Carbon Taxes and Misallocation in Chile

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Abstract

Carbon taxes are subject to a classic free rider problem: the benefits are global but the costs are often local. In an inefficient economy, however, carbon taxes might exacerbate or ameliorate existing domestic distortions. In Chile we find that fossil fuel use across firms is *negatively* correlated with their revenue productivity (i.e., revenue relative to inputs). We present evidence suggesting that this pattern may reflect higher price-cost markups at firms that produce higher quality products, with quality being intensive in primary inputs but not fossil fuel use. As a result, imposing a unilateral carbon tax may helpfully reallocate inputs away from low-markup, low-quality firms towards high-markup, high-quality firms. We calculate that a unilateral carbon tax in Chile could thereby increase allocative efficiency, consumption, and welfare.

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1. Introduction

Standard logic holds that carbon taxes have global benefits but local costs. The local costs take the form of induced substitution away from fossil fuel inputs, which can reduce local output and consumption. Thus countries may prefer to free ride rather than impose their own carbon tax.

The standard logic may falter, however, if the domestic economy is plagued by distortions other than those related to carbon consumption. These other distortions might stem from government taxes and subsidies, price markups, wage markdowns, financial frictions, government size-dependent policies, and more.[1] If such distortions are correlated with fossil fuel use across firms, then carbon taxes may amplify or mitigate misallocation of inputs across firms.

To investigate this possibility, we explore data from Chile on revenue and inputs, prices and quantities, and fossil fuel use across firms from 2015 to 2019. The dataset covers firms in all sectors. We find that revenue productivity (the ratio of revenue to inputs, a common proxy for price-cost markups) is negatively correlated with fossil fuel intensity across firms within industries. We find that firms with high residual demand (i.e., those who sell more output than one would expect given their relative prices) exhibit higher revenue productivity and lower fossil fuel intensity. We hypothesize that the higher residual demand reflects higher quality, and that firms with higher quality products charge higher markups. Under this interpretation, product quality may be intensive in labor and capital but not fossil fuels.

We write down a static general equilibrium model wherein intermediate good firms are heterogeneous in their fossil fuel intensity within and across industries. They also face heterogeneous revenue "tax" rates (a stand in for dispersion in markups, etc.). Fossil fuels are entirely imported and financed by exports of the final good. We back out firm-specific production technologies and revenue distortions to fit the firm data on input choices and revenue. Then we impose various carbon taxes to see what they do to output, allocative efficiency, and consumption.

We entertain carbon taxes ranging from 20% to 100%, which corresponds to

[1] See Restuccia and Rogerson (2017) for a recent survey on sources of misallocation.

a range of roughly \$9 to \$46 per ton – so well within the range implemented in many countries.[2] The carbon tax predictably reduces energy imports and gross output. Less obviously, it reduces value added. However, TFP rises monotonically up through a 100% carbon tax. The carbon tax usefully reallocates inputs from low-markup firms to high markup-firms. As a consequence, consumption is higher with a carbon tax, at least through a 100% tax. The peak is an increase of 2% in consumption at around a 20% tax. The increase in consumption is smaller for higher taxes but still positive. The upshot is that, at least in the case of Chile, imposing a carbon tax unilaterally may improve Chilean welfare.

Our paper relates to several recent efforts. Kim (2023) originated the same idea and arrived at a similar qualitative outcome using U.S. Compustat data. Kim's focus was the interaction of carbon taxes with the allocation of capital due to financial frictions and adjustment costs, and the optimal carbon tax in the presence of those frictions. In contrast, we look at a wider swath of firms in Chile, a small open economy that imports fossil fuels, and analyze the effects of a unilateral carbon tax on the efficiency of input allocation within and across firms. Moreover, we provide evidence for a distinct mechanism, namely the connection between product quality on the one hand and markups and fossil fuel intensity.

Conte, Desmet and Rossi-Hansberg (2023) find that a unilateral carbon tax can be welfare-enhancing for the European Union by concentrating more people and activity in high productivity areas. Aghion, Boppart, Peters, Schwartman and Zilibotti (2024) stress how the shift to services from agriculture and manufacturing reduces fossil-fuel intensity. They also emphasize that, as manufactured products improve in quality (e.g., from one iPhone model to another), they may not use more fossil fuels. This over-time result is complementary to our cross-firm finding that firms who seemingly product high quality products are less fossil-fuel intensive. Potentially related, Barrows and Ollivier (2018) show that larger firms in India have lower emissions intensity.

[2] World Bank (2024).

The rest of the paper is organized as follows. In Section 2 we describe the Chilean data, and document correlates with fossil fuel intensity. Section 3 we lay out a model of firms with differing production technologies and revenue productivity. In Section 4 we calculate what imposing a carbon tax would do in our model when it is calibrated to match the Chilean data. Section 5 concludes.

2. Dataset and Empirical Patterns

We use merged confidential administrative data on the universe of firms in Chile. The sample goes from 2015 and 2019. It includes firm-to-firm transaction data (prices and quantities) registered in VAT invoices. It also contains firm employment, physical capital, sales, intermediates, and fossil fuel use. We drop firms with less than 10 employees, non-positive value added and fixed assets below 10,000 Chilean pesos (about $15 U.S. dollars). We also exclude public administration and 2-digit sectors with fewer than five firms. This leaves us with a sample of about 25,000 firms per year across 70 2-digit sectors.

To identify transactions involving fossil fuel, we use the Central Product Classification (CPC) v.2 at the most disaggregated level available, implemented using the text field included VAT invoices data that describes the type of product transacted.[3] Table 1 displays the codes and descriptions that we consider "fossil fuel".

In order for a carbon tax to affect the allocation of inputs across firms, a necessary condition is that firms and sectors differ in their fossil fuel intensity. Figure 1 displays the density of fossil fuel shares in total costs across 2-digit sectors. Fossil fuel shares are averaged across firms in each sector in each year, and then averaged over time. Total costs include the wage bill, spending on non-energy intermediates, capital costs, and of course fossil fuels. Capital costs are simply a 15% user cost of capital multiplied by current fixed assets.[4] When aggregating firm shares up to the sector level in each year, the firm's share of total costs is used as a weight. In most

[3] The CPC v.2 is available here: https://stats.fao.org/caliper/browse/skosmos/cpc20/en/

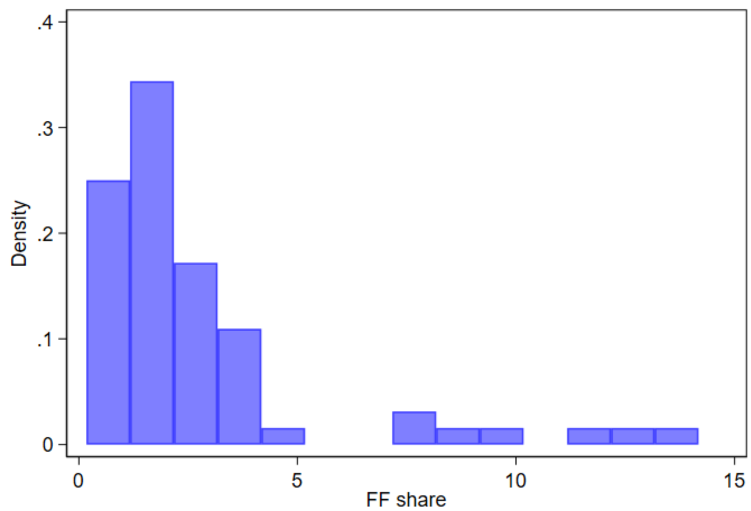
[4] The 15% user cost is chosen to reflect interest, depreciation, and taxes. The result are not too sensitive to this choice relative to 10% or 20%.

Table 1: CPC v.2 items included in fossil fuel

11010	Coal, not agglomerated
11020	Briquettes and similar solid fuels manufactured from coal
11030	Lignite, not agglomerated
11040	Lignite, agglomerated
12010	Petroleum oils and oils obtained from bituminous minerals, crude
12020	Natural gas, liquefied or in the gaseous state
12030	Bituminous or oil shale and tar sands
33100	Coke and semi-coke of coal, of lignite or of pear; retort carbon
33200	Tar distilled from coal, from lignite or from pear, and other mineral tars
33310	Motor spirit (gasoline), including aviation spirit
33330	Other light petroleum oils and light oils obtained from bituminous minerals (other than crude); light preparations n.e.c. containing not less than 70% by weight of petroleum oils or oils obtained from bituminous minerals (other than crude), these oils being the basic constituents
33341	Kerosene
33342	Kerosene type jet fuel
33350	Other medium petroleum oils and medium oils obtained from bituminous minerals (not kerosene), other than crude; medium preparations n.e.c containing not less than 70% by weight of petroleum oils or oils obtained from bituminous minerals (other than crude), these oils these oils being the basic constituents of the preparations
33360	Gas oils
33370	Fuel oils n.e.c.
33410	Propanes and butanes, liquefied
33420	Ethylene, propylene, butylene, butadiene and other petroleum gases or gaseous hydrocarbons, except natural gas
33500	Petroleum jelly; paraffin wax, micro-crystalline petroleum wax, slack wax, ozokerite, lignite wax, peat wax, other mineral waxes, and similar products; petroleum coke, petroleum bitumen and other residues of petroleum oils or of oils obtained from bituminous materials
69120	gas distribution through mains (on own account)

sectors, fossil fuels represent less than 5% of all costs, though in a few sectors (those related to transportation) it ranges from 5% to 15%.

Figure 1: Fossil Fuel Shares Across Sectors



Note: We exclude sectors with less than 25 firms to comply with the Central Bank of Chile's disclosure policy.

Figure 2 displays the density of fossil fuel shares across firms within each 2-digit sector. The industry-year mean is removed, and firm deviations are averaged across years before plotting. Most of the distribution lies within 5 percentage points of the industry-year mean. There is less dispersion across firms within sectors than across sectors, but firm output is also presumably more substitutable within sectors. Hsieh and Klenow (2009) and Baqaee and Farhi (2020) stress that input reallocation is more sensitive to differences within than across sectors for this reason.

In order for a carbon tax to affect allocative efficiency, fossil fuel intensity must be correlated with revenue productivity of inputs across firms. Figure 3 provides the distribution of the correlation of TFPR (the ratio of revenue to input costs) with fossil fuel intensity across firms within each industry. The correlation is negative in the vast majority of industries. That is, firms who use a lot of fossil fuels tend to have low marginal products for their inputs.

Figure 2: Fossil Fuel Shares Across Firms Within Sectors

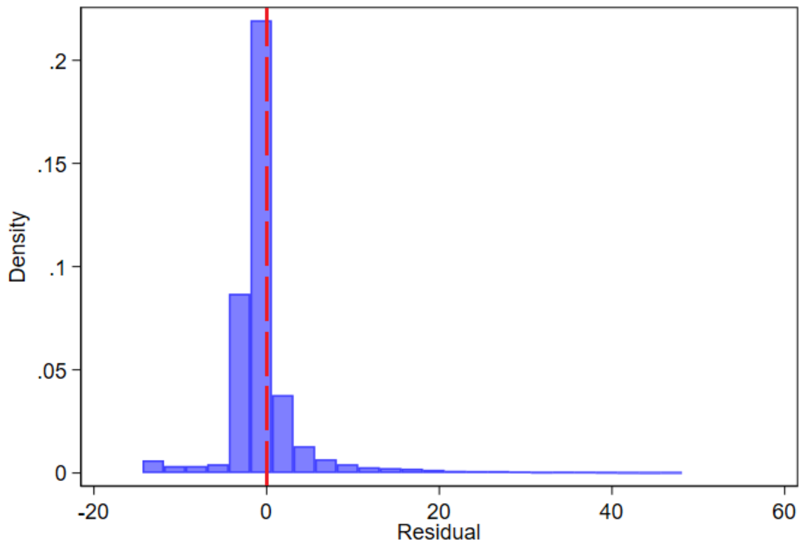


Figure 3: TFPR vs. Fossil Fuel Intensity

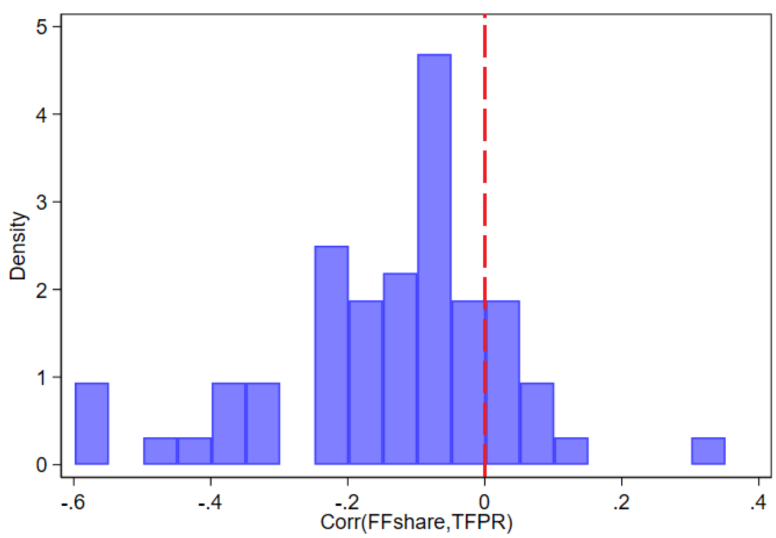
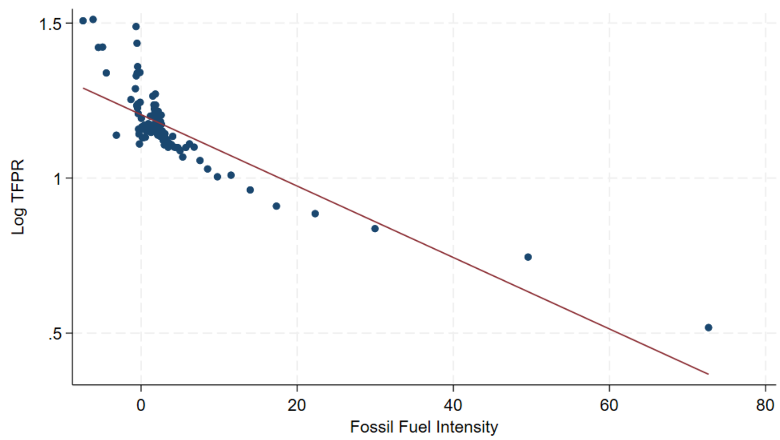


Figure 4: TFPR vs. Fossil Fuel Intensity once again



To provide a sense of the shape of the relationship, we calculate average TFPR across firms within 100 bins of fossil fuel intensity in Figure 4. Some highly fuel-intensive firms have very low TFPR, but the figure makes it clear that the negative relationship holds throughout the range of fossil fuel use.

Table 2 provides the related regressions of TFPR on fossil fuel. Sector fixed effects are included, so the coefficients reflect differences across firms within industries. Each of the three columns is a different year — 2015, 2017, and 2019. The relationship is negative: a one percentage point higher fossil fuel share in total costs is associated with one percent lower TFPR. The magnitude of the coefficient is fairly stable across the three years.

A related question is whether firm productivity is correlated with fossil fuel intensity. Here we use TFPQ, which captures both process efficiency and residual demand (e.g. product quality).[5] Figure 5 plots the histogram of within-industry correlations of TFPQ and fossil fuel intensity across firms within industries. Almost all industries feature a negative correlation. Thus firms with better technology seem to be able to economize on fossil fuel use.

[5] More on TFPQ in the model below. See Hsieh and Klenow (2009).

Table 2: 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

To delve into the potential mechanism further, we run pooled regressions of TFPQ and its components on fossil fuel intensity. We do this across firms within industries by controlling for sector-year fixed effects. As shown in Table 3, one percentage point higher fossil fuel share goes along with 1.25% lower TFPQ. Moreover, it is associated with over 4% lower relative prices. Process efficiency is 3% higher. So the lower TFPQ does *not* reflect lower process efficiency. On the contrary, such firms have lower TFPQ despite higher process efficiency. Combining the price and process efficiency results suggests that price-cost markups may be about 1% lower for firms with one percent higher fossil fuel share – consistent with TFPR regressions in Table 2.

The last column of Table 3 indicates that higher fossil fuel use is accompanied by over 4% lower residual demand. This is consistent with fossil fuel intensive firms producing lower quality products. If producing higher quality involves non-fuel inputs intensively, and higher product quality is associated with higher markups, then the negative relation we find between TFPR and fossil fuel use may be systematic rather than coincidental.

Figure 5: TFPQ vs. Fossil Fuel Intensity

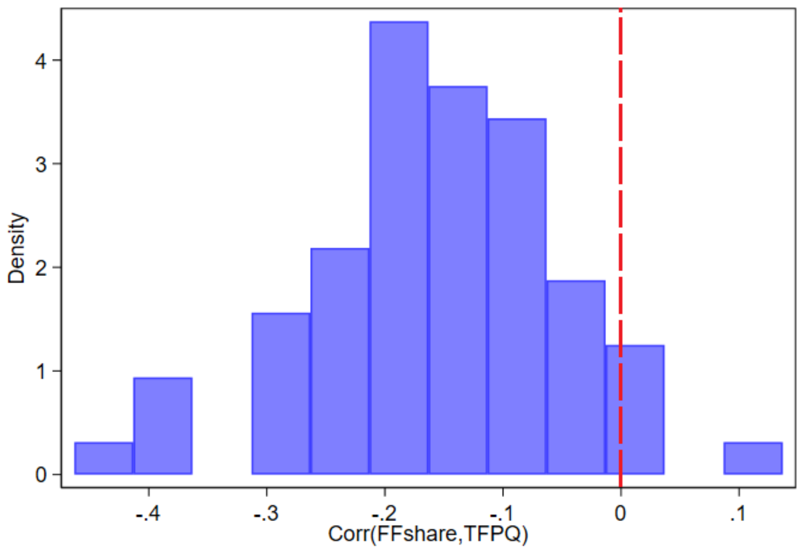


Table 3: Evidence of Mechanisms

Dep. var.:	ln(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

3. A Model of Fossil Fuel Use and Misallocation

Here we lay out of a static, small open economy model of firms with heterogeneous production technologies — including fossil fuel intensity. Given our focus on a small open economy, our model does not feature environmental externalities from fossil fuel use.

Endowments The aggregate endowments of labor L and physical capital K are exogenously fixed. Labor and capital are both homogeneous. Gross output Q can be devoted to either "value added" Y or non-energy intermediate goods M:

$$Q = Y + M$$

Households A representative household has discounted utility

$$U_t = \sum_{t=0}^{\infty} \beta^t \, L \, u(c_t)$$

where per capita consumption is $c_t \equiv C_t/L$ and flow utility is $u(c_t) = \ln(c_t)$. The household's intertemporal budget constraint is

$$A_{t+1} = w_t \cdot L + (R_t - \delta) \cdot A_t - C_t + T_t$$

where A are assets, w is the wage, R is the rental price of capital, δ is the depreciation rate on physical capital, and T_t are lump sum taxes or transfers. Note that $R_t \equiv r_t + \delta$, where r is the real interest rate. Here we implicitly normalize the price of the final good (and consumption) to 1.

Household utility maximization leads to the usual Euler equation:[6]

$$c_{t+1}/c_t = \beta(1 + r_t)$$

[6] We also assume the usual no Ponzi condition.

Production Technology Aggregate gross output is the geometric average of gross output in S sectors:

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

where θ_s is the geometric weight on sector s. Sectoral output, in turn, is a CES aggregate of firm-level gross output:

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

where $\sigma > 1$ is the elasticity of substitution across firms.

The production technology for firm i is a Cobb-Douglas aggregate of inputs

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

where A_{si} is factor-neutral technology, K_{si} is physical capital rented by the firm, L_{si} is labor input, M_{si} are non-energy intermediate inputs, and E_{si} are energy inputs. Firm-specific exponents will allow firms to differ in their fossil-fuel intensity, even within sectors.

Trade Firms take the global price of energy P^E as given and choose how much energy E to import. Imports are financed by exports of the final good, so the balanced trade condition is

$$P^E E = P \cdot (Q - M - C)$$

where P is the price of the final good (which we normalize to 1).

Taxes and Transfers Energy purchases are tax at the *ad valorem* rate τ_C. We relate this to the typical carbon tax below. There is also a revenue tax rate τ_{si} that is specific to firm i in sector s. This is a stand-in for not only firm-specific taxes and subsidies but also price-cost markups and size-dependent regulations. The resulting tax "revenue" is rebated lump sum as

$$T_t = \left(\tau_C P_E E + \sum_s \sum_i \tau_{si} P_{si} Q_{si} \right) / P$$

We divide by the price of the final output good (which is normalized to 1) to make it explicit that the energy and intermediate good prices should be interpreted as relative to the price of the final good.

Market Structure We assume perfect competition in the final goods sector. A representative final goods firm maximizes

$$\Pi = P \prod_{s=1}^{S} \left[\left(\sum_i^{N_s} Q_{si}^{1-\frac{1}{\sigma}} \right)^{\frac{1}{1-\frac{1}{\sigma}}} \right]^{\theta_s} - \sum_s \sum_i P_{si} Q_{si}$$

where P_{si} is the price of intermediate good i in sector s. The final good firm is a price taker in terms of both output and inputs, so it's first order condition for intermediate good i from sector s is

$$\frac{Q_{si}}{Q_s} = \left(\frac{P_{si}}{P_s} \right)^{-\sigma}. \tag{2}$$

Here the ideal price index for sector s is

$$P_s = \left(\sum_i^{N_s} P_{si}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}$$

and the ideal price index for the final good is

$$P = \prod_{s=1}^{S} \left(\frac{P_s}{\theta_s} \right)^{\theta_s}.$$

We assume the intermediate goods sector is monopolistically competitive. Each firm chooses P_{si} to maximize its current profits

$$\Pi_{si} = (1 - \tau_{si}) P_{si} Q_{si} - w L_{si} - R K_{si} - P^M M_{si} - (1 + \tau^C) P^E E_{si}$$

given its production technology (1) and residual demand (2), and taking P_s, Q_s, w, R, P_M and P_E as given.[7]

The profit-maximizing price of each intermediate good is the function

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

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

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

Notice that the carbon tax τ_C will have a differential effect on prices of different intermediate goods producers to to the extent that $\gamma_{si} + \eta_{si}$ differ across firms. That is, to the extent that fossil-fuel intensity differs across firms, they will be differentially affected by a common carbon tax.

Equilibrium An equilibrium is a 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: $Y - C = \sum_s \sum_i P^E E_{si}$

[7] Non-energy intermediate inputs M are produced directly from the final good, therefore $P^M = P$. We include P^M for clarity of exposition.

Allocative Efficiency The impact of a carbon tax on allocative efficiency depends on how its differential impact across firms relates to the other distortion those firms face. This can be seen by looking at the market share of firm i within sector s:

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

As emphasized by Hsieh and Klenow (2009), economies such as this one are allocatively efficient (ignoring any negative externalities from carbon consumption) if $\tau_{si} = 0$ for all firms. The variation in market shares due to dispersion in production technologies is efficient, but the variation due to idiosyncratic revenue taxes τ_{si} is inefficient. These taxes are sand in the gears of the market allocation. A higher τ_{si} causes a firm to raise its relative price and hence lower its market share.

Carbon taxes can affect allocative efficiency to the extent that their differential effect is correlated with the revenue tax rates. 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.

Another way to frame the effect of carbon taxes on allocative efficiency is by looking at the variance of market shares within a sector. For exposition purposes, suppose $A_{si}/\widetilde{P}_{si}$ is uncorrelated with τ_{si} and $1-\gamma_{si}-\eta_{si}$. Then we get

$$\begin{aligned}\frac{1}{(\sigma-1)^2}\,\text{Var}\ln\left(\frac{P_{si}Q_{si}}{P_sQ_s}\right) = {} & \text{Var}\ln\left(\frac{A_{si}}{\widetilde{P}_{si}}\right) + \\ & [\ln(1+\tau^C)]^2\,\text{Var}(1-\gamma_{si}-\eta_{si}) + \\ & \text{Var}\ln(1-\tau_{si}) + \\ & 2\ln(1+\tau^C)\text{Cov}[\ln(1-\tau_{si}),(1-\gamma_{si}-\eta_{si})]\end{aligned}$$

The first time on the right hand side is the efficient source of variation in market shares. The next three terms are all inefficient sources of variation. The second row shows the differential impact of carbon taxes based on firm variation in fossil fuel intensity. The third row represents variation in market shares due to the idiosyncratic revenue taxes. And the final row captures the effect of any correlation between fossil fuel intensity and idiosyncratic taxes. If the correlation is positive (negative) then a carbon tax will amplify (dampen) the inefficient dispersion in market shares.

4. Model Counterfactual: Imposing a Unilateral Carbon Tax

We now calibrate the model so that we can calculate the hypothetical impact of carbon taxes.

Parameter values We set $\sigma = 4$, a standard value in the literature — for example Bils, Klenow and Ruane (2021). For each firm we set its production elasticities based on its cost-shares. Costs shares should reflect production elasticites if input markets are competitive, there are no adjustment costs for inputs, and returns to scale are constant. Total costs are defined as

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

Then we get

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

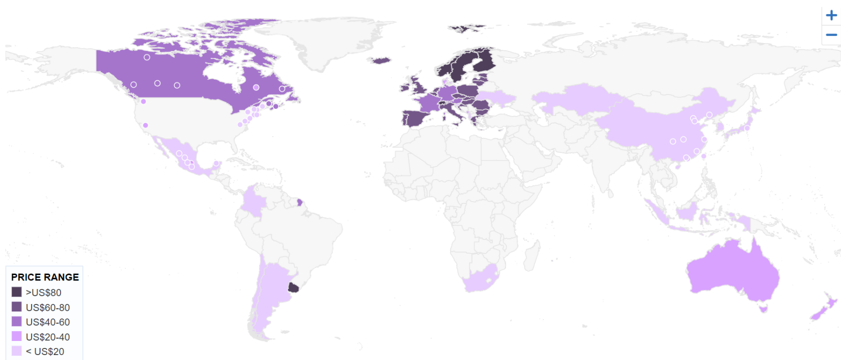
$$\gamma_{si} = \frac{RK_{si} + wL_{si}}{TC_{si}}$$

$$\eta_{si} = \frac{P^M M_{si}}{TC_{si}}$$

We infer the revenue tax based on dispersion in the gross profit margin, or revenue productivity (TFPR):

$$\tau_{si} = 1 - \frac{\sigma}{\sigma - 1} \frac{P_{si} Q_{si}}{TC_{si}}$$

Figure 6: Carbon taxes around the world in 2024



Source: World Bank (2024)

Table 4: Carbon taxes per ton and *ad valorem*

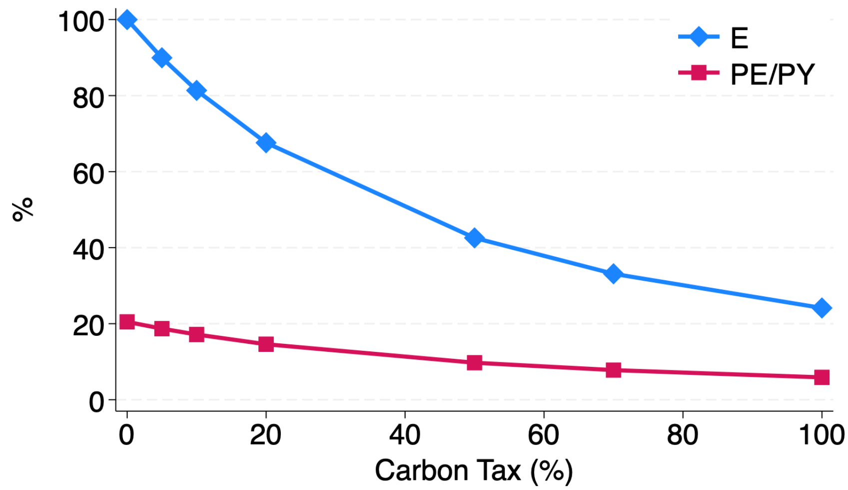
Carbon tax *rate*	Per ton equivalent
20%	9.3 $/TCO2
40%	18.6 $/TCO2
60%	27.8 $/TCO2
80%	37.1 $/TCO2
100%	46.3 $/TCO2

And we back out A_{si} (or TFPQ) from:

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

Carbon taxes When we compute the cost shares, we use $\tau_C = 0$ because this is approximately the case for Chile. Figure 6 shows levels of carbon taxes around the world in 2024, based on the World Bank (2024) dashboard. Levels of $20 to $40 a ton of CO_2 are most common. To translate carbon taxes per ton to an *ad valorem* rate, we leverage calculations in Conte et al. (2023) that of course depend on the price of energy. Table 4 shows that 40% carbon tax translates to roughly $18.6 dollars per ton, and and 80% tax is tantamount to a $37 tax per ton.

Figure 7: Energy and Energy Share of GDP



Counterfactuals We now impose various carbon tax rates $\tau_C > 0$ and assess the impact on $\Delta \ln(E), \Delta \ln(Q), \Delta \ln(Y)$, and $\Delta \ln(C)$. For TFP we use the Solow Residual:

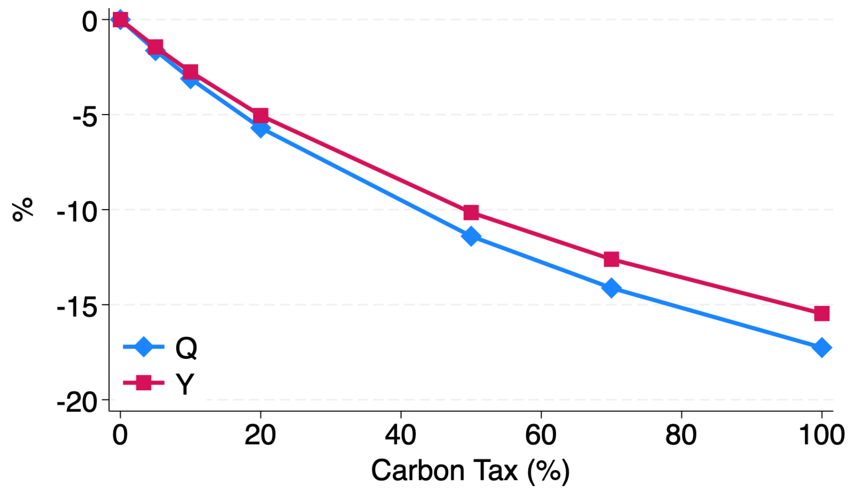
$$\ln\left(\frac{Y}{Y_0}\right) - \frac{(1-\bar{\gamma}-\bar{\eta})}{1-\bar{\eta}} \cdot \ln\left(\frac{E}{E_0}\right)$$

and Tornqvist aggregate cost shares: $\bar{\eta}$ and $\bar{\gamma}$ averaged over 2015-2019.

Figure 7 plots the impact of higher carbon taxes on real energy imports E and spending on energy (excluding the tax). As the figure shows, carbon taxes naturally reduce fossil fuel consumption. This occurs both within and across firms. Each firm substitutes away from energy toward other inputs (with an elasticity of substitution equal to one in the baseline Cobb-Douglas case). And firms that are more intensive in fossil fuels see an increase in their relative margin cost and a drop in their resulting use of inputs and sales share. There is also substitution across industries, but this is blunted by the lower (unitary) elasticity of substitution across industries relative to that within industries ($\sigma > 1$).

Figure 8 indicates that both gross output and "value added" decline monotonically with the level of a carbon tax. Gross output declines more than value added. Despite this, according to Figure 9 TFP rises steadily with the level of the carbon tax.

Figure 8: Output and GDP



This is precisely due to the effect of the carbon tax on allocative efficiency. When we counterfactually set all idiosyncratic revenue distortions to zero ($\tau_i = 0$), there is no impact of a carbon tax on TFP.

Figure 9 also shows that consumption is hump-shaped with respect to the carbon tax. This is due to the competing effects of carbon taxes on energy use (which is negative for consumption) and TFP (which is positive for consumption). That is, carbon taxes distort the use of energy but also usefully improve allocative efficiency. The second force is positive (increasing) even for carbon taxes as high as 100%. Consumption peaks at about 1.5% higher with a carbox tax of around 20%. The distortion to energy more than offsets any efficiency gains beyond that level. Consumption is fairly flat over the range of 20% to 50% for the carbon tax.

Figure 10 illustrates the effect of considering higher and lower elasticities of substitution between energy and a composite of physical capital, labor, and non-energy intermediate inputs. Compared to the baseline unitary elasticity of substitution, energy use predictably declines more slowly (quickly) with the carbon tax for elasticities below (above) one.

Figure 9: Consumption and TFP

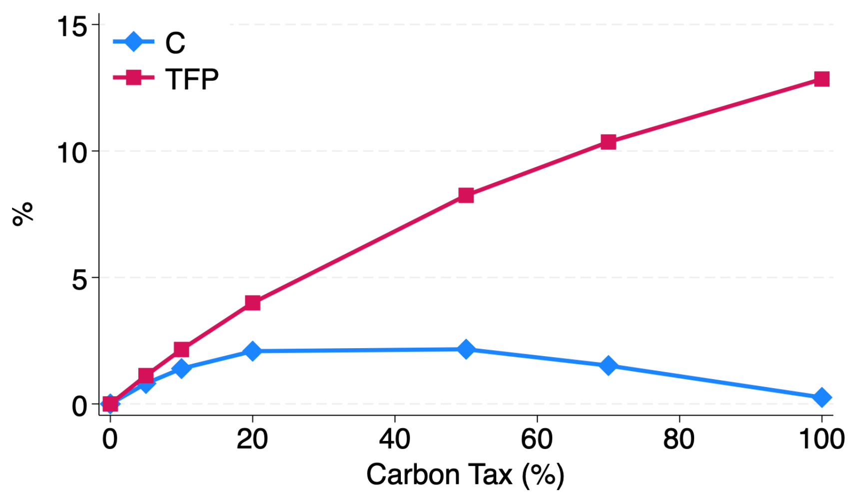


Figure 10: Energy and the elasticity between E and (K, L, M)

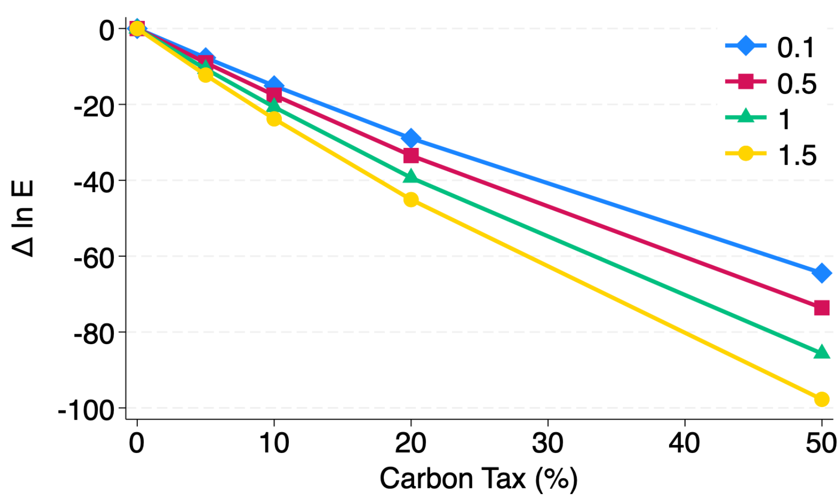
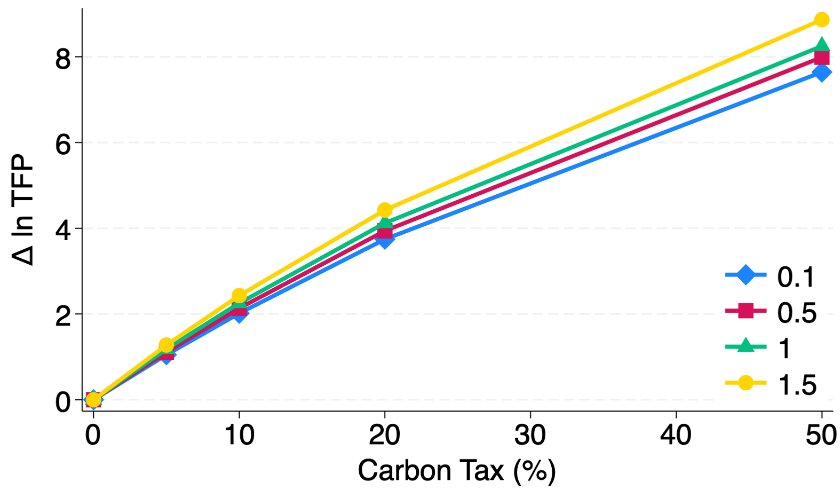


Figure 11: TFP and the elasticity between E and (K, L, M)



As revealed in Figure 11, TFP rises more quickly with the carbon tax when the elasticity of substitution between energy and other inputs is higher. The level of the elasticity affects the distribution of TFPQ, which can matter for allocative efficiency.

Figure 12 presents the response of consumption to the carbon tax under different elasticities of substitution between energy and other inpus. The bigger the elasticity, the smaller the increase in consumption. Energy use is distorted more the higher is this elasticity, which serves as a drag on consumption.

Our analysis begs the question of why Chile does not pursue policies to offset the idiosyncratic revenue distortions. The impact of getting rid of such idiosyncratic revenue distortions is portrayed in Figure 13. Gross output rises, energy use falls, and both consumption and TFP rise. The rise in TFP owes to better allocative efficiency. The fall in energy use reflects that the average revenue tax is negative, and that firms with higher fossil fuel intensity lower prices less in response. Thus a policy to offset revenue distortions (e.g. due to markup dispersion) may coincidentally help curtail carbon consumption.

Figure 12: Consumption and the elasticity between E and (K, L, M)

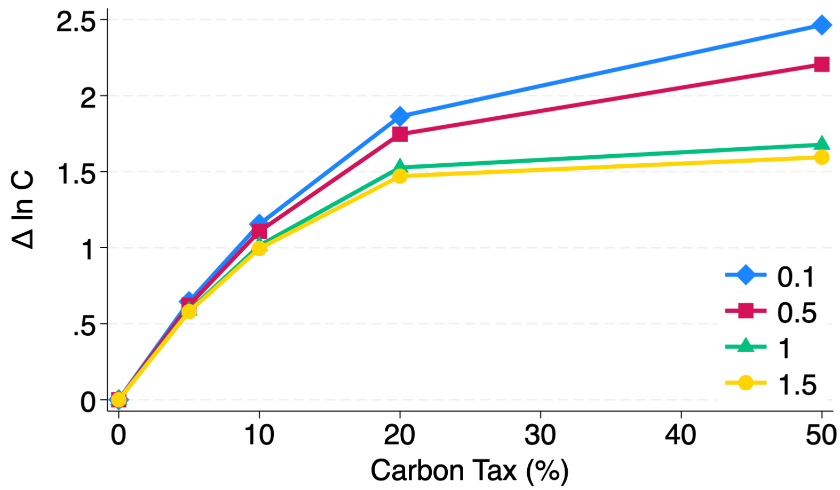
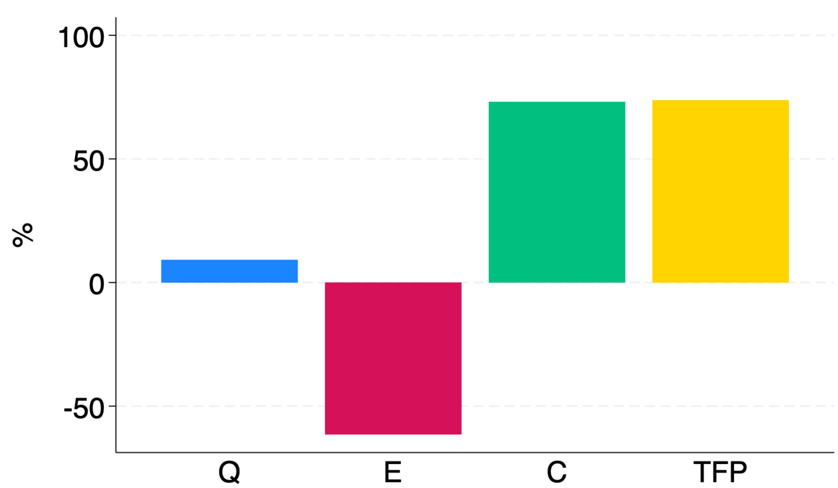


Figure 13: Impact of $\tau_{si} = 1$



5. Conclusion

We documented lower revenue productivity at fossil fuel intensive firms in Chile over 2015–2019. Fossil fuel use was correlated negatively with residual demand, a common proxy for product quality. So perhaps attaining high product quality requires skilled labor and advanced equipment, but not more fossil fuels. Thus the correlation could be due to quality variation that also affects markups. This raises the possibility that the patterns we find in Chile may hold elsewhere, such as found among firms in the U.S. (Kim, 2023).

We then analyzed the impact of a a hypothetical carbon tax in Chile. We found that a carbon tax of 20% to 40% would increase allocative efficiency in Chile. The mechanism: reallocating inputs away from low-quality, low-markup firms that are intensive in fossil fuels, towards high quality high-markup firms with low fossil fuel intensity. Over this same range a carbon tax would appear to increase consumption in Chile by one to two percentage points. Thus a unilateral carbon tax may raise Chilean welfare.

A natural follow-up question is why countries need to pursue a carbon tax to reduce misallocation from (say) markup dispersion. As revenue productivity tends to be higher at larger firms, such a policy might be seen as regressive in terms of its distribution implications. Size-dependent policies typically favor smaller firms, the opposite of what would be needed to help equalize markups. Thus political economy considerations could make a carbon tax more palatable than policies to directly mitigate misallocation.

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