The Carbon Tax and Allocative Efficiency

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Conventional wisdom

- Carbon taxes are subject to a free rider problem
- Global benefits, but private (national) costs
- May reduce country output and consumption
- So unwise to impose unilaterally

Our motivation

- The negative effects of carbon taxes rely on second-best logic
- May not generalize to an nth-best world
- See Restuccia and Rogerson (2017) for a survey on misallocation
- Carbon taxes may mitigate or amplify existing domestic distortions
- What does evidence on firms say?

What we do

- Data on all Chilean firms with at least 10 workers
- Document lower revenue productivity at fossil-fuel intensive firms
- Use a standard model to calculate allocative efficiency
- Estimate that a carbon tax would *increase* allocative efficiency
- Upshot: A unilateral carbon tax may raise Chilean welfare

Some related oiterature

- Seho Kim (2023)
  - Same general idea and qualitative findings
  - Financial frictions and adjustment costs
  - U.S. Compustat data
- Conte, Desmet, and Rossi-Hansberg (2023)
  - Find a unilateral EU carbon tax can be welfare-enhancing for the EU
  - Agglomerates more people and activity in high productivity areas
- Aghion, Boppart, Peters, Schwartzman, Zilibotti (2024)
  - Shift to services from agriculture and manufacturing reduces fossil-fuel intensity
  - As manufactured products improve in quality, they do not use more fossil fuels

Outline

1. Model
2. Dataset
3. Counterfactuals

Endowments and resource constraints

- Fixed endowment of labor: L
- Fixed endowment of capital: K
- Endogenous non-energy intermediate inputs: M
- Gross output: $Q = Y + M$
- Value added: $Y = Q - M$

Households

- Representative dynasty
- $U_t = \sum_{t=0}^{\infty} \beta^t \, L \, u(c_t)$
- $c_t \equiv C_t / L$
- $u(c_t) = \ln(c_t)$
- $A_{t+1} = w_t \cdot L + (R_t - \delta) \cdot A_t - C_t + T_t$
- $R_t \equiv r_t + \delta$
- Euler equation: $c_{t+1}/c_t = \beta(1 + r_t)$

Production technology

Aggregate output:

$$Q = \prod_{s=1}^{S} Q_s^{\theta_s}$$

Sector s output:

$$Q_s = \left(\sum_{i}^{N_s} Q_{si}^{1-\frac{1}{\sigma}} \right)^{\frac{1}{1-\frac{1}{\sigma}}}$$

Firm i output:

$$Q_{si} = A_{si} (K_{si}^{\alpha_{si}} L_{si}^{1-\alpha_{si}})^{\gamma_{si}} M_{si}^{\eta_{si}} E_{si}^{1-\gamma_{si}-\eta_{si}}$$

Trade

- Energy imports are E
- The exogenous price of imported energy is P^E
- Exports of the final good
- Balanced Trade: $P^E E = P \cdot (Y - C)$
- P is the price of the final good

Taxes and transfers

- τ_C is the carbon tax, which we treat as *ad valorem*
- τ_{si} is a revenue tax specific to firm i in sector s
- Revenue taxes are a stand-in for:
  - Actually taxes and subsidies
  - Price-cost markups
  - Size-dependent regulations
- Tax revenue is rebated lump sum as $T_t = \left(\tau_C P_E E + \sum_s \sum_i \tau_{si} P_{si} Q_{si}\right) / P$

Market structure

Perfect competition in the final goods sector.

Monopolistic competition in the intermediate goods sector:

$$\Pi_{si} = (1-\tau_{si})P_{si}Q_{si} - wL_{si} - RK_{si} - P^M M_{si} - (1+\tau^C)P^E E_{si}$$

$$P_{si} = \frac{\sigma}{\sigma-1}\frac{(1+\tau^C)^{1-\gamma_{si}-\eta_{si}}}{(1-\tau_{si})}\frac{1}{A_{si}}\widetilde{P}_{si}$$

where $\widetilde{P}_{si}$ is firm-specific input cost index:

$$\widetilde{P}_{si} = \left[\left(\frac{w}{1-\alpha_{si}}\right)^{1-\alpha_{si}}\left(\frac{R}{\alpha_{si}}\right)^{\alpha_{si}}\frac{1}{\gamma_{si}}\right]^{\gamma_{si}}\left[\frac{P^M}{\eta_{si}}\right]^{\eta_{si}}\left[\frac{P^E}{1-\gamma_{si}-\eta_{si}}\right]^{1-\gamma_{si}-\eta_{si}}$$

Equilibrium

Set of prices $w, r, \{P_{si}\}$ such that:

- Households maximize discounted utility
- Firms maximize current profits
- Output and input markets clear:
  - $\sum_s \sum_i L_{si} = L$
  - $\sum_s \sum_i K_{si} = K$
  - $\sum_s \sum_i M_{si} = M$
  - $Q = Y + M$
- Trade is balanced: $P(Y - C) = \sum_s \sum_i P_{si}^E E_{si}$

Allocative efficiency

Impact of τ^C on productivity depends on reallocation of market shares:

$$\frac{P_{si}Q_{si}}{P_s Q_s} \propto \left(\frac{(1-\tau_{si})}{(1+\tau^C)^{(1-\gamma_{si}-\eta_{si})}} \cdot \frac{A_{si}}{\widetilde{P}_{si}} \right)^{\sigma-1}$$

- τ^C has a direct impact on sales shares
- indirect impact by changing w and R (in $\widetilde{P}_{si}$)

Crucial question is whether $1-\gamma_{si}-\eta_{si}$ is correlated with τ_{si}

- A positive correlation between the firm's fossil fuel intensity and its revenue distortion means a carbon tax would lower allocative efficiency
- A negative correlation means a carbon tax may increase allocative efficiency

Variance of firm market shares within sectors

Assume $\frac{A_{si}}{\widetilde{P}_{si}}$ is uncorrelated with τ_{si} and $1-\gamma_{si}-\eta_{si}$. Then:

$$\frac{1}{(\sigma-1)^2}\,\text{Var}\ \ln\left(\frac{P_{si}Q_{si}}{P_sQ_s}\right) = \text{Var}\ \ln\left(\frac{A_{si}}{\widetilde{P}_{si}}\right)\ +$$

$$[\ln(1+\tau^C)]^2\,\text{Var}(1-\gamma_{si}-\eta_{si})\ +$$

$$\text{Var}\ \ln(1-\tau_{si})\ +$$

$$2\ln(1+\tau^C)\text{Cov}[\ln(1-\tau_{si}),(1-\gamma_{si}-\eta_{si})]$$

Dataset

- Merged confidential administrative data from Chile
- Sample goes from 2015 to 2019 (to avoid COVID).
- Firm-to-firm transactions (prices and quantities) registered in VAT invoices
- Firm employment, capital, sales, intermediates, fossil fuel use
- About 25,000 firms per year in 84 2-digit sectors.
- Keep firms with > 10 employees, value added > 0, fixed assets $>$ 10k CLP (about 15 USD). Exclude public admin and 2-digit sectors with < 5 firms.

Variable definitions

$$TC_{si} = wL_{si} + RK_{si} + P^M M_{si} + (1+\tau^C)P^E E_{si}$$

$$\alpha_{si} = \frac{RK_{si}}{RK_{si} + wL_{si}}$$

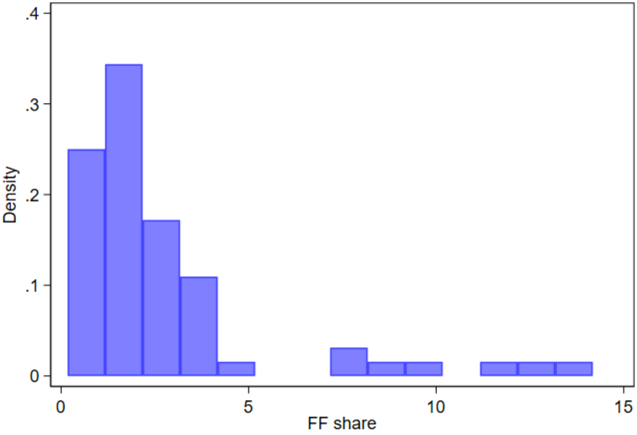
$$\gamma_{si} = \frac{RK_{si} + wL_{si}}{TC_{si}}$$

Fossil fuel intensity $\eta_{si} = \dfrac{P^M M_{si}}{TC_{si}}$

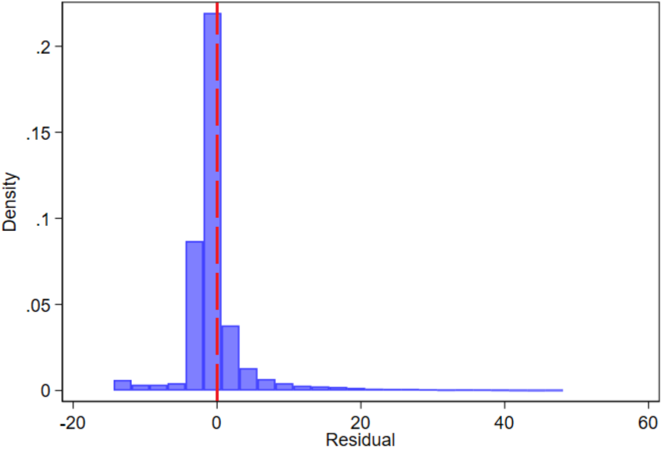
TFPR $1 - \tau_{si} \propto \dfrac{P_{si} Q_{si}}{TC_{si}}$

TFPQ $A_{si} = \dfrac{(P_{si}Q_{si})^{\frac{\sigma}{\sigma-1}}}{TC_{si}} \left[(1-\alpha_{si})^{1-\alpha_{si}} (\alpha_{si})^{\alpha_{si}} \gamma_{si} \right]^{\gamma_{si}} [\eta_{si}]^{\eta_{si}} [1 - \gamma_{si} - \eta_{si}]^{1-\gamma_{si}}$

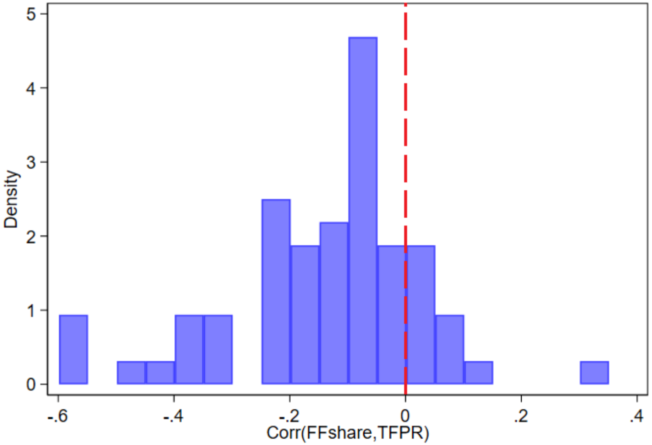
Fossil fuel shares across sectors



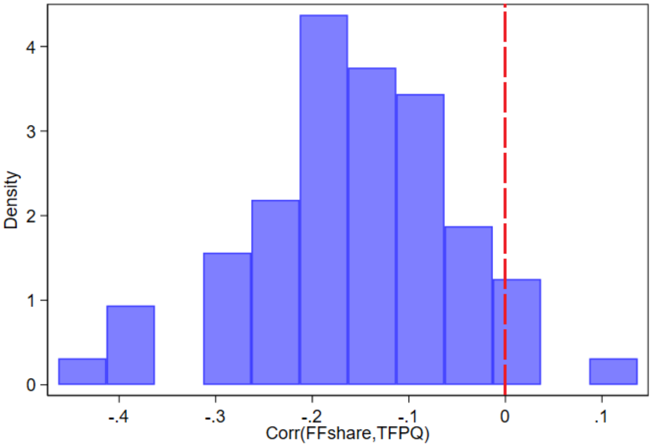
Fossil fuel shares across firms within sectors



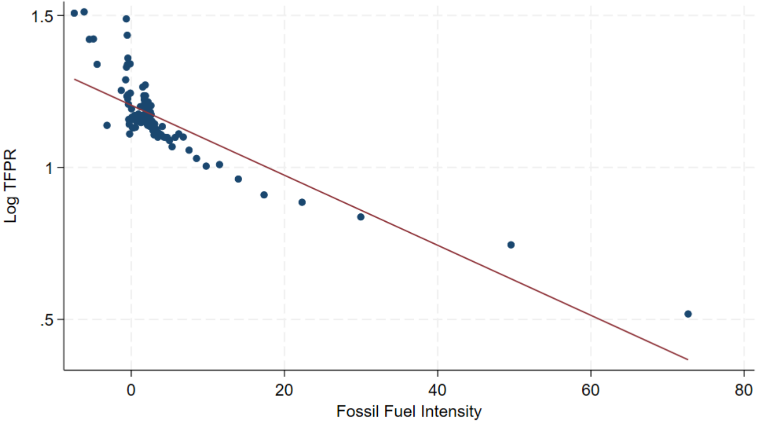
Corr. of TFPR and fossil fuel intensity within sectors



Corr. of TFPQ and fossil fuel intensity within sectors



TFPR vs. fossil fuel intensity within sectors



Regressions of TFPR on fossil fuel intensity

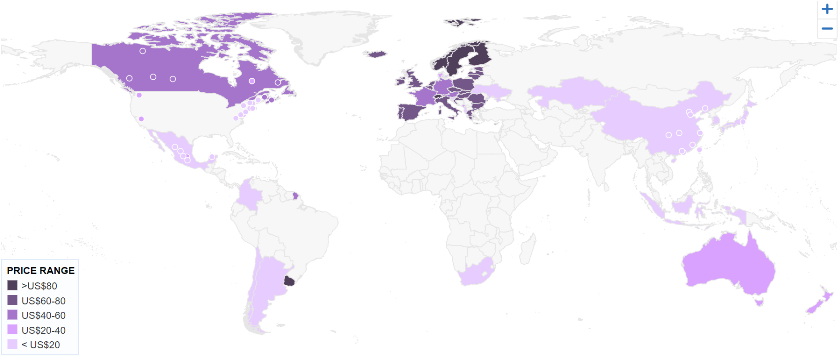
Dep. var.:	$\ln(\text{TFPR}_{it})$	$\ln(\text{TFPR}_{it})$	$\ln(\text{TFPR}_{it})$
Sample:	2015	2017	2019
FFshare_{it}	-0.0106***	-0.0104***	-0.0098***
	(0.0002)	(0.0002)	(0.0002)
FEsector	yes	yes	yes
Obs.	22,674	26,814	23,545
R^2_{adj}	0.186	0.265	0.269

Evidence of Mechanisms

Dep. var.:	$\ln(\text{TFPQ}_{it})$	$\ln(p_{it})$	$\ln(PE_{it})$	$\ln(RD_{it})$
FFshare_{it}	-0.0125***	-0.0419***	0.0304***	-0.0427***
	(0.0003)	(0.0015)	(0.0002)	(0.0016)
FE_{kt}	yes	yes	yes	yes
Obs.	124,945	106,372	106,372	106,370
Firms	38,741	35,132	35,132	35,132
R^2_{adj}	0.170	0.323	0.293	0.306

- Relatie price $p_{it} \equiv P_{it}/P_{st}$
- Process efficiency $PE_{it} \equiv \text{TFPR}_{it}/P_{it}$
- Residual demand $RD_{it} \equiv \text{TFPQ}_{it}/PE_{it}$

Carbon taxes around the world in 2024



Source: World Bank

Equivalence between taxation bases

- In to-do list: Translation from tax on fossil fuel expenditure to $\$/\text{TCO2}$.
- Leveraging calculations in Conte, Desmet, and Rossi-Hansberg (2023), which depend on the price of energy:

$$40\ \$/\text{TCO2} \Rightarrow 86.3\%\ \text{tax on fossil fuel expenditure.}$$

Carbon tax *rate*	Per ton equivalent
20%	9.3 $/TCO2
40%	18.6 $/TCO2
60%	27.8 $/TCO2
80%	37.1 $/TCO2
100%	46.3 $/TCO2

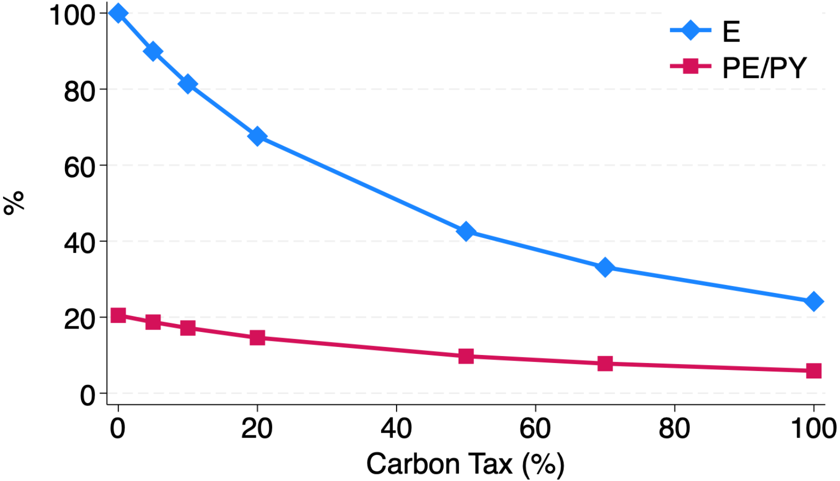
Counterfactuals

- Assume EoS across firms within sectors of $\sigma = 4$
- Introduce $\tau^C > 0$ on imports of energy
- $\Delta \ln(E), \Delta \ln(Q), \Delta \ln(Y), \Delta \ln(C)$
- Define TFP as Solow Residual:

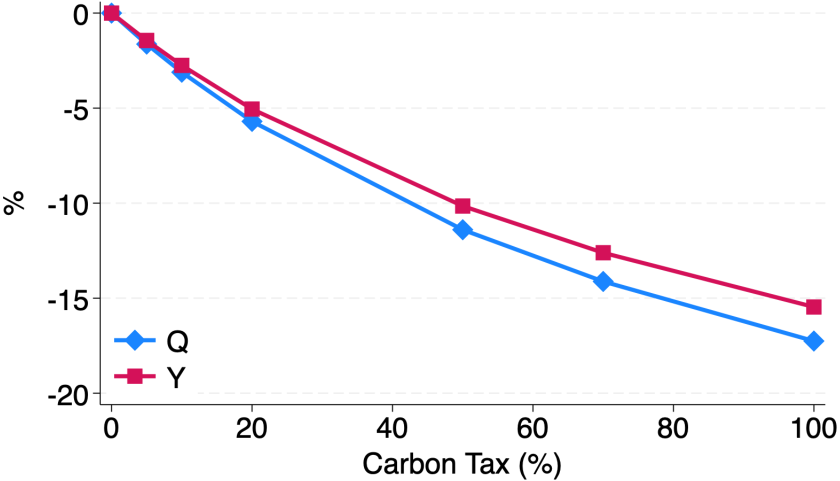
$$\ln\left(\frac{Y}{Y_0}\right) - \frac{(1-\bar{\gamma}-\bar{\eta})}{1-\bar{\eta}} \cdot \ln\left(\frac{E}{E_0}\right)$$

- Tornqvist aggregate cost shares: $\bar{\eta}$ and $\bar{\gamma}$
- Average across 2015-2019

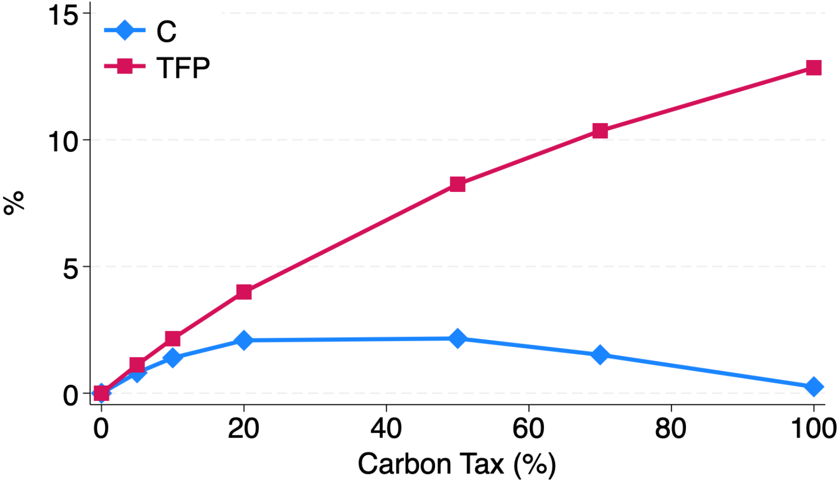
Energy and energy share of GDP



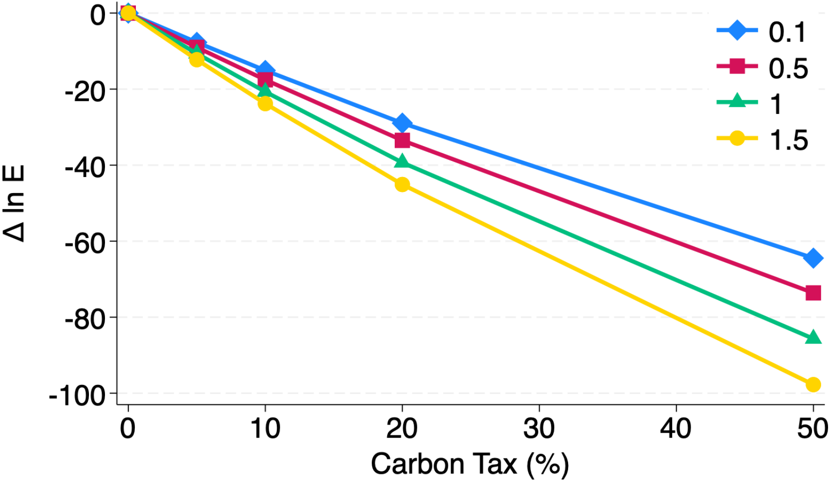
Output and GDP



Consumption and TFP



Robustness to elasticity between E and (K, L, M)



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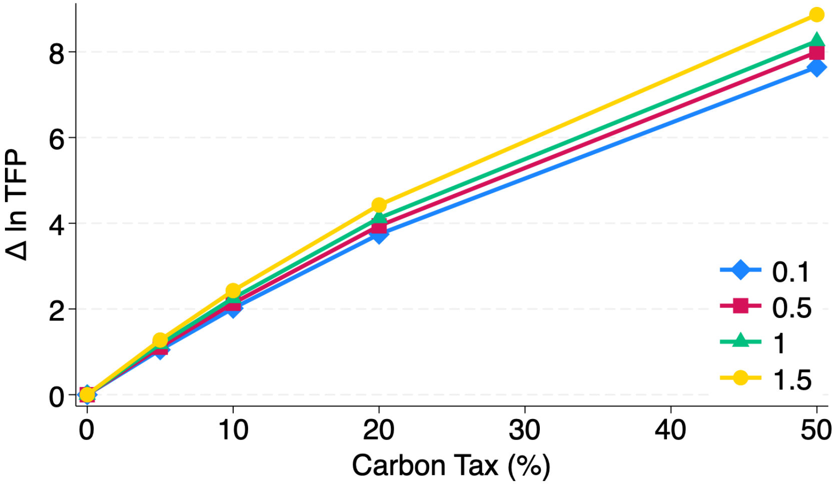

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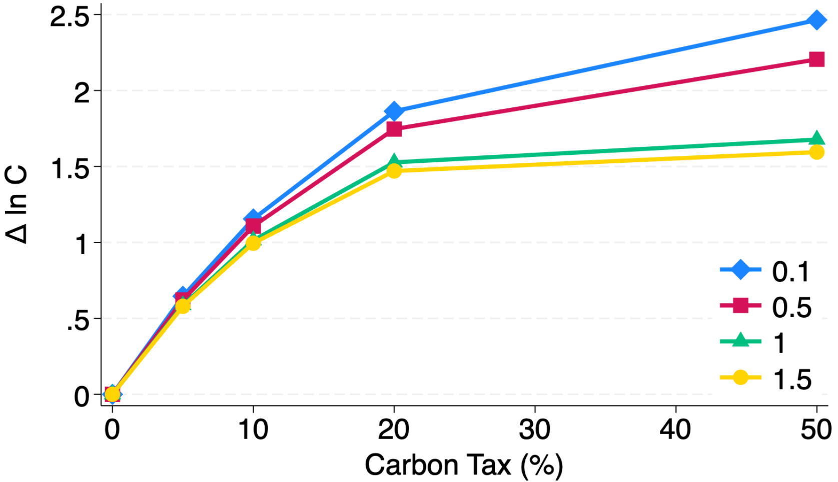
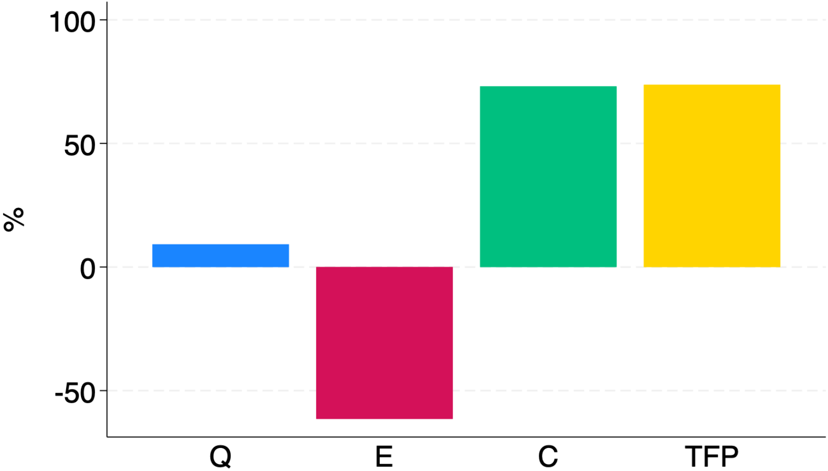


Impact of $\tau_{si} = 1$

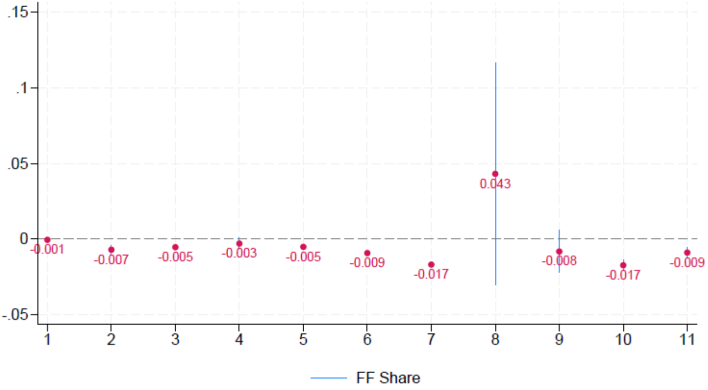


Conclusion

- Analyzed a hypothetical carbox tax in Chile
- Documented lower revenue productivity at fossil-fuel intensive firms
  - Correlated with firm's product quality, so may not be coincidental
- Estimated a carbon tax would *increase* allocative efficiency in Chile
- Reallocates inputs towards low fossil-fuel intensive high-quality, high-markup firms and away from high fossil-fuel intensive low-quality, low-markup firms
- Upshot: A unilateral carbon tax may raise Chilean welfare

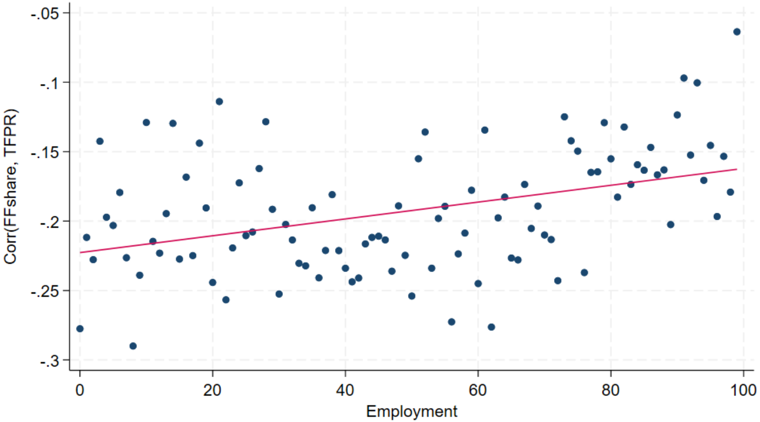
Appendix

Corr(FFshares,TFPR) in each 1-Digit Sector

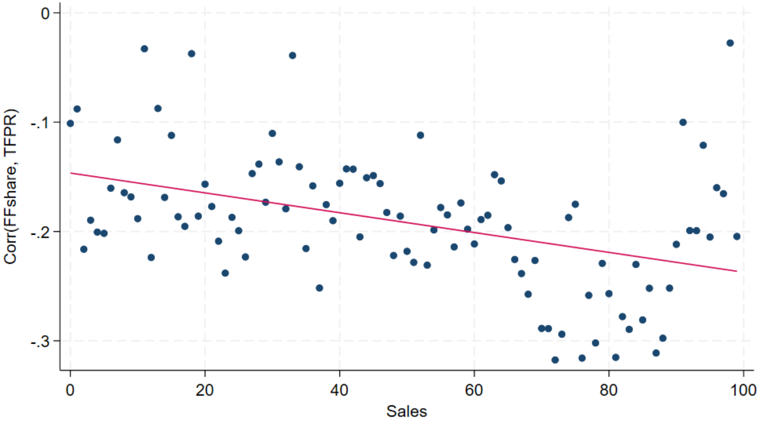


Note: 1: Agric., 2: Mining, 3: Manuf., 4: Elect., gas & water, 5: Const., 6: Commerce, 7: Transp. & telec., 8: FIRE, 9: Real Estate, 10: Business acts., 11: Personal acts.

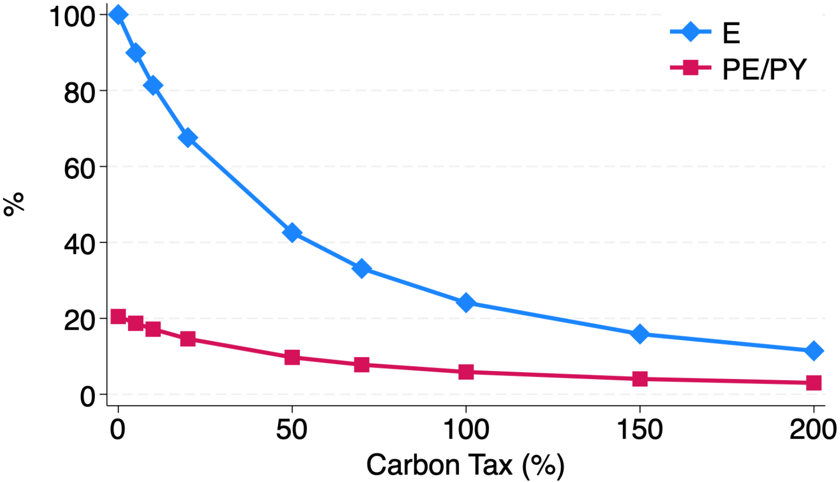
Corr(FFshares,TFPR) vs Firms Employment



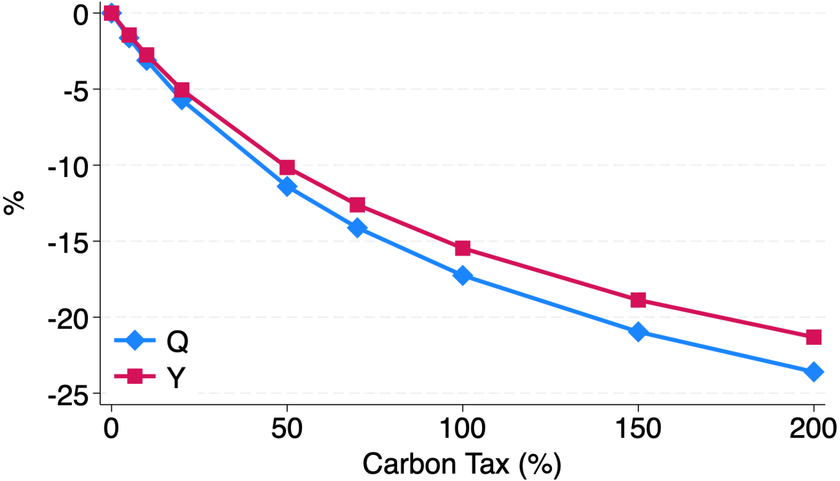
Corr(FFshares,TFPR) vs Firms Sales



Energy and Energy Share of GDP



Output and GDP



Consumption and TFP