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

[Preliminary Draft - Please do not circulate]

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Abstract

This project uses unique Chilean administrative data to shed light on how production networks might play a key role in shaping the macroeconomic impacts of a carbon tax. First, using customs and firm-to-firm transaction data that covers the universe of firms in Chile, we build the fossil fuel consumption and the direct CO2 emissions at the firm, sectoral, and aggregate levels. In line with the official national sources, the electricity generation sector is the most important contributor to aggregate CO2 emissions, followed by the manufacturing, transport, and mining sectors. Then, to study the potential spillovers arising from the input-output linkages, we estimate the carbon footprint by economic and final use sectors and we complement the analysis by constructing the production network at the firm level. The results show that electricity generation is a central sector in the network, having potential significant downstream spillover effects, while the mining sector is located in the outer part of the network with rich upstream connections. These results suggest that a carbon tax targeting the key contributor firms might have potentially important spillover effects due to their location and rich connections with the rest of the firms in the network.

*The views expressed are those of the author and do not necessarily represent the views of the Central Bank of Chile or its board members. The CBC has access to anonymized information from various public and private entities, by virtue of collaboration agreements signed with these institutions.

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1 Introduction

In order to achieve the commitments of CO2 emissions reduction established in the Paris Agreement 2015, economies worldwide are accelerating the decarbonization process by implementing mitigation policies such as carbon taxes. The impacts of such transition are expected to be heterogeneous among industries and firms with potential aggregate effects depending on the role that the targeted firms play in the economy.

Motivated by this context, this project aims to provide a better understanding of how the macroeconomic impacts of green transition policies, such as a carbon tax, can be shaped by the input-output linkages in the economy.

To do so, first, we start building the primary fossil fuels consumption base as the total imports of fossil fuels using Chilean customs data at a monthly frequency.[1] Then, to account for the fact that an important fraction of the imported fossil fuels in Chile corresponds to crude oil that is refined and transformed into other types of fuels (e.g., gasoline), we use the Chilean IRS firm-to-firm transaction data to identify each type of fossil fuel that is refined and sold to the firms in the economy. This allows us to build the consumption base of fossil fuels that will be burned by firms and households in Chile every month and to apply CO2 emission factors to each type of fossil fuel. We use the emission factors reported by the Intergovernmental Panel on Climate Change (IPPC) to do the latter.

This is the first result and contribution of this paper: we build monthly data series for fossil fuel consumption and direct CO2 emissions at the aggregate and sectoral levels, as well as disaggregated data for each type of fossil fuel, for the period January 2005 - December 2022. In order to construct these series and avoid double counting issues, we identify the firms that burn fossil fuels in the firm-to-firm transaction data as those that satisfy two conditions: i) they purchase at least one type of fossil fuel to use it as an input at their production stage, ii) their output is not a fossil fuel. Our results show that the electricity generation, manufacturing, transport, and mining sectors are the most fossil-intensive sectors, accounting for 43%, 33%, 12%, and 6% of total direct CO2 emissions in Chile in 2022, respectively. Therefore, these sectors are responsible for almost 95% of the direct aggregate

[1] In Chile, the total primary consumption is well approximated by fossil fuel imports because around 95% of the total fossil fuels that is burned is imported.

CO_2 emissions. Within the electricity generation sector, most of the direct CO_2 emissions are associated with coal-based generation. These results are consistent with those reported by the Chilean National Energy Balance (NEB) report and the National Greenhouse Gas Emissions Inventory (NGHGI), but our advantage from using administrative data from the Chilean IRS is that we can produce this series almost in real-time, with just two months of lags, which is two years ahead of the official sources.

Next, we turn the analysis to study the carbon footprint associated with each economic sector and the final use sectors. We follow closely the approach developed by Avilés-Lucero and Valladares (2021). To construct the carbon footprint at the sectoral level, we complement the direct CO_2 emissions data previously constructed with input-output data. This allows us to redistribute the previously estimated direct CO_2 emissions of each economic sector according to the input-output linkages and the final use in the aggregate demand. The results in terms of carbon footprint are different from those of the direct CO_2 emissions. The direct CO_2 emissions from the electricity generation sector are redistributed toward all the other sectors, leading to a major increase in the emissions associated with the mining sector. The emissions from the manufacturing sectors are absorbed by industries from the same sector, leaving them with a similar amount of indirect and direct emissions. In contrast, the indirect emissions of the transport sector are smaller than its direct emissions, a change that is driven by the use of retail and manufacturing sectors. Finally, the retail sector increases its emissions mostly because it absorbs a fraction of the CO_2 emissions produced by the electricity generation and transport sectors.

Regarding the carbon footprint of the aggregate demand components, the results show for 2022 that private consumption accounts for 47% of total emissions, with this component absorbing emissions from all the productive sectors of the economy according to the household consumption basket. It is followed by exports, which absorb almost 40% of total emissions, driven mostly by the emissions of the mining and manufacturing sectors. Investment accounts for 11% of the aggregate emissions, while the government component is responsible for the remaining 2%.

Next, to shed more light on how the key contributors of direct CO_2 emissions are connected to the other economic sectors in the economy, we take advantage of our rich firm-to-firm transaction data to construct the production network of the universe of firms in the Chilean economy. The results show, consistently with the previous carbon footprint exercise performed using the input-output matrix, that firms in the electricity generation and transport sectors are located at the center of the network. This implies that whatever happens with these sectors will not only have an impact on their direct buyers but also indirect effects on other firms in the economy due to the downstream propagation throughout the input-output linkages. In contrast, the mining sector is located at the outer border of the network because its production is mainly sold abroad. Still, firms in the mining sector are strongly connected with domestic firms by buying their products as intermediate inputs, so whatever happens in the mining sector will be propagated upstream throughout the network.

These results have some important implications for policies fostering the green transition. Suppose a carbon tax is implemented on the direct CO2 emissions generated at the production stage. In that case, the direct effects will depend on the emission intensity of the targeted firms. However, the total macroeconomic impact will be determined by the downstream and upstream propagation to the rest of the firms in the economy shaped by the input-output linkages. Therefore, 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.

Finally, we present a future work section in which detail a proposed quantitative empirical approach to study the sectoral propagation of fossil fuel price shocks, and ultimately of a carbon tax.

The rest of the document is organized as follows. Section 2 summarizes the related literature and contributions. Section 3 presents the quantitative analysis, including the construction of the primary fossil fuel consumption and aggregate CO2 emissions, the estimation of the carbon footprint by economic sector and final use, and the construction of the production network and the resulting input/output linkages. Section 4 presents a discussion the next steps to perform a quantitative empirical analysis. Section 6 concludes.

2 Related Literature and Contributions

Our paper is expected to contribute to two strands in the literature. First, it relates to the literature aimed to estimate the carbon footprint by economic sector and final use. At the international level, studies on household energy consumption and its effect on CO2 emissions are found for Korea (?), Brazil (Cohen et al. (2005)) and Italy (Cellura et al. (2012)), among others. For Australia, (Wood and Dey (2199)) presents a complete description of the footprint at the industry level and (Zheng et al. (2017)) performs a similar analysis for China. The closest work to ours is Avilés-Lucero and Valladares (2021) who estimates the carbon footprint at the sectoral level and by final demand component for the Chilean economy in 2017. However, all these works rely on official national sources of fossil fuel consumption to estimate the direct CO2 emissions and input-output tables to perform the analysis. Our contribution to this strand of the literature is twofold. By using firm-to-firm transaction data from the Chilean IRS, we are able to estimate the direct CO2 emissions in almost real-time, two years ahead of what is reported by Chilean official national sources for fossil fuel consumption and CO2 aggregate emissions, and producing granular information at the firm level rather than at the sectoral level. In addition, we are able to build the production network at the firm level, which allows us to study the downstream and upstream effects over the network from implementing environmental policies such as a carbon tax, something not feasible with the input-output sectoral data.

Second, our work also relates to the literature on the macroeconomic implications of climate change mitigation policies. Empirical work estimating the economic effects of carbon taxes with sectoral-level data has found the increase in energy prices as the primary channel by which this policy affects economic activity, employment, and inflation (e.g., Metcalf and Stock (2020)). Structural work has highlighted the role of endogenous green technology adoption as a critical channel to reduce these negative economic impacts (e.g., Acemoglu et al. (2015); Aghion et al. (2016); Finkelstein Shapiro and Metcalf (2023)). We contribute to this work by incorporating production networks into the analysis to capture the amplification and propagation effects arising from intersectoral input-output linkages and the spillover effect on CO2 emissions. A closely related work is , which shows that in the presence of intersectoral linkages, targeted King et al. (2010) sectoral carbon taxes might be a more effective way of reducing emissions than economy-wide carbon pricing.

3 Quantitative Analysis

There are three main tasks to be performed. First, we need to build the primary fossil fuel consumption base that will be burned by firms and households producing CO2 emissions. Second, we work with the inverse Leontief to the Chilean input-output matrix to estimate the carbon footprint by economic sector and aggregate demand component. Finally, we construct a production network using firm-to-firm transaction data to study where key CO2 emission sectors are located from a supplier and buyer perspective.

3.1 Data Description

Custom data

Chilean customs data provides the universe of transactions for imported goods. This data includes the importer's identifier, the product HS code, the quantity, and CIF and fob prices for the transaction. The provided HS code has 8 digits, which enable us to map it directly to fossil fuels described in the IPCC guidelines, hence obtaining its corresponding emission factor allowing us to estimate its global warming potential.

Firm-to-firm transaction data

The data is obtained from Electronic Invoices (EI), which have been mandatory for large firms since 2015. The EI includes unique identifiers for the seller and buyer, the total transaction value, the transaction date, and several other variables. It also includes a free text description of the good or service traded, the price and quantity for each item included in the EI, and other variables. We use a Machine Learning algorithm to classify each item description into standardized classes defined by classifiers like the Central Product Classification 2 (CPC2) and the Unique Product Classification (UCP. A simplified version of CPC2 adapted to Chile), further details about this methodology and its results are described in Acevedo et al. (work in progress). This allows us to identify fossil fuels in firm-to-firm transactions.

Table 1. DTE 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 canceled electronic invoices. M: Monthly average; Y: Yearly average; Total includes all data. Modified from Acevedo et al. (work in progress).

National Balance of Energy

The National Balance of Energy is published yearly and reports the total energy available in Chile, how it was used, and by whom. It includes data regarding imports: crude oil, oil derivatives, carbon, etc., the local transformation from crude oil into oil derivatives, and which industries or final consumption sectors use each fuel or energy.

The National Greenhouse Gases Inventory

It is the official Chilean report regarding Greenhouse gas emissions and Carbon Sequestration. It uses as one of its main data sources the National Balance of Energy. It reports emissions and sequestration for five categories: Energy (it considers all activities that directly burn fuel, we compare our results to this section); Industry Processes and Product Use (it accounts for all emissions not directly related to fuel burning); Agriculture; Land use, Land use change and forestry; Waste. The report is published every two years with a 3 or 4-year lag (2019-2020 data was published in 2023).

3.2 Primary Fossil Fuel Consumption Base and Aggregate CO2 Emissions

Primary Fossil Fuel Consumption: Construction with Custom Data

A 95% of the total fossil fuel that is burned in Chile is imported. Therefore, we use Custom Chilean administrative data to construct the primary fossil fuel consumption base. Custom data provides information with standardized classification codes for the imported products, which allows us to identify all the different types of fossil fuels defined in the IPPC guidelines. In addition, because an important fraction of the imported fossil fuels in Chile corresponds to crude oil that is refined and transformed into other types of fuels (e.g., gasoline), we use the Chilean IRS firm-to-firm transaction data to identify each type of fossil fuel that is refined and sold to the firms in the economy.

After building the primary consumption data for each type of fossil fuel, we proceed to estimate the CO2 emissions by applying the corresponding IPPC emission factors. We compare our estimates with the official ones reported by the NBE. The results are presented in Figure 1. We aggregate each type of fossil fuel in categories and produce the series in annual frequency to be able to compare it with NBE reports. The upper panel shows the official series reported by the NBE for the period 2005-2021, and the lower panel shows our series constructed with Custom data, everything expressed in units of teracalories. Our results are ahead of BNE data by one year because the official BNE data is released with a lag of two years.

We can observe very similar trajectories for each fossil fuel category and also for the aggregate. We take this successful comparison as a validation for our data construction approach. In particular, crude oil and coal stand out as the most important components of fossil fuels consumption in Chile, and the aggregate consumption of fossil fuels exhibits a slightly increasing trend but with a switch in the composition in the last years from coal and crude oil to natural gas.

Aggregate CO2 Emissions and by Fossil Fuel Type

Next, we construct the CO2 emission data for each type of fossil fuel, for each economic sector, and for the aggregate. We start by constructing the direct CO2 emissions at the firm level. In order to avoid double counting issues, we identify the firms that burn fossil fuels in the firm-to-firm transaction data as those that satisfy two conditions: i) they purchase some type of fuel from other firms to use it as an input at their production stage, ii) their output is not a fossil fuel. The resulting estimates correspond to the direct CO2 emissions at the firm level, which is constructed according to equation 1.

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

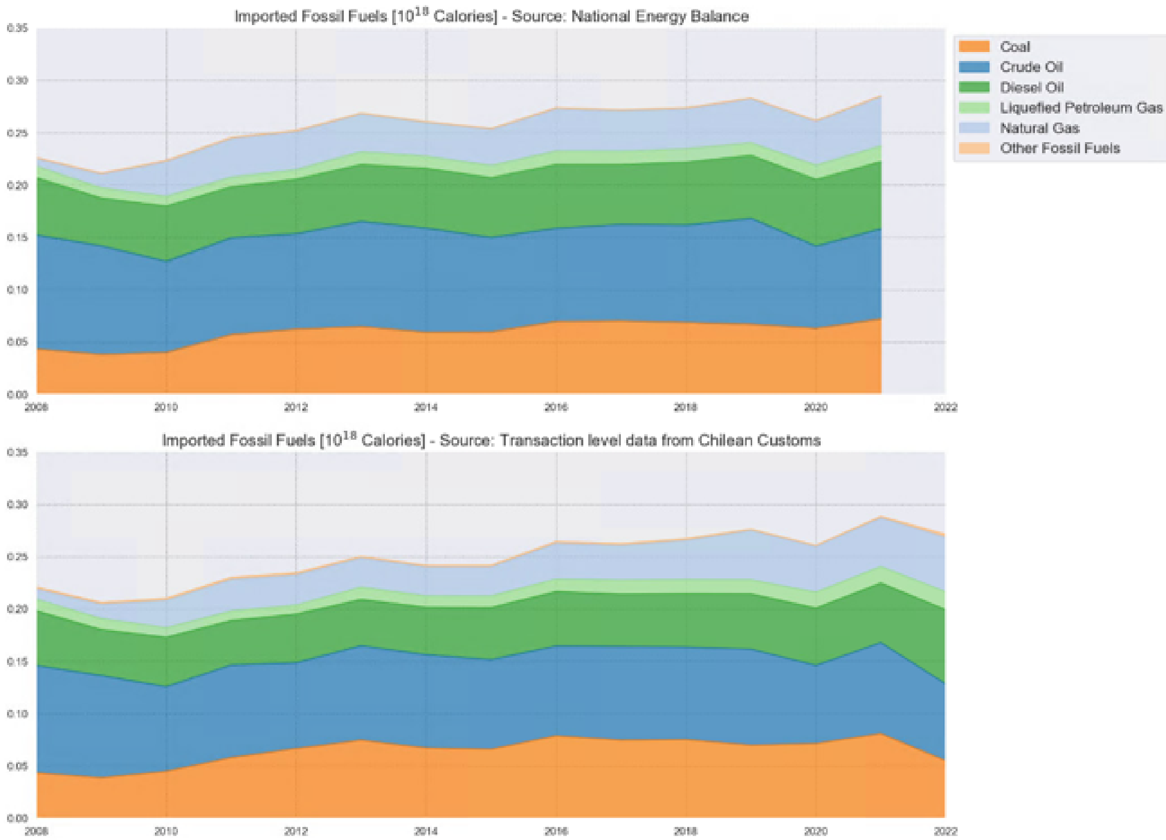

Figure 1. Primary Fossil Fuel Consumption

where Emissions_{ijt} is the CO2 emissions of firm i associated with burning a fossil fuel of type j at time t. Fossil Fuel_{ijt} corresponds to the quantity of fossil fuel type j burn by firm i at time t. Emission Factor_j is the emission factor reported by the IPPC guidelines for fossil fuel of type j.

Then, we construct the CO2 emissions at the sectoral level as the sum of the direct CO2 emissions of all firms belonging to each sector, as it is shown in equation 2.

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

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

In a similar way, the aggregate CO2 emissions by type of fossil fuels are computed as the sum of the sectoral emissions, according to equation 3.

$$\text{Emissions}_{jt} = \sum_{i=1}^{N} \text{Emissions}_{ijt} \tag{3}$$

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

Finally, we compute the aggregate CO2 emissions as the sum of the emissions of each type of fossil fuel following equation 4.

$$\text{Emissions}_{t} = \sum_{j=1}^{N} \text{Emissions}_{jt} \tag{4}$$

where Emissions_t corresponds to the aggregate CO2 emissions at time t.

Figure 2 presents the aggregate CO2 emissions for Chile between 2005 and 2022. The orange line corresponds to our data in monthly frequency, and the blue line corresponds to the official NGHGI data reported at annual frequency, which is available only until 2019. In line with the previous primary fossil fuels consumption results, our estimates for the national CO2 emissions show a very similar trajectory to the one reported by the NGHGI, with just small differences in the levels.

The fact that our data advances in at least two years the official source is an important contribution, that allows us to inform in almost real-time the effectiveness of policies aimed at fostering the decarbonization of the Chilean economy.

The results for the national CO2 emission disaggregated by type of fossil fuel are presented in Figure 3. In line with the primary fossil consumption results, we observe that crude oil and coal account for the most part of the national CO2 emissions. We can also note that in the last years, there has been a reduction in the CO2 emissions associated with crude oil and coal, which responds to the decrease in the use of this type of fuel in the electricity generation sector due to the growing penetration of non-conventional renewable technologies. The comparison for the most important fossil fuel types between our data and the reported by NBE is presented in Figure 8 in the Appendix.

Finally, Figure 4 shows the results for the national CO2 emissions disaggregated by economic sector. Our results show that the electricity generation, manufacturing, transport,

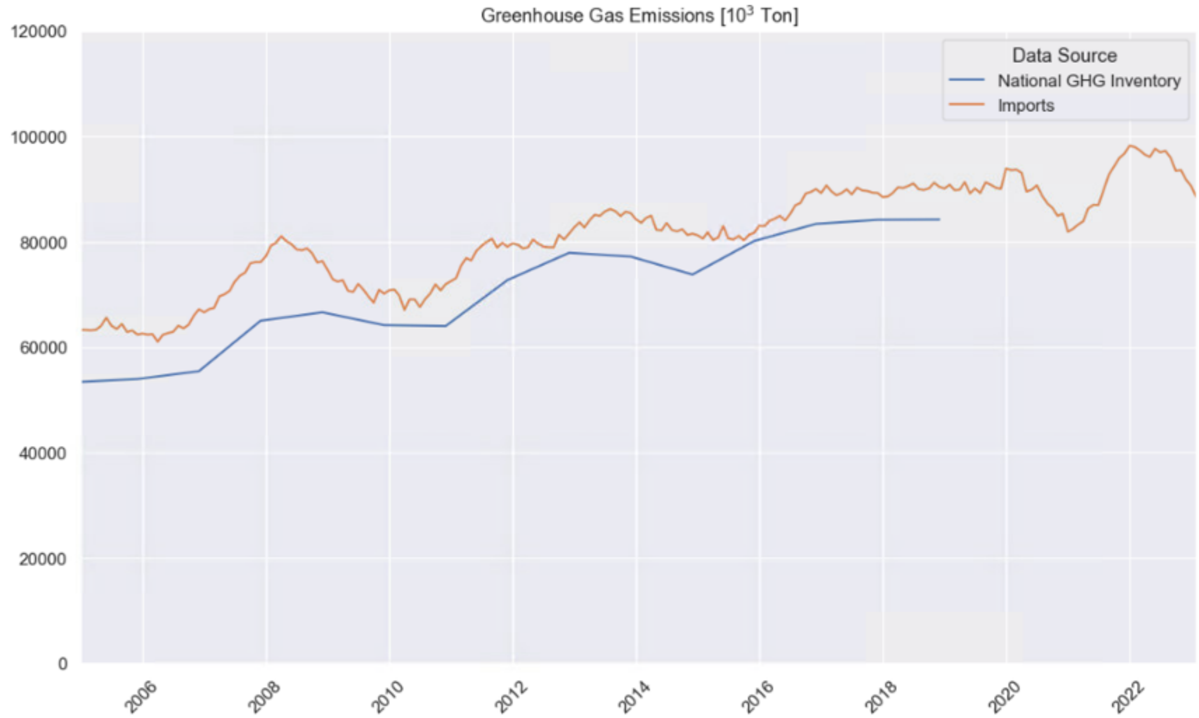

Figure 2. Chilean Aggregate CO2 Emissions

and mining sectors are the most fossil-intensive sectors, accounting for 43%, 33%, 12%, and 6% of total direct CO2 emissions in Chile in 2022, respectively. Therefore, these sectors are responsible for almost 95% of the direct aggregate CO2 emissions. Within the electricity generation sector, coal-based generation is the biggest contributor to the CO2 emissions generated by this sector.

3.3 Carbon Footprint by Economic Sector and Final Use

The previous results at the sectoral level (Figure 4 correspond to the direct CO2 emissions, i.e., we identified the firms that burn fossil fuels, and we attributed the CO2 emissions to the sector they belong. From a policymaker perspective, this is an important result. For instance, might be desired to impose a carbon tax on those firms with a higher level of direct CO2 emissions. However, another interesting question is to know what other firms in the economy will be indirectly affected by such a policy. Acknowledging that input-output linkages play a key role in propagating the direct effect from the targeted firms throughout the rest of the economy, our first approach to address this question is to use the Chilean input-output

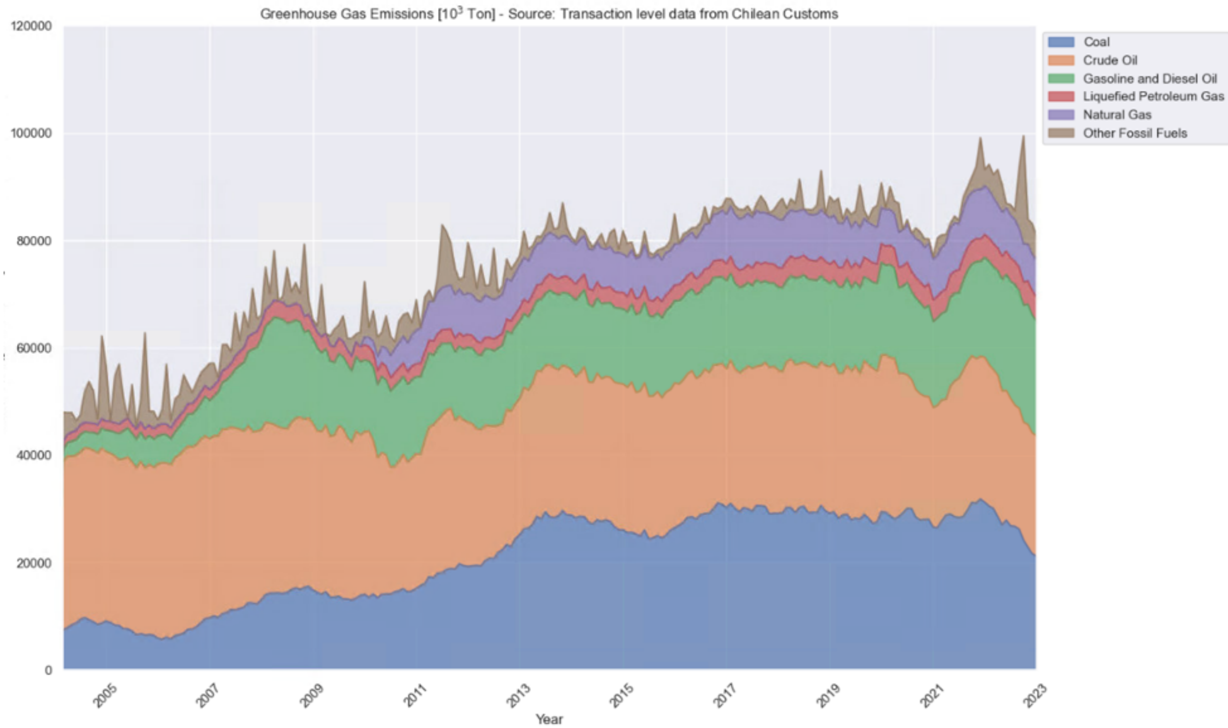

Figure 3. CO2 Emissions by Fossil Fuel Type

matrix to study which are the more connected sectors to those with a high level of CO2 direct emissions. In other words, we need to estimate the carbon footprint of each sector in order to understand how the initial direct CO2 emissions estimated at the sectoral level are absorbed by other sectors in the economy throughout the intersectoral linkages.

Data Construction and Empirical Approach

To perform the analysis, we use the Chilean input-output matrix 2018 that provides disaggregated information for 181 products and 111 activities, and we work with the intermediate imported inputs matrix and the final use of the imported inputs matrix.[2] The former provides information on the use that each economy activity gives to each imported intermediate good, while the latter shows the final use associated with private consumption, investment government expenditure, and exports.

First, we apply the intermediate imported inputs matrix to our previously constructed

[2]The Chilean input-output matrix data is available at https://www.bcentral.cl/web/banco-central/cuentas-nacionales-anuales-excel

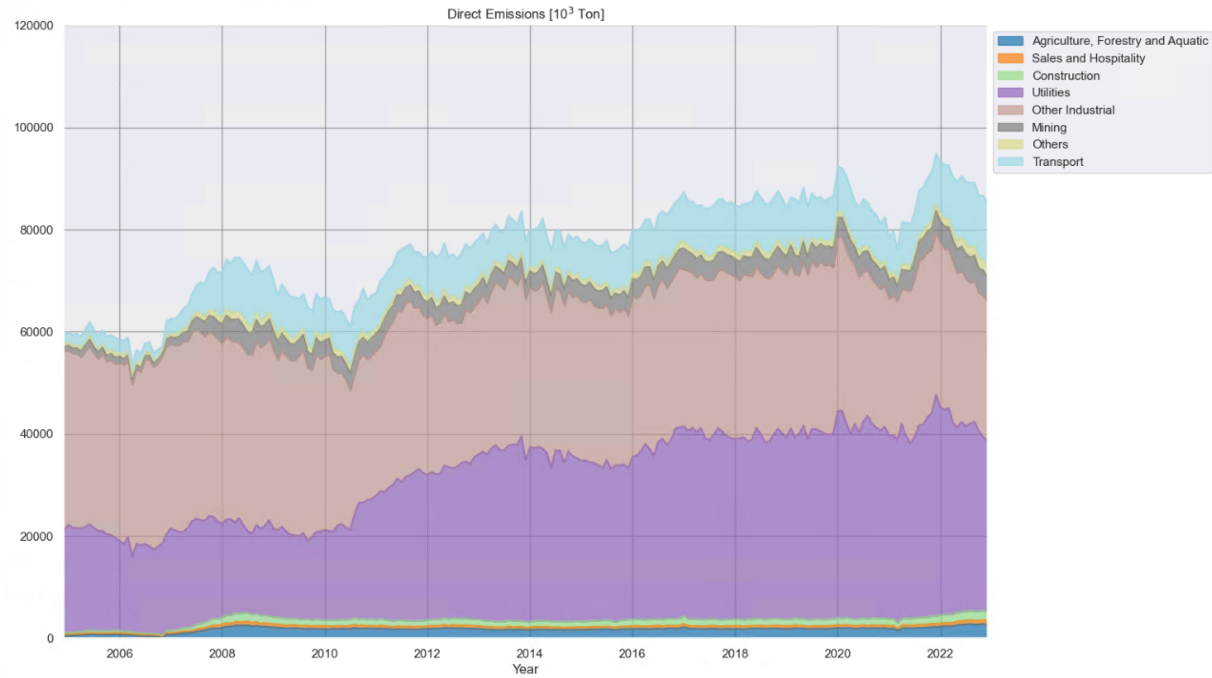

Figure 4. Direct CO2 Emissions by Economic Sector

primary fossil fuel consumption base. The resulting matrix shows which are the sectors that burn the imported fossil fuels. Formally, for the N sectors in the economy, denoted by $i \in \{1, ..., N\}$, we calculate their direct CO2 emissions e_s expressed in tons of CO2. Then, the resulting vector of CO2 emissions for all the sectors in the economy is given by $e = (e_1, ..., e_N)$.

Then, We follow closely the approach developed by Avilés-Lucero and Valladares (2021), in which the widely used input-output model proposed by **?** is extended with CO2 emissions to compute the carbon footprint. According to the input-output model, the total production of goods q in the economy can be expressed as in equation 5.

$$q = Aq + y \tag{5}$$

where A (NxN) is the matrix of the direct coefficient, with the columns showing the quantity of inputs required to produce one unit of q. The final demand is represented by y, which corresponds to the sum of private consumption, investment, government expenditure, and exports. Equation 5 shows that total output has two possible uses: as intermediate inputs for the production of other goods or services Aq or as part of the final demand y. Equation 5 can be rewritten as it is shown in equation 6.

$$q = (I - A)^{-1} y \tag{6}$$

where the matrix $L = (I - A)^{-1}$ is known as the inverse-Leontief, and its elements show the impact of an exogenous increase in the final demand on the production of each economic sector. For instance, l_{ij} corresponds to the quantity of input in sector i needed in the production of sector j for a unit of good j that is used in the final demand.

Now, we can augment this model with the vector of the sectoral direct CO2 emissions e. If a sector j demands a quantity $l_{ij} y_j$ of intermediate inputs from sector i in order to sell one additional unit to the final demand sector, the direct emissions generated in sector i are given by $e_i l_{ij} y_j$. Then, if we sum all the direct emissions of all the sectors $i \in \{1, ..., N\}$ that sell intermediate inputs to the sector j we get the indirect emissions associated with the production of sector j, Ej. This is also what we know as the carbon footprint of sector j. Then, the extended model to estimate the sectoral carbon footprint can be expressed as it is shown in equation 7.

$$E = e(I - A)^{-1} y = eLy \tag{7}$$

Results

Here we present the resulting carbon footprint by economic sector and final use. Figure 5 shows the carbon footprint disaggregated by economic sector. The results in terms of carbon footprint are different from those of the direct CO2 emissions in Figure 4. The direct CO2 emissions from the electricity generation sector are absorbed almost completely by all the other sectors in the economy. This transfer of emissions leads to a major increase in the emissions associated with the mining sector. The emissions from the manufacturing sector are absorbed mostly by industries from the same sector, leaving it with a similar amount of indirect and direct emissions. In contrast, the indirect emissions of the transport sector are smaller than its direct emissions, a change that is driven by a transfer of emissions toward the retail and manufacturing sectors. Finally, the retail sector increases its emissions mostly because it absorbs a fraction of the CO2 emissions produced by the electricity generation

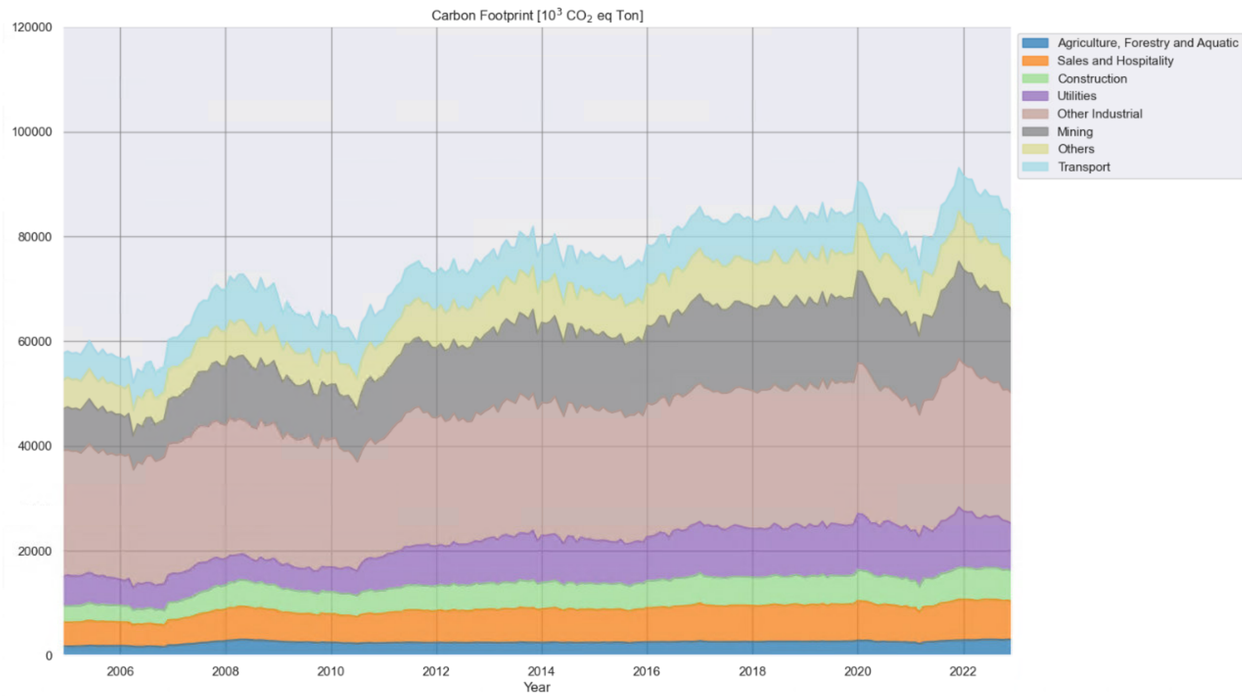

Figure 5. Carbon Footprint by Economic Sector

and transport sectors.

Regarding the carbon footprint of the aggregate demand components, the results in Figure 6 show for 2022 that private consumption accounts for 47% of total emissions, with this component absorbing emissions from all the productive sectors of the economy according to the household consumption basket. It is followed by exports, which absorb almost 40% of total emissions, driven mostly by the emissions of the mining and manufacturing sectors. Investment accounts for 11% of the aggregate emissions, while the government component is responsible for the remaining 2%.

3.4 Production Network and Centrality Measures

In order to give more light on how the key contributors of direct CO2 emissions are connected to the other economic sectors in the economy, we take advantage of our rich firm-to-firm transaction data to construct the supplier and consumer networks for the universe of firms in the Chilean economy. To do so, we follow the approach proposed by Acemoglu et al. (2015).

We define downstream and upstream centrality measures in the following way. It is said

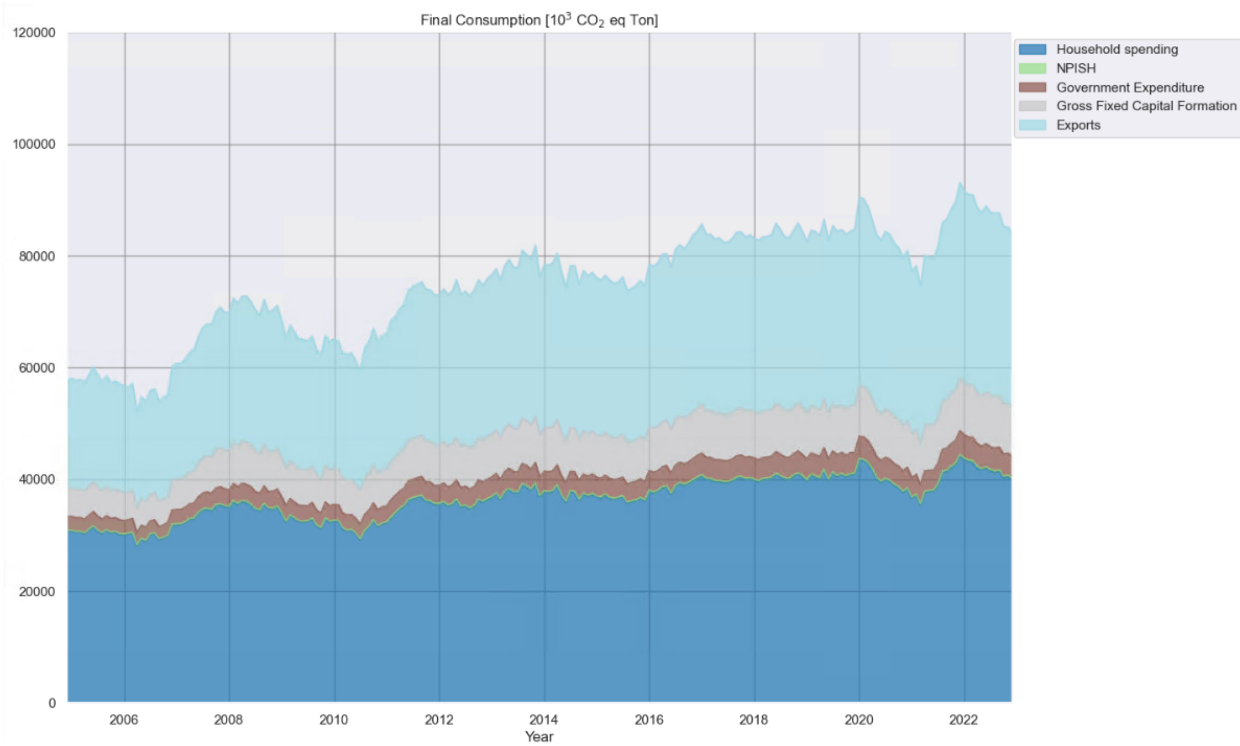

Figure 6. Carbon Footprint by Final Use

that a firm i is downstream related to a firm j when firm i is a direct or indirect supplier of firm j. Being a direct supplier implies that firm j buys the good from firm i to be used as intermediate input in its production process. Similarly, a firm i is upstream related to a firm j when firm i is a direct or indirect buyer of firm j.

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

$$Supplier_i = \sum_{j=1}^{N} \Psi_{ji} \tag{8}$$

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

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

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

An element Ω_{ji} represents the share of intermediates that firm i supplies to firm j ($P_i M_{ij}$)

as a fraction of firm j's sales (P_jQ_j). This shows the direct importance of producer i as a supplier to producer j. Then, an element Ψ_{ij} represents the importance of producer i as a direct or indirect supplier to producer j. This idea is shown precisely by the infinite sum of the direct and indirect linkages across producers. $Supplier_i$ 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.

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

$$Customer_i = \sum_{j=1}^{N} \tilde{\Psi_{ij}} \tag{9}$$

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

$$\tilde{\Psi} = (I - M)^{-1} = \sum_{s=0}^{\infty} M^s$$
$$M_{ij} = \frac{P_j M_{ji}}{P_j Q_j}$$

An element M_{ji} represents the share of intermediates that firm i buys from firm j (P_jM_{ji}) as a fraction of firm j's sales (P_jQ_j). This shows the direct importance of firm i as a buyer to producer j. Then, an element $\tilde{\Psi_{ji}}$ represents the importance of firm i to producer j after considering direct and indirect linkages. $Customer_i$ 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.

Using firm-to-firm transaction data, which correspond to the electronic invoices registered by the Chilean IRS, we construct both *Supplier* and *Customer* centrality measures. [3] The results are presented in Figure 7, at a 170 industry level of disaggregation. We also identify the top 10 industries that are largest contributors to aggregate CO2 emissions by burning directly fossil fuels in their productive processes, which are are highlighted in red.

Consistently with the previous carbon footprint exercise performed using the input-output

[3]To secure the privacy of workers and firms, the Central Bank of Chile mandates that the development, extraction and publication of the results should not allow the identification, directly or indirectly, of natural or legal persons. Officials of the Central Bank of Chile processed the disaggregated data. All the analysis was implemented by the authors and did not involve nor compromise the Chilean Internal Revenue Service."

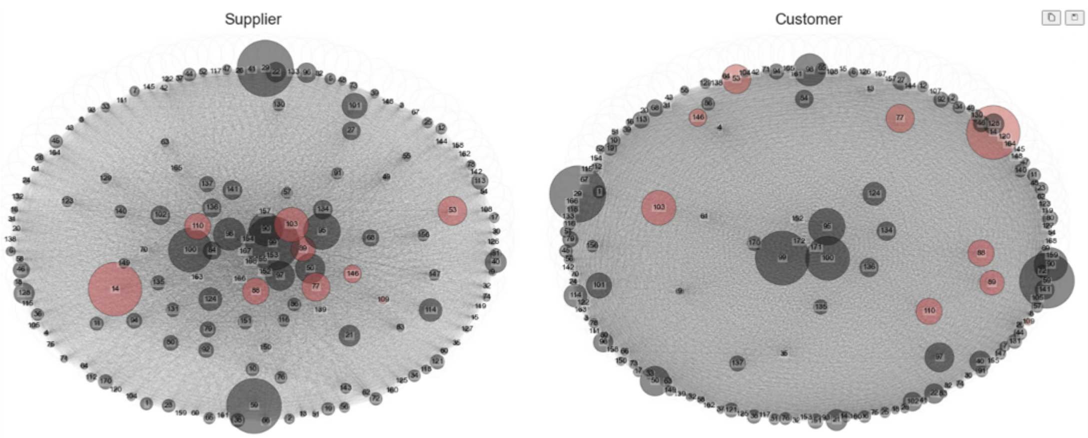

Figure 7. Inter-sectoral Linkages for the Chilean Economy in 2022
An arrow from sector j to sector i represents intermediate inputs flowing from j o i. Each node (circle) is a different sector in the economy, the size of the node represents its sales, and the node location how important that sector is as a direct and indirect supplier (left panel) and buyer (right panel) of intermediate inputs. Top 10 largest contributors to CO2 eq. emissions are drawn in red.

matrix, the results show that firms in the electricity generation and transport sectors are located at the center of the supplier network. This implies that whatever happens with these sectors will not only have an impact on their direct buyers but also indirect effects on other firms in the economy due to the downstream propagation throughout the input-output linkages. In contrast, the mining sector is located at the center of the customer network because its production is mainly sold abroad, but mining firms are strongly connected with domestic firms by buying their products as intermediate inputs, so whatever happens in the mining sector will be propagated upstream throughout the network.

These results have some important implications for policies aimed at fostering the green transition. If a carbon tax is implemented on the direct CO2 emissions generated at the production stage, the direct effects will depend on the emission intensity of the targeted firms, but the total macroeconomic impact will be determined by the downstream and upstream propagation to the rest of the firms in the economy shaped by the input-output linkages.

4 Future work: Quantitative Analysis

The next step of this work is to take advantage of the production network to study the macroeconomic implications of a carbon tax. The propagation of the effects from the targeted industries/firms to the rest of the economy will depend on the network structure. On the one hand, once a carbon tax is implemented, the change in the relative price of the dirty inputs used by the targeted firm is expected to be passed to their chain of buyers, leading to an adjustment of their production and input demand. In other words, a carbon tax should generate a downstream propagation effect throughout the chain of buyers. On the other hand, there might also be an upstream propagation effect through the supply chain if the targeted firms switch their demand from polluting inputs to cleaner ones.

4.1 Fossil fuel price shocks propagation via production networks

This section presents the proposed empirical approach to study the sectoral propagation of fossil fuel price shocks, and ultimately of a carbon tax. Following Acemoglu et al. (2015), we propose a reduced form specification based on downstream and upstream centrality measures built previously to study the propagation of shocks throughout the production network. We follow more closely the framework proposed by Silva et al. (2024), but instead of being interested on studying the propagation of international commodity price shocks from commodity sectors to the rest of the domestic economy, we focus the analysis on understanding how international fossil price shocks are propagated by the burning sectors to the rest of the economy via input-output linkages.[4]

4.2 Reduced form approach

To study the propagation of fossil fuel price shocks via direct and indirect linkages, and taking advantage of the previously constructed upstream and downstream centrality, we propose the following firm-level reduced form specification

$$\Delta logY_{it} = \alpha_i + \delta_t + \delta_{it} + \phi_1 \Delta \tilde{P}_{kt}^{Down} + \phi_2 \Delta \tilde{P}_{kt}^{Up} + \nu X_{it-1} \epsilon_{it} \tag{10}$$

where $\Delta logY_{it}$ is the log deviation of the price or quantities of firm i with respect to its steady state value, α_i, δ_t and δ_{it} correspond to firm, time and firm-time fixed effects. $\tilde{P}_{ikt}^{Down}$ and

[4] Silva et al. (2024) develops a small open economy model with production networks in which firms use labor and domestic and imported goods as intermediate inputs. Instead, we simplify the framework by assuming that firms only use domestic goods and imported fossil fuels as intermediate inputs.

$\tilde{P}_{ikt}^{Up}$ correspond to the sectoral-specific network spillover measures of the sector to which firm i belong. The construction of these measures is detailed below.

4.3 Data construction

First, to estimate equations 10 we need to construct the downstream and upstream sectoral network spillover measures, $\tilde{P}_{ikt}^{Down}$ and $\tilde{P}_{ikt}^{Up}$ respectively. Each one of these measures has three components: a sector-specific centrality ($\Phi_k j$), exposure to fossil fuels (as cost share) and fossil fuel price shocks ($shock_{jt}$). In other words, we convert the upstream and downstream effects into a weighted average of exposures and shocks in other industries using the Leontief inverse elements of weights.

$$\Delta \tilde{P}_{kt}^{Down} = \sum_{j=1}^{N} (\Psi_{jk} * \eta_F * Shock_{jt}) \tag{11}$$

$$\Delta \tilde{P}_{kt}^{Up} = \sum_{j=1}^{N} (\Psi_{kj} * \eta_F * Shock_{jt}) \tag{12}$$

Second, we need to build firm-level price and quantity indexes that are going to be our dependent variables. To do so, we use the electronic invoices from the Chilean IRS to construct weighted average indexes using the ratio of a product sales over total sales as weights. Third, we have to build the exposure of a firm to a fossil fuel price shock for which we use as a proxy the ratio of expenditure in fossil fuels over the total cost in intermediate inputs. Fourth, we need to build the fossil fuel price shocks that will affect each burning sector. For this, we use again the electronic invoices data to construct a weighted average index of the effective fossil fuel price at the sectoral level, in which the weights correspond to the share of each fossil fuel type in the total cost of fossil fuels.

4.4 Carbon tax via production networks

Using the estimated elasticities from the previous exercise, we would be able now turn to address the main question of interest: How does the implementation of a carbon tax affect prices in the economy via the production networks?

The results from the estimated equation 10 will give us he elasticity of how fossil fuel prices changes affect the burning and non-burning sectors in the economy in terms of prices and quantities. Then, by using the emission factor of each type of fossil we can translate the carbon tax of any amount into a fossil fuel price change and use the previously estimated elasticity to predict the change in prices and quantities of any firm/sector in the economy.

5 Conclusions

The impacts of the transition to a low-carbon economy are expected to be heterogeneous among industries and firms, with potential aggregate effects depending on the role that the targeted firms play in the economy. This project aims to provide a better understanding of how the macroeconomic impacts of green transition policies, such as a carbon tax, can be shaped by the input-output linkages in the economy.

First, using customs and firm-to-firm transaction data that covers the universe of firms in Chile, we build the fossil fuel consumption and the direct CO2 emissions at the firm, sectoral, and aggregate levels. In line with the official national sources, the electricity generation sector is the most important contributor to aggregate CO2 emissions, followed by the manufacturing, transport, and mining sectors. The estimated sectoral carbon footprint and firm-level production network show that electricity generation is a central sector, having potential significant downstream spillover effects, while the mining sector is located in the outer part of the 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.

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Figure 8. Primary Fossil Fuel Consumption by Fuel Type