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Carbon taxation and firm behaviour in emerging economies

Evidence from South Africa

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Abstract: This paper provides the first comprehensive analysis of how firms in emerging economies respond to carbon taxation, leveraging detailed administrative data from South Africa—a potential trailblazer for other developing countries with limited state capacity amid the growing global push for carbon pricing. We examine the dynamic impacts of the carbon tax on firm-level outcomes—such as profits, sales, capital, and labour inputs—across manufacturing and mining firms, which are key sectors in the context of the carbon tax. Contrary to concerns that carbon taxes may hinder economic growth or reduce employment, our findings show no evidence of negative average impacts on firm performance or jobs. However, this overall result masks significant heterogeneity in the tax's effects across sectors, driven by the sector-specific design elements of the South African carbon tax. Firms expecting higher effective tax rates may have intensified their use of emission-intensive machinery and depreciated capital in anticipation of the tax. This behaviour appears to stem from firms resolving regulatory uncertainty or seeking to recover costs from stranded assets.

Key words: carbon pricing, carbon tax, firm performance, employment outcomes

JEL classification: H23, Q52, Q58, O13, O55

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1 Introduction

Reducing carbon emissions is essential for combating climate change. Although this is widely recognized and prioritized on policy agendas, global carbon emissions continue to rise (Friedlingstein et al. 2023). Among the various policy tools available to curb emissions, carbon pricing is widely regarded as the most efficient approach (Gordon 2023; Marron and Toder 2014; Timilsina 2022). Yet, implementing carbon pricing—particularly carbon taxes—poses challenges for emerging markets and less developed countries. Many low and middle income countries (LMICs) have so far been reluctant to embrace carbon taxation. One main concern is that a carbon tax may come with negative economic effects and hinder economic development (Strand 2020). LMICs' relatively strong reliance on carbon-intensive energy, their lower levels of technological development and adaptive capacity, and oftentimes weak economic resilience may render them particularly vulnerable to negative economic effects of carbon taxation (Marron and Toder 2014; Metcalf 2021).

This paper provides the first comprehensive analysis of how firms in an emerging economy respond to carbon taxation. It focuses on South Africa, the 13th largest carbon emitter globally and the first African nation to introduce a nationwide carbon tax in 2019. As a potential trailblazer for other developing countries, South Africa's experience is particularly relevant given the growing global emphasis on carbon pricing, with 65 carbon pricing schemes worldwide and 46 more underway (UNFCCC 2024). While carbon pricing can in general take the form of carbon taxes or emissions trading schemes, carbon taxes are easier to implement, which may make them relatively more attractive for LMICs.[1] To make it politically feasible, South Africa introduced its carbon tax with substantial allowances during the initial phase to ease the transition.

Using novel and comprehensive administrative tax data, we analyze the dynamic effects of the policy on firm behaviour. Our findings show that the carbon tax did not negatively affect key firm outcomes such as sales, profits, or employment. Notably, the announcement of the tax—made four years before its implementation—appears to have spurred an increase in firm activity, suggesting anticipatory behaviour.

To quantify the economic impacts of the carbon tax, we examine firm responses to both its announcement and implementation. Our analysis focuses on manufacturing and mining firms, which are key sectors in the context of the carbon tax. Using matching techniques, we address imbalances in observable pre-treatment characteristics between taxed and non-taxed firms.

[1] When relying on a carbon tax, countries can leverage existing tax authorities and target large emitters. But they may face political resistance due to public aversion to new taxes. ETS, on the other hand, are more politically feasible as they allow free distribution of emissions permits to firms, but require establishing and regulating a market, often necessitating a new agency, which can be challenging for developing countries due to limited state capacity.

Our matched sample performs well in terms of trend comparisons between treated and untreated firms, and achieves a matching ratio comparable to a recent study evaluating the EU ETS (Colmer et al. 2024). Based on this matched sample, we estimate event-study regressions to capture the dynamic effects of the tax announcement (draft bill released in 2015) and its implementation (enacted in 2019).

The analysis leverages the universe of corporate income tax returns filed from 2011 to 2021, allowing us to track firms for six years after the release of the draft carbon tax bill and two years following the tax's implementation in 2019.[2] Beginning in 2019, we integrate detailed data on emissions and tax payments with other firm-level tax records. This enables an in-depth analysis of the carbon tax base, which we find covers over 80% of nationwide emissions. Although the statutory tax rate is uniform across industries, we identify significant variation in *effective* tax rates—the amount firms actually pay per tonne of CO_2. Our descriptive analysis reveals a non-linear relationship between emissions and tax payments, driven by the tax's design, which includes allowances, exemptions, and special provisions for certain industries.

The main results indicate that the announcement of the Carbon Tax Bill in 2015 led to increases in sales, capital, employment, and profits. The effects over time are consistent across manufacturing and mining sectors, except for capital, which exhibits a more muted reaction in the mining sector. These positive effects grew gradually and remained significant even after the carbon tax was implemented in 2019. For example, by 2019, sales, capital, employment, and profits had increased by approximately 20%. Contrary to concerns that carbon taxes may hinder economic growth, we find no evidence of negative impacts on firm performance on average. Using a synthetic control approach, however, we provide suggestive evidence that the increased firm activity following the tax announcement coincided with a temporary rise in carbon emissions.

To examine how differences in exposure to the carbon tax influence firm responses, we conduct a heterogeneity analysis. Our findings reveal that firms with fewer allowances—and therefore facing higher *effective* tax rates—experienced significant increases in sales and employment following the tax announcement. In contrast, firms with more allowances showed more muted responses, with estimated effects on sales and employment that are less pronounced and, in some cases, statistically indistinguishable from zero after the tax's implementation. These results might sound counterintuitive because one would typically expect that firms facing higher effective tax rates (due to fewer allowances) would experience negative economic outcomes, given the increased cost burden.

[2] The fiscal year in South Africa begins in March and ends in February of the following year. Therefore, the 2020 fiscal year started in March 2019 and ended in February 2020. This timing means that our estimated effects for 2020 are largely influenced by the implementation of the carbon tax (introduced in June 2019) but remain unaffected by the COVID-19 pandemic, which impacted the subsequent fiscal year.

We explore two mechanisms that could explain these seemingly counterintuitive results. First, the four-year gap between the release of the carbon tax bill and its implementation allowed firms to manage uncertainty, not only by gaining clarity on the future cost of production but also by confirming that there would be no cap on emissions, as long as the tax was paid. This resolution of uncertainty may have enabled firms to plan strategically for the transition. Our findings show that firms with higher exposure to the carbon tax experienced increased sales and significantly higher depreciation following the announcement of the bill. These results suggest that these firms not only used their capital more intensively but also accelerated the depreciation of their emission-intensive machinery in anticipation of the tax. The accelerated depreciation, in particular, likely reflects an effort to mitigate the risk of stranded assets—emission-intensive machinery that could become uneconomical or obsolete under the new tax regime.

As a second potential mechanism, we explore whether the carbon tax incentivized firms to upgrade their production technology. While we find no evidence of increased investments in R&D, treated firms did slightly increase imports between 2018 and 2020. This could suggest they sourced more production inputs from abroad, either to replace domestically taxed inputs or to upgrade their technology. Notably, our analysis shows that, on the intensive margin, treated firms primarily imported products within the same categories as in previous years. However, on the extensive margin, they also introduced new products, indicating some level of technology or product innovation. While we cannot completely rule out technology upgrading, our evidence suggests that this channel is less significant in explaining the substantial effects of the tax announcement and implementation.

This study makes three main contributions to the literature. First, it contributes to the literature on the economic impacts of carbon pricing, which has predominantly focused on cap-and-trade schemes and/or developed world settings (Andersson 2019; Bushnell et al. 2013; Calel and Dechezlepretre 2016; Colmer et al. 2024; Cui et al. 2021, 2023; Dechezlepretre et al. 2023; Martin et al. 2014a,b; Yamazaki 2017, 2022). In contrast, we estimate the impacts of a carbon tax in an emerging economy context, where carbon taxes may be more favorable than cap-and-trade schemes due to limited state capacity.

Second, it contributes to the literature on environmental policy and labour market outcomes, particularly in the context of politically contentious carbon taxes. Market-based approaches, such as carbon pricing, are widely regarded as more cost-effective than command-and-control regulations (Carlson et al. 2000; Fowlie et al. 2012).[3] While command-and-control policies have been shown to reduce employment and earnings in developed economies (Greenstone 2002; Walker 2013), market-based approaches, including carbon taxes, generally do not ap-

[3] Yet carbon taxes often face significant public resistance (Anderson et al. 2023; Douenne and Fabre 2022; Ewald et al. 2022). This resistance is often tied to the tax's distributional implications, which can be politically challenging to defend (Fried et al. 2022; Känzig 2023; Steckel et al. 2021).

pear to adversely affect employment (Martin et al. 2014a; Yamazaki 2017). Our study aligns with this developed world evidence by demonstrating that flexible environmental policies, such as carbon taxes, do not seem to harm economic activity and employment, even in the context of a less developed country with a higher degree of informality.

Third, it contributes to the literature on anticipatory firm behaviour, particularly the so-called 'green paradox', where environmental policies may temporarily worsen environmental outcomes due to pre-emptive actions by firms (Di Maria et al. 2014; Lemoine 2017; Lueck and Michael 2003), unless the output is not storable (Clay et al. 2024). We provide evidence that a carbon tax, even in a setting without emissions caps in the short run, may induce such behaviour. This appears to arise from firms resolving uncertainty or seeking to recover costs from stranded assets, offering new insights into how carbon taxes might influence firm behaviour in the absence of emissions caps.

The remainder of the paper is organized as follows: Section 2 provides an overview of the institutional background. Section 3 introduces the data sources used in the empirical analysis. Section 4 introduces a conceptual framework that clarifies the key mechanisms driving the impacts of the carbon tax. Section 5 details the empirical methodology, while Section 6 reports and discusses results. Section 7 explores the mechanisms behind the main estimates. Finally, Section 8 offers concluding remarks.

2 Institutional background

South Africa is a middle-income country with a GDP per capita of USD 7,055 and a tax-to-GDP ratio of 21% in 2023. It is one of the few countries in the world to have adopted a carbon tax and, to date, the only African country to have implemented any sort of carbon pricing scheme (World Bank 2024). Appendix Figure A.1 shows that, in 2023, the carbon tax increased the government revenue by about ZAR 1.5 billion.[4] This section explains the institutional setting and the legal framework of the carbon tax.

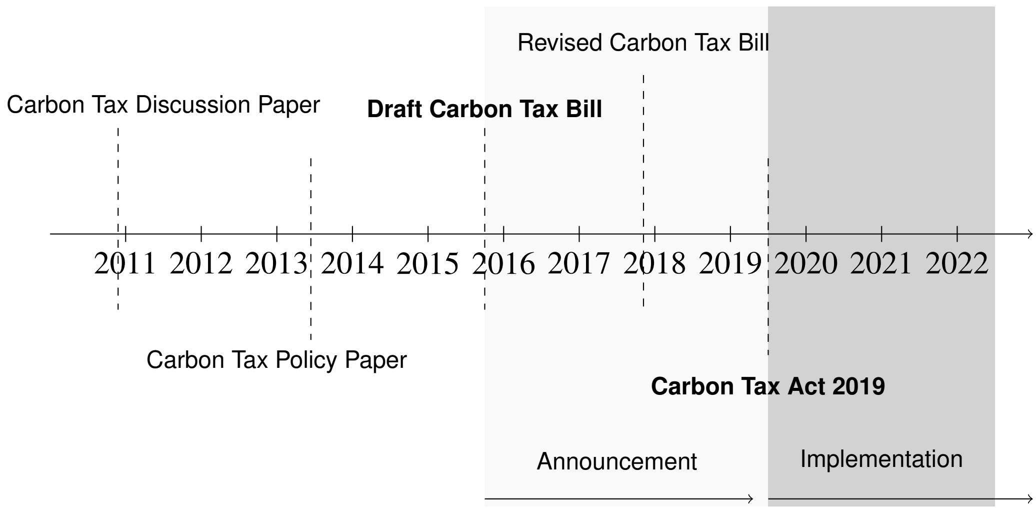
Policy process. The implementation of the South African carbon tax in 2019 has been preceded by a long political process in which a variety of private and public stakeholders discussed and pushed their interests. Figure 1 shows the timeline of the main events until the Carbon Tax Act in 2019. In 2010, the Carbon Tax Discussion Paper marks the first official mentioning of a 'carbon tax'. The paper outlined potential ways a carbon policy could be designed and already signaled the clear intention to regulate carbon emissions in South Africa. Three years later, the Carbon Tax Policy Paper was a more concrete proposal, still, however without detail-

[4] To put this figure into perspective, it is comparable to the increase in the early childhood development grant. For details, see **https://shorturl.at/taDvq**.

ing the final framework. It was not until the end of 2015 that the first draft of the Carbon Tax Bill was published. The draft detailed the various allowances for different sectors and activities. Importantly, it also included the schedule of GHG emission factors, i.e., if unaware before, firms learned at that point how much emissions they produced and consequently how much they were going to pay. Finally, the Carbon Tax Act was implemented in 2019 and became effective in June 2019. The empirical analysis will focus on these latter two events, which we interpret as the *announcement* and the *implementation* of the carbon tax.

The process of the carbon tax enactment was accompanied by much resistance from affected industries (Baker 2022). In addition, the policy process was open for public comments, allowing affected industries or interest groups to actively engage and participate in the discussions around the design of the carbon tax policy. The opportunity for public comment was heavily used—Appendix C shows the distribution of comments from various stakeholders, ranging from industry associations to individuals. The content of the comments ranged from demanding further clarifications to substantial criticism and contesting of the the carbon tax. While some comments were taken into consideration, the final Carbon Tax Act still featured all the main elements proposed in the initial Carbon Tax Bill in 2015. Nevertheless, this heavy public engagement illustrates the pressure the legislation was facing in pushing the carbon tax through. It may have led to the initial design of granting various allowances and exemptions meant to attenuate the alleged negative consequences of the tax.

Figure 1: Timeline of the main events until the Carbon Tax Act in 2019



Note: this figure plots the main events between the Carbon Tax Discussion Paper and the Carbon Tax Act in 2019.
Source: authors' illustration.

Exemptions and allowances. In principle, the carbon tax applies to all firms emitting CO_2 if the extent of their polluting activity exceeds a certain threshold as defined in the Carbon Tax Act (2019). These thresholds can be industry- or activity-specific. For example, the threshold for firms with combustion activities was set at 10 MW of installed thermal input capacity. This means that regardless of utilization or fuel type, if a firm has the capacity to combust 10 MW(th), then its emissions will be subject to the carbon tax. If the firm has a smaller capacity, carbon taxes do not apply. This ensures that the smallest firms are exempted altogether.

Initially, the first phase of the carbon tax was set to run from June 1, 2019, to December 31, 2022. However, the government extended this phase by three years to support economic recovery in the wake of the COVID-19 pandemic. At the time of the introduction of the carbon tax in 2019, the statutory tax rate amounted to $120 ZAR ($\sim$ $7 USD) per tonne of CO_2. Despite being relatively low compared to other carbon pricing policies (Timilsina 2022), the statutory tax rate increases annually by inflation plus 2 percent for the first few years. As of 2024, the statutory tax rate amounts to $190 ZAR ($\sim$ $11 USD). This low rate is expected to increase after the end of the transition phase, in December 31, 2025. The government plans to raise the carbon tax rate to at least US$ 20/tCO_2 by 2026, to US$ 30/tCO_2 by 2030, and accelerating to higher levels up to US$ 120/tCO2 beyond 2050 (Qu et al. 2023).[5]

Having said that, in the first few years following the introduction of the carbon tax, the effective tax rate could be reduced further through various allowances, as part of the transition from the initial phase of the carbon tax program. First of all, for the majority of sectors, there is a basic tax-free allowance of at least 60% of emissions, which means that only 40% of firms' emissions are taxed. Additionally, there are specific allowances for fugitive emissions, for the extent of trade exposure, performance allowances (for firms emitting less than their industry-specific standard) as well as carbon budget and offset allowances. These last two types of allowances refer to credits for voluntarily participating in the carbon budget program or for purchasing carbon offsets, provided the offsets are generated within the country. As a result of the tax-free allowances, which can total up to 95%, the effective rate could be as small as $6 ZAR (US$ 0.40) per ton of CO_2 emissions (Steenkamp 2022). The low rate aimed at allowing large emitters enough time to transition to clean technologies, but are set to be phased out at the end of the transition phase in December 31, 2025.

In addition to the carbon tax allowances, firms in South Africa can deduct the petroleum and diesel levies, as well as the electricity levy, from their carbon tax liabilities. These levies are pre-existing fiscal tools that interact with the carbon tax policy, all aiming at managing environmental impacts and promote energy efficiency. The petroleum and diesel levies, introduced in 2003, are charged on petrol and diesel to fund road infrastructure and public transport sys-

[5] See more details at **https://tinyurl.com/54xwt25z**.

tems, while also incentivizing fuel efficiency. The electricity levy, implemented in 2009, is applied to electricity consumption to reduce reliance on coal-fired power generation and support the transition to cleaner energy sources. Alongside the carbon tax allowances, these levies are deductible, reducing the overall carbon tax liabilities.[6]

As a result, the Net Emissions Equivalent (NEE), which represents the emissions subject to the carbon tax after accounting for allowances and deductions, is calculated as:

$$NEE = ((E - S) \times (1 - C)) - (D \times (1 - M)) + P \times (1 - J) + F \times (1 - K), \quad (1)$$

where E refers to all fuel combustion-related emissions of a taxpayer, from which sequestrated emissions S may be subtracted. C represents the sum of allowances applicable to fuel combustion activities. D corresponds to the CO_2 emissions from petrol and diesel. Since petrol and diesel are already subject to a fuel levy, their emissions are multiplied by their respective allowances M and subtracted, effectively exempting them from carbon taxation to avoid double taxation. P represents industrial process-related CO_2 emissions, and J denotes the corresponding allowances that can be deducted. Lastly, F refers to fugitive emissions, and K represents the applicable allowances for these emissions.

The net emissions, as calculated above, still do not directly correspond to actual carbon tax payments, as certain expenditures on other taxes can be credited against the carbon tax liability. For instance, as mentioned above, electricity providers can deduct the costs incurred from complying with the electricity levy. Thus, electricity providers are effectively 'exempt' from the carbon tax during its current introductory phase.

3 Data

Our analysis uses detailed administrative tax data from the South African Revenue Service (SARS), accessed confidentially through the South African National Treasury (see more information in Appendix D). The individual data components are described below, but all three data sources can be linked using anonymized tax reference numbers provided by SARS.

Carbon tax data. SARS provides information on all individual carbon tax filings since the implementation of the carbon tax in 2019 (National Treasury and UNU-WIDER 2024a). Overall, about 300 South African firms are subject to the carbon tax, reporting detailed information on their emissions inventories and tax payments. The reported emissions are further broken down by the components as shown in equation (1). This includes detailed information on fuel usage

[6] As stated by South Africa Revenue Services, the fuel and electricity levies are excluded from the carbon tax calculation to avoid double taxation (South African Revenue Service 2021).

and various types of industrial process and fugitive emissions.[7] In addition, we observe the extent of allowances that are claimed by firms.

Financial and customs data. As a second source of information, we rely on the CIT-IRP5 firm panel, which harmonizes and combines corporate income tax (CIT) information, value-added-tax (VAT) as well as customs tax data on imports and exports (Ebrahim et al. 2021; National Treasury and UNU-WIDER 2023; Pieterse et al. 2018). The CIT-IRP5 firm panel encompasses the entire population of South African firms, totaling over 600,000 annual firm observations. Only 0.05% of these firms are subject to the carbon tax, leaving the vast majority outside its scope. These non-taxed firms provide a large pool for identifying a suitable control group. The CIT data is based on corporate tax returns submitted to SARS and comprises information on total sales and profits, capital stock, and the total wage bill. The information is based on the South African tax year which runs from March to February of the following year.[8] Customs information is obtained from transaction-level customs declaration forms containing information on the value of the transaction, product code as well as information on the partner country. From the customs derived data we mainly use firm-level aggregates of imports and exports. Finally, the data contain information of various transaction-level VAT-forms, which are aggregated to the firm-level.

Employment data. The final source of information we use is the individual panel, which contains individual-level data submitted by employers registered under the pay-as-you-earn (PAYE) scheme (Ebrahim and Axelson 2019; National Treasury and UNU-WIDER 2024b). Since the 2010/2011 tax year it is mandatory for employers to be part of PAYE. As the data is still incomplete for the early years up to 2013, we only use the individual panel starting in 2013. Most importantly, the data allow us to calculate the number of employees and the distribution of wages within each firm by linking it with the CIT-IRP5 firm panel.

Descriptive statistics. Compared to the total population of firms in South Africa, only a small fraction is in principle liable for the carbon tax. Only about 300 firms have declared emissions associated with the carbon tax. This implies that the emissions from many firms are not covered. However, Panel (a) of Figure 2 shows that CO_2 are highly concentrated among firms. The gross emissions reported in carbon tax returns represent approximately 80% of total nationwide emissions (coloured in red) (Crippa et al. 2024).[9] This suggests that carbon emissions in South Africa are concentrated among a relatively small number of firms, but also that

[7] See Figure A.2 in the Appendix for details.

[8] In contrast to the fiscal year, the reporting period for the carbon tax follows the calendar year and runs from January until December.

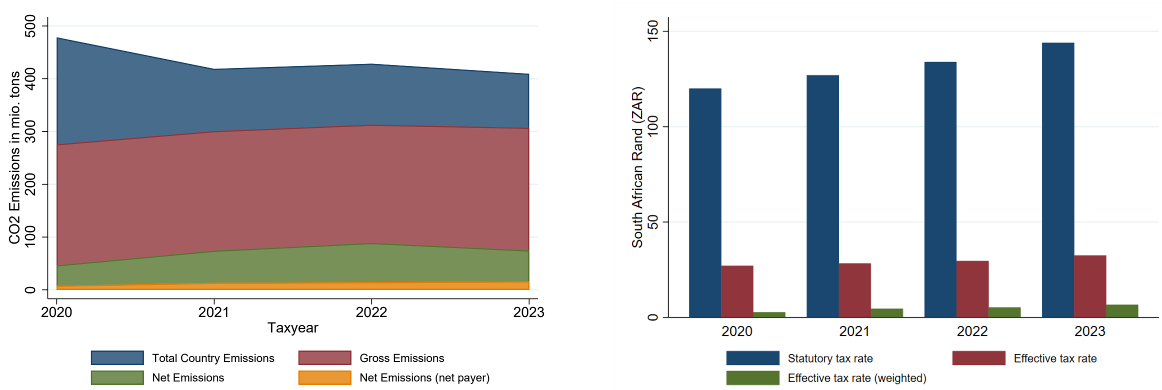
[9] Country-wide emissions are obtained from the Emissions Database for Global Atmospheric Research (EDGAR), which can be accessed under the following link: **https://edgar.jrc.ec.europa.eu/**.

the carbon tax would theoretically be able to cover the majority of emissions despite exempting the majority of firms.

Turning to net emissions (coloured in green), which are calculated using equation (1) and represent the emissions subject to the carbon tax after applying various allowances, it becomes evident that this potential remains largely untapped. Over the years, only about 18% of nationwide emissions have been effectively taxed. The gap between gross emissions (total firm emissions) and net emissions (those subject to the carbon tax) is primarily due to the substantial allowances that firms can claim, which reduce their carbon tax base. This discrepancy is more pronounced when excluding firms that report emissions but effectively pay no tax (shown in orange). In most cases, this is because firms can offset their carbon tax payments by crediting the electricity levy, as detailed in Section 2. As a result, the proportion of taxed *and paid for* emissions out of total nationwide emissions drops to around 4%.

Figure 2: Emissions covered by carbon tax

(a) Gross and net emissions **(b) Effective tax rate**



Note: this figure plots in Panel (a) the nationwide emissions of South Africa (blue) from the Emissions Database for Global Atmospheric Research (EDGAR), the total emissions from the carbon tax firms (red), the net-of-allowances emissions (green), and net-of-allowances emissions of firms that are effectively paying the carbon tax (yellow). Panel (b) shows the effective tax rate filed by each company. Blue bars represent the statutory tax rate, and red and green bars are the effective tax rate paid after allowances. The tax year always refers to the reporting period in the previous calendar year. Hence, the tax year 2021 refers to the reporting period of January 2020 until December 2020.

Source: authors' illustration based on SARS and EDGAR data.

This discrepancy can be illustrated at the firm level by examining the *effective tax rates*, which reflect how much firms in different sectors are actually paying per ton of emitted CO_2. The statutory tax rate, as defined by law, started at \$120 ZAR per ton of CO_2 and gradually increased to \$134 ZAR in 2023, as shown in Panel (b) of Figure 2. However, the average effective tax rate is significantly lower, as indicated by the red bar. When the average effective tax rate is weighted by firm-level emissions, it becomes clear that the effective tax rate per ton of CO_2 decreases even further. In other words, the green bars indicate that, on average, larger emitters are able to claim more allowances, leading to a reduced effective tax rate.

Naturally, the extent of emissions and, consequently, carbon tax payments vary across industries. Panel (a) of Figure 3 shows that the composition of net emissions differs by industry, which affects tax liability. Petrol and diesel are taxed through the fuel levy. To avoid double taxation, emissions from petrol and diesel combustion can be deducted from fuel combustion emissions and are thus exempt from the carbon tax. Fuel combustion accounts for about two-thirds of emissions in the mining sector, while it represents only half of the emissions in the manufacturing sector. The remaining emissions in both sectors are due to fugitive and industrial process emissions. Panel (b) displays the distribution of carbon tax firms by industry. Nearly half of all firms operate in the manufacturing sector, while another fifth are in the mining sector.

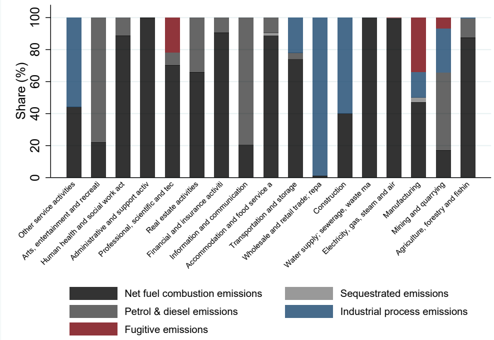
Next, we investigate heterogeneity in tax payments. Panel (c) of Figure 3 plots the distribution of carbon tax revenues across sectors. More than 80% of the tax revenues come from manufacturing firms and another 10% from mining firms. Panel (d) suggests, however, that the largest emitters do not necessarily pay the most. In fact, while we see manufacturing firms contributing over 80% of carbon tax payments but only about 25% of emissions, the electricity sector is responsible for about 64% of emissions but contributes only less than 2% of carbon tax payments. This is due to the deduction of the electricity levy. A similar pattern is observed for wholesale traders, where the share of emissions far exceeds their carbon tax payments. In the mining sector, although on a smaller scale, the share of carbon tax payments is three times larger than its share of emissions.

It is noteworthy that a substantial share of firms filing carbon tax returns report no tax liability, effectively categorizing them as non-payers. In our sample, this applies to 17% of the filings (see Appendix A). There are several reasons why firms may report no carbon tax liability. First, some firms may have no emissions to declare for a given tax period. Second, electricity providers can offset the carbon tax by crediting the electricity levy. Third, firms might have zero net emissions, either because they only have emissions from petrol and fuel or because their emissions are fully sequestrated elsewhere (see Eq. (1)). In fact, most firms with zero emissions only report emissions from petrol and diesel, meaning they are effectively exempt from explicit carbon taxation.[10]

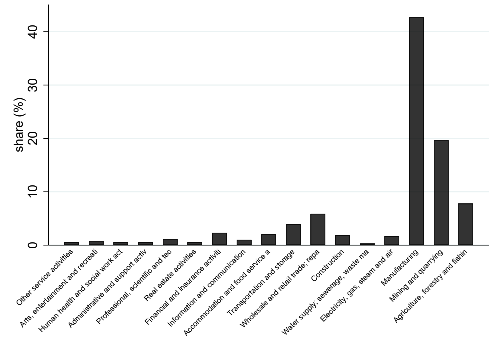
[10] The fuel levy, however, was aligned with the carbon tax rate so that their emissions are equivalent taxed via the fuel levy.

Figure 3: Industry heterogeneity

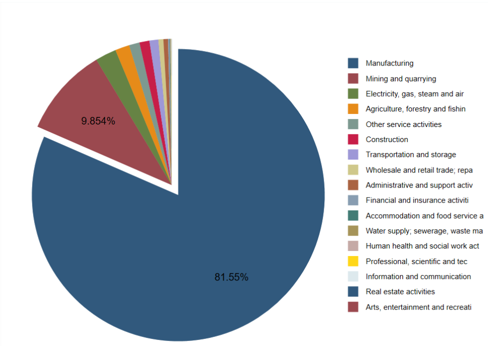
(a) Emission type by industry



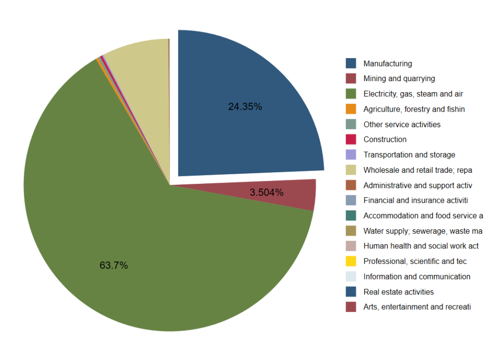
(b) Share of firms by industry



(c) Carbon tax revenue by industry



(d) Gross emissions by industry



Note: this figure plots various descriptive statistics based on the carbon tax returns filed by South African firms. Panel (a) depicts the share of emissions types by industry disaggregated according to Equation (1). Panel (b) plots the share of treated carbon tax firms by industry. Panel (c) displays the aggregate carbon tax revenue for the tax years 2020-2023 by industry. Panel (d) displays the aggregate emissions of treated carbon tax firms for the tax years 2020-2023 by industry.

Source: authors' illustration based on SARS data.

4 Conceptual framework

To better understand the factors driving the impacts of the carbon tax on firm outcomes, we present a simple conceptual framework. To fix ideas, we assume competitive markets and express the profits of firm i as:

$$\pi_i = PQ_i - C_i(Q_i, \mathbb{1}(\tau > 0)\tau) - \mathbb{1}(\tau > 0)\tau E_i(Q_i, \tau),$$

where $C_i(Q_i, \mathbb{1}(\tau > 0)\tau)$ represents the total cost of producing Q_i, considering the presence or absence of a carbon tax τ, and $E_i(Q_i, \tau)$ denotes the total CO_2 emissions required to produce Q_i, with or without a carbon tax τ. Thus, the total impact on profits from a marginal change in τ can be expressed as:

$$\frac{d\pi_i}{d\tau} = P\frac{dQ_i}{d\tau} - \frac{\partial C_i}{\partial Q_i}\frac{\partial Q_i}{\partial \tau} - \mathbb{1}(\tau > 0)\left[\frac{\partial C_i}{\partial \tau} + E_i(Q_i, \tau) + \tau\left(\frac{\partial E_i}{\partial Q_i}\frac{\partial Q_i}{\partial \tau} + \frac{\partial E_i}{\partial \tau}\right)\right]. \quad (2)$$

Assuming that firms maximize profits with respect to Q_i, and for shocks that have marginal influence on Q_i, the envelope theorem implies:

$$\frac{\partial \pi_i^*}{\partial Q_i} = P - \frac{\partial C_i}{\partial Q_i} - \mathbb{1}(\tau > 0)\tau \frac{\partial E_i}{\partial Q_i} = 0. \tag{3}$$

Combining (2) and (3), we derive the following expression for how a carbon tax affects firm i's profits:

$$\frac{d\pi_i}{d\tau} = -\left[E_i(Q_i, \tau) + \tau \frac{\partial E_i}{\partial \tau} + \frac{\partial C_i}{\partial \tau} \right] \lesseqgtr 0. \tag{4}$$

The sign of this effect is ambiguous because $E_i(Q_i, \tau)$ is positive, $\frac{\partial E_i}{\partial \tau}$ is negative by policy design, as emissions are internalized as an additional input. Furthermore, $\frac{\partial C_i}{\partial \tau}$ can be positive or negative, depending on innovation or the transitional costs of the implementation of the carbon tax.

To further explore the factors influencing total cost, we express it as:

$$C_i = r^L[1 - \delta(\tau)]K_i^L + r^N K_i^N + wL_i,$$

where L denotes 'legacy', N represents 'new', and $\delta(\tau)$ represents depreciation. Thus,

$$\frac{\partial C_i}{\partial \tau} = r^L[1 - \delta(\tau)] \frac{\partial K_i^L}{\partial \tau} - r^L K_i^L \frac{\partial \delta}{\partial \tau} + r^N \frac{\partial K_i^N}{\partial \tau} + w \frac{\partial L_i}{\partial \tau} \lesseqgtr 0. \tag{5}$$

The sign of this effect is also ambiguous because $\frac{\partial K_i^L}{\partial \tau}$, $\frac{\partial K_i^N}{\partial \tau}$, and $\frac{\partial L_i}{\partial \tau}$ may be positive if capital and labour substitute for emissions or negative if they complement emissions. Note that these derivatives are taken with respect to the carbon tax, which effectively sets the price of emissions as a new input. As for the impact of the carbon tax on depreciation, $\frac{\partial \delta}{\partial \tau}$, it is expected to be positive, as firms seek to minimize losses from stranded assets.

Lastly, the total impact of the carbon tax on emissions $E_i(Q_i, \tau)$ is given by:

$$\frac{dE_i}{d\tau} = \frac{\partial E_i}{\partial Q_i} \frac{\partial Q_i}{\partial \tau} + \frac{\partial E_i}{\partial \tau} \lesseqgtr 0, \tag{6}$$

The sign of this total derivative is ambiguous. Although $\frac{\partial E_i}{\partial \tau}$ is negative by policy design—since emissions are internalized as an additional input—$\frac{\partial E_i}{\partial Q_i}$ can be either positive or negative, depending on the extent of innovation and the length of the transitional period for tax implementation. Firms might expand production using renewable energy, for example, but might be slow to adjust if the transition period is relatively long. Similarly, $\frac{\partial Q_i}{\partial \tau}$ can also take either sign, depending on its effect on productivity. While firms often argue that environmental policies reduce productivity, the Porter Hypothesis suggests that such policies can drive innovation, improving overall production efficiency and leading to a positive productivity impact. However, if a command-and-control regulation is imposed—directly capping emissions—$\frac{dE_i}{d\tau}$ is more likely to be negative due to potential productivity losses, particularly in emissions-intensive industries.

This conceptual framework predicts that the impacts of a carbon tax on firm profits and emissions are ambiguous, making it an empirical question. Additionally, the effects on capital and labour depend on whether they are substitutes or complements to emissions. If capital and labour are substitutes for emissions, the cross-elasticities with respect to the carbon tax would be positive, leading to increases in both capital and labour. However, if they are complements to emissions, the cross-elasticities would be negative, resulting in decreases in both capital and labour, which could lead to underutilized capacity and unemployment.

5 Empirical approach

In this section, we outline our empirical approach to examine the mechanisms proposed by the conceptual framework using real-world data. The analysis relies on a matched difference-and-differences strategy, where matching is based on firms' observable characteristics before the announcement of the carbon tax.

Coarsened exact matching. In principle, firms that are liable for carbon tax might be different from those that are not. Due to various exemptions and size thresholds (cf. Section 2), simple comparisons of treated and non-treated firms are prone to selection bias. We overcome this issue by relying on matching techniques that reduce imbalances in the characteristics of treated and non-treated firms. Matching has become the leading approach to finding an appropriate control group in the field of environmental economics (Colmer et al. 2024; Dechezlepretre et al. 2023).

In our analysis, we use coarsened exact matching (CEM). This involves temporarily coarsening the data based on observed firm characteristics before the treatment period. The coarsening process applies a predefined common binning strategy, creating unique observations within the coarsened data. Each of these unique observations constitutes a stratum. Treated and untreated firms are then exactly matched on these strata. Observations whose strata do not contain at least one treated and one untreated observation are dropped, and weights are used to compensate for the different strata sizes (Iacus et al. 2012). Importantly, and contrary to many other matching strategies, coarsened exact matching does not only account for imbalances in means but also for imbalances in higher moments and interactions (Blackwell et al. 2009; Iacus et al. 2012). We match firms exactly at the 3-digit industry level. Additionally, firms are matched on the basis of profits, sales, import and export volume, number of employees, total wage bill, and capital stock. Each of these variables is divided into five equally sized bins. The baseline year is chosen to be the tax year of 2014-15, just before the first Carbon Tax Bill was drafted and made public. We excluded treated firms with sales and capital equal to zero in 2015, i.e., we kept only firms that were operating in 2015.

Estimation strategy. After creating a comparison group through matching, we estimate the causal effect of carbon taxation on firm behaviour. In particular, we estimate an event-study type model as follows:

$$\ln(y_{it}) = \sum_{k=2011, k\neq 2015}^{2021} \theta_k \mathbf{1}[t=k] \times \mathbf{1}[i = CarbonTax] + \alpha_i + \gamma_{pt} + {}_{it}, \qquad (7)$$

where y_{it} is an outcome of interest for firm i in year t. $\mathbf{1}[i = CarbonTax]$ is an indicator for whether a firm ever files a carbon tax return.[11] α_i and γ_{pt} are firm and province-by-year fixed effects, respectively. Our coefficients of interest are the θ's. We exclude 2015 as the baseline year to accommodate anticipatory effects upon the release of the draft of the Carbon Tax Bill but before the actual implementation of the tax. Further, the year 2015 corresponds to the year for which we apply coarsened exact matching. In order to estimate the effect of the carbon taxes on firm behaviour, it is required to establish a meaningful comparison group. To this end, we run eq. (7) with the weights obtained from the coarsened exact matching. The baseline estimation sample comprises 168 treated firms, i.e., about two thirds of all treated mining and manufacturing firms, and to 2,465 comparison (non-treated) firms from the same sectors.[12]

Identifying assumptions. Our empirical strategy for isolating the causal impact of the carbon tax on firm activity is based on two key identifying assumption. The first is the assumption of parallel trends of treatment and comparison groups. Put differently, we assume that in the absence of the carbon tax both treated and untreated firms would have followed the same economic trends over time. Although it is impossible to observe these counterfactual trends, we can scrutinize the plausibility of this assumption by inspecting whether the treatment and comparison groups have followed similar trends prior to the treatment. Given that a lengthy policy process preceded the implementation of the carbon tax, we explicitly allow for anticipatory behaviour and define our first treatment as the announcement of the Carbon Tax Bill in 2015. Hence, we would need to assume parallel trends prior to the announcement in 2015.

[11] Note, however, that due to the deduction of allowances, not all firms that file a carbon tax return have an actual carbon tax liability. However, we classify them as treated since they will begin paying the tax after the end of the transitional period. Therefore, our estimates reflect intent-to-treat effects. See Figure A.3 in the Appendix for details.

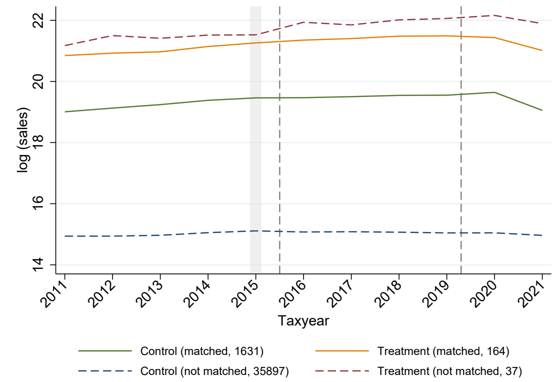
[12] This ratio of matched to unmatched treated firms, as well as the absolute number of matched firms, is comparable to other studies (e.g., Colmer et al. 2024).

Figure 4 plots the averages over time for our variables of interest such as sales, capital, employment, and profits by treatment status. While the dashed lines display the unmatched sample, the solid lines indicate the averages for the matched sample. The visual co-movement prior to 2015 supports the parallel trends assumption needed for a causal interpretation of the treatment effects. Although the parallel trends assumption relies on changes over time, the pre-treatment matching helps to alleviate further validity concerns by reducing cross-sectional differences between the treatment and comparison groups. The reasoning behind this is that carbon tax firms in South Africa are particularly large and could be exposed to systematically different types of contemporaneous shocks. As shown in Figure 4, the matching reduces the differences in pre-treatment characteristics substantially and thereby the likelihood of an estimation bias stemming from idiosyncratic differences in contemporaneous shocks.

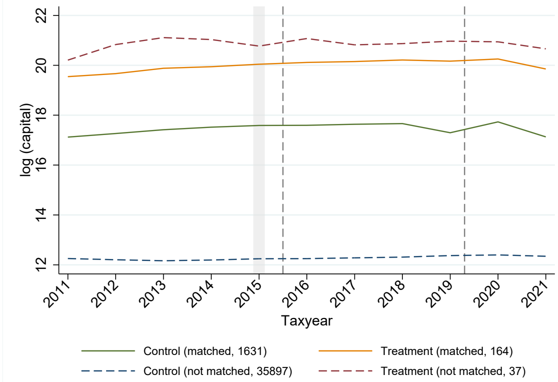
The second identifying assumption is the Stable Unit Treatment Value Assumption (SUTVA). This assumption states that the observed trajectories of the treatment and comparison groups depend only on their respective treatment statuses. This assumption would be violated if the matched comparison firms would be indirectly treated by the carbon tax policy as well. For instance, if firms strategically adjust economic activity to stay below the liability thresholds. Depending on the direction of the effects, this can either lead to an upward or downward bias in our estimates. In order to alleviate this concern, we run our estimation with different matching stringencies. If we assume that the violation of SUTVA is increasing in the similarity of treatment and comparison firms, the estimation bias arising from SUTVA should become more prevalent the more similar treatment and comparison firms are. On the other hand, allowing for larger cross-sectional differences between treatment and comparison firms would attenuate potential biases arising from SUTVA violation. Appendix B shows our estimation results when using different forms of matching. The reported results are comparable across different matching approaches, indicating that SUTVA violations might not be a major concern in our empirical setting. Moreover, it is important to note that the thresholds defining carbon tax liability are based on thermal input capacity, making them less susceptible to manipulation compared to metrics like sales. This limits the scope for firms to strategically bunch below the treatment threshold.

Figure 4: Coarsened exact matching means

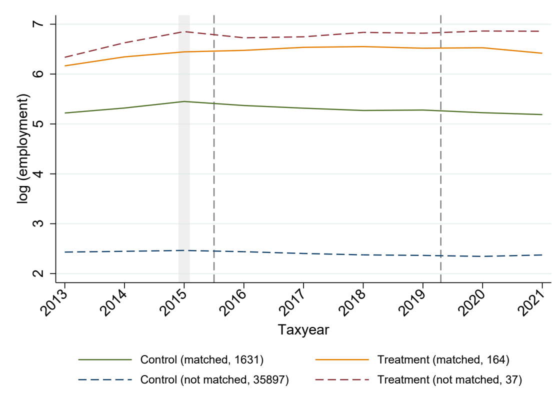
(a) Sales



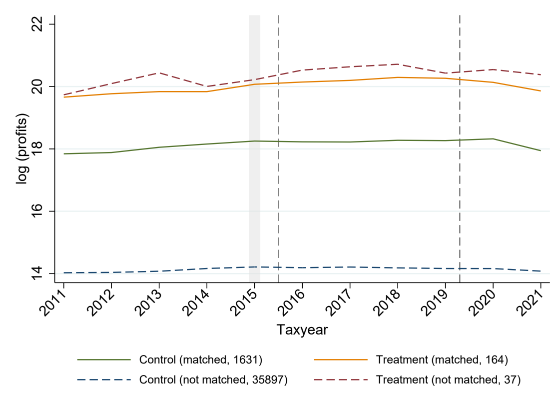
(b) Capital



(c) Employment



(d) Profits



Note: this figure plots the raw means of observable firm characteristics differentiated by treatment and matching status. The dashed red line depicts unmatched treated firms that are subject to the carbon tax. The yellow line depicts matched treated firms, and the green line matched comparison firms that are not subject to the carbon tax. The dashed blue line depicts all remaining untreated firms that were not matched. Firms were matched exactly on the 3-digit industry and coarsened with 3 cutpoints for sales, capital, number of employees, and profits based on the year 2015.

Source: authors' illustration based on SARS data.

6 Results

In this section, we report and discuss our estimation results. Based on the matched sample, we estimate equation (7). First, we present the results of the effects of the carbon tax on sales, capital, employment, and profits for all sectors. Then, we explore the heterogeneity by sector and allowance take-up. Finally, we provide evidence of potential mechanisms that explain our results.

6.1 Baseline results

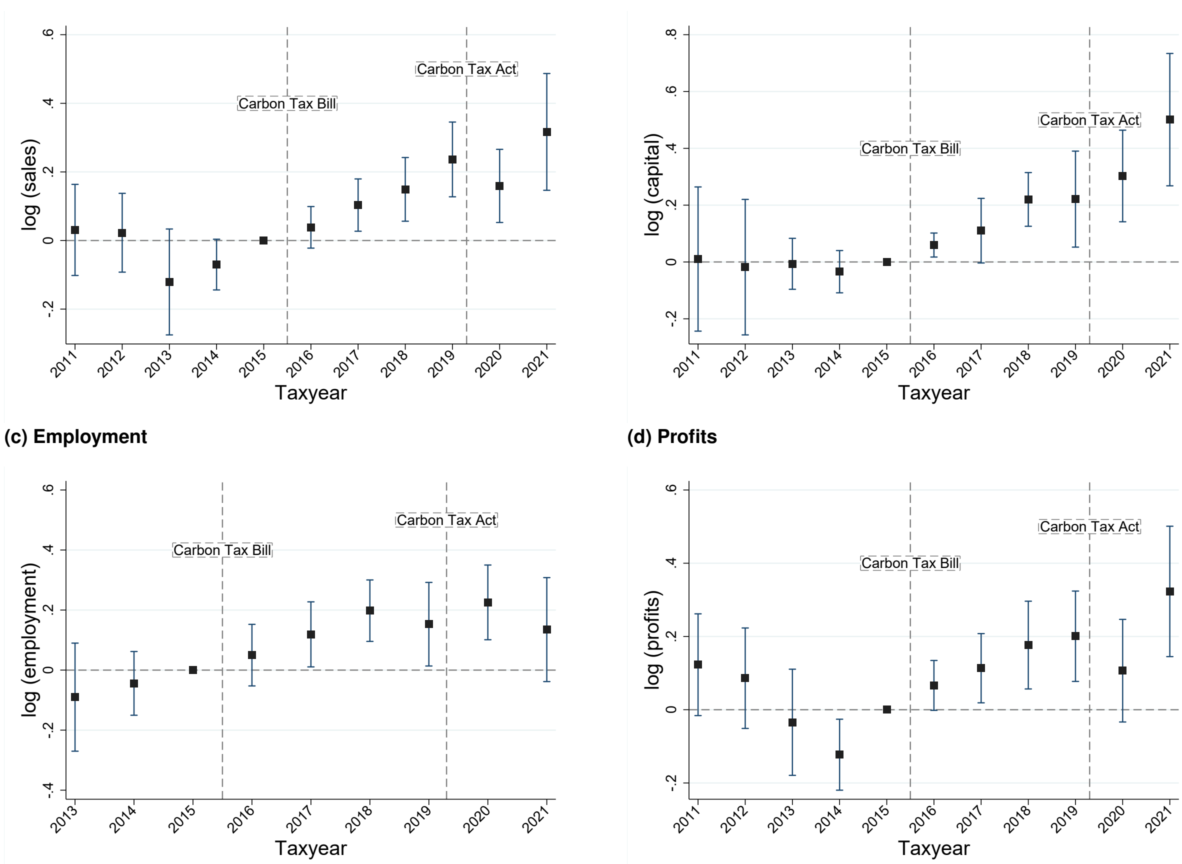
Figure 5 presents the results from the dynamic event-study specification for four main outcomes across all firms: sales, capital, employment, and profits. The dashed vertical lines indicate two key events. First, at the end of 2015, the first Carbon Tax Draft Bill was published.

To account for anticipation effects that may have begun at that time, we use 2015 as our baseline year (which is omitted from the graph). Second, the actual implementation of the Carbon Tax Act occurred in 2019. It is important to note that the fiscal year in South Africa runs from March to February. Therefore, the fiscal year 2020 started in March 2019 and ended in February 2020. As a result, the estimated effects for 2020 largely reflect the impact of the carbon tax (which was implemented in June 2019), without being influenced by the COVID-19 pandemic, which began in the following fiscal year (Burger and Calitz 2021).

In all panels, we observe that prior to 2015, there were no significant differences in the evolution of outcomes between taxed and non-taxed firms. It is only after 2016, following the carbon tax announcement, that the outcomes begin to show positive effects on sales, capital, employment, and profits. This suggests that the announcement did not hinder firm growth; instead, firms may have had an anticipatory incentive to expand operations *before* the carbon tax was implemented. After the actual implementation in 2019, these positive effects persist. Appendix B shows that these results remain robust to different matching strategies.

Figure 5: The effects of the carbon tax policy on firm outcomes

(a) Sales **(b) Capital** **(c) Employment** **(d) Profits**



Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors' illustration based on SARS data.

6.2 Environmental effects

A limitation of the administrative records is that we cannot observe firms' emissions before the carbon tax policy was implemented, making it impossible to directly measure the policy's impact on emissions at the firm level. To address this, we turn to more aggregate measures and estimate the environmental effects at the country level using a synthetic control method. This approach involves constructing a 'synthetic' version of South Africa by combining data from countries that did not implement a carbon tax or similar carbon pricing schemes. The synthetic control is essentially a weighted combination of these countries, designed to resemble South Africa in terms of key characteristics such as emissions patterns before the policy was introduced (Abadie et al. 2010; Andersson 2019). This method is widely used in the empirical literature to overcome the challenge of not having a well-defined comparison group (Abadie 2021).

For this analysis, we use country-level emissions data from the Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al. 2024), combined with data from the Penn World Table for population and GDP figures (Feenstra et al. 2015). The counterfactual in this case is a 'synthetic South Africa', which is constructed using average of annual CO_2 emissions data averaged from 2011 until 2015. To more closely match the composition of our firm-level sample, we exclude emissions from the energy and transport sectors. Therefore, the focus of the environmental analysis is on country-level emissions primarily arising from fuel combustion in the manufacturing sector, as well as fugitive and industrial process emissions.

Additionally, we match countries based on the average GDP as well as their average emission intensity (measured as the ratio of emissions and GDP) between 2011 and 2015. The resulting 'synthetic South Africa' is a weighted average consisting primarily of the following countries: United Arab Emirates (66.7%), India (3%), Trinidad and Tobago (2.9%), Vietnam (2%) and Saudi Arabia (0.5%).[13] This synthetic counterfactual is used to estimate what emissions in South Africa would have looked like in the absence of the carbon tax policy.

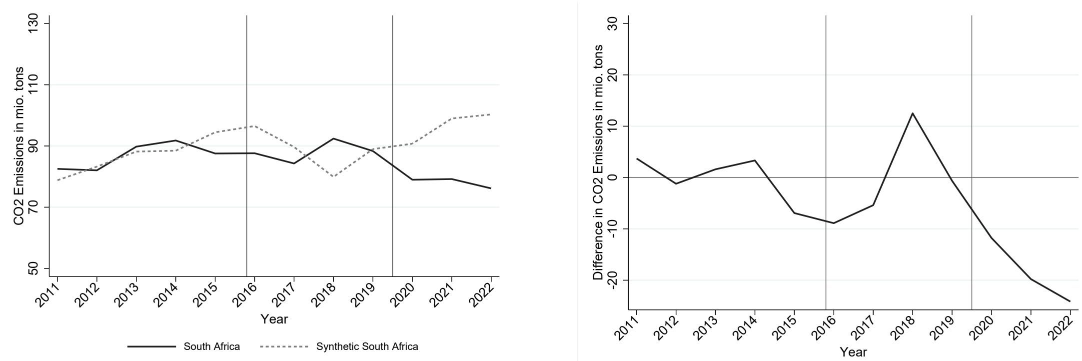
Figure 6 compares the emissions of South Africa to those of the 'synthetic South Africa'. The latter is supposed to represent the counterfactual scenario in which no carbon tax would have been introduced. Panel (a) plots the evolution of both while Panel (b) illustrates the absolute differences over time. The results show a temporary increase in CO_2 emissions between the announcement of the carbon tax and its actual implementation with a drop in emissions after the actual policy implementation. Although only suggestive in nature, the emission pattern aligns well with the positive economic impacts on firm outcomes. They suggest that the positive effect of the tax announcement on firm activity has been accompanied by a temporary

[13] Overall 'synthetic South Africa' comprises 130 countries, of which 125 countries have a weighted contribution of less than 0.5%. Appendix Table B.1 features the full list of countries comprising 'synthetic South Africa'.

increase in emissions. As the firms we observe under the carbon tax account for about 80% of nationwide emissions (cf. Figure 2), it is reasonable to assume that their behaviour affects overall country emissions.

Figure 6: The effect of the carbon tax policy on CO_2 emissions

(a) Absolute values **(b) Differences**



Note: this figure plots the effect carbon tax policy CO_2 emissions using the synthetic control method. In Panel a) absolute values of CO_2 emissions are shown. Panel b) depicts the difference in CO_2 emissions between South Africa and its synthetic counterpart. The plotted emission values cover emissions from the following IPCC codes: 1.A.2, 1.B., 2.A., 2.B., 2.C. and 2.D.. Synthetic South Africa is constructed based on South Africa's average annual emissions in these sectors as well as the average GDP and emissions intensity (emissions/GDP) between 2011-2015. Countries that have implemented a carbon pricing policy are removed from the pool of potential donor countries.

Source: authors' illustration based on EDGAR and Penn World Tables data.

6.3 Heterogeneity by sector and allowance take-up

Figure 7 presents the results for the two types of firms in the sample. First, the patterns differ by sector depending on the outcome. The carbon policy announcement has positive effects on both sales and profits for firms in both sectors, with stronger effects observed for mining firms. However, these effects are more imprecise for mining firms due to the smaller sample size. In contrast, the effects on capital and employment vary by sector: there is little to no effect on capital for the mining sector. Regarding employment, the impact is immediate for the mining sector following the Carbon Tax Draft Bill, while it takes two years for the effect to materialize in the manufacturing sector.

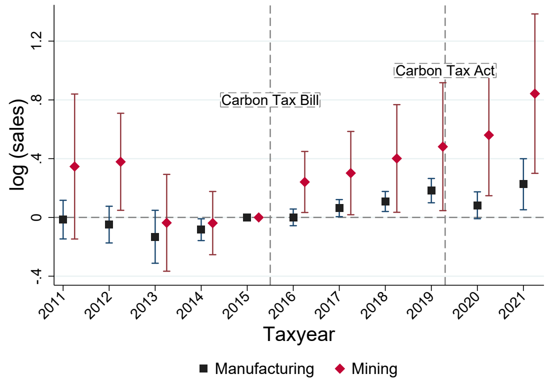
These findings align with a South African National Treasury's 2019 memorandum, which highlighted that the carbon tax implementation would be complemented by transitional tax incentives designed to minimize the policy's initial impact. Specifically, the government aimed to cushion potential adverse effects on energy-intensive sectors, such as mining. This could explain why mining firms, despite being heavily impacted by the policy, experienced quicker adjustments in sales and employment following the policy announcement.

As explained earlier, allowances are a key feature of the South African carbon tax policy, as they determine the effective tax rate and, consequently, the treatment intensity. Figure 8 presents the results separately for firms that benefited the least from allowances (1st quintile) and the most (5th quintile). The results suggest that firms in the 1st quintile, which are limited in claiming allowances, respond quickly to the policy announcement. In contrast, the observable effects for firms in the 5th quintile, which benefit the most from allowances, are much smaller and often statistically indistinguishable from zero.

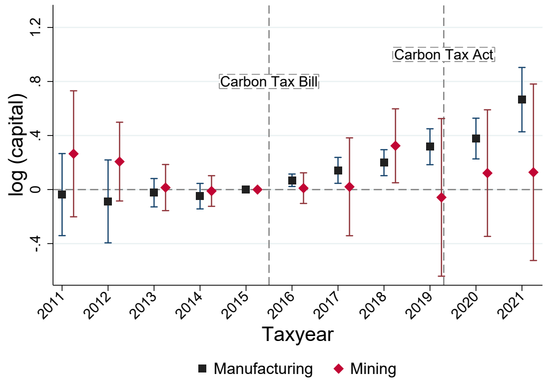
These results might sound counterintuitive because one would typically expect that firms facing higher effective tax rates (due to fewer allowances) would experience negative economic outcomes, given the increased cost burden. However, the quicker response of firms in the 1st quintile could be due to their anticipation of higher tax liabilities, prompting them to adjust their behaviour more rapidly in response to the policy announcement. On the other hand, firms in the 5th quintile, which benefit more from allowances, might feel less pressure to alter their operations, leading to a more muted response. This suggests that the financial cushioning provided by allowances could reduce the urgency for firms to make immediate adjustments, despite facing lower effective tax rates. We will explore these and other potential mechanisms further in the next section.

Figure 7: Heterogeneous effects of the carbon tax policy by sector (manufacturing vs. mining)

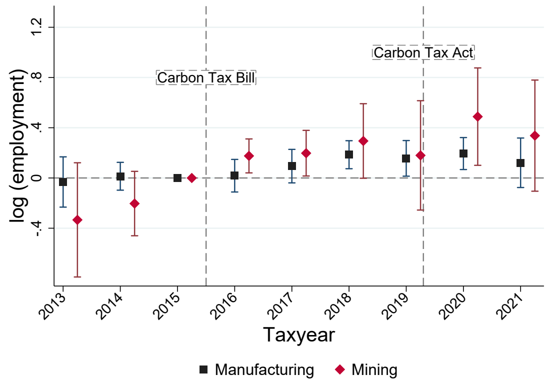
(a) Sales



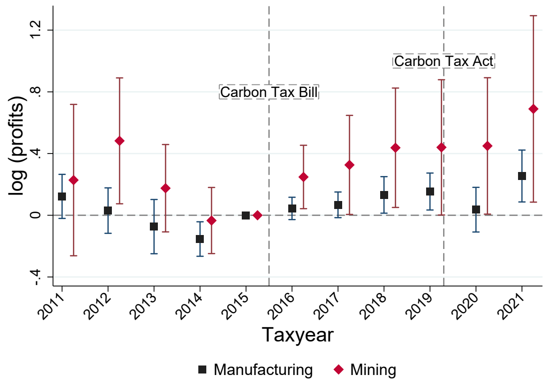
(b) Capital



(c) Employment



(d) Profits

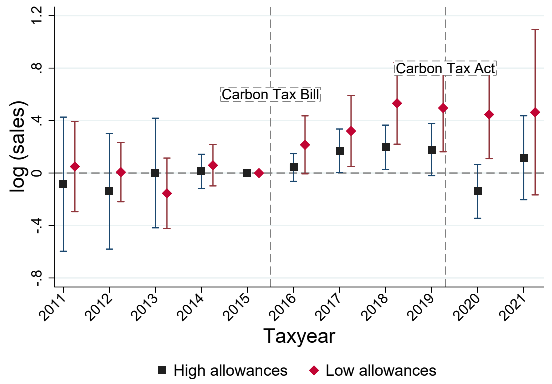


Note: this figure plots θ_k coefficients estimated from equation (7). The blue squares depict the point estimates for the manufacturing sector. The red diamonds depict the point estimates for the mining sector. The blue and red vertical bars around the point estimates represent the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

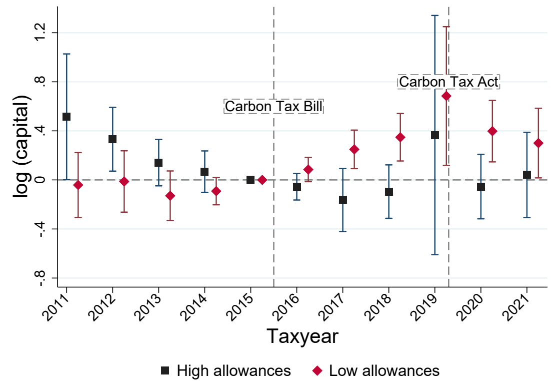
Source: authors' illustration based on SARS data.

Figure 8: Heterogeneous effects of the carbon tax policy by allowance take-up

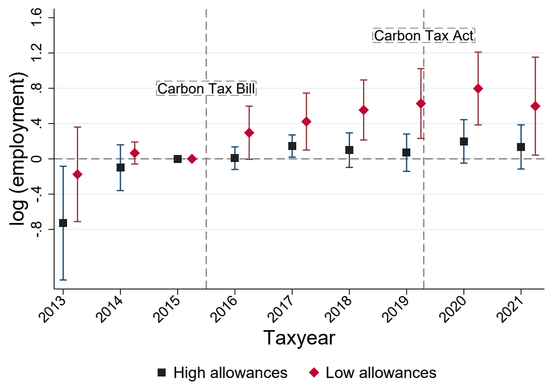
(a) Sales



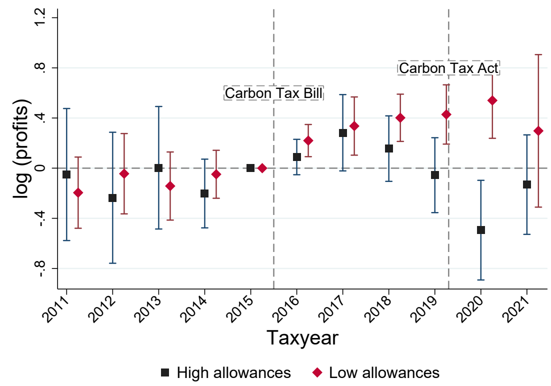
(b) Capital



(c) Employment



(d) Profits



Note: this figure plots the θ_k coefficients estimated from equation (7). The blue squares represent the point estimates for firms with high allowance take-up (5th quintile), while the red diamonds represent the point estimates for firms with low allowance take-up (1st quintile). The blue and red vertical bars around the point estimates represent the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors' illustration based on SARS data.

7 Mechanisms

In previous sections, we showed that the announcement and implementation of the carbon tax led to positive effects on sales, capital, employment, and profits. In this section, we explore two potential channels that could explain this pattern. Specifically, we focus on how uncertainty resolution, firms' anticipation of future costs, and technology upgrading may have driven firms to increase their activity following the tax announcement.

7.1 Uncertainty and anticipation

Firms must make decisions under uncertainty across many dimensions, including the regulatory framework in which they operate, particularly regarding taxation. Environmental accountability through taxation had been part of the South African policy agenda well before its formal implementation in 2019, with discussions about its structure and purpose taking place as early as 2010 (cf. Figure 1). However, the release of the Carbon Tax Bill in 2015 represents a key milestone in this process, as it outlined the core elements of what would later become the Carbon Tax Act.

The Carbon Tax Bill provided critical details, such as the emission factors—how much CO_2 a specific production activity would generate—as well as the applicable tax rates and the allowance structure. These disclosures allowed firms to calculate their likely tax liability with a greater degree of certainty. Furthermore, the tax design itself, which does not impose an emissions cap as a cap-and-trade system would, likely eased concerns about production limits. Under the carbon tax framework, firms retained the flexibility to produce as much as they desired, as long as they found it economical to pay the associated tax. This aspect reduced a significant layer of uncertainty by ensuring that firms' production decisions would not be constrained by a rigid emissions cap. Overall, the 2015 Carbon Tax Bill clarified several previously uncertain aspects of the policy, enabling firms to better anticipate its financial implications and adapt their strategies accordingly.

This resolution of uncertainty might thus have improved the efficiency of firms that were uncertain of how costly their production in the near future would be. It is reasonable to assume that the Carbon Tax Bill in 2015 constitutes a positive information update to firms' expectations as it already incorporated many aspects to attenuate concerns that firms had at the outset (see Appendix C for details). If a firm's activity is correlated with its expectation of the future, this channel can rationalize the observed positive effects.

Uncertainty about carbon pricing has been shown to be high and relevant for firm decisions in more developed settings (Fuchs et al. 2024). Arguably, uncertainty might be even higher in less developed economies and thus relevant for our setting. To investigate this channel, we focus on the response of the mining sector, in which the resolution of uncertainty was especially prevalent. In fact, they were explicitly mentioned in a press release accompanying the release of the Carbon Tax Bill in 2015, stating that '*taking into account the current state of the mining and other distressed sectors [the carbon tax] will be designed to ensure that such sectors are not adversely affected when the tax is implemented.*' This suggests that these sectors were uncertain and concerned about the future cost of production before 2015, and thus updated their expectations positively afterwards. In line with these arguments, subsection 6.3 reports that mining firms responded more strongly than manufacturing firms, which supports this hypothesis.

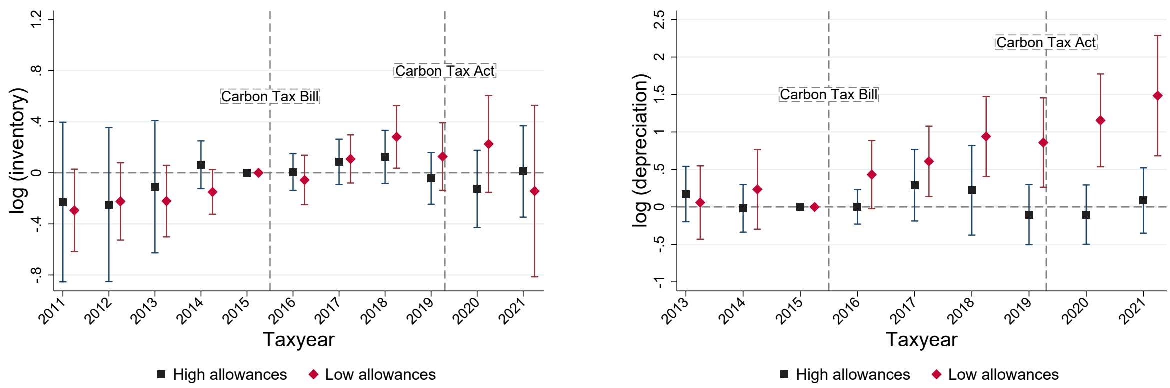
The resolution of uncertainty clarified the future costs for firms subject to the carbon tax. One clear example of how these updated expectations influence firm behaviour is through strategic anticipation of future production costs. In the sense of Sinn (2012), firms might shift polluting activities from the expensive future (under carbon tax) to the cheaper present (without carbon tax). As firms decide on how to use their capital and how to extend production across time, it could be that firms increase production upon policy announcement and stop increasing or even decrease it after the carbon tax is implemented. While this idea primarily stems from the mining sector, manufacturing firms might have a similar incentive by using up their existing 'dirty' capital for the production of goods. Our analysis has revealed that firms were affected heterogeneously by the carbon tax. In particular, the allowances varied across sectors but also across firms within sectors. These allowances and, therefore, approximately the effective tax rates became known to firms upon the announcement in 2015. Considering the anticipation of future costs as an explanation, firms with higher expected tax rates should react more strongly, which is corroborated in Figure 8.

We present two additional observations in Figure 9 that support this channel. First, Panel (a) shows the dynamic effects of the announcement on the inventory levels of treated firms, distinguishing by their allowance take-up. The results indicate a modest increase in inventory following the 2015 announcement for firms with low allowance take-up (and therefore facing relatively higher effective tax rates). This upward trend continues until 2019, with an observed inventory increase of approximately 30% in 2018, significant at the 5% level, but statistically indistinguishable from firms with high allowance take-up. This pattern suggests that some firms accumulated inventory in anticipation of the tax implementation. After the tax came into effect in 2019, the estimated coefficients decline, consistent with a reduction in production.

Second, Panel (b) illustrates a sharp rise in capital depreciation following the announcement, with effects concentrated among firms with low allowance take-up. Together with the positive effects on sales reported in Panel (a) of Figure 8, these findings collectively imply that firms expecting higher tax rates may have intensified the use of emission-intensive machinery before the tax implementation. The accelerated depreciation likely reflects an effort to mitigate the risk of stranded assets—machinery that could become uneconomical or obsolete under the new tax regime. We cannot rule out, however, that firms may have also employed bookkeeping strategies or asset management practices to speed up depreciation, potentially to reduce taxable income or to adjust the valuation of assets on their balance sheets in response to the anticipated tax burden. This could have been a way to optimize their financial position under the carbon tax.

Figure 9: Heterogeneous effects of the carbon tax policy by allowance take-up: inventory and depreciation

(a) Inventory **(b) Depreciation**



Note: this figure plots the θ_k coefficients estimated from equation (7). The blue squares represent the point estimates for firms with high allowance take-up (5th quintile), while the red diamonds represent the point estimates for firms with low allowance take-up (1st quintile). The blue and red vertical bars around the point estimates represent the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors' illustration based on SARS data.

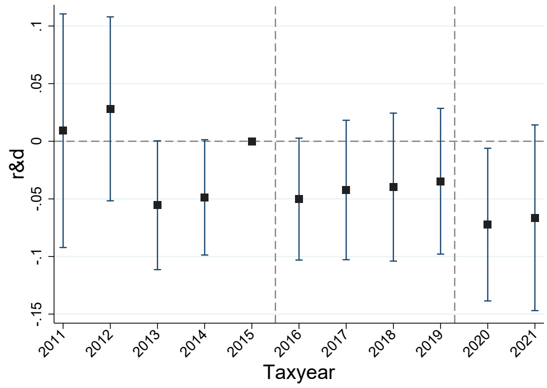
7.2 Technology upgrading

Another explanation for the increased firm activity upon the tax announcement is technology upgrading. Firms could change production technologies to lower emissions and thus avoid high tax payments. Ultimately, this could increase the competitiveness and profitability of firms and, therefore, explain the positive effects we observe (Acemoglu et al. 2012; Porter and Linde 1995). In other contexts, it has been shown that the introduction of an Emissions Trading System (ETS), in fact, triggered innovation and investments in cleaner technology (Calel 2020; Calel and Dechezlepretre 2016). For the case of China, for instance, Cui et al. (2023) show that the ETS induced innovation by firms leading to a comparative advantage over non-ETS firms and thus higher productivity. In South Africa, we find only limited evidence pointing toward innovation or investments in cleaner technology as the main drivers of the positive effects of the carbon tax on firm outcomes.

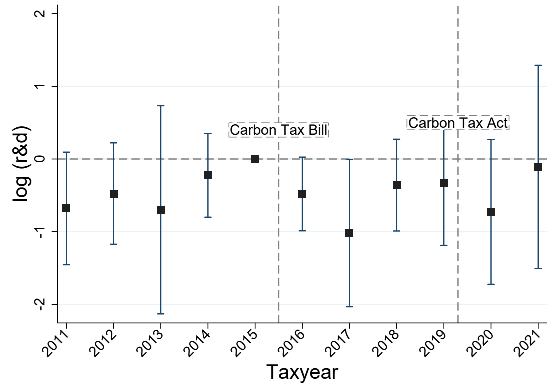
In Figure 10, we re-estimate our baseline specification using three indicators of innovation or technology upgrading as dependent variables. It is important to note that we did not have access to patenting data for these firms, which is why we use these alternative proxies instead. Panels (a) and (b) show that there is generally no significant effect on R&D expenditures—if anything, the point estimates are often negative. This suggests that firms subject to the carbon tax did not increase innovation. Panels (c) and (d) display the dynamic effects on total imports, which can serve as an indicator of whether firms are purchasing clean technology or new machinery from abroad. We observe positive effects on import volume following the carbon tax announcement, but these are only statistically significant on the extensive margin. When focusing on *new imports* in Panels (e) and (f), we find a positive effect on the extensive margin after the tax announcement, but no effect on the intensive margin. While we cannot rule out some impact on innovation and technology upgrading, these analyses collectively suggest that these factors are unlikely to play a major role in explaining the positive baseline results.

Figure 10: Effects of the carbon tax policy on R&D and imports (total vs. new products)

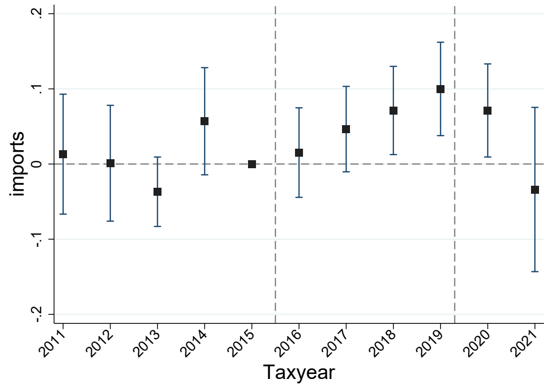
(a) R&D (binary)



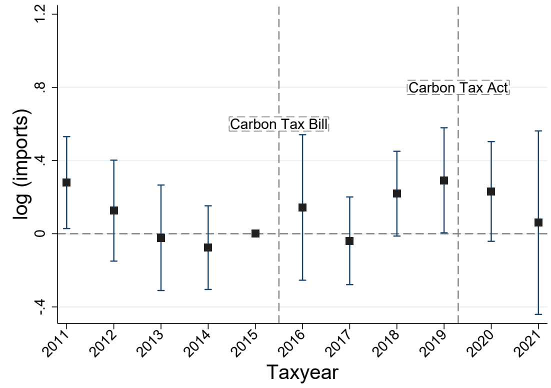
(b) R&D (continuous)



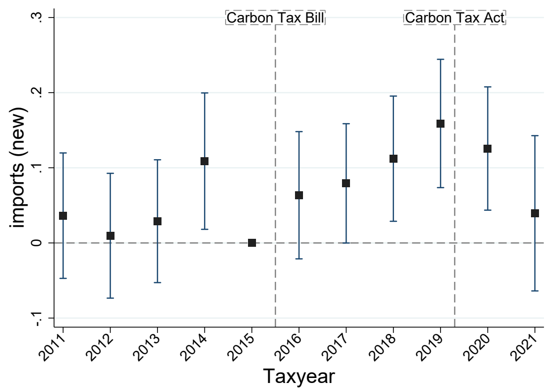
(c) Total imports (binary)



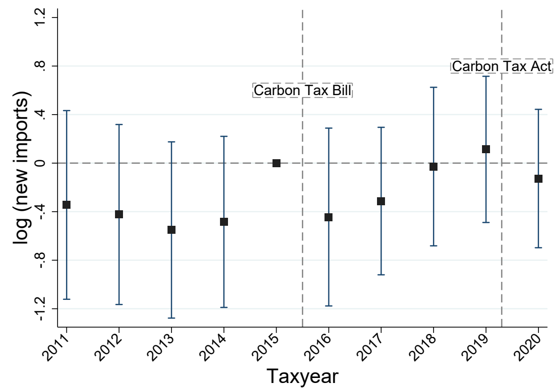
(d) Total imports (continuous)



(e) New imports (binary)



(f) New imports (continuous)



Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. 'Binary' refers to an outcome that is a dummy variable (extensive margin), while 'continuous' refers to an outcome that is measured on a continuous scale (intensive margin). The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors' illustration based on SARS data.

8 Concluding remarks

This paper provides the first comprehensive analysis of how carbon taxation affects firm performance in a large emerging economy. Using detailed administrative data from South Africa, we quantify the impact of the introduction of a nationwide carbon tax on various firm outcomes. Contrary to many expectations, our findings suggest that the carbon tax does not have negative effects on sales, capital, employment, and profits. In fact, treated firms seem to experience greater growth in these outcomes compared to their matched counterparts. Upon the announcement of the tax—four years prior to its implementation—treated firms begin to increase activity, and this positive trend continues even after the tax is implemented.

Additional analyses suggest that these positive effects may result from firms anticipating the tax and adjusting their economic activities in the short term to shift polluting behaviour. In particular, firms may have intensified their use of emission-intensive machinery or accelerated capital depreciation to avoid the risk of stranded assets—machinery that could become uneconomical or obsolete under the new tax regime. While we cannot fully rule out alternative explanations, we do not find robust evidence that firms are investing in cleaner production methods through R&D or importing new, cleaner equipment.

From a policy perspective, these findings suggest that the introduction of a carbon tax may not necessarily harm firm performance in the short term, even in emerging economies. The ability of firms to adapt and adjust may help mitigate the anticipated costs. However, this raises important questions about the carbon tax's effectiveness in driving long-term environmental improvements, as we find no robust evidence of firms investing in cleaner technologies or practices in response to the tax.

Looking ahead, the end of the transition period on December 31, 2025, when allowances are supposed to be phased out and the carbon tax rate increases to its statutory value, could provide firms with a stronger financial incentive to transition to cleaner production methods. As the tax burden becomes more substantial, firms may be more inclined to invest in greener technologies or adopt more sustainable practices to mitigate higher tax liabilities. However, this transition could be gradual and challenging for some firms, especially in sectors heavily reliant on emission-intensive processes. Given these dynamics, policymakers may consider complementary measures to accelerate this transition. This could include subsidies for green technology, direct incentives for R&D in sustainable practices, or additional regulatory measures that encourage firms to adopt cleaner production methods. Without such support, the carbon tax at the current statutory rate alone may not be sufficient to drive the necessary long-term environmental shifts.

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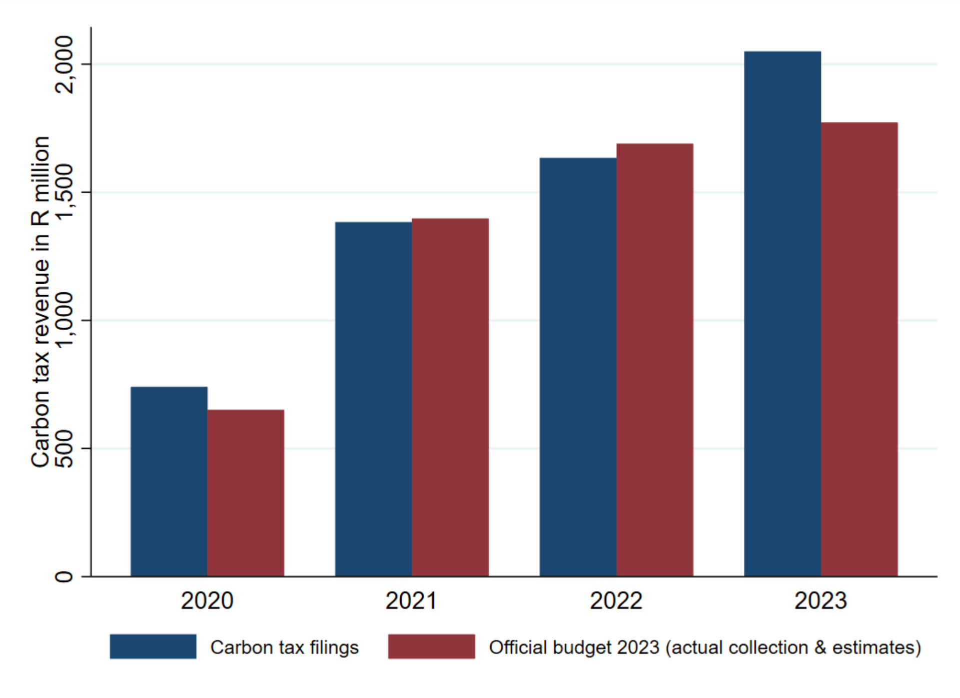
Appendix

A Additional descriptive results

This appendix provides additional descriptive results on the anatomy of the carbon tax, complementing Section 3. Figure A.1 shows the annual carbon tax revenue as depicted by the official budget as well as by aggregating the raw carbon tax micro data. Figure A.2 depicts the different emissions sources for fuel combustion, industrial process emissions as well as for fugitive emissions. Figure A.3 breaks down carbon tax firms that eventually do not pay any carbon tax.

Figure A.1: Aggregate carbon tax revenue

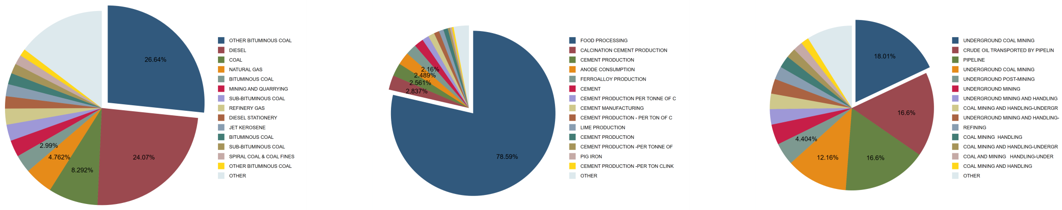


Note: this figure depicts the annually aggregated carbon tax payments. Blue bars show the aggregate numbers for the carbon tax filings provided by SARS. Red bars indicate the aggregate figures by the Treasury in their budget review for 2023. The red bars for 2022 and 2023 are estimations by the Treasury, while 2020 and 2021 refer to actual revenue.

Source: authors' illustration based on SARS data.

Figure A.2: Emissions sources

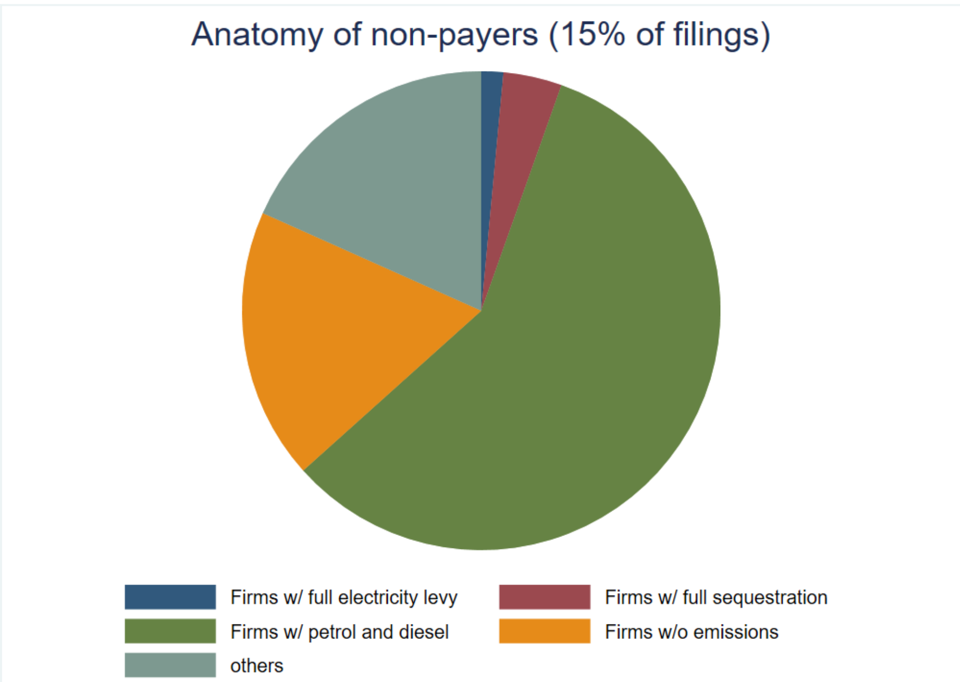
(a) Fuel combustion emissions **(b) Industrial process emissions** **(c) Fugitive emissions**



Note: this figure plots various descriptive statistics based on the carbon tax returns filed by South African firms. Panel (a) depicts the share of fuel combustion emissions disaggregated by fuel type. Panel (b) plots industrial process emissions disaggregated by activity. Panel (c) plots fugitive emissions disaggregated by activity. All data is based on reported emissions of carbon tax firms for the taxyears 2020-2023.

Source: authors' illustration based on SARS data.

Figure A.3: Anatomy of non-payers



Note: this figure plots the anatomy of carbon tax firms that eventually do not pay any carbon tax during the period 2020-2023. The green area depicts firms that only use petrol and diesel. The red area refers to firms that can fully sequestrate their emissions. The blue area depicts electricity firms that can fully deduct the electricity levy. The orange area depicts firms that report zero gross emissions. The remaining firms are all other firms that can not be exclusively classified in one of those categories.

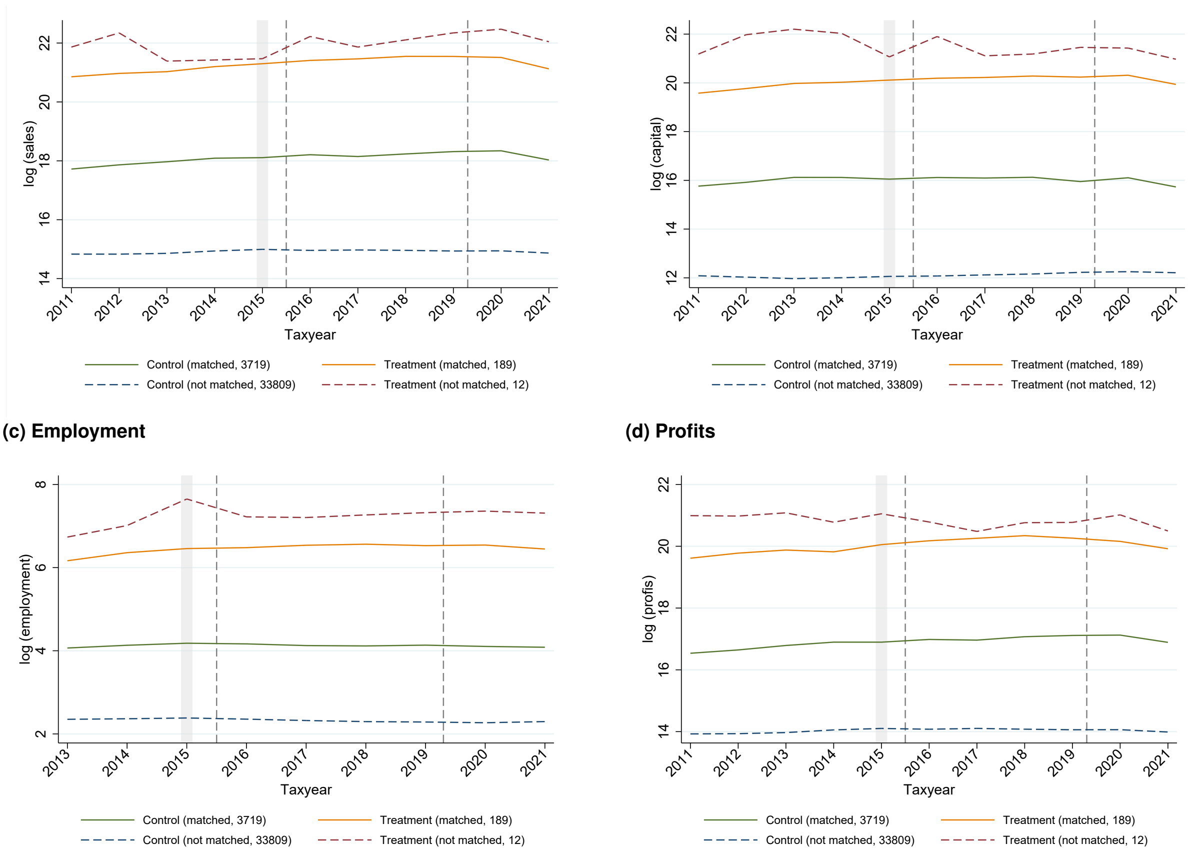
Source: authors' illustration based on SARS data.

B Robustness

This appendix complements Section 6 by providing robustness checks to the main results. Figures B.1 and B.2 plot the raw means, when matching less or more restrictively on observable than in the main specification (see figure notes for details). Figures B.3 and B.4 show the corresponding event study results. In figure B.5, we demonstrate that the results are insensitive to the choice of the baseline year.

Figure B.1: Coarsened exact matching means (less stringent / wide matching)

(a) Sales **(b) Capital** **(c) Employment** **(d) Profits**

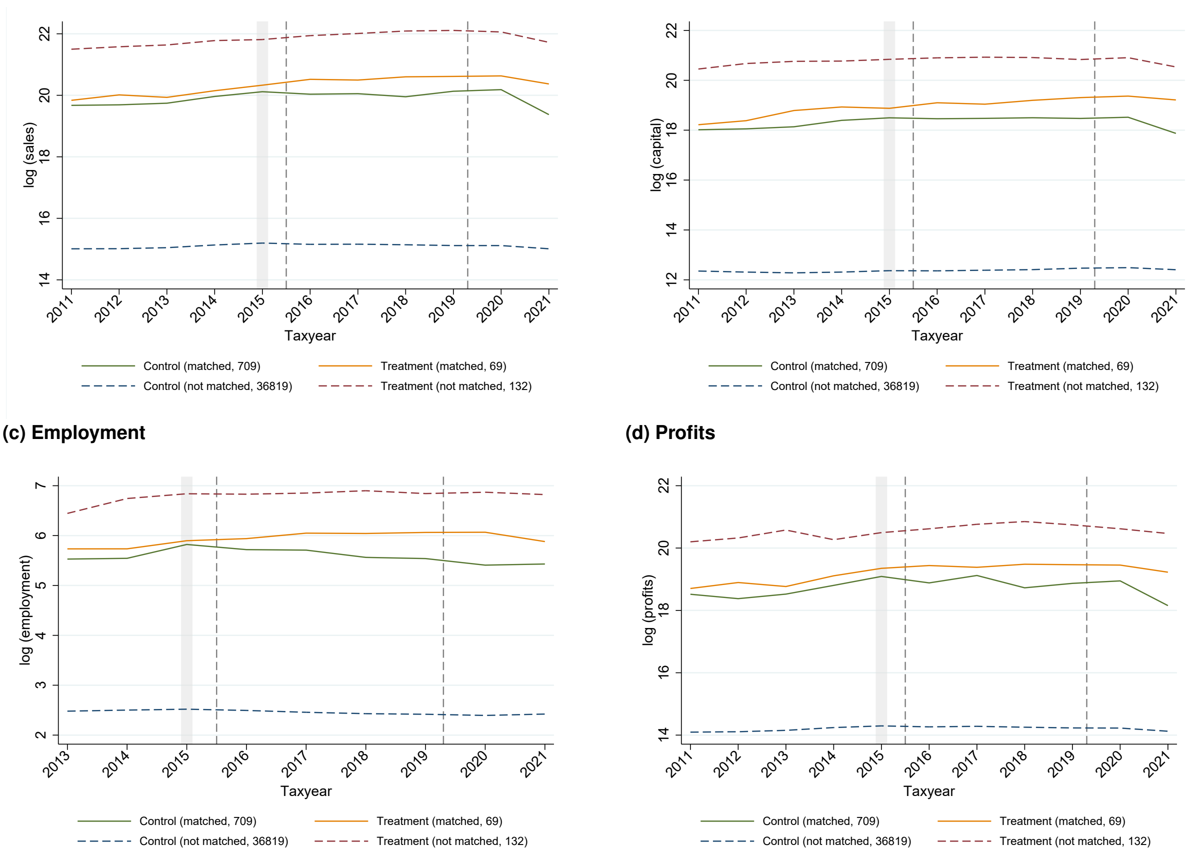


Note: this figure plots the raw means of observable firm characteristics differentiated by treatment and matching status. The dashed red line depicts unmatched treated firms that are subject to the carbon tax. The yellow line depicts matched treated firms, and the green line matched comparison firms that are not subject to the carbon tax. The dashed blue line depicts all remaining untreated firms that were not matched. *Firms were matched exactly on the 3-digit industry and coarsened with only 1 cutpoint* for sales, capital, number of employees, and profits based on the year 2015.

Source: authors' illustration based on SARS data.

Figure B.2: Coarsened Exact Matching Means (more stringent / narrow matching)

(a) Sales **(b) Capital**



Note: this figure plots the raw means of observable firm characteristics differentiated by treatment and matching status. The dashed red line depicts unmatched treated firms that are subject to the carbon tax. The yellow line depicts matched treated firms, and the green line matched comparison firms that are not subject to the carbon tax. The dashed blue line depicts all remaining control firms that were not matched. *Firms were matched exactly on the 1-digit industry and coarsened with 10 cutpoints* for sales, capital, number of employees, and profits based on the year 2015.

Source: authors' illustration based on SARS data.

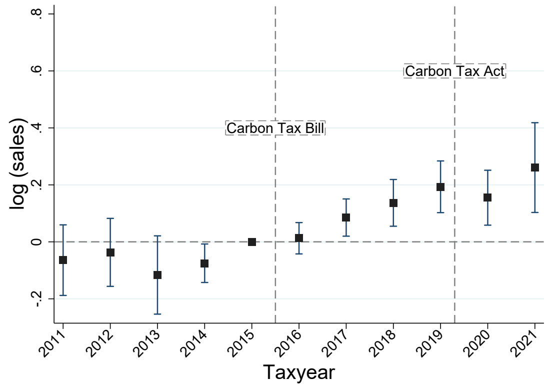
Table B.1: Composition of 'synthetic South Africa'

Per cent (%)	Countries
66.7	United Arab Emirates
3.0	India
2.9	Trinidad and Tobago
2.0	Vietnam
0.5	Saudi Arabia
0.4	Oman
0.2	Lebanon Haiti Suriname Madagascar Macao Zimbabwe Yemen Kuwait Lesotho Grenada
0.2	Cameroon Burundi Jamaica Aruba Comoros Brunei Darussalam Montserrat Anguilla Burkina Faso Turkmenistan
0.2	Cape Verde Dominica Nicaragua Bahamas Qatar Tajikistan Macedonia, the former Yugoslav Republic of Costa Rica Guinea Seychelles Congo
0.2	Niger Gabon Paraguay Egypt Chad Azerbaijan Mozambique Bahrain Botswana Guinea-Bissau
0.2	Kyrgyzstan Uganda Bermuda Guyana Guatemala Ghana Mali Gambia Iraq Cote d'Ivoire
0.2	Mauritania Rwanda British Virgin Islands Senegal Cambodia Togo Sierra Leone Laos Ethiopia Moldova, Republic of
0.2	Angola Namibia Turks and Caicos Islands Bosnia and Herzegovina Peru Mongolia Uruguay Cayman Islands Sri Lanka Benin
0.2	Belarus Kenya Saint Kitts and Nevis Bolivia Armenia Belize Thailand Ecuador Israel Djibouti
0.2	Panama Algeria Liberia El Salvador Bhutan Zambia Sudan Maldives Mauritius Tanzania
0.2	Malaysia Fiji Tunisia Equatorial Guinea Cyprus Saint Vincent and the Grenadines Barbados Central African Republic Pakistan Nepal
0.2	Georgia Swaziland Sao Tome and Principe Dominican Republic Albania Myanmar Morocco Saint Lucia Honduras Jordan
0.2	Antigua and Barbuda Malawi Uzbekistan Democratic Republic Congo Indonesia Brazil Taiwan Australia Hong Kong Turkey
0.2	Nigeria Philippines Bangladesh

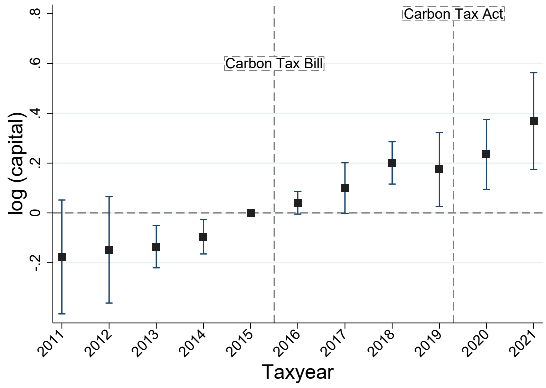
Note: This table features the contributed weights of each country in order to construct a 'synthetic South Africa'. 'Synthetic South Africa' is constructed based on South Africa's average annual emissions in the following IPCC sectors: 1.A.2, 1.B., 2.A., 2.B., 2.C., and 2.D. In addition, average GDP and emissions intensity (emissions/GDP) between 2011 and 2015 are used to construct a 'synthetic South Africa'.

Figure B.3: The effects of the carbon tax policy on firm outcomes (less stringent / wide matching)

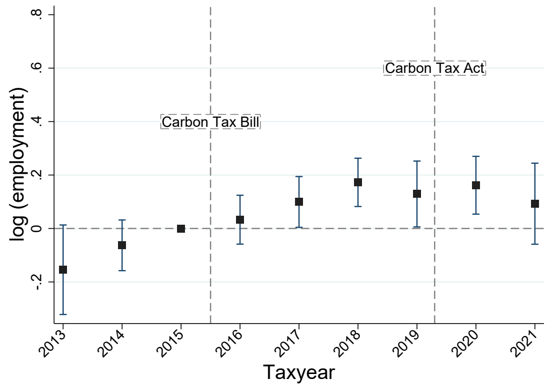
(a) Sales



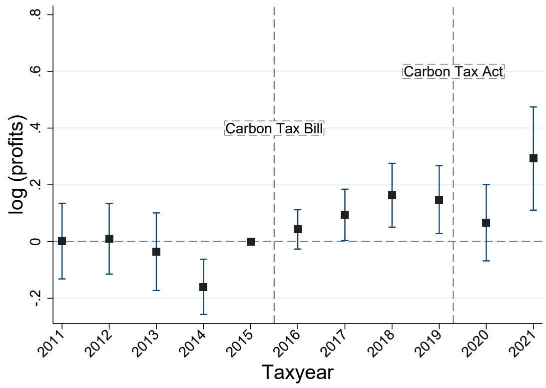
(b) Capital



(c) Employment



(d) Profits

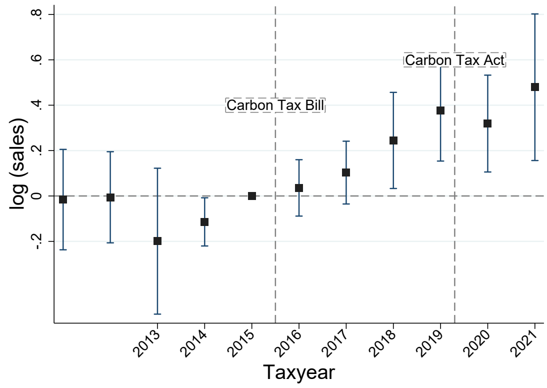


Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

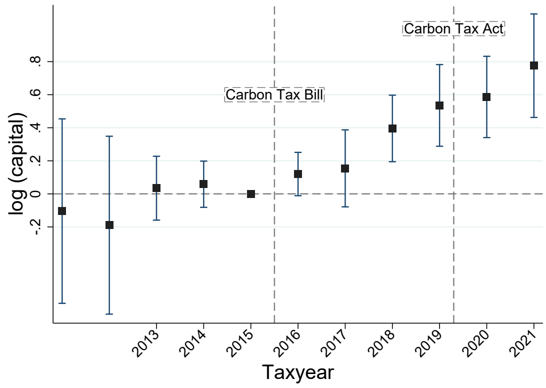
Source: authors' illustration based on SARS data.

Figure B.4: The effects of the carbon tax policy on firm outcomes (more stringent / narrow matching)

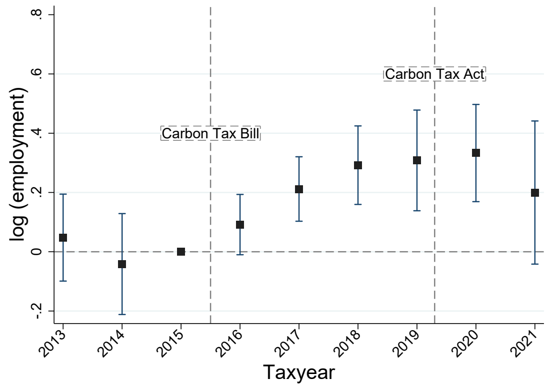
(a) Sales



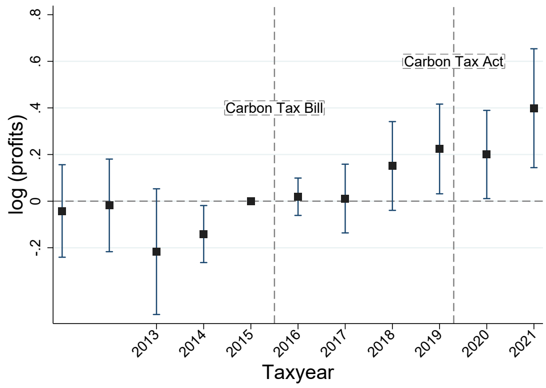
(b) Capital



(c) Employment



(d) Profits

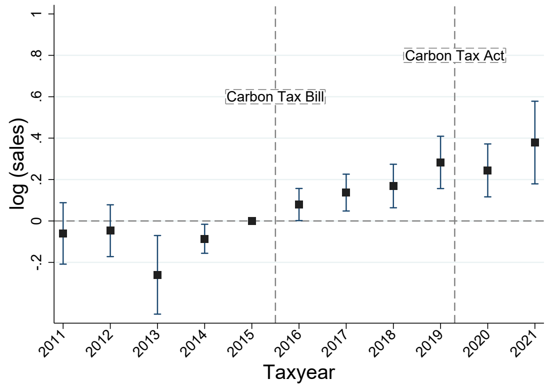


Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

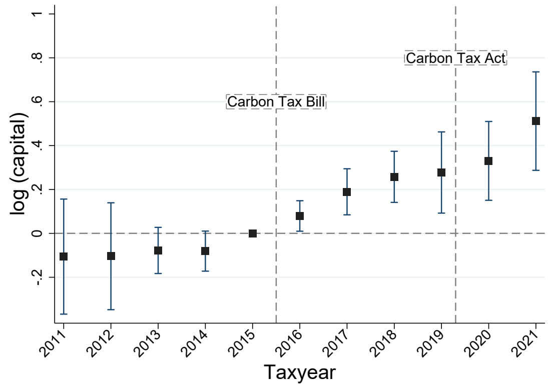
Source: authors' illustration based on SARS data.

Figure B.5: Main event study results using 2013 instead of 2015 as the baseline year

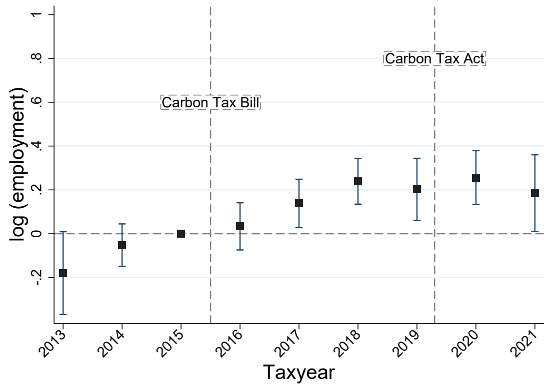
(a) Sales



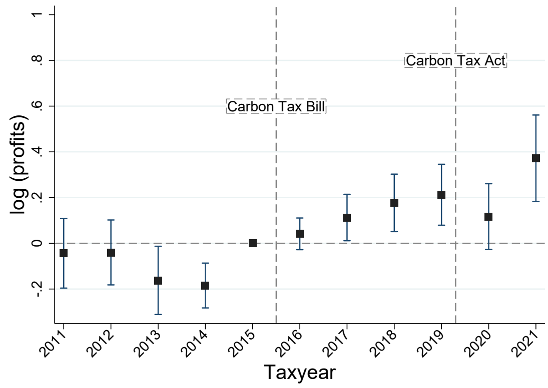
(b) Capital



(c) Employment



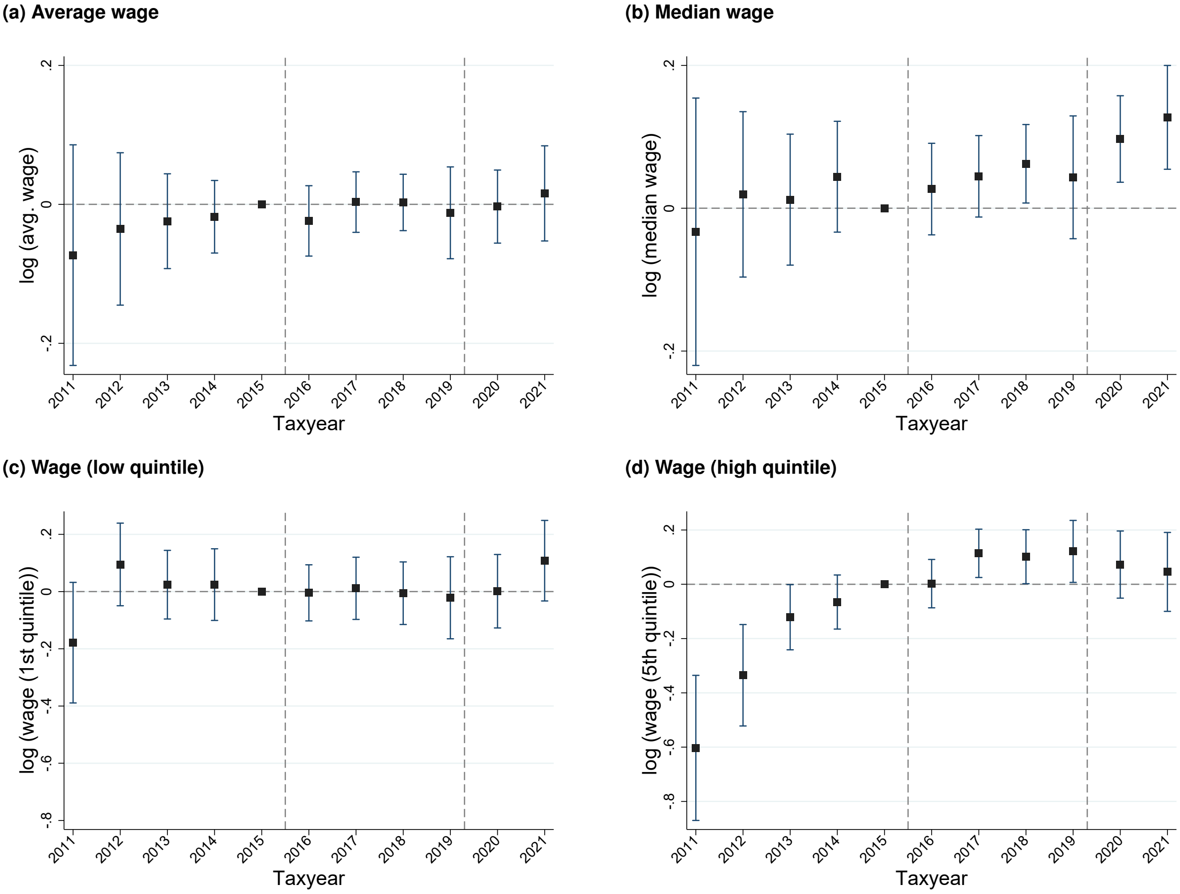
(d) Profits



Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors' illustration based on SARS data.

Figure B.6: The effects of the carbon tax policy on wages within firms

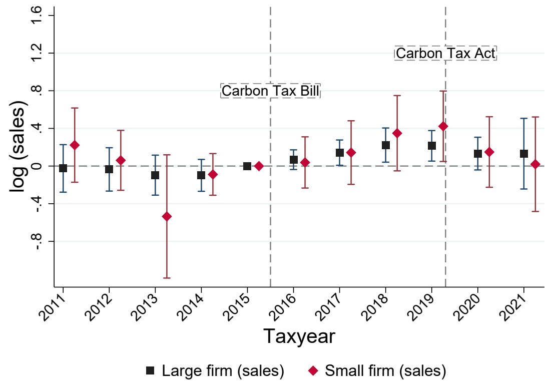


Note: this figure plots the θ_k coefficients estimated from equation (7). The vertical bars around the estimates, represented by the squares, show the 95% confidence intervals. The 'tax year' always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

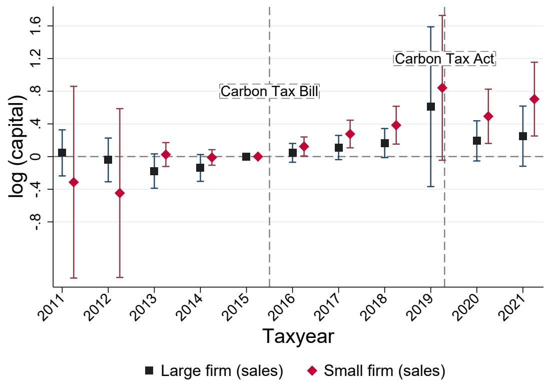
Source: authors' illustration based on SARS data.

Figure B.7: Heterogeneous effects of the carbon tax policy by firm size

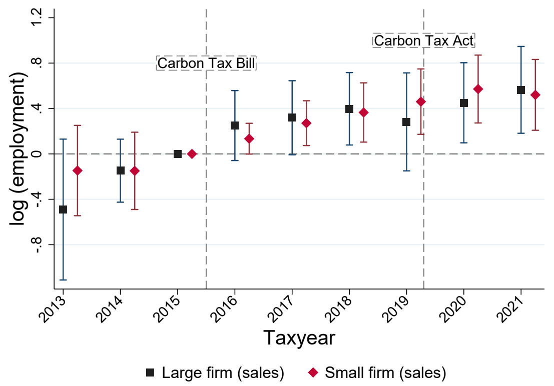
(a) Sales



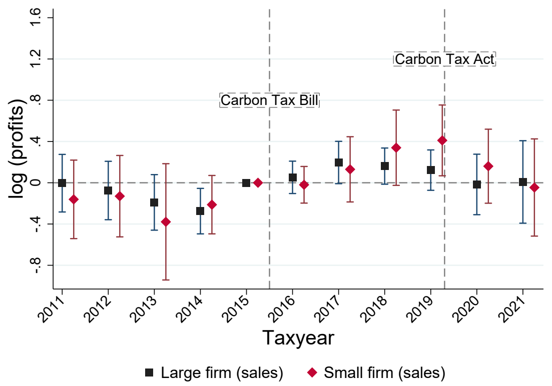
(b) Capital



(c) Employment



(d) Profits

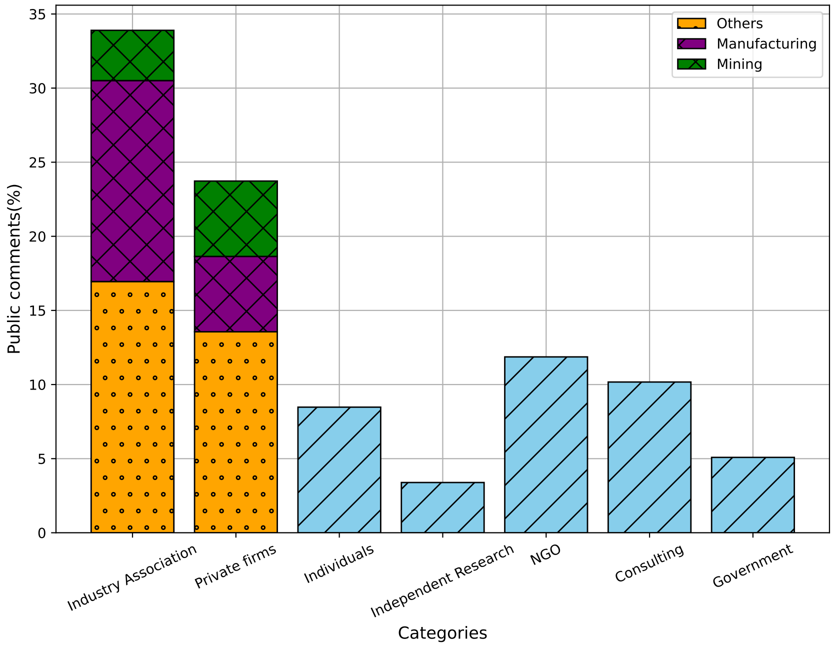


Note: this figure plots the θ_k coefficients estimated from equation (7). The blue squares represent the point estimates for firms with high pre-treatment sales (5th quintile), while the red diamonds represent the point estimates for firms with low pre-treatment sales (1st quintile). The blue and red vertical bars around the point estimates represent the 95% confidence intervals. The ‘tax year’ always refers to the previous fiscal year; for example, 2020 corresponds to the period from March 2019 to February 2020. The first dashed line marks the publication of the first draft of the Carbon Tax Bill, and the second dashed line marks the implementation of the Carbon Tax Act in June 2019.

Source: authors’ illustration based on SARS data.

C Public comments

Figure C.1: Type of commentators



Note: this figure plots categorization of public comments from the Carbon Tax Bill 2018. Industry associations and private firms are further categorized by their main industry denomination.
Source: authors' illustration.

Some examples of public comments include:

- It is suggested that the formula to calculate the tax liability as in equation (1) is amended to allow sequestration to be deducted not only from fuel combustion emissions but also for process and fugitive emissions (*Not accepted.* Carbon Tax Bill 2018).

- Inconsistency of the tax treatment of waste management activities in the bill, where the provision of the 100 percent allowance for GHG emissions needs to be applied consistently across all sectors and provision should be made accordingly in the Bill (*Accepted. The bill has been amended to allow for a 90 percent tax-free threshold for waste incineration activities.* Carbon Tax Bill 2018).

- For performance allowances, developing an industry benchmark for the lime industry in South Africa may be challenging as there are currently only two large lime manufacturers in the country and three smaller producers. (*Noted.* Carbon Tax Bill 2018).

- The recognition of a renewable energy premium included in the electricity tariff is welcomed. It is proposed that this rebate should be extended to include renewable energy allowed as a recovery of cost by Eskom as well and not limited to the Independent Power Producers only (*Accepted. The bill has been amended to provide the credit for all renewable energy producers.* Carbon Tax Bill 2015).

- Nampak estimates that the emission factor should be closer to 0.1500 to 0.1700 tonnes CO2 per tonne of glass excluding cullet production. This factor is overstated by 25 per cent. The 2006 IPCC Guidelines emissions factor of 0.200 tonnes CO2 per tonnes of glass does not necessarily hold true for all glass production. (*Noted. The emissions factors provided in the Schedule 1 of the carbon tax bill are default emissions factors based on the 2006 IPCC Guidelines and are aligned with the Mandatory reporting regulations and Technical Guidelines. A process to submit alternative emission factors is clearly stated in the NGERs and associated technical guidelines of the DEA.* Carbon Tax Bill 2015).

D Data

This data appendix has been prepared in accordance with UNU-WIDER guidelines for users of the National Treasury Secure Data Facility (NT-SDF) and details the data generation process and data sets that have been used in the NT-SDF.

Data access
The tax administrative micro-data was accessed at the NT-SDF in Pretoria. Access to the data was granted under a non-disclosure agreement and all produced results were reviewed to ensure that the anonymity of any firm or individual remained protected. The results do not represent any official statistics of the National Treasure or South Africa revenue Services.

Data used: SARS Treasury Matched Firm Panel (`stmfp_2008_2022_e5_v1`) (National Treasury and UNU-WIDER 2023), year-by-year IRP5 job-level data (v4) (National Treasury and UNU-WIDER 2024b), and the firm-level carbon tax data (beta-version) (National Treasury and UNU-WIDER 2024a). Date of first access for this project: 5 January 2024. Last accessed: 22 January 2025.

Software
The data generation and econometric analysis was conducted using STATA 17. User-written programmes include `reghdfe` (Correia 2014), `cem` (Blackwell et al. 2009), and `ftools` (Correia 2017).

Variables
Variables used from the Treasury Matched Firm Panel include `imp_mic_sic7_1d`, `c_type`, `g_sales`, `x_labcost`, `g_grossprofit`, `k_ppe`, `k_faother`, `k_inventory`, `cust_export`, `cust_import`, `x_rd`, `x_officel`, `x_cprof`.

For calculating employment and the wage distribution within firms the following variables have been used from the year-by-year IRP5 job-level data (v4): `totalperiodsinyearofassessment`, `totalperiodsworked`, `periodemployedto`, `periodemployedfrom`, `kerr_income`, `ptrs_income`, `kerr_emp`, `kerr_emp_inc`, `ptrs_emp`, `ptrs_emp_inc`, `revisionnumber`, `transactionyear`, `amtpaye`.

In order to construct the descriptive characteristics of carbon tax firms the following variables from the carbon tax data haven been used `net_emissionequiv`, `grosslevypayamt`, `netlevypayamt`, `totpaymentamt`, `gross_emissionequiv`, `totfuelcombustionemissions`, `sequestratedemissions`, `petrolanddieselemissions`, `totindustrialprocessemissions`, `totfugitiveemission`.

Cleaning and sample notes

We have excluded all dormant firms in the SARS Treasury Matched Firm Panel (`c_type = 0` and `c_type = 1`. Further, all firms without an anonymized tax reference number (`taxrefno`) have been dropped. The variable on capital used in the analysis is constructed as the sum of the variables `k_ppe` and `k_faother`. For the firm-level employment information and wage distribution, individuals employed in public sector firms are excluded. If individuals have worked in multiple jobs, we keep their income record of the main job so the each individual is assigned to a single firm. Further details on the construction of employment and income varibles are outlined in Pieterse et al. (2018) and Kerr (2021). These notes highlight key data cleaning and sample construction steps; full details are available in our do-files at the NT-SDF.