Firm-level CO2 Emissions and Production Networks: Macroeconomic Implications of a Carbon Tax

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This paper: What?, Why?, How?

- **What:**
  - ✓ How important are production networks in shaping the macroeconomic impacts of a carbon tax?
- **Why:**
  - ✓ Firms adapt their production and selling prices when face inputs price changes
  - ✓ Potential indirect effects due to spillovers via input-output linkages.
- **How:**
  1) Fossil fuels consumption and CO2 emissions
     - Fossil fuel use and direct CO2 emissions at the firm-level → (customs + firm-level data)
  2) Production networks: Downstream and Upstream spillovers
     - 1st approach: carbon footprint by economic sector and the final use → (input-output data)
     - 2nd approach: Downstream and Upstream centrality measures → (F-to-F transaction data)
     - Estimate direct and indirect firm-level responses in prices and quantities to fossil fuel price shocks (work in progress)

Related literature

1. Carbon footprint by economic sector and final use

   Avilés-Lucero and Valladares (2021); Cohen et al. (2005); Cellura et al. (2012); Wood and Dey (2009); Zheng et al. (2017)

   Contribution: Use of administrative data allows to estimate fossil fuel consumption, direct CO2 emissions and carbon footprint at the sectoral-level in real time.

2. Macroeconomic implications of climate change mitigation policies:

   Metcalf and Stock (2020); Acemoglu et al. (2012); Aghion et al. (2016); Finkelstein Shapiro and Metcalf (2023); King et al. (2019)

   Contribution: Incorporation of production networks to take into account indirect effects via input-output linkages.

3. Shocks propagation via production networks:

   Acemoglu et al. (2012, 2015); Liu (2019); Silva et al. (2024); Aghion et al. (2024)

   Contribution: Empirical downstream and upstream input-output linkages measures between fossil fuel burning sectors and non-fossil fuel burning sectors.

Roadmap

Data description

Fossil fuel consumption and direct CO2 emissions

1st approach: Carbon footprint by economic activity and final use

2nd approach: Production Network - Centrality Measures

Next steps: Empirical Analysis

Conclusions

Data description

1. Chilean customs data:
    - 95 % of fossil fuel burned in Chile are imported.
    - Customs data accounts for the universe of transactions of imported goods.
    - It provides importer's identifiers, HS codes, quantities, and CIF and fob prices.
    - HS codes allow us to map directly fossil fuels to those in the IPCC guidelines.
2. Firm-to-firm transaction data (Chilean IRS):
    - Electronic Invoices (EI) cover the universe of firm-to-firm transactions. 2015-present.
    - Each EI includes unique seller and buyer identifiers, total transaction value, date, unitary price and quantity, and a text description of the good or service traded.
    - We use a Machine Learning algorithm to classify each item description into an Unique Product Classification (Acevedo et al. 2024).
3. Other datasets:
    - National Balance of Energy (NBE), National Greenhouse Gases Inventory (NGHGI), IPCC fossil fuels factor emissions

Firm-to-firm transaction data

Table 1: Electronic Invoices - summary statistics

Dataset	Documents (million)	Sellers (thousands)	Buyers (million)	Descriptions (billion)
EI M	26.9	296.353	1.7	0.111
EI Y	323.1	466.946	3.7	1.316
EI Total	2,584.6	1.006.100	9.4	10.529

Notes: Comprises data between 2015 and 2022. EI excludes void electronic invoices. M: Monthly average; Y: Yearly average; Total includes all data. Modified from Acevedo et al. (work in progress).

Roadmap

Primary fossil fuel consumption: Customs data

- Good match with National Balance of Energy (NBE).
- Administrative data allows for "real time" series, advancing in 2 years NBE report.

Firm-level CO2 emissions

- To avoid double counting issues, we identify the burning firms in the economy as those who satisfy the following two conditions:
  1. they purchase some type of fossil fuel from other firms to use it as an input at their production stage.
  2. their output is not a fossil fuel.

- Direct CO2 emissions at the firm level are constructed as follows:

$$\text{Emissions}_{ijt} = \text{Fossil Fuel}_{ijt} * \text{Emission Factor}_j \tag{1}$$

  - Emissions_{ijt}: CO2 emissions of firm i from burning a fossil fuel of type j at time t.
  - Fossil Fuel_{ijt}: quantity of fossil fuel type j burned by firm i at time t.
  - Emission Factor_j: IPCC emission factor for fossil fuel of type j.

Sectoral and Aggregate CO2 emissions

- Sectoral CO2 emissions by fossil fuel type

$$\text{Emissions}_{sjt} = \sum_{i=1}^{N} \text{Emissions}_{ijt} \tag{2}$$

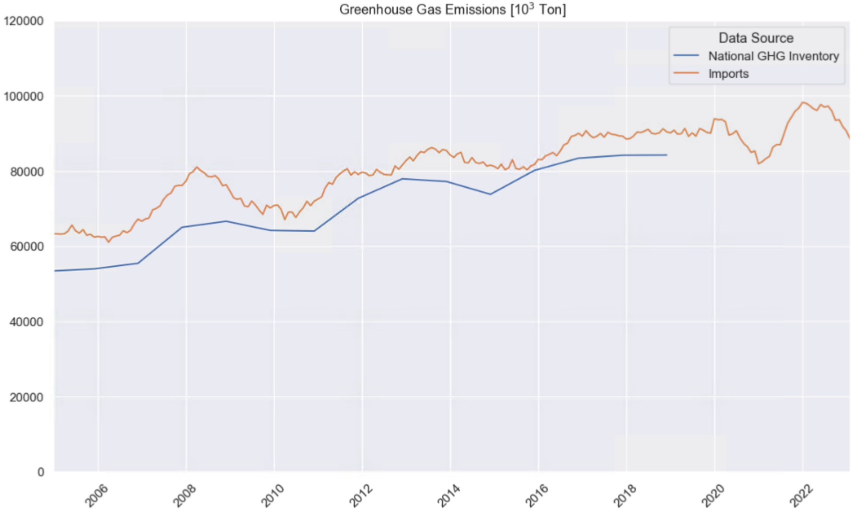
  - Emissions_{sjt} is the CO2 emissions of sector s associated with burning a fossil fuel of type j at time t.

- Aggregate CO2 emissions by fossil fuel type

$$\text{Emissions}_{jt} = \sum_{s=1}^{K} \text{Emissions}_{sjt} \tag{3}$$

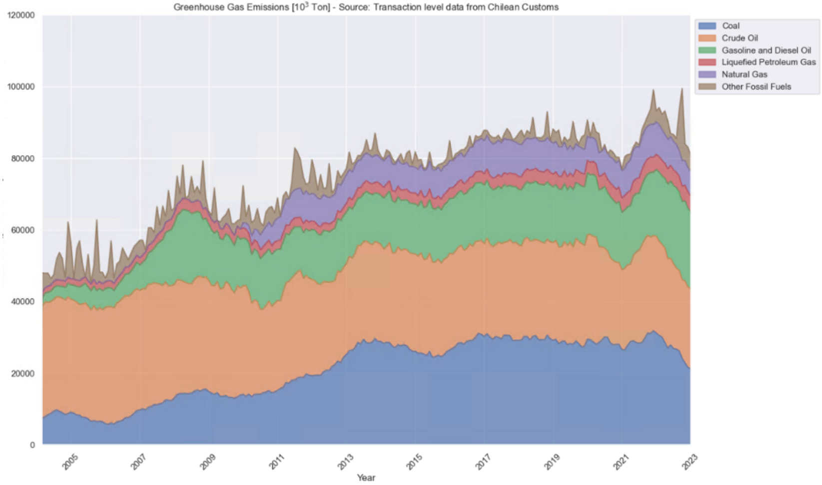
  - Emissions_{jt} is the aggregate CO2 emissions associated with fossil fuel of type j at time t.

Direct CO2 Emissions: Aggregate Results



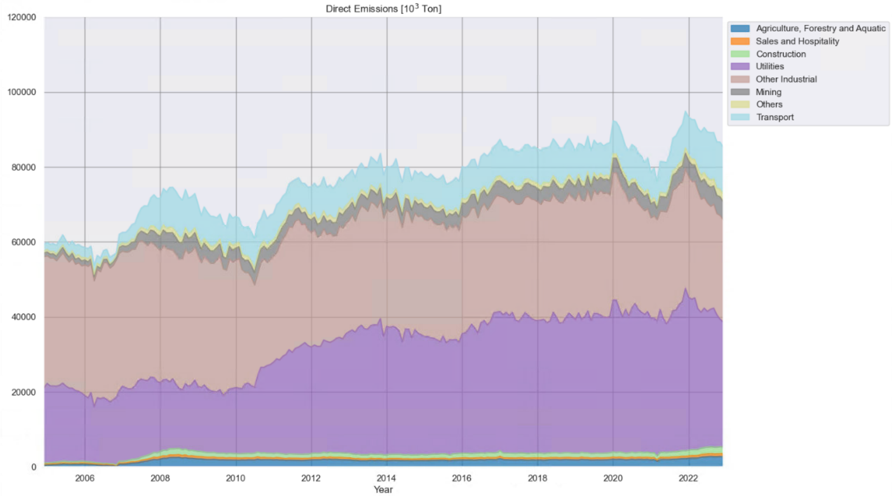
- Good fit with NGHGI data, but we advance it in two years using administrative data.

Direct CO2 Emissions: by type of fossil fuel



- Crude oil and coal account for more than 50% of CO_2 emissions, but are declining due to the entry of NCRE in the EG sector over recent years.

Direct CO2 Emissions: by economic sector



- Electricity generation (43%), manufacturing (33%), transport (12%), and mining sectors (6%) are the most fossil-intensive sectors in Chile in 2022.

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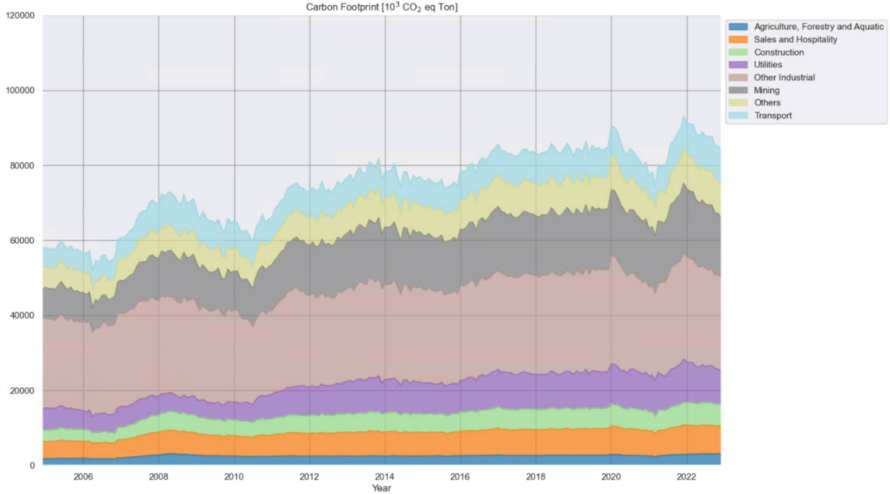
Carbon footprint: Framework

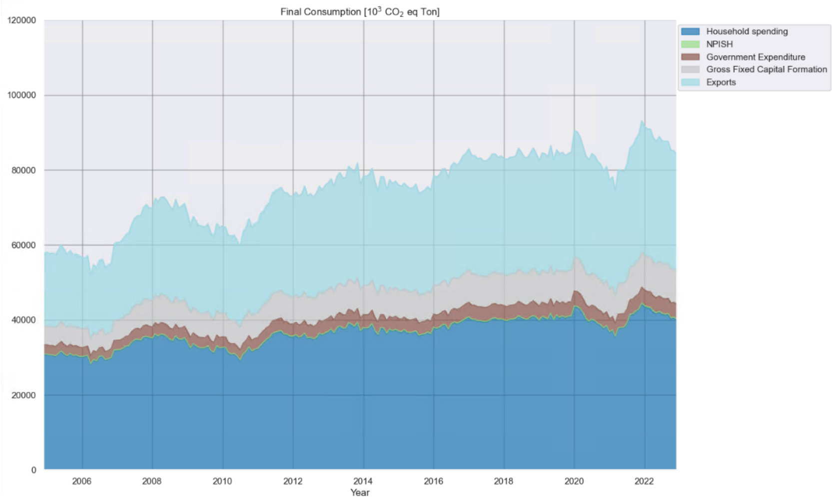
- As first exercises to understand how important might be the spillovers arisen from input-output linkages, we use the 2018 input-output data together with the sectoral CO2 emissions to construct the carbon footprint by economic sector and final use.
- The procedure is as follows:
  1. The total production of goods q used as intermediate inputs by other firms (Aq) or absorbed by the final demand components (y) must satisfy equation 4
  $$q = Aq + y \tag{4}$$
  2. Then, we can compute the Leontief inverse as
  $$q = (I - A)^{-1} y \tag{5}$$
  3. Next, we extend the Leontief inverse with the direct sectoral CO2 emissions denoted by the vector $e = (e_1, \ldots, e_N)$
  $$E = e(I - A)^{-1} y = eLy \tag{6}$$
  the component eL represents the carbon footprint by economic sector and, then, by multiplying it by y we get the carbon footprint by final use.

Carbon footprint: Results by economic sector in 2022



- Electricity generation direct CO2 emissions are moslty absorbed by other sectors. Emissions from the manufacturing sector are absorbed by the same sector.

Carbon footprint: Results by final use in 2022



- Private consumption 47% (absorbing from all sectors according household basket), exports 40% (mining and manufacturing), investment 11%, government 2%.

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Production Network - Centrality Measures

- As a second approach, we build downstream and upstream centrality measures following Acemoglu et al. (2015) to capture how well connected are the fossil fuel burning firms to the rest of the firms in the economy.
- But, rather than using input-output data, we take advantage of the rich firm-to-firm transaction data.
- Formally, we say that
  - a firm i is **downstream** related to a firm j when firm i is a direct or indirect **supplier** of firm j.
  - a firm i is **upstream** related to a firm j when firm i is a direct or indirect **buyer** of firm j.

Downstream centrality measure

- We measure the supplier or downstream centrality of a given firm i as

$$Supplier_i = \sum_{j=1}^{N} \Psi_{ji} \tag{7}$$

where Ψji is an element of the Leontief-Inverse matrix defined as

$$\Psi = (I - \Omega)^{-1} = \sum_{s=0}^{\infty} \Omega^s$$

$$\Omega_{ji} = \frac{P_i M_{ij}}{P_j Q_j}$$

  - Ω_{ji}: represents the share of intermediates that firm i supplies to firm j as a fraction of firm j's sales (direct importance of producer i as a supplier to producer j).
  - Ψ_{ij}: represents the importance of producer i as a direct or indirect supplier to producer j.
  - $Supplier_i$: adds across all buyers of goods i and measures the producer's i importance as as supplier to the economy after considering direct and indirect linkages.

Downstream centrality measure

- In the same fashion, we measure the customer or upstream centrality of a firm i as

$$Customer_i = \sum_{j=1}^{N} \tilde{\Psi}_{ij} \tag{8}$$

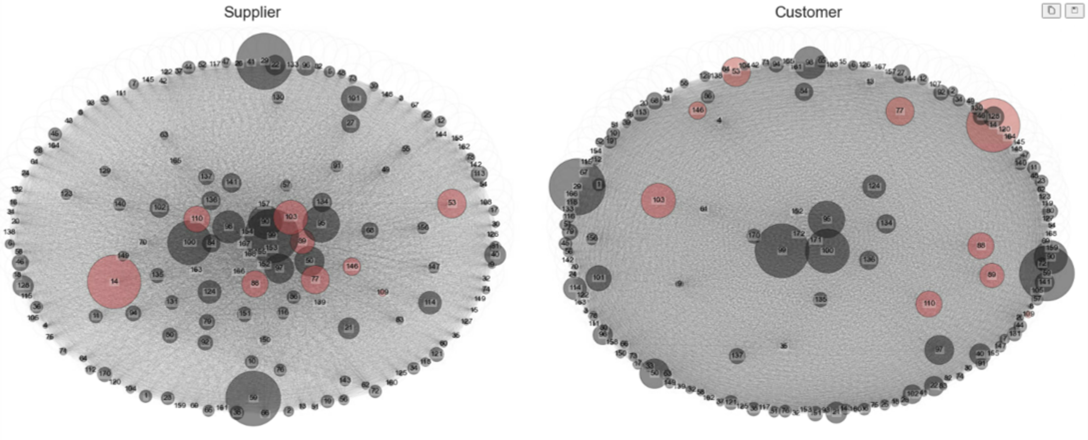
where $\tilde{\Psi}ij$ is an element of the matrix defined as

$$\tilde{\Psi} = (I - M)^{-1} = \sum_{s=0}^{\infty} M^s$$

$$M_{ij} = \frac{P_j M_{ji}}{P_j Q_j}$$

  - M_{ji} represents the share of intermediates that firm i buys from firm j as a fraction of firm j's sales (direct importance of firm i as a buyer to producer j).
  - $\tilde{\Psi}_{ji}$ represents the importance of firm i to producer j as a direct and indirect buyer.
  - $Customer_i$: adds across all suppliers to firm i and measures the importance of firm i as as buyer to the economy after considering direct and indirect linkages.

Inter-sectoral Linkages for the Chilean Economy in 2022



- Electricity generation and transport firms are located at the center of the supplier network with rich downstream connections. Mining firms are located in the outer part of the network with rich upstream connections.

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Empirical analysis - Reduced Form approach (work in progress)

- We are now working on studying how fossil price shocks propagate from fuel-consuming sectors to the rest of the economy through input-output linkages.
- Following the literature on the transmission of international commodity price shocks via production networks (e.g., Silva et al. (2024)), we focus on the responses of non-fossil fuel burning firms in prices and quantities to fossil fuel price shocks affecting firms in the burning sectors.
- We plan to take advantage of the previously constructed downstream and upstream centrality measures to estimate the dynamic responses conditional on the initial production network.
- Using the estimated elasticities w.r.t. fossil fuel price shocks, we can simulate the propagation of a carbon tax via the production network, which is the ultimate goal.

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To conclude

- This project uses unique Chilean administrative data to shed light on how production networks might shape the macroeconomic impacts of a carbon tax.
  1. Using customs and F-F transaction data, we build the fossil fuel consumption and the direct CO2 emissions at the firm-, sector- and aggregate-level. Electricity generation sector is the most important contributor to direct aggregate CO2 emissions, followed by the manufacturing, transport, and mining sectors.
  2. The carbon footprint and production network analysis show that electricity generation and transport sectors are also central in the supplier network, having potential significant downstream spillover effects. Mining sector is located in the outer part of the customer network with rich upstream connections.
- These results suggest that policies such as a carbon tax targeting the key contributor firms might have potentially important general equilibrium effects due to their location and rich connections with the rest of the firms in the network.

References I

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. “The Environment and Directed Technical Change.” *American Economic Review* 102 (1): 131–66. 10.1257/aer.102.1.131.

Acemoglu, Daron, Ufuk Akcigit, and William Kerr. 2015. “Networks and the Macroeconomy: An Empirical Exploration.” In *NBER Macroeconomics Annual 2015, Volume 30*, 273–335, University of Chicago Press, . 10.1086/685961.

Aghion, Philippe, Lint Barrage, David Hemous, and Ernest Liu. 2024. “Transition to Green Technology along the Supply Chain.” *INSEAD Working Paper No. 2024/15/EPS*. http://dx.doi.org/10.2139/ssrn.4771374.

Aghion, Philippe, Antoine Dechezleprêtre, David Hémous, Ralf Martin, and John Van Reenen. 2016. “Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry.” 124 (1): 1–51. 10.1086/684581, Publisher: The University of Chicago Press.

References II

Avilés-Lucero, Peraita G., F., and C. Valladares. 2021. "Huella de Carbono para la Economía Chilena 2017." *Studies in Economic Statistics N°135, Central Bank of Chile* (2): .

Cellura, Maurizio, Sonia Longo, and Marina Mistretta. 2012. "Application of the Structural Decomposition Analysis to assess the indirect energy consumption and air emission changes related to Italian households consumption." 16 (2): 1135–1145. 10.1016/j.rser.2011.11.016.

Cohen, Claude, Manfred Lenzen, and Roberto Schaeffer. 2005. "Energy requirements of households in Brazil." 33 (4): 555–562. 10.1016/j.enpol.2003.08.021.

Finkelstein Shapiro, Alan, and Gilbert E. Metcalf. 2023. "The macroeconomic effects of a carbon tax to meet the U.S. Paris agreement target: The role of firm creation and technology adoption." 218 104800. 10.1016/j.jpubeco.2022.104800.

King, Maia, Bassel Tarbush, and Alexander Teytelboym. 2019. "Targeted carbon tax reforms." 119 526–547. 10.1016/j.euroecorev.2019.08.001.

References III

Liu, Ernest. 2019. “Industrial Policies in Production Networks*.” *The Quarterly Journal of Economics* 134 (4): 1883–1948. 10.1093/qje/qjz024.

Metcalf, Gilbert E., and James H. Stock. 2020. “Measuring the Macroeconomic Impact of Carbon Taxes.” 110 101–106. 10.1257/pandp.20201081.

Silva, Alvaro, Petre Caraiani, Jorge Miranda-Pinto, and Juan Olaya-Agudelo. 2024. “Commodity prices and production networks in small open economies.” *Journal of Economic Dynamics and Control* 168 104968. https://doi.org/10.1016/j.jedc.2024.104968.

Wood, Richard, and Christopher J. Dey. 2009. “Australia’s Carbon Footprint.” 21 (3): 243–266. 10.1080/09535310903541397, Publisher: Routledge _eprint: https://doi.org/10.1080/09535310903541397.

Zheng, Haitao, Qi Fang, Cheng Wang, Huiwen Wang, and Ruoen Ren. 2017. “China’s Carbon Footprint Based on Input-Output Table Series: 1992–2020.” 9 (3): 1–17, `https://ideas.repec.org//a/gam/jsusta/v9y2017i3p387-d92278.html`.