main contributions

1) **Policy Relevant:** Recover HH distribution of CV across cities and sectors

- Use model to understand role that coal electricity has in incidence

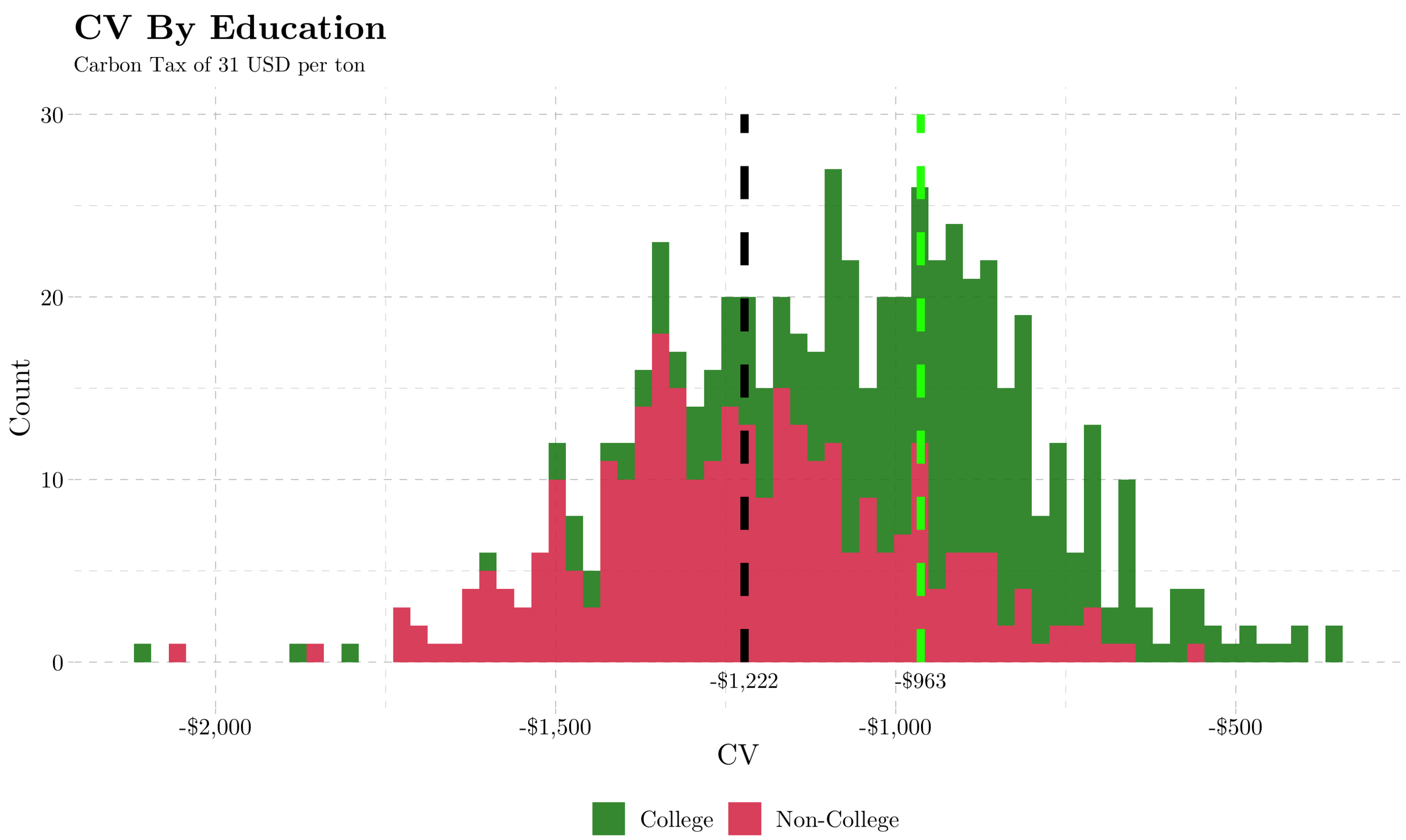
2) **Methodological:** Add and estimate new elements to QSE models

- Choice across cities *and* sectors
- Energy in production function

3) **Equity-Emissions tradeoff:** Lower-wage workers are in more emissions intensive sectors.

- This implies more equitable re-distribution schemes will lead to higher overall levels of emissions
- Still ongoing

Preview of Results



Road map

- Intro: ✅
- Model
- Data + Estimation
- Results (preliminary)

Model

Model: Households

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

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

where

- W_{ejn} is income, R_j is rents
- P_j^m is price of energy type $m \in \{\text{elec,gas,oil}\}$
- $f(\mathcal{D}(j, \mathcal{B}_i))$ moving cost as a function of euclidean distance $\mathcal{D}$ from j to i's birthstate
- $f(\cdot) = \mathit{\Theta}_e^{div} \mathbb{I}\left(\mathcal{B}_{ij}^{div}\right) + \mathit{\Theta}_e^{\text{dist}} \phi\left(j, \mathcal{B}_i^{st}\right) + \mathit{\Theta}_e^{\text{dist2}} \phi^2\left(j, \mathcal{B}_i^{st}\right)$
- $\hat{\lambda}_{ijn} = \xi_{ejn} + \sigma_e \epsilon_{ijn}$ amenities:
  - ξ_{ejn} unobserved (to me), shared by all agents in skill group/city/sector
  - ϵ_{ijn} iid pref shock with shape parameter σ_e

Model: Firms

Firms in perfectly competitive markets produce the output good with tech:

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

where

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

$$\mathcal{E}_{jn} = \left(\zeta_{jn} E_{jn}^{\rho_{e}^{n}} + (1-\zeta_{jn}) G_{jn}^{\rho_{e}^{n}} \right)^{\frac{1}{\rho_{e}^{n}}}$$

E and G: Energy and Gas consumed

ζ : city-sector electricity intensity

$\rho_e^n = \frac{\sigma_e^n - 1}{\sigma_e^n}$: sector elasticity of sub. for energy

$$\mathcal{L}_{jn} = \left(\theta_{jn} S_{jn}^{\rho_{l}^{n}} + (1-\theta_{jn}) U_{jn}^{\rho_{l}^{n}} \right)^{\frac{1}{\rho_{e}^{n}}}$$

S and U skilled and unskilled labor quantities

θ : city-sector educated labor intensity

$\rho_l = \frac{\sigma_l - 1}{\sigma_l}$: sector elasticity of sub. for energy

Electricity and Emissions

Electricity is supplied in one of 9 distinct NERC regions. LR supply curve is given by:

$$\log(P_{mj}^{\text{elec}}) = a_{mj} + \kappa \log(Q_{\mathcal{R}}(j))$$

where

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

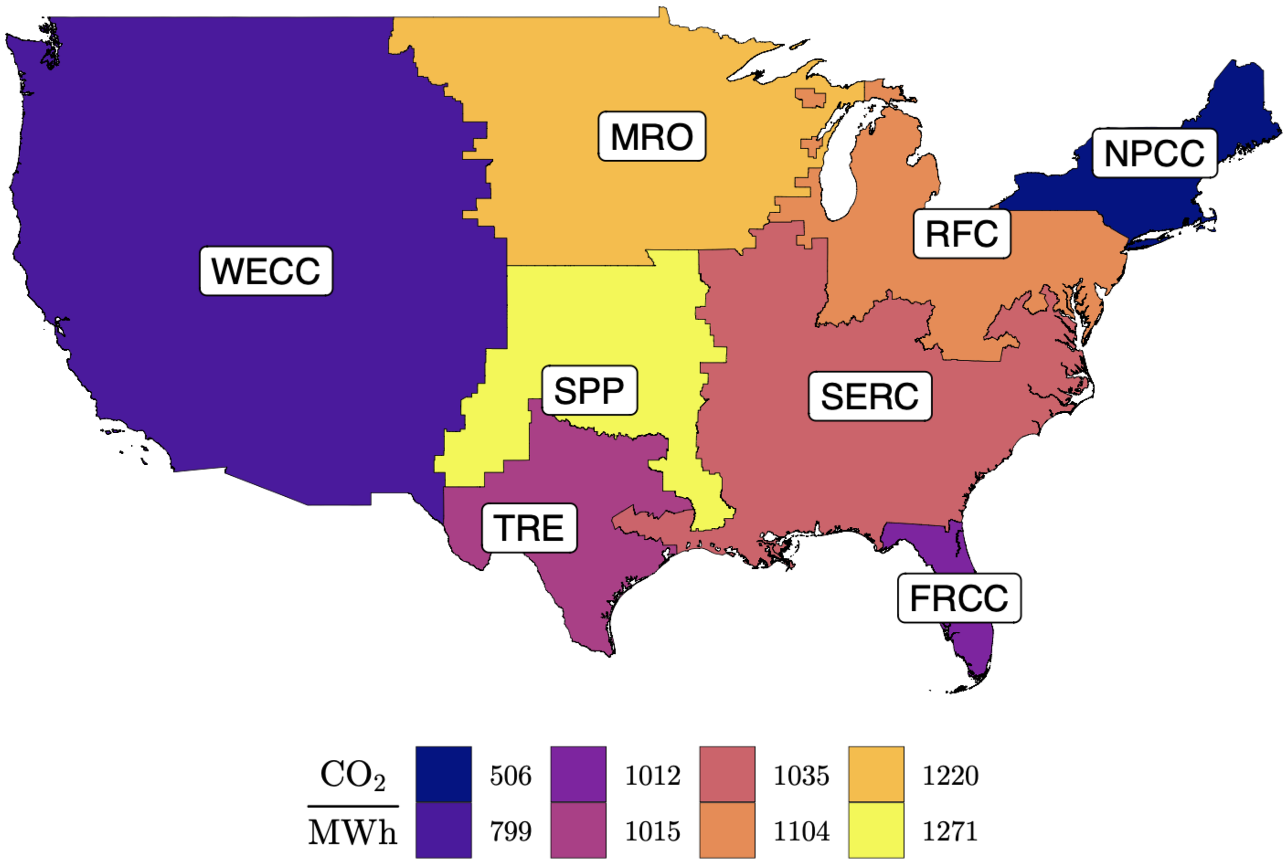
Emissions

- Emissions for natural gas and oil are fixed across space
- Regional emission factor for elec is the weighted avg. carbon intensity of all plants in the region:

$$\delta_{\mathcal{R}}^{elec} = \sum_{g \in \mathcal{R}} \frac{\text{elec}_g}{\text{elec}_{\mathcal{R}}} \times \frac{\text{CO}_{2,g}}{\text{elec}_g}$$

NERC Map

Carbon Emissions from Electricity Across NERC Regions



Rents

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

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

Differences in:

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

Model Summary

Households

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

Locations

- Wages, rents, and energy prices (endogenous)
- Carbon efficiency of power plants
- Amenities (location-specific consumption)

Firms

- Use energy, labor; produce numeraire
- Vary across sector by: Input use intensities & elasticities of sub

Mechanism:

- Carbon price $\implies$ higher energy prices
  - Price Δ depends on carbon efficiency of regional power plants
  - Energy prices enter utility for home consumption and production function
- Change in energy prices $\implies$ change in wages
  - 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

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Data

Data comes from multiple sources:

1) Census and ACS: HH level data with location,birth-location, education, rent, wages, and energy expenditure

- Use HH data to:
  - Estimate choice model. **Unit of choice:** Core-Based Statistical Area-Sector
  - Wages, energy cons, rent indices via OLS (fairly standard, robust to selection correction)

2) EIA: Energy prices

- Uses prices + expenditures to back out HH energy consumption

3) EPA: Emissions data + Aggregated Energy Consumption

Estimation + Calibration

The model has a *ton* oparameters. Some details:

Parameter Name	Notation	Source
Labor Supply		
Moving Costs	$\Theta_e^{div}, \Theta_e^{dist}, \Theta_e^{dist2}$	MLE
Marginal Utility of Income/Rents	Θ_e^w, Θ_e^r	IV
Variance of pref. shock	σ_e	Algebra
Housing Parameter	α_e^H	Algebra
Energy Share of Budget	α_{ej}^m	Algebra
Wage Index	W_{ejn}	Mincered (OLS)
Firm Parameters		
Energy-Lab, Gas- Elec EoS	$\sigma_{el}^n, \sigma_e^n$	Koesler & Shymura (2012)
College-No College EoS	σ_l	Card (2009)
Factor Intensities	$\alpha_{jn}, \theta_{jn}, \zeta_{jn}$	Algebra
TFP	A_{jn}	Algebra
Energy and Rent Parameters		
Intercepts	β_j, a_{mj}	Algebra
Energy Supply Elasticity	κ	Dahl & Duggan (1996)
Rent Supply Elasticity	γ_j	Saiz (2010)
Carbon Emissions Factor	δ^m	Data
Rent Index	R_j	Hedonic Reg

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Let's zoom in on labor supply. Ready for some math? 🤓

Estimation

I'll focus briefly on labor supply. I use a **two-step** estimation procedure

1) Treat locations-sectors as "products" with characteristics by skill group

- Recover moving cost parameters using "**micro-BLP**" (Berry, 1995)
- Use repeated cross-sections of census. Estimate parameters and corresponding mean utilities for 4 sample years

2) Estimate β_e^w and β_e^r in **first-differences with IV**

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

Estimation: Step 1

With EV1 assumption on error term, choice probabilities are:

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

where

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

Given this, the LL function is:

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

Estimation: Step 2

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

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

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: $\Delta Z_{ejnt} = \sum_{\iota \in n} \omega_{ej\iota}^{1990} \times \left(\Delta \mathbf{Hours}_{e,-j,\iota}\right)$
  - $\omega_{ej\iota}^{1990}$: initial shares in *industry* ι
  - $\Delta\mathbf{Hours}_{e,-j,\iota}$ is the change in national hours worked in all cities except city j
- **Rents:** $\Delta Z_{ejnt} \times \gamma_j$ where γ_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

Estimates: Labor Supply

Indirect utility: (HH i, education e, city j, sector n)

- $V_{ijn} = \delta_{ejn} + f(\mathcal{D}(j, \mathcal{B}_i)) + \epsilon_{ijn}$
- $\delta_{ejn} = \beta_w \log(w) + \beta_r \log(R) + \xi_{ejn}$
- $$f(\cdot) = \Theta_e^{div} \mathbb{I}\left(\mathcal{B}_{ij}^{div}\right) + \Theta_e^{\text{dist}} \phi\left(j, \mathcal{B}_i^{st}\right) + \Theta_e^{\text{dist2}} \phi^2\left(j, \mathcal{B}_i^{st}\right)$$

Estimation procedure:

1) "Micro BLP": **estimate moving cost parameters**

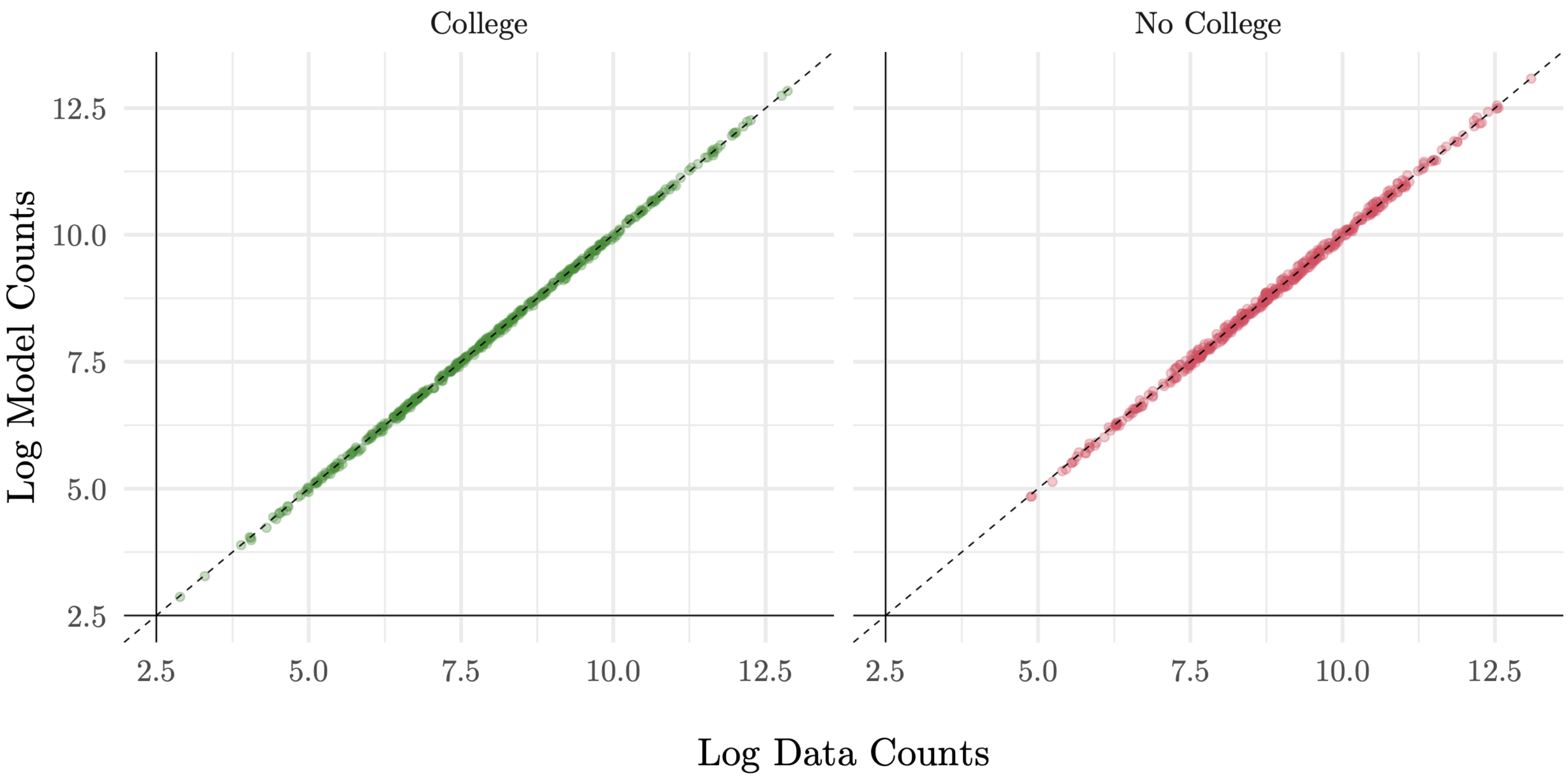
2) Bartik Instruments: **marginal utilities of income and rents parameters**

	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

IV-Estimated Parameters	No College	College
β_e^w	3.558***	7.0362***
	(0.59124)	(0.815)
β_e^r	-2.160***	-3.731***
	(0.37206)	(0.348)

Adjusted-R^2: 0.2183 **F-Statistic**: 83.72

Model Fit


College
No College
Log Model Counts
12.5
10.0
7.5
5.0
2.5
2.5
5.0
7.5
10.0
12.5
Log Data Counts

Road map

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Counterfactuals

I use the estimated model to solve for counterfactual **equilibrium** under two scenarios🦆

1: Baseline carbon tax, $31 per ton (SCC à la Nordhaus (2017))

- Look at incidence by region and sector

2: Carbon tax under a "no-coal" scenario

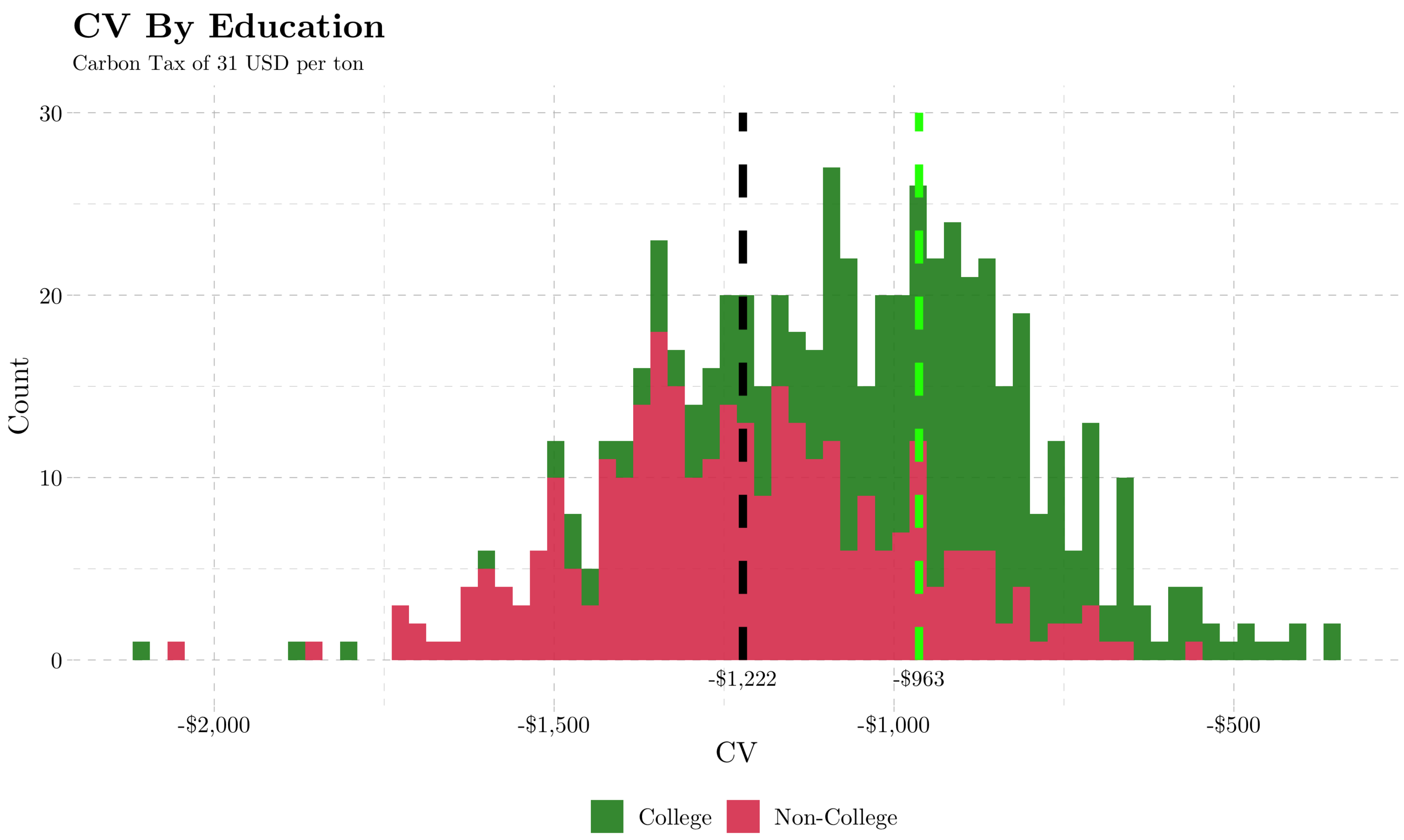
- I re-calculate electricity emissions by region *without coal* and implement a $31 tax in the model

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

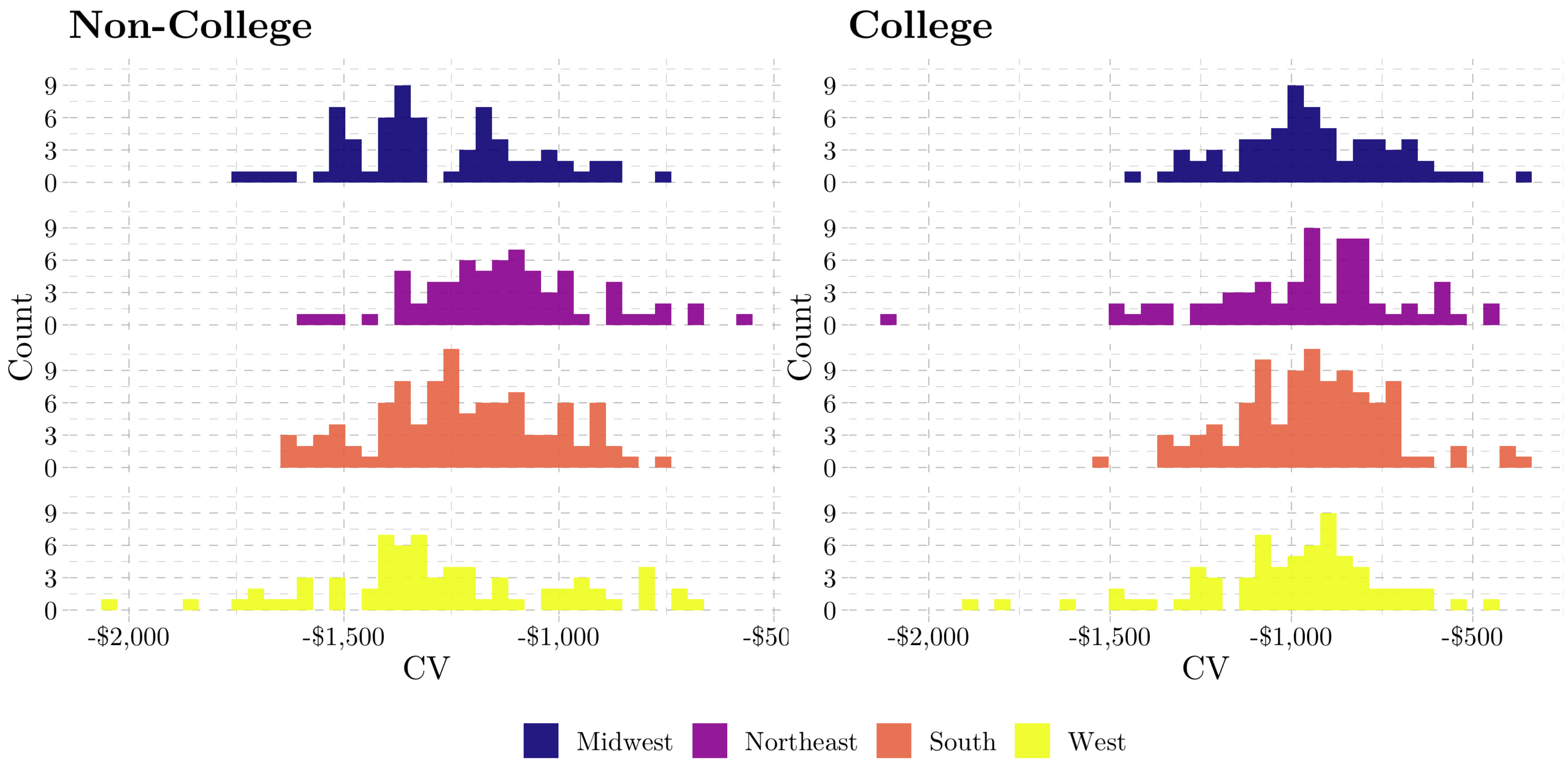
$$CV_i = \underbrace{(\mathbb{E}[V(\tau > 0)] - \mathbb{E}[V(\tau = 0)])}_{\%\Delta\text{Expected Utility}} \times \underbrace{\frac{w_i}{\beta^w}}_{\text{Wage conversion}}$$

🦆 An **equilibrium** in this model is characterized by price vectors (wages, rents, and electricity prices) that satisfy: i) utility and profit maximization and ii) relevant markets clear

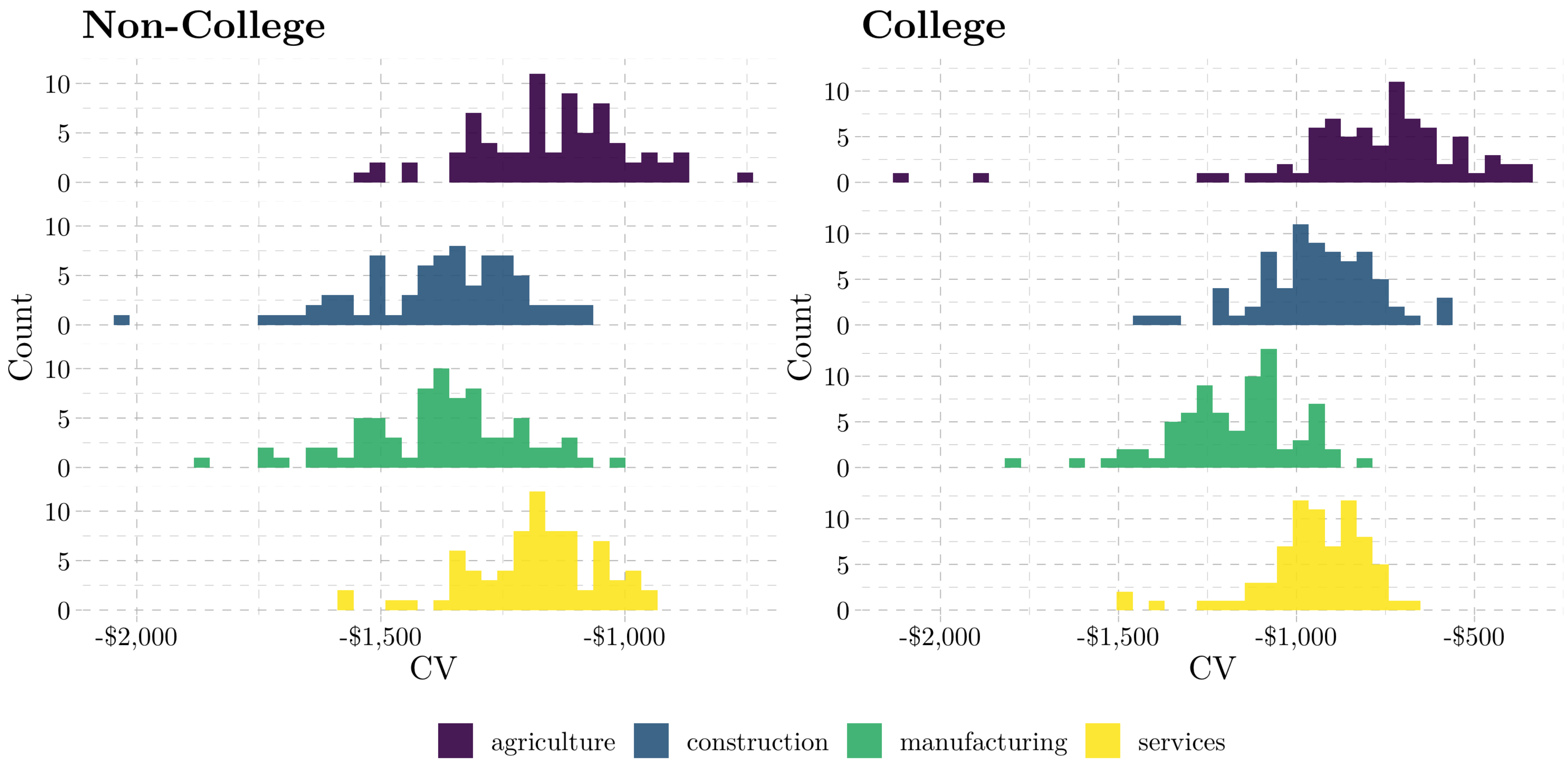
Main Results



Results: Geography

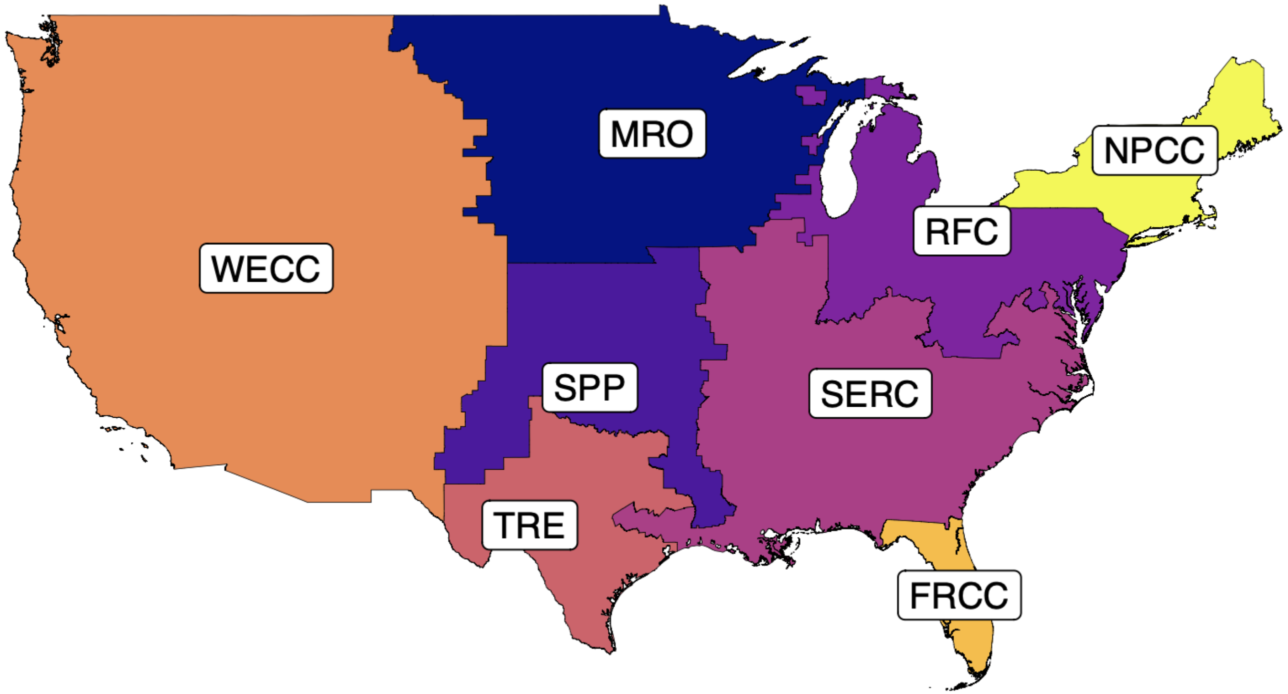


Results: Industry



No Coal

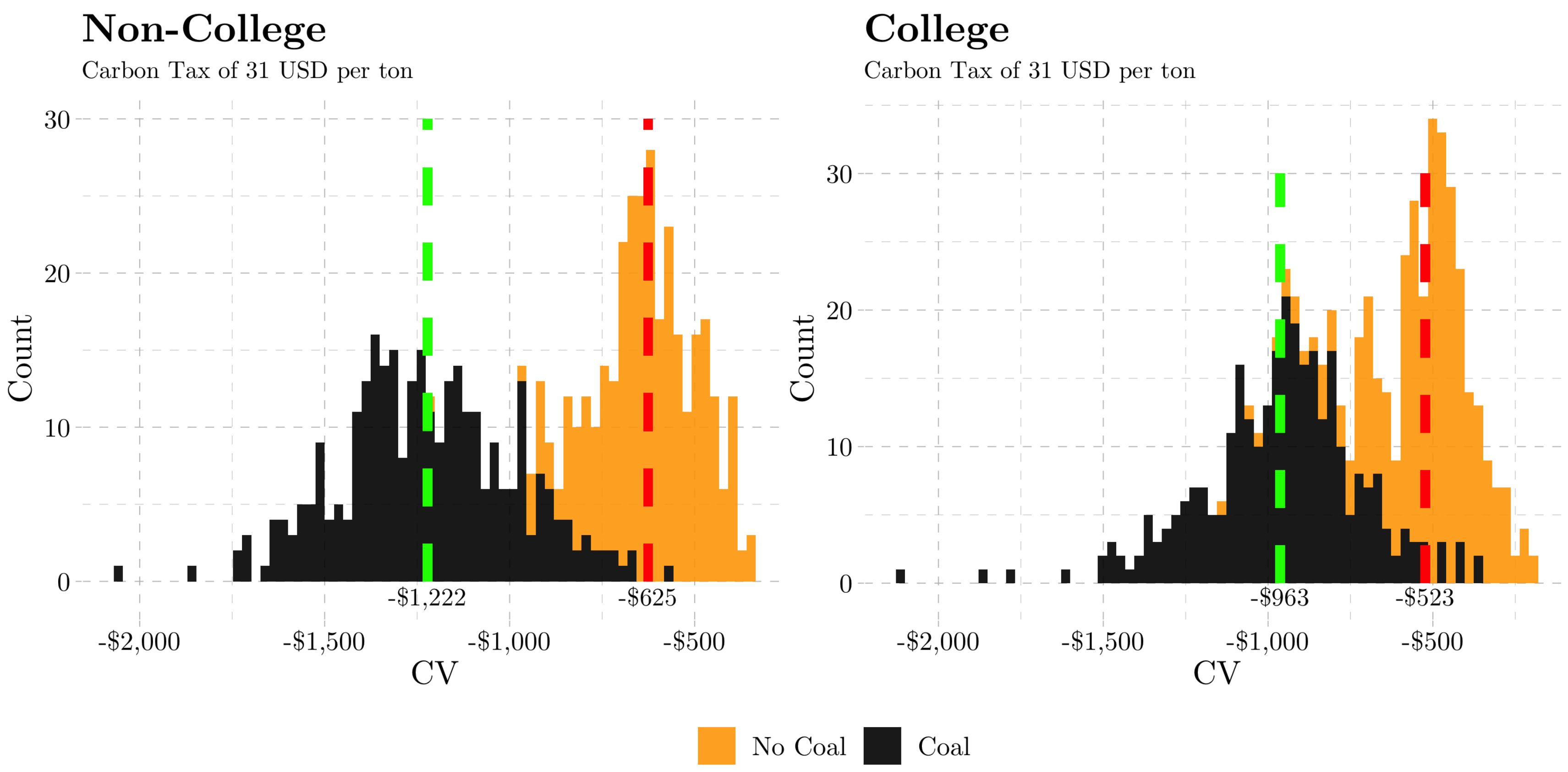
Carbon Emissions from Electricity Across NERC Regions



$\Delta \frac{CO_2}{MWh}$

-1045	-717	-468	-262
-742	-573	-443	-29

Results



Non-College
Carbon Tax of 31 USD per ton
College
Carbon Tax of 31 USD per ton
Count
CV
-$1,222
-$625
-$963
-$523
-$2,000
-$1,500
-$1,000
-$500
0
10
20
30
No Coal
Coal

Conclusions

Main Takeaways:

- Recovered HH distribution of CV from a national carbon tax across cities and sectors
- *Significant* heterogeneity across cities and sectors in tax incidence
    - Carbon taxes are regressive in all areas and regions.
    - Incidence is largest in energy intensive sectors and regions (manufacturing and midwest)
    - Estimate that coal powered electricity drives roughly 50% of incidence
- Wage changes are small and thus general equilibrium effects are small
- **Preliminary:** General equilibrium effects much more important with distortionary transfers

Thank You!!

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