The Effect of Carbon Pricing on Firm Emissions: Evidence from the Swedish CO_2 Tax

Gustav Martinsson[*], László Sajtos[†], Per Strömberg[‡], Christian Thomann[§]

This version: October 2023

Abstract

Sweden was one of the first countries to introduce a carbon tax in 1991. We assemble a unique dataset tracking CO_2 emissions from Swedish manufacturing firms over 26 years to estimate the impact of carbon pricing on firm-level emission intensities. We estimate an emission-to-pricing elasticity of around two, albeit with substantial heterogeneity across subsectors and firms, where higher abatement costs and tighter financial constraints are associated with lower elasticities. A simple calibration suggests that 2015 CO_2 emissions from Swedish manufacturing would have been roughly 30% higher without carbon pricing.

Keywords: Carbon taxation, Emissions trading, Climate Policy, Climate change, Green growth, Tax policy, Financial constraints

JEL codes: H23, Q54, Q58, G32

[*]Stockholm University, SHoF & MISUM, gustav.martinsson@sbs.su.se

[†]Konjunkturinstitutet & SHoF, laszlo.sajtos@hhs.se

[‡]Stockholm School of Economics, CEPR, ECGI, SHoF, & MISUM per.stromberg@hhs.se

[§]Royal Institute of Technology, SHoF, & MISUM christian.thomann@hhs.se

Forthcoming, *Review of Financial Studies*. This paper was previously entitled "Carbon Pricing and Firm-Level CO_2 Abatement: Evidence from a Quarter of a Century-Long Panel." We would like to thank Caroline Gredenborn, Dolan Haddad, Fredrik Kanlé, Marina Kumlin, Ingrid Mawdsley, and Barbro Olsson, Andreas Rasku, and Susanna Roth for providing data support of this project. The paper has greatly benefited from comments by two anonymous referees, Bo Becker, Jakop Dalunde, Susanne Åkerfeldt, Stefano Giglio (editor), Michael Halling, Fredrik Hannerz, Thomas Hörnefeldt, Daniel Metzger, James Stock, Chad Syverson, and seminar participants at Vienna Graduate School of Finance, University of Gothenburg, University of North Carolina, NHH, IFN, Studieförbundet Näringsliv och Samhälle (SNS), MISUM, the Swedish House of Finance, the 2022 American Economic Association meetings, the 2021 EUROFRAME conference, the 2022 CSEF-IGIER Symposium on Economics and Institutions, the 2023 Bank of Italy, CEPR, CompNet, EBRD & IWH Conference 3rd Finance and Productivity (FINPRO), and the UN Subcommittee on Environmental Taxation Issues. We are grateful for financial support from Mistra Financial Systems, the Handelsbanken Research Foundations, the Nasdaq Nordic Foundation, and the Swedish Research Council. Jiayu Zhang provided excellent research assistance.

1 Introduction

Anthropogenic climate change is one of the most pressing issues of our time, representing a massive market failure in need of urgent policy intervention (Stern, 2008). Many economists have argued the most important policy tool to combat climate change is to price CO_2 emissions through a global carbon tax (e.g., Golosov et al., 2014; Nordhaus, 1993; Rockström et al., 2017; Sterner et al., 2019), ideally in combination with subsidies for green innovation (e.g., Acemoglu et al., 2016; Aghion et al., 2016). While there is still no agreement on a global carbon tax, many countries around the world have implemented local or regional carbon pricing schemes (World Bank 2022). Despite the risk of carbon leakage, Conte et al. (2022) argue that such unilateral schemes, if properly designed, can still be effective.

Until just a few years ago, there was little empirical evidence on whether existing carbon pricing schemes had actually reduced firm CO_2 emissions (Burke et al. 2016; Martin et al. 2016). While the literature has grown over the last few years, the evidence on the effectiveness of carbon pricing is still mixed (see Green, 2021; Rafaty et al., 2021; Timilsina, 2022, for recent reviews). One reason why results differ is that carbon pricing schemes vary greatly in their structure, coverage, and magnitude. In addition, the majority of studies examine aggregated data at the sector- and/or country-level, which makes it difficult to account for important heterogeneity in marginal pricing and abatement costs across firms.[1] The relatively few studies that analyze micro-data on individual firms or plants estimate average treatment effects around the introduction of a particular carbon pricing scheme. Since emission pricing differs significantly in magnitude across schemes and over time, however, it is perhaps not surprising that results vary greatly across studies.[2]

[1] Examining sector-level emissions and using synthetic control methods, Rafaty et al. (2021) conclude that the introduction of carbon pricing has only reduced aggregate emissions by 1-2%, with most abatement occurring in the electricity and heat sector (rather than manufacturing). They also estimate a small and imprecisely estimated carbon pricing elasticity. Using a differences-in-differences approach, Pretis (2022) finds small effects on sector-level emissions from the introduction of carbon taxation in British Columbia, particularly outside of transportation. In contrast, using synthetic panel methods on individual sectors, Andersson (2019) finds that the Swedish carbon tax reduced transport emissions by 11%, and Leroutier (2022) estimates that UK power sector emissions declined by 20-26% following the implementation of the UK Carbon Price Support scheme. Using aggregate data for 31 European countries, Metcalf and Stock (ming) estimate a 4-6% reduction in emissions for a \$40/ton carbon price covering 30% of emissions.

[2] These studies include Bartram et al. (2022), who find that the California cap-and-trade system failed to reduce CO_2 emissions and led to substantial carbon leakage to other U.S. states; Colmer et al. (2022) who estimate that French manufacturing firms reduced their CO_2 emissions by 14-16% after the introduction of EU ETS; Dechezleprêtre et al. (2023) who use a broader set of EU ETS countries and find average emission reductions of around 10%; and Ahmadi et al. (2022) who estimate that the introduction of the British Columbia carbon tax reduced emissions by 4%.

Using data from Sweden, we construct the longest firm-level panel to date on economic activity and CO_2 emissions for the population of manufacturing firms during 1990-2015. Our analysis aims to contribute to the existing literature in several ways.

First, we provide estimates of carbon pricing elasticities for the manufacturing sector by relating the marginal cost of emitting a unit of CO_2 to actual emissions for every firm and year. Such elasticities can be used to assess different carbon pricing schemes, e.g., by calibrating macroeconomic models of optimal climate policy (such as Acemoglu et al., 2016; Golosov et al., 2014). Our data set is large in both the cross-sectional and time-series dimensions, which enables econometric identification due to numerous changes in tax rates and firm-level exemptions over time. It also allows estimation of the full dynamic response to carbon pricing, where we can account for the time it takes for firms to adapt their technologies and business models (Dessaint et al., 2022). We are thus able to provide precise estimates of carbon pricing elasticities, unlike the earlier literature, which either bases estimates on aggregated country- or sector-level time-series data, or estimates average treatment effects around the introduction of a given carbon pricing scheme.[3]

Second, our micro-data enables us to investigate the heterogeneity in carbon pricing elasticities across firms and subsectors. Both the incentive and the ability of firms to lower their emissions in response to carbon pricing will differ depending on, e.g., production technology, abatement costs, financial constraints, mobility of production, and the competitive environment (e.g., Ederington et al., 2005; Gillingham and Stock, 2018; Lyubich et al., 2018; Martin et al., 2014; Xu and Kim, 2022). Since the bulk of CO_2 emissions are concentrated to a few sub-sectors, and often to a few large firms within each sub-sector, such heterogeneity has large implications for the aggregate impact of carbon pricing.

Third, existing evidence on the effectiveness of carbon pricing have been mixed, and several studies have found limited impact of carbon pricing schemes on aggregate CO_2 emissions from manufacturing (see e.g., Rafaty et al., 2021, and the references therein). In contrast, the elasticities we uncover from micro-data imply economically significant effects of carbon pricing on manufacturing emissions. These elasticities can be applied to infer

[3]Two exceptions are Germeshausen (2020), who estimate the price sensitivity of CO_2 emissions from German power plants in the EU ETS; and Dussaux (2020), who estimates the elasticity of energy use to fuel (rather than carbon) prices for a sample of French manufacturing firms, which are then used to simulate the economic effects of carbon pricing.

expected emission reductions across carbon pricing schemes with different price levels and industry structures, which increases the external validity compared to previous studies.

Our data set includes comprehensive information on financials and CO_2 emissions for the universe of Swedish manufacturing firms over the period 1990-2015. Sweden serves as an ideal testing ground for analyzing the incidence and impact of carbon pricing. It was one of the first countries to introduce a carbon tax in 1991, levied on the heating emissions from manufacturing firms, and the Swedish carbon tax rate is currently the highest in the world.[4] In addition, several subsequent changes in tax rates, various tax exemptions, and the introduction of the EU Emissions Trading System (ETS) towards the end of our sample lead to substantial variation in effective marginal tax rates across firms and over time, facilitating econometric identification.

When the carbon tax scheme was introduced in 1991, it contained various tax exemptions for the highest emitters, motivated by the desire to mitigate "carbon leakage" (i.e., CO_2-emitting plants closing in Sweden and/or moving to other jurisdictions). As a result, the 10% of firms with the highest CO_2 emissions had significantly lower (sometimes even zero) marginal carbon tax rates, despite facing a high average tax rate (reducing average EBIT margins by more than 6 percentage points). Consistent with reduced marginal incentives, we find that the emission intensity of the highest-emitting firms decreased only modestly between 1990 and 2015, while the remaining 90% of firms facing higher marginal carbon tax rates experienced significantly higher reductions.

To measure short-term responses, we follow previous literature and perform differences-in-differences analysis around the introduction and subsequent changes of the carbon tax regime, utilizing the caps on total tax payments for the highest emitters. In the first test, we focus on the 10% most emitting sectors and sort firms into two groups: those qualifying for exemptions around the introduction of the carbon tax in 1991-1992 and those that did not. The results show that a rise (decline) in marginal cost is associated with decreasing (increasing) firm level emission intensity. We also study the re-introduction of a carbon tax payment exemption in 1997 and obtain similar results.

We then examine the longer-term relationship between emission intensity and the

[4]According to World Bank (2022), there are just under 70 carbon pricing schemes in place in 2022, covering just under one quarter of global CO_2 emissions. Only six of these were introduced before 2000 and two-thirds of them were introduced after 2010.

marginal emission tax a firm faces, including both the explicit CO_2 tax as well as the implicit tax from the price of emission rights for firms with installations under the EU ETS. Using data from about 4,000 manufacturing firms, covering 85-90% of Sweden's manufacturing CO_2 emissions over 1990-2015, we find a significantly negative relationship between firm-level CO_2 emission intensity and the marginal cost of emissions. In our main specification, which includes firm and year fixed effects, we estimate that a one percent increase in the marginal emissions cost share reduces carbon emissions per unit of (PPI-deflated) sales by roughly two percent over a three-year period. This magnitude is stable over the introduction of the EU ETS in 2005 and robust to including tighter sets of fixed effects, more lags, and various firm-level controls.

We also document significant heterogeneity in the response to carbon pricing. We first sort firms into two groups based on the ex ante costs of reducing CO_2 emissions, using data on air pollution abatement costs and expenditure (PACE; see Becker, 2005). Firms in low PACE sectors, i.e., where it is relatively cheaper and easier to reduce emissions, display a carbon pricing elasticity of around three, compared to an elasticity less than two in high PACE sectors. To get at carbon leakage risk, we further separate low and high PACE sectors based on the ex ante mobility of their assets (Ederington et al., 2005). The smallest point estimate is for firms in high PACE and low mobility sectors, with an elasticity of 1.7. This group, containing firms that face high abatement costs and are less able to avoid tax by moving production, comprises between 80-90% of aggregate manufacturing CO_2 emissions. We find similar results when we instead separate firms by whether their sub-sector is included on the EU "carbon leakage list" (European Commission, 2009).

Since access to external financing might affect the ability of firms to invest in abatement, we explore whether financial constraints affect carbon pricing elasticities. Following the literature, we consider firms that are privately held (rather than listed), smaller, younger, and with lower dividend payout ratios as being more financially constrained (see e.g. Saunders and Steffen 2011, Hadlock and Pierce 2010, and Bartram et al. 2022). Less constrained firms display elasticities between two and three whereas estimates for their more constrained counterparts are insignificant and consistently less than one. The difference in elasticities is only found among firms with high abatement costs, while financial constraints have no visible effect on firms with low abatement costs, consistent with financial constraints primarily hurting firms for which abatement requires significant investment.

To assess the economic importance of these findings, we relate the estimated elasticities to changes in aggregate manufacturing emissions of CO_2 in our sample period. Following Grossman and Krueger (1993) and Levinson (2009), we decompose the change in aggregate emissions into scale, composition, and technique effects. CO_2 (heating) emissions from the Swedish manufacturing sector decreased by 31% during 1990-2015. The decomposition attributes 3 percentage points of this decrease to lower aggregate output ("scale") and 10 percentage points to the changing composition of Swedish manufacturing towards lower-emitting sub-sectors. By definition, the remaining 18 percentage points (58% of the total reduction) is attributed to changes in technology ("technique"). We then use our estimated carbon elasticities to calculate the contribution from carbon pricing on these aggregate reductions. Our calculations suggest that carbon pricing, through its effect on reduced emission intensities, can account for between one third up to almost all of the total decrease in CO_2 emissions from manufacturing over our sample period.

In terms of implications, we believe that our findings are relevant for discussions on optimal carbon taxation more generally (e.g., Bovenberg and De Mooij, 1994; Bovenberg and Golder, 1996; Gillingham and Stock, 2018; Nordhaus, 1993; Pindyck, 2013; Stock, 2020). While our reduced-form estimates ignore potentially important general equilibrium effects, they confirm that even in a unilateral carbon pricing scheme (as in Conte et al., 2022), firms do respond to the marginal cost of emitting CO_2 in a way consistent with economic theory. Our results also imply that Sweden could have achieved significantly larger reductions in CO_2 without the various tax exemptions that reduced marginal incentives to reduce emissions for the highest-emitting firms.

We also contribute to the literature examining the effects of environmental policy on firms (e.g., Bartram et al., 2022; Brown et al., 2022; Fowlie, 2010; Fowlie et al., 2016; Greenstone et al., 2012; Hartzmark and Shue, 2023; He et al., 2020).[5] By estimating elasticities rather than average treatment effects, we uncover several sources of heterogeneity in firms' responses to carbon pricing and show that they are of economic importance.

Finally, our paper is part of a growing literature documenting the connections between

[5] A related literature documents empirical evidence of how changes in price and policy induce a shift away from dirty fossil-fuel based technical change to clean technologies (e.g., Hassler et al., 2021; Newell et al., 1999; Popp, 2002).

finance and the environment (e.g., Bartram et al., 2022; Bolton and Kacperczyk, 2021; Giannetti et al., 2023; Giglio et al., 2021b; Hong et al., 2019; Ilhan et al., 2021).[6] Specifically, our study adds to the work examining the legal and financial determinants of environmental behavior (e.g., Akey and Appel, 2021; Bartram et al., 2022; Brown et al., 2022; Xu and Kim, 2022) by showing that financial constraints play an important role in determining the response of firms' CO_2 emissions to carbon pricing.

2 Carbon Pricing in Sweden

Sweden introduced its carbon tax in 1991 alongside a handful of countries.[7] The tax was part of a comprehensive reform and included elements of so called green tax shifting with the idea to increase costs on polluting and lower, for instance, labor taxes (see e.g., Jonsson et al., 2020).[8] Some reasons for Sweden being an early adopter of carbon pricing are the lack of significant fossil-fuel resources and (perhaps as a result) the absence of significant anti-climate lobbying (e.g., Meckling et al., 2017; Sterner, 2020). Appendix A provides further background on the introduction and evolution of Swedish carbon taxation.

The Swedish carbon tax is levied on fossil fuels used either in combustion engines ("mobile emissions") or for heating ("stationary emissions"). The tax on mobile emissions primarily affects road transportation (and is included in the after-tax price of fuel "at the pump"), while the tax on stationary emissions is levied on power plants and manufacturing firms. This study focuses on the stationary emissions tax on manufacturing firms, summarized in Figure 1. Manufacturing production releases heating and process CO_2 emissions and the carbon tax on stationary emissions is levied on emissions from heating only, while process CO_2 emissions are exempt. A plant must declare the use of its fossil fuel separately for production and heating and the tax is levied on heating fuel inputs in proportion to the implied emissions of CO_2 during combustion.[9] Since the Swedish manufacturing sector

[6]See Giglio et al. (2021a) for a survey.

[7]The other countries introducing carbon taxation around this time were Finland (1990), the Netherlands (1990), Poland (1990), Norway (1991) and Denmark (1992). See World Bank (2022) and Shah and Larsen (1992) on international carbon pricing schemes, and Brännlund et al. (2014) and Scharin and Wallström (2018) for reviews of the Swedish carbon tax.

[8]This is in line with arguments that optimal carbon pricing should be revenue neutral (e.g., Conte et al., 2022; Timilsina, 2022). We control for the possible confounding effects from concurrent changes in labor and corporate income taxation in the empirical analysis below (see Table 5).

[9]See Statistics Sweden (2018) for details on how the Swedish emissions data is collected. Inferring CO_2 emissions from fuel consumption is the dominant measurement method among environmental agencies

uses about one third of its fossil fuel for production and the remainder for heating, about two thirds of the sector's stationary CO_2 emissions are subject to carbon taxation.

Figure 2 plots the evolution of the Swedish carbon tax rate over time. When it was introduced in 1991, the tax was levied at a rate of 0.25 Swedish Krona (SEK) per kilogram (kg) of emitted CO_2 across all sectors in the economy.[10] Already at this point, however, Swedish carbon taxation incorporated various caps and exemptions (summarized in Table 1) for the highest-emitting firms. We discuss these in greater detail in subsection 3.2.

In 2005, the European Union introduced a cap-and-trade scheme for CO_2 emissions, the *European Union Emissions Trading System* (EU ETS), which had major implications for Swedish carbon taxation. Installations covered by the EU ETS were gradually phased out of the Swedish carbon tax regulation during 2008-2011 (Government Bill 2007/2008:1, 2007). Emission allowances were allocated for free to the participating plants (or "installations") in the pilot phase (i.e., 2005-2007), and the bulk of emission rights were distributed for free in the second trading phase (2008-2012) as well. In the third phase, starting in 2013, auctions of emission rights were introduced, although for manufacturing plants most emission rights were continued to be distributed for free, motivated by carbon leakage concerns.[11]

3 Carbon Pricing Across Firms, Sectors, and Over Time

3.1 Data and sample construction

Our sample is constructed by matching plant- and firm-level registry data (including accounting variables, number of workers, sector classifications, etc.) with CO_2 emissions for the time period 1990-2015. The Swedish Environmental Protection Agency (SEPA) provided data on CO_2 emissions at plant- and firm-level (including emissions under the EU ETS). We obtain registry data for listed and unlisted Swedish corporations from *Upplysningscentralen* (UC) for the period 1990-1997 and *Bisnode Serrano* for 1998-2015.

In order to compute emission intensities, our sample firms need to have data on both

around the world, while direct measurement using Continuous Emissions Monitoring Systems (CEMS) is less common (see United States Environmental Protection Agency, 2016). The fuel consumption method has been found to be at least as accurate as the CEMS method (see Bryant et al., 2015; Quick, 2014).

[10] In 1991, one USD was roughly equal to 6.50 SEK. Over our sample period, the exchange rate fluctuated between 6 and 9 SEK per USD.

[11] Dechezleprêtre et al. (2023) provides an overview of the EU ETS and its different trading phases.

sales and CO_2 emissions. The number of firms with CO_2 emissions data changes during our sample period (see Table B.1), most notably in 1997-1999 and 2003-2006 when only emissions by larger plants were collected by SEPA. Since the largest emitters are always sampled, our data consistently covers between 80-95% of aggregate manufacturing CO_2 emissions in any given year (Figure A.1). Over the entire period 1990-2015, our sample covers 85% of aggregate CO_2 heating emissions and 87% of total (process plus heating) CO_2 emissions (Figure A.2) from the Swedish manufacturing sector.

Since historical firm-level records of actual carbon taxes paid could not be provided by the Swedish tax authority, we calculate both the effective marginal tax and the overall carbon tax payments from the actual CO_2 heating emissions for each plant and firm each year, using the carbon tax schedule (including possible exemptions) that was in place for the corresponding year.[12] For the EU ETS period, we infer the emissions subject to the Swedish carbon tax as the difference between emissions reported in SEPA and emissions according to the European Union Transaction Log (the official registry of EU ETS). For the regression analysis, we require sample firms to have at least four consecutive yearly observations to allow for lagged independent variables. A detailed description of the sample construction are provided in subsection B.1 and subsection B.2 of the appendix and in Sajtos (2020). Table 2 provides summary statistics for the key variables.

We then sort our sample firms into different manufacturing sub-sectors based on CO_2 emissions intensity in 1990. Specifically, we sum up all (heating) CO_2 emissions as well as PPI-deflated sales across all firms in each four-digit industry each year. For deflating sales, we use 2010 as the base year and deflate using the Swedish Producer Price Index at the four-digit NACE code level. Removing the effect of sector-level price variation on sales is important to ensure that changes in emission intensities are not completely driven by changing output prices (e.g., resulting from producers passing on carbon tax to their customers). We then rank the industries depending on the ratio between aggregate emissions divided by aggregate sales in 1990 (the year before the introduction of the carbon tax) from highest to lowest and divide them into deciles. This results in 10 bins of about 20 four-digit industries each. We describe how Swedish manufacturing CO_2 emissions have

[12] We use the plant-level emissions data collected by Statistics Sweden to construct official statistics. The same methodology is used by the Swedish tax authority to calculate carbon taxes. For a description of how the Swedish carbon tax is levied see pp. 6-9 in Hammar and Åkerfeldt (2011).

evolved over our sample period in Appendix C.

Appendix Table B.2 shows the distribution of emissions across 2-digit NACE sectors. The most emission intensive manufacturing firms are found in non-metallic mineral products, (such as cement, plaster, mortar, and glass production), coke and refined petroleum products, paper and paper products, textiles, basic metals (particularly iron and steel production), chemicals, and food (particularly sugar production). These seven sectors contain 82% of the 4-digit subsectors in deciles 9 and 10 and jointly account for almost 88% of aggregate manufacturing CO_2 emissions in 1990.

3.2 The effect of changing carbon tax regimes

Our identification relies on cross-sectional variation in firms' marginal tax rates, allowing us to control for time, firm, and year times sector dummies to isolate the effect of carbon pricing on emissions. This variation is due to the various exemptions that high-emitting firms enjoyed at various times during our sample period, summarized in Table 1. Figure 3 illustrates the tax rates a hypothetical firm would face across different regimes.

The numerous changes in the tax schedule lead to substantial variation in carbon taxation both in the time-series and the cross-section. Figure 4 shows how the average, effective tax rate, computed as total carbon taxes paid divided by total CO_2 (heating) emissions (*Average tax*), and the marginal tax rate for the next emitted unit of CO_2 (*Marginal tax*) evolves over time for two types of firms. The first type is a firm with emissions consistently below the thresholds for tax exemptions and that does not have any plants included in the EU ETS. For such firms, the average tax rate equals the marginal tax rate throughout the sample period. The second type is a firm whose emissions consistently lie above the carbon tax exemption thresholds and whose plants eventually transition into the EU ETS. Before EU ETS, the average tax rate exceeded the marginal tax rate high-emitting firms, except for 1993-1996 when exemptions had been removed. After EU ETS was introduced in 2007, the implicit marginal tax rate, reflected in the price of emission rights, increased considerably, while the average tax rate stayed roughly constant due to free allocations of emission rights.[13]

[13]During the 2008-2011 transition period, the marginal cost of emissions equalled the weighted sum of emission allowance prices and marginal carbon tax rates for firms under the EU ETS (the latter could be equal to 0 if the combined costs of emissions exceed the designated exemption threshold). From 2011 plants

The significant differences in marginal and average tax rates across groups have important economic implications, as a firm's incentive to reduce CO_2 emissions depends on the former while its effective tax payments depend on the latter. Before the introduction of the EU ETS, high-emitting firms thus had relatively low marginal incentives to reduce emissions, despite paying a large fraction of their profits in carbon tax. After the introduction of EU ETS, marginal emission costs for high emitters increased substantially, while overall carbon tax payments decreased due to the free allowance of rights.

3.3 Decomposing Sweden's manufacturing CO_2 emissions

In Figure 5, we decompose the change in aggregate CO_2 emissions from Swedish manufacturing using the framework developed in Grossman and Krueger (1991) and Grossman and Krueger (1993).[14] The actual level of CO_2 emissions in 2015 was 31% lower than in 1990, representing the combined scale, composition and technique effects. Holding sector composition and emission intensities constant from 1990 and onwards, CO_2 emissions would only have decreased by 3% in 2015, reflecting a 3% decrease in manufacturing output. Keeping emission intensities constant, but also allowing sector composition to change as in the data, CO_2 emissions would have been 13% lower. The 10% difference is the composition effect, indicating that a move towards less carbon-intensive manufacturing sub-sectors accounts for almost a third of the aggregate decrease in emissions. The residual technique effect is 18%, or almost two thirds of the reduction in CO_2 emissions 1990–2015.

The technique effect incorporates the impact of carbon pricing on emission intensities that is the focus of our study. A few caveats are in order, however. First, it is likely that at least part of the decrease attributed to scale and composition was also affected by carbon pricing. Since it is difficult to estimate carbon pricing elasticities of output reliably using our reduced-form approach, we choose to focus on emission intensities in this study.[15] To the extent carbon pricing also decreased the consumption of goods produced by higher-emitting firms, we will be underestimating the total effect of carbon pricing on

covered by the EU ETS were completely exempt from the carbon tax.

[14] This approach is formalized in Copeland and Taylor (1994) and further discussed in Copeland and Taylor (2004). We follow the approach described in Section I of Levinson (2009), who apply this decomposition to U.S. sulphur dioxide emissions. See Appendix D for a detailed description of how Figure 5 was constructed.

[15] One reason is that total output changes are more likely to be due to "carbon leakage", i.e., goods produced in Sweden simply being replaced by foreign-produced goods. We discuss the potential impact of "carbon leakage" on our emission elasticity estimates in subsection 5.3.

aggregate emissions. Second, our emission intensity measure normalizes emissions with sales (e.g., revenues of a steel company) rather than actual output (e.g., tons of steel produced). While we deflate sales with PPI at the 4-digit NACE level, our estimates can still be affected by relative price changes across firms within each 4-digit subsector (see Foster et al., 2008). As a result, the carbon pricing elasticities we estimate may also capture other strategic responses beyond changes in production technology, such as within-sector differences in pricing power (as in De Loecker and Warzynski, 2012) and/or product mix across firms, and should therefore be interpreted in a broader sense.[16]

4 Short Term Effects of Carbon Pricing

Before estimating carbon pricing elasticities, we first examine the short-run responses of firm-level emission intensities to the introduction and subsequent changes in the Swedish carbon taxation scheme. Similar to Colmer et al. (2022), we use a difference-in-differences approach that compares the changes in emission intensities between otherwise similar firms whose marginal cost of emissions is affected differently by a change in taxation.

As is typical in event studies, the interpretation of the results implicitly depends on assumptions regarding the expectations and rationality of relevant decision makers. To the extent the subsequent changes in tax rates are anticipated by firms, this would affect their response to a current tax change. While it is plausible that the initial introduction of the carbon tax in 1991 was at least partly anticipated (which biases against finding a short-term response), the bipartisan political commitment to environmental taxation in Sweden in the wake of the major tax reform of 1991 (Government Bill 1989/90:111, 1989) and the strong reliance of the government on environmental tax revenues (Tax Shift Commission, 1997) makes it less likely that firms anticipated subsequent changes in carbon taxation, at least until the introduction of the EU ETS.[17]

The introduction of carbon taxation in 1991 and its first revision in 1993 provide

[16] This is a problem we share with much of the productivity literature (see e.g., Foster et al., 2008)

[17] We provide additional detail on climate policy expectations in a Swedish setting in Appendix A. However, expectations aside, the direct effect of carbon taxes on firms' cash flows can also lead to an immediate response in and of itself (see Zwick and Mahon, 2017). Furthermore, changes in carbon taxation can also coincide with other changes in taxation and the overall economic environment. We address the potential role of industry specific shocks unrelated to carbon taxation and other tax changes (e.g., green tax shifting) in the econometric tests below.

relatively clean events to analyze. In 1991 and 1992, there were caps in place so that a firm's carbon tax never exceeded a certain percentage of sales. In 1993, these caps were removed in conjunction with an overall reduction in the statutory carbon tax rate. Accordingly, we divide firms into those who qualified for an exemption in 1991-92 and those that did not. Table 3 reports average marginal costs (panel A) and emissions-to-sales (panel B) for the periods 1990, 1991-1992 and 1993-1996 . We focus on firms from decile 10 as most emissions are concentrated there and the vast majority of firms are present in the sample for all years. We exclude firms in the cement, lime and glass sectors from this test as the tax changes did not apply to them.[18]

In 1990, before the tax was introduced, both groups of firms face a zero marginal cost of emitting carbon. After the introduction in 1991-1992, firms not qualifying for exemptions experienced a marginal tax increase of 0.203 Swedish Krona (SEK) per kg of emitted CO_2, while firms with exemptions, despite paying substantial amounts of carbon taxes, still faced a zero marginal tax rate. In the 1993-1996 period, following the first tax change, both groups were taxed at 0.084 SEK/kg with no exemptions. This led to a marginal tax increase of 0.084 for firms with exemptions in the 1993-1996 period and a marginal tax decrease for the non-exemption group of -0.119. The difference-in-difference changes in marginal tax across groups are highly significant both around the introduction (-0.203) and the subsequent change 1993-1996 (0.203).

By construction, firms in the exemption group have higher emissions-to-sales than the non-exemption group (0.087 versus 0.011 in 1990). After the introduction of the tax in 1991-1992, firms in the non-exempt group display similar emissions-to-sales ratios as they did in 1990. In contrast, firms in the exempt group, who still faced a zero marginal tax rate, increase their emissions-to-sales by about 18% (from 0.087 to 0.103). The diff-in-diff estimate of 0.016 is significant at the 1%-level, consistent with higher marginal carbon taxes leading to lower emission intensities. In the 1993-1996 period, following the tax change, non-exempt firms (whose marginal tax was cut), experience a statistically significant increase in their emissions-to-sales of about 45%. Firms in the exempt group (whose marginal tax rate increased) instead saw a slight 3% decrease emissions-to-sales

[18]Cement, lime and glass firms consistently enjoyed tax exemptions and effectively faced a zero marginal tax rate until the introduction of EU ETS.

ratios. The diff-in-diff estimate between groups between 1991-92 and 1993-96 is a negative -0.007. While the diff-in-diff is not statistically significant at conventional levels, the change is again consistent with firms responding to carbon taxes by reducing emissions. Both diff-in-diff estimates are robust to including four-digit industry dummies (column 4).

In panels C and D of Table 3, we consider the subsequent tax change in 1997. The preceding years (1993-96) was the only time during our sample period when all manufacturing firms (except for cement, lime and glass) faced the same marginal carbon tax rate. The tax change in 1997 more than doubled the marginal tax rate (from around 0.09 to 0.19 SEK/kg) but re-introduced an exemption for firms with tax payments above 0.8% of sales, for whom the marginal tax was reduced to one quarter of the statutory rate. We again focus on decile 10 subsectors, and divide firms into those qualifying for the exemption and those that did not. We require firms to be present during the entire period 1993-2000, to avoid capturing effects due to changes in the sample composition.

Panel C reports changes in marginal taxes. The two groups of firms face the same marginal cost of emitting CO_2 in the pre-period 1993-96. The 1997 changes led exempt firms to experience a small marginal tax reduction of 0.009, while non-exempt firms faced a large increase in marginal tax of 0.087. Panel D shows the corresponding changes in emission intensities around this event. Again, by construction, exemption firms have higher emissions-to-sales ratios in the pre-period. While the differences within each group are not statistically significant, they both evolve as predicted: average emissions intensities increased by about 11% for exemption firms (whose marginal tax decreased) whereas it fell by about 11% for non-exempt firms (whose marginal tax increased). The diff-in-diff estimate of 0.0098 is positive and statistically significant, again indicating a negative short-run relationship between marginal carbon pricing and emission intensities.

The results from these event studies suggest that carbon pricing can have a visible impact on emissions even in the short run. But since significant adjustments of technology and/or strategy probably take several years for firms to fully implement, it is more relevant to evaluate the longer-term effects of such policies.

5 Estimation of Carbon Pricing Elasticities

5.1 Main specification

We now turn to the longer-term impact of carbon pricing on CO_2 emissions. As firms' incentives should depend on the marginal (rather than the average) cost (e.g., Cropper and Oates, 1988), we let emission intensity be a function of the marginal carbon tax rate.

There are a few specification issues that need to be dealt with. First, some of the responses to carbon pricing involve significant investments and possibly other strategic changes that take time to implement. In addition, expectations about future tax changes may affect the speed of the response to current taxes. Since it is not theoretically clear at what time lag carbon pricing should affect firms' CO_2 emissions, we allow for the lag length to differ across specifications.[19] Second, the elasticity of emissions to carbon pricing is likely to be heterogeneous across firms and/or industries, since it depends on factors such as the ability of firms to pass the tax on to their customers through higher prices,[20] the ability to move production to other jurisdictions, costs of emissions abatement, and the ability to finance such abatement. In addition to including fixed effects, we will address such heterogeneity by estimating elasticities for relevant subsamples.

Following Shapiro and Walker (2018) we estimate the base-line regression

$$\Delta ln\left(\frac{E_{\mathrm{i,t}}}{Y_{\mathrm{i,t}}}\right) = \alpha + \sum_{s=1}^{q} \beta_{\mathrm{s}} \cdot \Delta ln(1 - C_{\mathrm{i,t\text{-}s}}) + \mu_{\mathrm{i}} + \mu_{\mathrm{t}} + \epsilon_{\mathrm{i,t}}, \tag{1}$$

where E is kilograms of CO_2 heating emissions divided by PPI-adjusted sales (in 2010 SEK) for firm i in year t. $C_{i,t\text{-}s}$ is the emissions cost share relative to sales for firm i in year t-s.[21] For firms with plants covered under EU ETS we compute the marginal tax

[19]Similar issues around lag length also comes up when modeling of the response of the capital-output ratio to changes in corporate taxation (e.g. Bond and Xing, 2015). Using text from regulatory findings, Dessaint et al. (2022) estimate an average investment horizon of 4.45 years for U.S. listed firms, ranging between 3.12 years (Defense) to 7.15 years (Utilities) across FF49 industries (Fama and French, 1997). In particular, Steel, Chemicals, and Refining – three of the sectors with the highest emission intensities – can be found among the ten industries (out of the 49) with the longest investment horizon in their sample.

[20]It should be noted that most Swedish manufacturing firms are limited in their ability to pass on the tax cost to customers, since the bulk of their production is exported in competitive world markets. Exports make up about 70% of manufacturing value added in Sweden, and over 80% in high emitting sectors such as basic metals, chemicals and paper and paper products (Flam, 2021).

[21]In Shapiro and Walker (2018), the specification in log differences is partly motivated by the need to account for firm-specific heterogeneity. While we are able to add firm fixed effects thanks to our long panel, we choose to keep the log differences specification to alleviate problems of unit roots in our variables.

rate (per kg of CO_2 emissions) as the average marginal tax rate in a given firm-year under the Swedish carbon tax system (for the installations not under EU ETS) and the average market price of the emission trading permits in the corresponding year (for the installations covered by EU ETS). $ln(1 - C_{i,t-s})$ captures the share of sales left after paying for one more unit of CO_2 emissions and makes it possible to take logs when $C_{i,t\text{-}s} = 0$. The lagged terms of C allow for a delayed response to tax changes. We expect $\sum_{s=1}^{q} \beta_s > 0$ if firms reduce emission intensities in response to marginal carbon pricing. μ_i captures firm-specific time-invariant factors that could impact the relation between CO_2 emissions and sales. μ_t absorbs changes in CO_2 emissions that are common to all firms in a given year.

5.2 Baseline results

Table 4 presents baseline results from estimating Equation 1 with q=1 up to q=3. In columns 1 and 2, we display results with the marginal cost share of sales at the beginning of the year without and with firm fixed effects. The change in the marginal cost of CO_2 emissions is strongly related to changes in firm-level carbon emissions intensity. The result implies that a change in the marginal cost of emissions to sales is associated with a change in carbon intensity by about a factor of one. (We will further discuss the economic magnitude of these estimates in section 6.) Adding $\Delta ln(1 - C_{\text{i,t-2}})$ (column 3) yields a larger estimate of the $t-1$ coefficient and a joint impact of around 1.6. In column 4 we also include a third lag $\Delta ln(1 - C_{\text{i,t-3}})$, which increases the estimated joint impact to a total elasticity of 2.1 (with all three lag coefficients being statistically significant). In unreported regressions, we show that additional lags have small and a statistically insignificant coefficients and leave the joint estimated magnitude largely unchanged. We therefore choose the specification with $q = 3$ as our baseline model.[22] In column 5 we include a full set of four-digit industry by year fixed effects to control for differences in industry trends and shocks over time, which results in a slightly higher estimated total elasticity of 2.2.

Since the top deciles of emitters account for a disproportionately large fraction of total CO_2 emissions, it is particularly relevant to investigate possible heterogeneity in this dimension. The remaining three columns in Table 4 show results for three subsamples split

[22] In order to make sure our results are not sensitive to the reduction in sample size from using three lags in column 4 we re-estimate the specifications in columns 1-3 and find very similar results (see Table B.5).

according to 1990 subsector emission deciles as in Table B.3 and Table B.4.

Column 6 shows estimates for firms with low emission intensities in 1990 (the bottom 40% of four-digit sectors in terms of CO_2 emissions to sales in 1990). The joint effect is three times larger for this sub-sample. Recall from Table B.3 that firms from these sectors comprise under 6% of CO_2 emissions. In column 7 we consider the group of firms from deciles 5-8. The estimated joint carbon pricing effect is 2.7 and highly statistically significant. In column 8, we consider firms from deciles 9 and 10, which have significantly higher emissions-to-sales ratios compared to firms in other manufacturing sub-sectors and jointly account over 80% of CO_2 emissions in 1990. The joint carbon pricing effect in this sub-sample is considerably lower than in the other deciles (reported in columns 6-7) and also lower than the one estimated for the full sample in column 4. The results in the final three columns in Table 4 suggest that firms in subsectors with production technologies associated with higher CO_2 emissions also have the highest cost of abatement. We carry out additional tests to shed more light on this possible mechanism below.

Table 5 reports the results from a set of additional robustness tests. To account for the possibility that EU's cap-and-trade system leads to different carbon pricing elasticities, we interact our marginal cost variable with an indicator variable taking on the value one if the firm-year is regulated under EU ETS and zero otherwise. We report results both for the full sample and for the subsample of firms in deciles 9 and 10, where almost all EU ETS regulated firms belong. We also control for the impact of broader changes to corporate taxation (by including the cost share of income taxes to sales) and for green tax shifting (by including labor taxes to sales) respectively on firm CO_2 emissions.[23] Finally, following Brännlund et al. (2014), we include firm size and capital intensity as control variables. The estimated elasticities are essentially unchanged across these alternative specifications.

[23] As discussed in section 2, the carbon tax was initially a part of a larger tax reform which included elements of so called tax shifting. However, the correlations between the firm level emissions cost share ($C_{i,t\text{-}s}$) and the corporate income tax ($CIT_{i,t\text{-}s}$) and the labor tax ($Labor_{i,t\text{-}s}$) shares respectively are only modest (-0.023 and -0.083). Our results are robust to including these firm controls in all tests.

5.3 Heterogeneity and carbon leakage

5.3.1 Abatement costs and mobility

We now consider two additional sources of heterogeneity that have been shown in previous literature to affect firms' responses to environmental taxation: abatement cost and mobility.

First, while the marginal benefit of reducing a unit of emissions depends on the marginal tax rate, this has to be weighed against the marginal cost, which should be different depending on production technologies and other firm- or industry-specific characteristics. While we do not have access to marginal abatement costs (MAC) for different manufacturing subsectors (see Gillingham and Stock, 2018), we utilize estimates of pollution abatement costs expenditures (PACE) (e.g., Becker, 2005) as a proxy. Under the assumption that abatement cost curves are increasing and convex, industries with higher PACE would also have higher MAC. We use Swedish data on environmental protection expenditure to mitigate air pollution to construct an industry-level measure of PACE. Specifically, we first calculate the ratio of the sum of PACE and aggregated industry sales for each four-digit industry and take the average over the sample years.[24] We split the sample into low (below median-industry PACE) and high (above median-industry PACE) abatement costs and expenditures in columns 1 and 2 of Table 6. We estimate an elasticity of around 3 for firms in low-PACE sectors, compared to an estimate below 2 for firms in high-PACE sectors. This suggests that firms with lower abatement costs respond more to changes in the marginal CO_2 emission cost, consistent with the hypothesized cost-benefit trade-off.

Second, we consider how the geographic mobility of assets impacts firms operating across low- and high-PACE sectors. Firms in high mobility industries should be more likely to move their production facilities to other countries in order to avoid paying Swedish carbon tax compared to those in low-mobility industries. If firms move their most emission-intensive plants in response to an increase in carbon pricing, this might result in

[24] The environmental expenditure data is based on a survey from Statistics Sweden and spans 2002-2015. There is a potential issue of endogeneity, since total abatement costs over this period may have been a function of carbon pricing (although it should be noted that these costs primarily refer to pollution abatement in general, rather than reduction of greenhouse gases). This is mitigated by the fact that we are only using this measure to rank industries above versus below median, and these rankings are very stable over time. Moreover, our inferences on PACE are similar if we instead use US PACE data from U.S. Bureau of the Census (1990) normalized by value of shipments for each four-digit sector in 1990 to rank industries (using data from Becker et al., 2013).

a higher estimated emission elasticity, since lower-emitting plants have higher elasticities.[25] Following Ederington et al. (2005), we use Swedish investment survey data to calculate the ratio of the sum of the real structures capital stock to aggregate sales for each four-digit industry and average over the sample years.[26] Firms in sectors with a fixed-cost ration above (below) the median are defined as having low (high) mobility.

Results are shown in columns 3–6 of Table 6. Firms in sectors defined as low PACE have a similar carbon pricing elasticity irrespective of how mobile their assets are. This is intuitive, since firms with low costs of abating should be less likely to relocate in the face of higher carbon pricing. The mobility results for the high PACE sub-sample stand out for two reasons. First, almost two thirds of the high PACE firms are located in sectors defined as being low mobility (similar to the finding in Ederington et al., 2005). Second, the joint effect of $\Delta ln(1\ \text{-}\ C)_{(i,t\text{-}s)}$ in the sub-sample of high PACE and high mobility firms results in a higher estimated elasticity. This is noteworthy as the group of firms facing the highest costs of abating and at the same time have moveable assets are the most likely to consider relocation when faced with higher cost of emitting. The result should be interpreted with caution, however, as the subsample is small and the estimate is only marginally significant.

5.3.2 EU leakage list

In its effort to mitigate the risk that carbon pricing in the ETS would lead production to move outside of the European Union, EU classifies all industrial (four-digit) sectors with respect to their risk of such "carbon leakage". Plants in industries on the leakage list in turn receive a higher share of free allowances under the EU ETS.[27] Sectors can be deemed at risk because of i) high costs of carbon pricing (i.e., sectors with high emission intensity), ii) high level of international competition (i.e., high levels of trade outside of the EU) or,

[25] Another potential source of carbon leakage could be that firms reduce emissions through importing rather than manufacturing certain high-emission inputs. Analyzing Swedish data similar to ours, Forslid et al. (2021) find that while increasing imports are associated with lower emission intensity, this effect is not due to the offshoring of dirty activities.

[26] Specifically, in order to measure the real structures capital stock we i) take for each firm-year from the investment survey the expenditure in real structures over total capital expenditure (structures plus equipment) and ii) multiply this fraction with the value of tangible assets (Plant, Property and Equipment) from the firm's balance sheet. In the case when there are missing values for four digit industries we use the mobility measure of the two-digit industry. Our results with mobility are robust to using US data from the NBER-CES Manufacturing Industry Database as in Ederington et al. (2005).

[27] For details, see https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/free-allocation/carbon-leakage_en. European Commission (2009) containst the initial carbon leakage list. Free allowances will be phased out in the EU ETS starting in 2026.

iii) being exposed to both of these factors. In addition to capturing differences related to PACE and mobility, this classification also accounts for the ability of an industry to pass on the carbon emission cost to their customers.

Estimation results are reported in Table 7. We first differentiate between sectors that are on versus outside the leakage list. While sample sizes are similar across groups, it is worth noting that over 90% of aggregate manufacturing emissions originate from firms on the carbon leakage list. We estimate a carbon pricing elasticity of around 2.6 for firms not on the carbon leakage list, compared to an elasticity below 2 for those on the list. The lower elasticity for firms deemed as being at risk of carbon leakage is consistent with those firms facing a larger difficulty in reducing their emission-to-sales ratios.

We further split firms into different categories considered by the EU for assessing the risk of carbon leakage. In column 3 we separately consider sectors on the list due to trade concerns (based on criterion "C"). Firms in these sectors face high international competition, but operate with technologies having relatively low emission ratios. We retrieve a considerably higher carbon pricing elasticity of 3.3 for this group. This implies that these firms, while having a limited ability to pass on tax costs to customers due to competition, are able to reduce emissions through technological or strategic means at a relatively low cost. In the final column, we report the carbon pricing elasticity of carbon leakage sectors with high emission intensities.[28] For this group we find a considerably lower elasticity of around 1.5, similar in size to the results for firms in deciles 9 and 10 in Table 4 and for those in high PACE and low mobility sectors in Table 6 . The similarity is not surprising given the substantial overlap in sector classifications across these sub-samples.

5.4 Financial frictions and carbon pricing

The effect of carbon pricing may also depend on the severity of other externalities and market frictions.In particular, capital market imperfections widen the gap between the external and internal cost of capital (e.g., Hubbard, 1998), which impedes the ability of firms dependent on external financing to fund abatement investments. Oehmke and Opp (2022) present a theory of socially responsible investment and show that carbon taxes alone

[28] These are all sectors outside those categorized as "C" in the EU classification, and is mutually exclusive to the sample in column (3). This subsample includes firms categorized in group "A" (high emissions and some trade concerns) or group "B" (very high emissions but no trade concerns.)

may not achieve first-best outcomes in the presence of financing constraints. Empirically, Xu and Kim (2022) provide evidence from U.S. listed firms that financial constraints lead to increased toxic releases; Ng et al. (2023), using listed-firm data for 51 countries, document that financially constrained firms emit more CO_2; and Bartram et al. (2022) find that financially constrained firms under California's CO_2 cap-and-trade program moved capacity to unregulated states and increased emissions.[29] In contrast, Shive and Forster (2020) find that U.S. independent private firms emit less greenhouse gases than comparable listed firms or PE-backed firms, even though listed and PE-sponsored firms would be expected to have easier access to external financing (Saunders and Steffen, 2011).[30] We add to this literature by noting that the impact of financial constraints on emissions should also depend on the firm's marginal benefit of abatement (captured in the marginal tax rate) relative to the marginal cost (captured by the carbon pricing elasticity). In particular, we test whether carbon elasticities are different across groups of firms based on their ex ante likelihood of being financially constrained. Since we only have ownership data from 1996, the tests in this section are conducted on the 1996-2015 subsample.[31]

We focus on four proxies used in the literature that are available for most firm-years in our data set: listing status (Pagano et al., 1998; Saunders and Steffen, 2011), size (Gertler and Gilchrist, 1994; Hadlock and Pierce, 2010), dividend payouts (Bartram et al., 2022; Fazzari et al., 1988), and age (Gertler, 1988; Hadlock and Pierce, 2010). To conserve space we report the sum of the three lags of the marginal cost share and their statistical significance in Table 8. For each firm sort we also display the elasticity across sectors with comparatively lower abatement costs (deciles 1-4 and low PACE sectors) and for those facing higher costs (deciles 9-10 and high PACE sectors). The complete regression results for each firm sort are compiled in Table B.6, Table B.7, Table B.8, and Table B.9.[32]

[29] Related work include De Haas and Popov (2023), who find that CO_2-intensive industries reduce emissions faster in countries with more developed stock markets; and Lanteri and Rampini (2023) analyze how financial constraints affect clean technology adoption. In addition, the corporate finance literature on firm environmental responses has shown that stronger liability protection is associated with higher toxic emissions (Akey and Appel, 2021), and that pollution taxes make high-emitting firms increase R&D, which in turn facilitates their adoption of existing abatement technologies (Brown et al., 2022). A number recent papers also document a climate risk premium (see Giglio et al., 2021a, for a review), and listed CO_2-emitters face higher costs of capital (Bolton and Kacperczyk 2021, Bolton and Kacperczyk 2022)

[30] Shive and Forster (2020) argue that their result is more consistent with listed companies being less stakeholder oriented due to short-term profit maximization (as in Farre-Mensa and Ljungqvist 2016).

[31] Our other reported regression results are very similar when re-estimated on this shorter sample.

[32] In robustness test we also sort according to the financial constraints indexes from Hadlock and Pierce (2010) (Size-Age) and Whited and Wu (2006) with very similar results (Table B.10).

We first sort firms according to their public listing status, where public firms are expected to be less capital constrained on average compared to private firms. We classify a firm as listed if at least one firm in the corporate group to which they belong is listed at least once during the sample period; the firm is otherwise classified as private.[33] Panel A shows the results from re-estimating Equation 1 for these two sub-samples. For listed firms, the estimated elasticity is larger than for the sample as a whole and highly statistically significant. In contrast, for unlisted firms, the elasticity is around one and insignificant.

Access to finance should also matter the most for firms in high-emitting sectors, since we would expect the investment needed for reducing emissions to be higher. Thus, if the difference in estimates between columns 1 and 2 of Panel A is due to financing constraints, we would expect this difference to be more pronounced for high-emitting sectors. Columns 3 and 4 of Panel A show a sizable elasticity for both public and private firms in low emitting sectors (7.5 vs 3.9). In high-emitting sectors, we estimate a statistically significant elasticity of 2.3 for listed firms (column 5), while it is only 0.4 and insignificant for privately held high-emitting firms (column 6). We find very similar results if we instead divide firms based on PACE (as in Table 6): firms in low PACE sectors have a similar elasticity regardless of listing status (columns 7 and 8), while in high-PACE sectors, only publicly listed firms display a significant elasticity (columns 9 and 10). These results suggest that financial constraints stifle CO_2 abatement for firms with large marginal benefits of abatement.[34]

In panels B-D we consider firm size, dividend payout status and age as alternative measures of ex ante financial constraints. These sorts are all defined within each four digit NACE sector.[35] Firms that are smaller, younger, and that pay lower dividends are expected to be more financially constrained. Across all three sorts, we first take the average for each firm over the sample period and then we find the median firm by four digit sector. We consider a firm as large (small), high (low) dividend payer or mature (young) if it is above the median in book value of assets, dividend-to-assets and number

[33] We define a firm as listed in two other ways as robustness. In Table B.11, a is firm classified as listed if at least one firm in the corporate group to which they belong is listed during the entire sample period, where we drop all firms with switching ownership status in the corporate group. In Table B.12 we consider a firm as being publicly owned in a given year if at least one firm in the corporate group that year is listed at least once during the sample period.

[34] The listing results are also opposite to what Shive and Forster (2020) found for the U.S., where firms were not subject to carbon pricing.

[35] Size and payout ratio are used in Bartram et al. (2022) to classify financially constrained firms. Age is also a widely financial constraint proxy (e.g., Hadlock and Pierce, 2010).

of years since incorporation respectively (measured at the corporate group level). We creating the sub-samples within sectors since the ability to reduce CO_2 depends on the sector-specific production technology. Within-sector sorting also controls for differential investment opportunities across sectors and ensures that sub-samples are of similar size.

Results using different financial constraint indicators are similar. Across all sectors in columns 1 and 2, firms less likely to be financially constrained (larger, higher dividend payers, and older) display statistically significant elasticities between 2.1-2.9 compared to firms more likely to be constrained (smaller, lower dividends and younger) with statistically insignificant elasticities between 0.5-0.7. In low-emitting sectors (deciles 1-4) constrained and unconstrained firms exhibit similar elasticities of around 4, and we find no systematic differences within low-PACE sectors either. Instead, the effect of financial constraints is driven by firms in sectors with higher abatement costs (deciles 9-10 and high PACE sectors): larger, higher dividend, and older firms in high abatement sectors display elasticities between 2.1-3.6 compared to 0.4-0.7 for smaller, lower dividend, and younger firms.[36]

We also consider how financial crises affect emissions abatement and report the results in Table B.13. We follow the classification in Laeven and Valencia (2018), according to which 2008 and 2009 are considered banking crisis years during our sample period 1996-2015. The emission-to-pricing elasticity is significantly lower (between 1-1.5) during crisis years across all firm sorts. During non-crisis years, firms classified as less financially constrained display highly significant elasticities between 2.5-3.2, while firms classified as financially constrained have elasticities of around one. During crisis years, the elasticity drops to around one for less constrained firms and around zero for more constrained firms. Overall, these results suggest that financial sector instability can further impede the ability of manufacturing firms to lower their carbon footprint.

[36] This is consistent with Hartzmark and Shue (2023), who find that financing costs have a negligible effect on greenhouse gas emissions for low emitters but a large effect on high emitters. They argue that responsible investment policies that increase the cost of capital for brown firms might therefore be counterproductive.

6 Aggregate Effects: Quantifying the Economic Importance of Emission Elasticities

The results reported in section 5 imply that emission intensities would have been higher in the absence of carbon pricing. To assess the economic significance of these estimates, we perform a reduced form calibration, which takes total output and the firms present in the market as exogenously given, and abstract from scale and composition effects from carbon pricing. Since those effects are also likely to be important, our calibration is not a proper equilibrium counterfactual (Lucas, 1976), but rather a back-of-the envelope way to gauge the quantitative importance of our elasticity estimates.[37]

Since we only perform this calibration with respect to emission intensities, while overall output, industry composition, and carbon tax rates vary across years, the estimated aggregate effect depends on the base year chosen for the counterfactual. We choose to focus on 2015, which marks the end of our sample and is also the year of the most recent change of the Swedish carbon pricing scheme (see Table 1).

From elasticity estimates in section 5 we derive the implied change in firm-level emission intensities due to carbon pricing and then retrieve what the emissions intensity would have been in the absence of such pricing. Specifically, we calculate counterfactual emissions in the absence of carbon pricing for the year $t = 2015$ as follows:

$$\widehat{\left(\frac{E_{\mathrm{t}}}{Y_{\mathrm{t}}}\right)}^{\text{No tax}} = \left(\frac{E_{\mathrm{t}}}{Y_{\mathrm{t}}}\right) - \left(\sum_{s=1}^{3} \hat{\beta}_{\mathrm{s}} \cdot \left[ln(1 - C_{\text{t-s}}))\right]\right) \tag{2}$$

The top row in Table 9 evaluates the baseline elasticity which is retrieved from using variation across all firm-years (column 4 in Table 4) in Equation 2. The observed, average carbon intensity across all firms in 2015 is 0.0049. Combining the estimated elasticities and the actual carbon pricing each firm faced in 2015, we estimate that the observed carbon intensity in the absence of carbon pricing would have been 0.0071 (column 4), or 47% higher than what was actually observed (column 5) in 2015.

This first calibration does not account for the significant heterogeneity across subgroups documented in Table 6, however. Panel A reports additional calibration results

[37] See Shapiro and Walker (2018) for a structural, general equilibrium approach to this question.

which accounts for heterogeneity with respect to PACE and mobility. Here we compute Equation 2 separately for the four sub-groups in columns 3-6 in Table 6. We estimate that firms in low PACE sectors operating with low and high mobility assets respectively would have had 74% and 68% higher emissions intensity in 2015 without carbon pricing. Among high PACE firms the corresponding numbers are 27% and 38% higher for low and high mobility sectors, respectively. We then weigh each sub-groups' implied emissions intensity with its share of CO_2 emissions. Based on these estimates, the emissions intensity in Swedish manufacturing would have been around 30% higher in the absence of carbon pricing, which is a smaller implied difference compared to the one obtained in the previous calibration. This can be explained by firms in high PACE and low mobility sectors (with lower elasticities) accounting for 90% of manufacturing CO_2 emissions in 2015.Keeping the size and composition of manufacturing sales constant over time, our 30% effect on carbon intensity would translate in to an aggregate CO_2 emissions reduction of the same magnitude. Given that aggregate manufacturing CO_2 emissions declined by 31% over the sample period (see subsection 3.3), this suggests that the effect of carbon pricing on emission intensities was an important driver of these reductions.

For completeness, panel B displays the implied carbon intensities for the other sub-samples considered in section 5. Calibrating based on these dimensions yields similar magnitudes, because of the substantial overlap across the different classifications.

Panel C also shows the aggregate economic significance of financial constraints on emission intensities using the estimates from Table 8. Had all Swedish manufacturing firms had the same carbon-pricing elasticities as less financially constrained firms, the aggregate effect of carbon pricing would have been between 38% and 69% (rather than of 30%). In contrast, if all firms would had had elasticities similar to financially constrained firms, the aggregate carbon pricing effect would have ranged from 0% to 14%. This implies that financial constraints can have an economically significant impact on carbon reductions.

Table B.14 displays results from calibrating Equation 2 using alternative base-years, chosen to coincide with major changes in Swedish carbon taxation (1991, 1997, 2008 and 2011). The calibration results for 2008 or 2011 are similar to Table 9. If we instead base our calibration on 1991 or 1997, however, the implied emissions intensity in the absence of carbon pricing would only be 12-14% higher, i.e., a third of the effect for the other base-years.[38] This reflects the fact that the highest emitters faced much lower marginal carbon tax in those years, due to the exemptions they enjoyed. After these firms transitioned into the EU ETS, this was no longer the case.

To summarize: when we base our calibration on the post 2005 period in Sweden (with marginal costs consistently equal or higher than average costs) we predict that emission intensity would have been around 30% higher without taxation, which implies that the entire decline in manufacturing emissions 1990-2015 could potentially be attributed to carbon pricing. Under the carbon tax schedule in place prior to the EU ETS, the reduction in emissions would have been substantially lower.

7 Conclusions

In 1991, Sweden introduced a tax on CO_2 emissions that currently remains the highest in the world. We assemble a comprehensive data set of around 4,000 Swedish manufacturing firms and track firm-level CO_2 emissions during 1990-2015. Our results imply a statistically robust and economically meaningful inverse relationship between CO_2 emissions and the marginal cost of emitting CO_2. While the average emissions-to-carbon pricing elasticity is around two for manufacturing as a whole, there is considerable heterogeneity across firms and subsectors, with the highest emitters having substantially lower elasticities. Financial constraints significantly reduce the carbon pricing elasticity for firms in sectors with high abatement costs, but have no visible impact in low abatement cost sectors. Aggregate emissions of CO_2 from Swedish manufacturing decreased by about 31% between 1990 and 2015, while total manufacturing output only decreased by 3% over the same period. Simple calibrations imply that carbon pricing, through its effect on emission intensities, can account for a major part of the emission reductions.

An advantage of our approach is that we estimate carbon pricing elasticities that account for heterogeneity across firms and sectors, which can be used for evaluating other carbon pricing schemes where the price level and industry composition differ. That said, the fact that we consider one particular country may obviously limit the external validity of our results. The fact that Sweden is well-endowed with fossil-free energy resources is likely

[38] We report the share of CO_2 emissions for each event year across sub-samples in Table B.15.

to have contributed to the substantial reduction of CO_2 emissions. Also, a relatively low level of political uncertainty, particularly with respect to climate policy, may have increased the willingness of firms to make the necessary investments in emissions abatement (Baker et al., 2016). Moreover, Sweden is a small open economy with a highly export-dependent manufacturing sector. As a result, the ability of Swedish manufacturing firms to pass on carbon pricing to their customers is likely to be more limited compared to countries with larger home markets, such as the U.S.

We believe our findings raise several avenues for future research. In particular, it would be important to investigate the mechanisms through which firms achieved their emission reductions. Were reductions achieved by switching to lower-emitting production processes for existing products (technological improvements), increasing the prices of existing products (pass-through) or changing their product mix towards products with lower emissions and/or higher prices (compositional changes)? What role did investments in capital and R&D, plant openings or closings, and changing imports and exports play in reducing emissions? Finally, by using a structural general equilibrium approach (e.g., Shapiro and Walker, 2018) one could estimate the effects of carbon pricing not just on emission intensities, but also on aggregate output and industry composition.

References

Acemoglu, D., Akcigit, U., Hanley, D., and Kerr, W. (2016). Transition to clean technology. *Journal of Political Economy*, 124(1):52–104.

Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R., and Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *Journal of Political Economy*, 124(1):1–51.

Ahmadi, Y., Yamazaki, A., and Kabore, P. (2022). How do carbon taxes affect emissions? Plant-level evidence from manufacturing. *Environmental and Resource Economics*, 82:285–325.

Akey, P. and Appel, I. (2021). The limits of limited liability: Evidence from industrial pollution. *The Journal of Finance*, 76(1):5–55.

Andersson, J. J. (2019). Carbon taxes and CO_2 emissions: Sweden as a case study. *American Economic Journal: Economic Policy*, 11(4):1–30.

Baker, S., Bloom, N., and Davis, S. (2016). Measuring economic policy uncertainty. *Quarterly Journal of Economics*, 131(4):1593–1636.

Bartram, S. M., Hou, K., and Kim, S. (2022). Real effects of climate policy: Financial constraints and spillovers. *Journal of Financial Economics*, 143(2):668–696.

Becker, R. (2005). Air pollution abatement costs under the Clean Air Act: Evidence from the PACE survey. *Journal of Environmental Economics and Management*, 50:144–169.

Becker, R., Gray, W., and Marvakov, J. (2013). NBER-CES manufacturing industry database: Technical notes. *NBER Working Paper*, 5809.

Benincasa, E., Kabas, G., and Ongena, S. (2022). "there is no planet b", but for banks "there are countries b to z": Domestic climate policy and cross-border lending.

Bolton, P. and Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, 142(2):517–549.

Bolton, P. and Kacperczyk, M. (2022). Global pricing of carbon-transition risk. *Journal of Finance*, forthcoming.

Bond, S. and Xing, J. (2015). Corporate taxation and capital accumulation: Evidence from sectoral panel data for 14 OECD countries. *Journal of Public Economics*, 130:15–31.

Bovenberg, A. L. and De Mooij, R. A. (1994). Environmental levies and distortionary taxation. *The American Economic Review*, 84(4):1085–1089.

Bovenberg, L. and Golder, L. (1996). Optimal environmental taxation in the presence of other taxes: General-equilibrium analyses. *American Economic Review*, 86(4).

Brown, J. R., Martinsson, G., and Thomann, C. (2022). Can environmental policy encourage technical change? Emissions taxes and R&D investment in polluting firms. *The Review of Financial Studies*, 35(10):4518–4560.

Brännlund, R., Lundgren, T., and Marklund, P.-O. (2014). Carbon intensity in production and the effects of climate policy—Evidence from Swedish industry. *Energy Policy*, 67:844–857.

Bryant, R., Bundy, M., and Zong, R. (2015). Evaluating measurements of carbon dioxide emissions using a precision source—a natural gas burner. *Journal of the Air & Waste Management Association*, 65(7):863–870.

Burke, M., Craxton, M., Kolstad, C. D., Onda, C., Allcott, H., Baker, E., Barrage, L., Carson, R., Gillingham, K., Graff-Zivin, J., et al. (2016). Opportunities for advances in climate change economics. *Science*, 352(6283):292–293.

Colmer, J., Martin, R., Muûls, M., and Wagner, U. J. (2022). Does pricing carbon mitigate climate change? Firm-level evidence from the European Union Emissions Trading Scheme. *CEPR Discussion Paper 16982*.

Conte, B., Desmet, K., and Rossi-Hansberg, E. (2022). On the geographic implications of carbon taxes. *NBER Working Paper 30678*.

Copeland, B. R. and Taylor, M. S. (1994). North-south trade and the environment. *The Quarterly Journal of Economics*, 109(3):755–787.

Copeland, B. R. and Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, 42(1):7–71.

Cropper, M. and Oates, W. (1988). Environmental economics: A survey. *Journal of Economic Literature*, 30(2):675–740.

De Haas, R. and Popov, A. (2023). Finance and green growth. *Economic Journal*, 133(February):637–668.

De Loecker, J. and Warzynski, F. (2012). Markups and firm-level export status. *American Economic Review*, 102(6):2437–2471.

Dechezleprêtre, A., Nachtigall, D., and Venmans, F. (2023). The joint impact of the European Union Emissions Trading System on carbon emissions and economic performance. *Journal of Environmental Economics and Management*, 118:102758.

Dessaint, O., Foucault, T., and Fresard, L. (2022). The horizon of investors' information and corporate investment. *HEC Paris Research Paper No. FIN-2022-1462*.

Dussaux, D. (2020). The joint effects of energy prices and carbon taxes on environmental and economic performance: Evidence from the french manufacturing sector. *OECD Environment Working Paper No.154*.

Ederington, J., Levinson, A., and Minier, J. (2005). Footloose and pollution-free. *Review of Economics and Statistics*, 87(1):92–99.

Environmental Charges Commission (1989). Ekonomiska styrmedel i miljöpolitiken: Energi och trafik. Delbetänkande.
https://lagen.nu/sou/1989:83#S2.

European Commission (2009). Determining, pursuant to directive 2003/87/ec of the European Parliament and of the council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage.
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010D0002&from=EN.

European Commission (2021). Special eurobarometer 513: Climate change. https://climate.ec.europa.eu/system/files/2021-07/report_2021_en.pdf.

Eurostat (2008). NACE rev.2. statistical classification of economic activities in the European community. https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

Eurostat (2016). Glossary: Statistical classification of economic activities in the European Community (NACE). https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_{E}uropean_Community_({NACE}).

Fama, E. F. and French, K. R. (1997). Industry costs of equity. *Journal of Financial Economics*, 43:153–193.

Farre-Mensa, J. and Ljungqvist, A. (2016). Do measures of financial constraints measure financial constraints? *The Review of Financial Studies*, 29(2):271–308.

Fazzari, S. M., Hubbard, R. G., and Petersen, B. C. (1988). Financing constraints and corporate investment. *Brookings Papers on Economic Activity*, 1988(1):141–195.

Flam, H. (2021). Den internationella handelns betydelse för sverige. https://www.svensktnaringsliv.se/sakomraden/internationell-handel/den-internationella-handelns-betydelse-for-sverige_1177364.html.

Forslid, R., Akerman, A., and Prane, O. (2021). Imports and the CO_2 emissions of firms. *CEPR Discussion Paper 16090.*

Foster, L., Haltiwanger, J., and Syverson, C. (2008). Reallocation, firm turnover, and efficiency: Selection on productivity or profitability? *American Economic Review*, 98(1):394–425.

Fowlie, M. (2010). Emissions trading, electricity restructuring, and investment in pollution abatement. *American Economic Review*, 100(3):837–69.

Fowlie, M., Reguant, M., and Ryan, S. P. (2016). Market-based emissions regulation and industry dynamics. *Journal of Political Economy*, 124(1):249–302.

Germeshausen, R. (2020). The European Union Emissions Trading Scheme and fuel efficiency of fossil fuel power plants in Germany. *Journal of the Association of Environmental and Resource Economists*, 7(4):751–777.

Gertler, M. (1988). Financial structure and aggregate economic activity: An overview. *Journal of Money, Credit and Banking*, 20(3):559–588.

Gertler, M. and Gilchrist, S. (1994). Monetary policy, business cycles, and the behavior of small manufacturing firms. *Quarterly Journal of Economics*, 198(2):309–340.

Giannetti, M., Jasova, M., Loumioti, M., and Mendicino, C. (2023). “glossy green” banks: The disconnect between environmental disclosures and lending activities.

Giglio, S., Kelly, B., and Stroebel, J. (2021a). Climate finance. *Annual Review of Financial Economics*, 13:15–36.

Giglio, S., Maggiori, M., Rao, K., Stroebel, J., and Weber, A. (2021b). Climate change and long-run discount rates: Evidence from real estate. *The Review of Financial Studies*, 34(8):3527–3571.

Gillingham, K. and Stock, J. H. (2018). The cost of reducing greenhouse gas emissions. *Journal of Economic Perspectives*, 32(4):53–72.

Golosov, M., Hassler, J., Krusell, P., and Tsyvinski, A. (2014). Optimal taxes on fossil fuel in general equilibrium. *Econometrica*, 82(1):41–88.

Government Bill 1989/90:111 (1989). Government bill 1989/90:111. Regeringens proposition 1989/90:111 reformerad mervärdesskatt m.m. http://www.riksdagen.se/Webbnav/index.aspx?nid=37&dok$_$id=GD03111.

Government Bill 2007/2008:1 (2007). Budgetpropositionen för 2008. https://www.regeringen.se/49bb06/contentassets/0cea7c72952947a7825d8c9e75abe51d/forslag-till-statsbudget-for-2008-inklusive-finansplan.

Green, J. F. (2021). Does carbon pricing reduce emissions? A review of ex-post analyses. *Environmental Research Letters*, 16:1–17.

Greenstone, M., List, J. A., and Syverson, C. (2012). The effects of environmental regulation on the competitiveness of US manufacturing. *NBER Working Paper 18392*.

Grossman, G. M. and Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. Technical report, National Bureau of Economic Research.

Grossman, G. M. and Krueger, A. B. (1993). Environmental impacts of a North American free trade agreement. In Garber, P., editor, *The US-Mexico free trade agreement*. MIT Press, Cambridge, MA.

Hadlock, C. J. and Pierce, J. R. (2010). New evidence on measuring financial constraints: Moving beyond the KZ index. *The Review of Financial Studies*, 23(5):1909–1940.

Hammar, H. and Åkerfeldt, S. (2011). CO_2 taxation in Sweden: 20 years of experience and looking ahead. *Fiscalidad Verde en Europa-Objetivo 20/20*, 20.

Hartzmark, S. M. and Shue, K. (2023). Counterproductive sustainable investing: The impact elasticity of brown and green firms. *Working paper*, Yale School of Management.

Hassler, J., Krusell, P., and Olovsson, C. (2021). Directed technical change as a response to natural resource scarcity. *Journal of Political Economy*, 129(11):3039–3072.

He, G., Wang, S., and Zhang, B. (2020). Watering down environmental regulation in China. *The Quarterly Journal of Economics*, 135(4):2135–2185.

Hong, H. G., Li, F. W., and Xu, J. (2019). Climate risks and market efficiency. *Journal of Econometrics*, 208:265–281.

Hubbard, R. (1998). Capital–market imperfections and investment. *Journal of Economic Literature*, 36(1):193–239.

Ilhan, E., Sautner, Z., and Vilkov, G. (2021). Carbon tail risk. *The Review of Financial Studies*, 34(3):1540–1571.

Jonsson, S., Ydstedt, A., and Asen, E. (2020). Looking back on 30 years of carbon taxes in sweden. *Fiscal fact*, (727).

Laeven, M. L. and Valencia, M. F. (2018). *Systemic banking crises revisited*. International Monetary Fund.

Lanteri, A. and Rampini, A. A. (2023). Financing the adoption of clean technology.

Leroutier, M. (2022). Carbon pricing and power sector decarbonization: Evidence from the UK. *Journal of Environmental Economics and Management*, 111:102580, 1–22.

Levinson, A. (2009). Technology, international trade, and pollution from US manufacturing. *American Economic Review*, 99(5):2177–92.

Lucas, R. E. (1976). Econometric policy evaluation: A critique. *Carnegie-Rochester Conference Series on Public Policy*, 1:19–46.

Lyubich, E., Shapiro, J., and Walker, R. (2018). Regulating mismeasured pollution: Implications of firm heterogeneity for environmental policy. *AEA Papers and Proceedings*, 108:136–142.

Martin, R., Muûls, M., de Preux, L. B., and Wagner, U. J. (2014). Industry compensation under relocation risk: A firm-level analysis of the EU Emissions Trading Scheme. *American Economic Review*, 104(8):2482–2508.

Martin, R., Muûls, M., and Wagner, U. J. (2016). The impact of the European Union Emissions Trading Scheme on regulated firms: What is the evidence after 10 years? *Review of Environmental Economics and Policy*, 10(1):129–148.

Meckling, J., Sterner, T., and Wagner, G. (2017). Policy sequencing toward decarbonization. *Nature Energy*, 2(12):918–922.

Metcalf, G. E. (2019). On the economics of a carbon tax for the united states. *Brookings Papers on Economic Activity*, 2019(1):405–484.

Metcalf, G. E. and Stock, J. H. (forthcoming). The macroeconomic impact of Europe's carbon taxes. *American Economic Journal: Macroeconomics*.

Newell, R. G., Jaffe, A. B., and Stavins, R. N. (1999). The induced innovation hypothesis and energy-saving technological change. *The Quarterly Journal of Economics*, 114(3):941–975.

Ng, L., Wang, X., and Yu, J. (2023). Corporate decarbonization under financial constraints: International evidence. *ECGI Finance Working Paper*, 877.

Nordhaus, W. D. (1993). Optimal greenhouse-gas reductions and tax policy in the "DICE" model. *The American Economic Review*, 83(2):313–317.

Oehmke, M. and Opp, M. M. (2022). A theory of socially responsible investment. *Swedish House of Finance Research Paper*, (20-2).

Pagano, M., Panetta, F., and Zingales, L. (1998). Why do companies go public? *Journal of Finance*, 53(1):27–64.

Pindyck, R. S. (2013). Climate change policy: What do the models tell us? *Journal of Economic Literature*, 51(3):860–72.

Popp, D. (2002). Induced innovation and energy prices. *American Economic Review*, 92(1):160–180.

Pretis, F. (2022). Does a carbon tax reduce CO_2 emissions? Evidence from British Columbia. *Environmental and Resource Economics*, 83:115–144.

Quick, J. (2014). Carbon dioxide emission tallies for 210 coal-fired power plants: A comparison of two accounting methods. *Journal of the Air & Waste Management Association*, 64(1):73–79.

Rafaty, R., Dolphin, G., and Pretis, F. (2021). Carbon pricing and the elasticity of CO_2 emissions. Technical Report 21-33, Resources for the Future.

Ramadorai, T. and Zeni, F. (2021). Climate regulation and emissions abatement: Theory and evidence from firms' disclosures. *European Corporate Governance Institute–Finance Working Paper*, (730).

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., and Schellnhuber, H. J. (2017). A roadmap for rapid decarbonization. *Science*, 355(6331):1269–1271.

Sajtos, L. (2020). *Essays on Environmental Regulation*. PhD thesis, Stockholm School of Economics.

Saunders, A. and Steffen, S. (2011). The costs of being private: Evidence from the loan market. *The Review of Financial Studies*, 24(12):4091–4122.

Scharin, H. and Wallström, J. (2018). The Swedish CO2 tax – An overview. http://www.enveco.se/wp-content/uploads/2018/03/Anthesis-Enveco-rapport-2018-3.-The-Swedish-{CO}2-tax-an-overview.pdf.

Shah, A. and Larsen, B. (1992). *Carbon taxes, the greenhouse effect, and developing countries*, volume 957. World Bank Publications.

Shapiro, J. S. and Walker, R. (2018). Why is pollution from US manufacturing declining? the roles of environmental regulation, productivity, and trade. *American Economic Review*, 108(12):3814–54.

Shive, S. A. and Forster, M. M. (2020). Corporate governance and pollution externalities of public and private firms. *The Review of Financial Studies*, 33(3):1296–1330.

Statistics Sweden (2003). Meddelanden i samordningsfrågor för Sveriges officiella statistik – SNI 2002 standard för svensk näringsgrensindelning 2002. http://share.scb.se/ov9993/data/publikationer/statistik/ov/ov9999/2003m00/x71op0301.pdf.

Stern, N. (2008). The economics of climate change. *American Economic Review*, 98(2):1–37.

Sterner, T. (2020). The carbon tax in sweden. In *Standing up for a Sustainable World*, pages 59–67. Edward Elgar Publishing.

Sterner, T., Barbier, E. B., Bateman, I., van den Bijgaart, I., Crépin, A.-S., Edenhofer, O., Fischer, C., Habla, W., Hassler, J., Johansson-Stenman, O., et al. (2019). Policy design for the Anthropocene. *Nature Sustainability*, 2(1):14–21.

Stock, J. H. (2020). Climate change, climate policy, and economic growth. *NBER Macroeconomics Annual*, 34(1):399–419.

Swedish National Audit Office (2013). Energieffektivisering inom industrin -– effekter av statens insatser. https://www.riksrevisionen.se/download/18.78ae827d1605526e94b300b8/1518435473932/Bilaga%205.pdf.

Swedish Tax Authority (2012). Taxes in Sweden. https://www.skatteverket.se/download/18.3684199413c956649b57c66/1361447643691/10413.pdf.

Tax Shift Commission (1997). Skatter, miljö och sysselsättning. https://www.skatteverket.se/download/18.3684199413c956649b57c66/1361447643691/10413.pdf.

Statistics Sweden (2018). Total environmental statistics in Sweden. https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/emissions/greenhouse-gas-emissions-and-removals/.

Timilsina, G. R. (2022). Carbon taxes. *Journal of Economic Literature*, 60(4):1456–1502.

United States Environmental Protection Agency (2016). Greenhouse gas inventory guidance: Direct emissions from stationary combustion sources. https://www.epa.gov/sites/default/files/2016-03/documents/stationaryemissions_3_2016.pdf.

U.S. Bureau of the Census (1990). Pollution abatement costs and expenditures. https:https://www.epa.gov/sites/production/files/2016-08/documents/pace_1990.pdf.

Whited, T. M. and Wu, G. (2006). Financial constraints risk. *The review of financial studies*, 19(2):531–559.

World Bank (2022). State and trends of carbon pricing 2022. http://hdl.handle.net/10986/37455.

Xu, Q. and Kim, T. (2022). Financial constraints and corporate environmental policies. *The Review of Financial Studies*, 35(2):576–635.

Zwick, E. and Mahon, J. (2017). Tax policy and heterogeneous investment behavior. *American Economic Review*, 107(1):217–48.

Figure 1: Carbon and energy taxation of an industrial plant

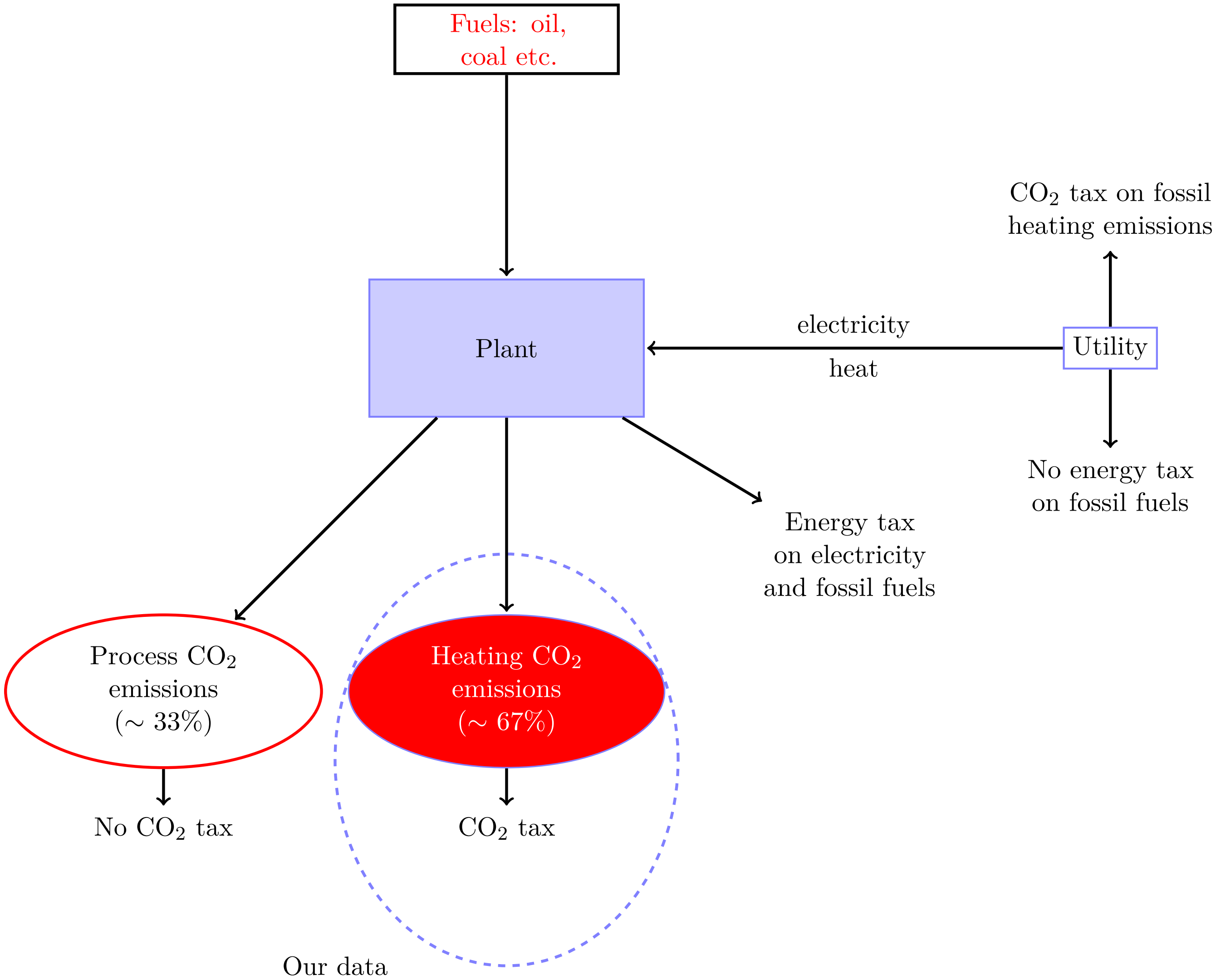

Figure 1 illustrates the carbon and energy taxation for a manufacturing plant in Sweden in 2019. *Heating CO_2 emissions* refers to the emissions released from the combustion of fossil fuels. *Process CO_2 emissions* refers to the carbon dioxide emissions released in the actual manufacturing process (i.e. not combustion of fossil fuels). *Utility* is the power plant that produces heat and/or electricity, *Plant* is the industrial manufacturing plant.

Figure 2: Carbon tax rate, in nominal values

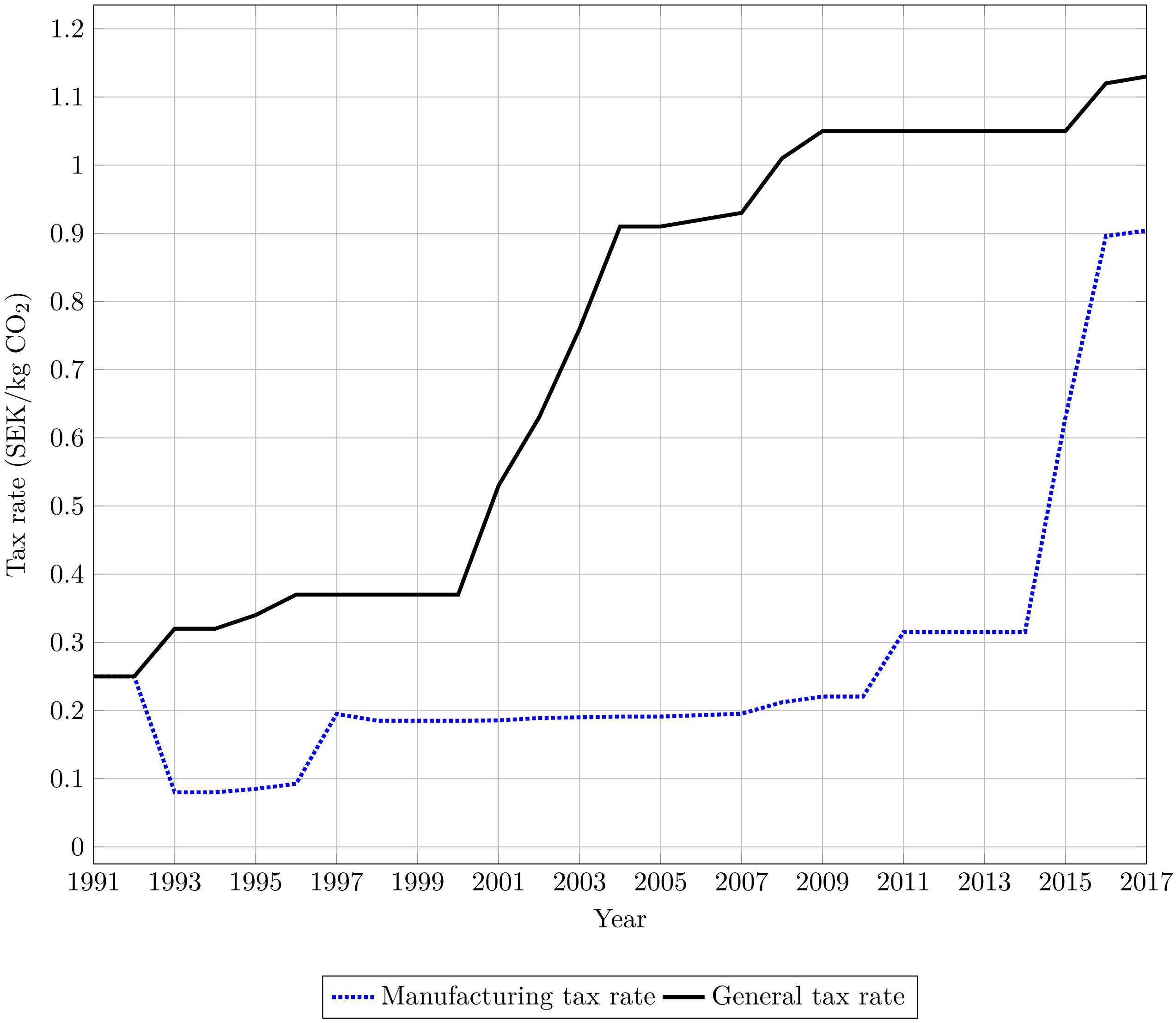

Figure 2 displays the nominal carbon tax rates (Swedish krona per kilogram of emitted carbon dioxide) for Sweden from 1991 to 2017. *Manufacturing tax rate* refers to the tax rate for the manufacturing sector (SNI 10-33 in the SNI2007 nomenclature), while *General tax rate* refers to the tax rate for non-industrial firms and households.

Figure 3: Changes to the carbon tax: emissions and carbon tax payments by regime

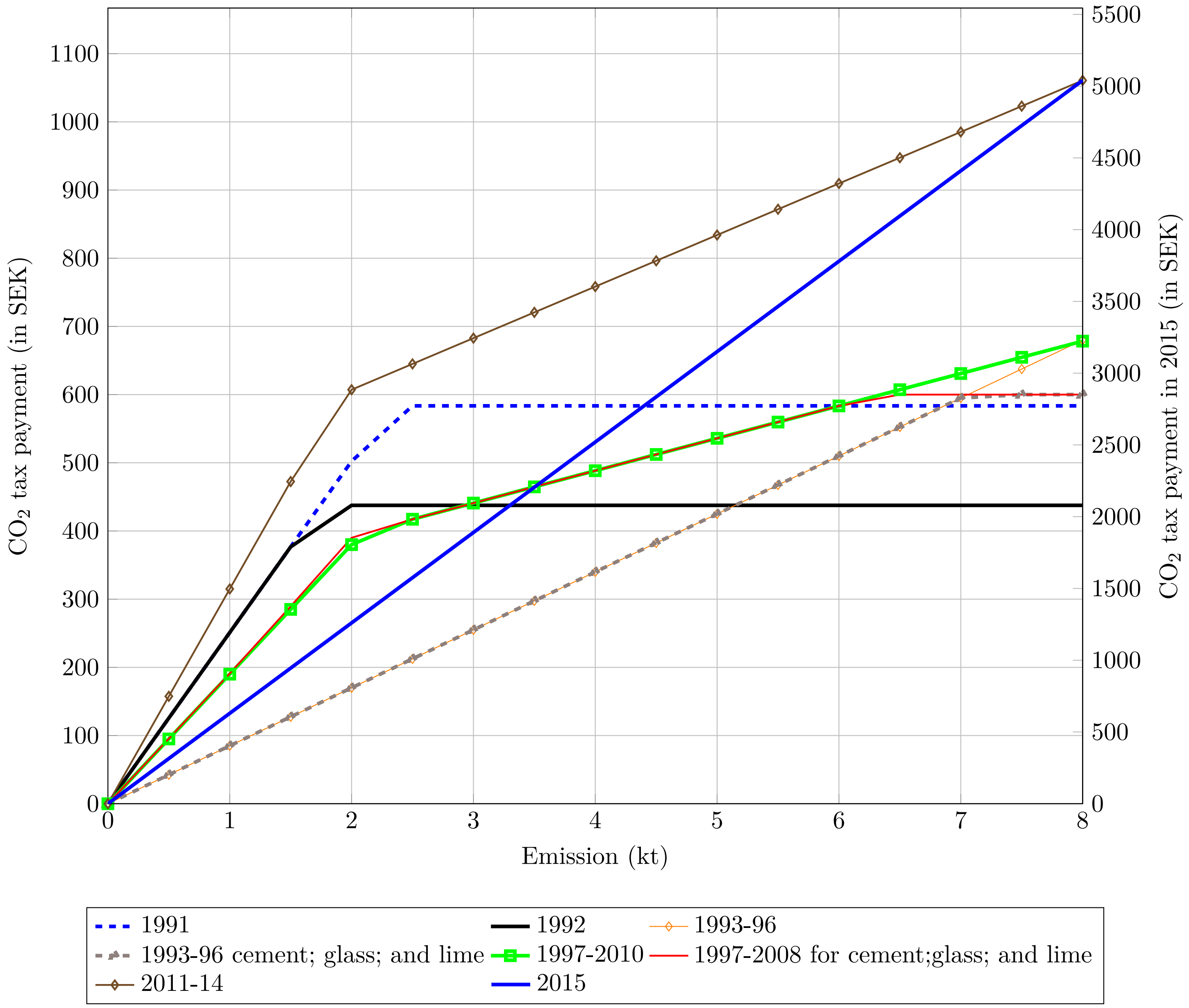

Figure 3 compares the carbon tax payments under the different regimes through a representative manufacturing firm. The hypothetical firm earns 50,000 SEK each year, and assumed to burn only coal in 1991 and 1992. All carbon tax payments with the exception of 2015 are shown on the vertical axis on the left side. Carbon tax payments in 2015 are shown on the vertical axis on the right side.

Figure 4: Average and marginal tax rates (1990-2015)

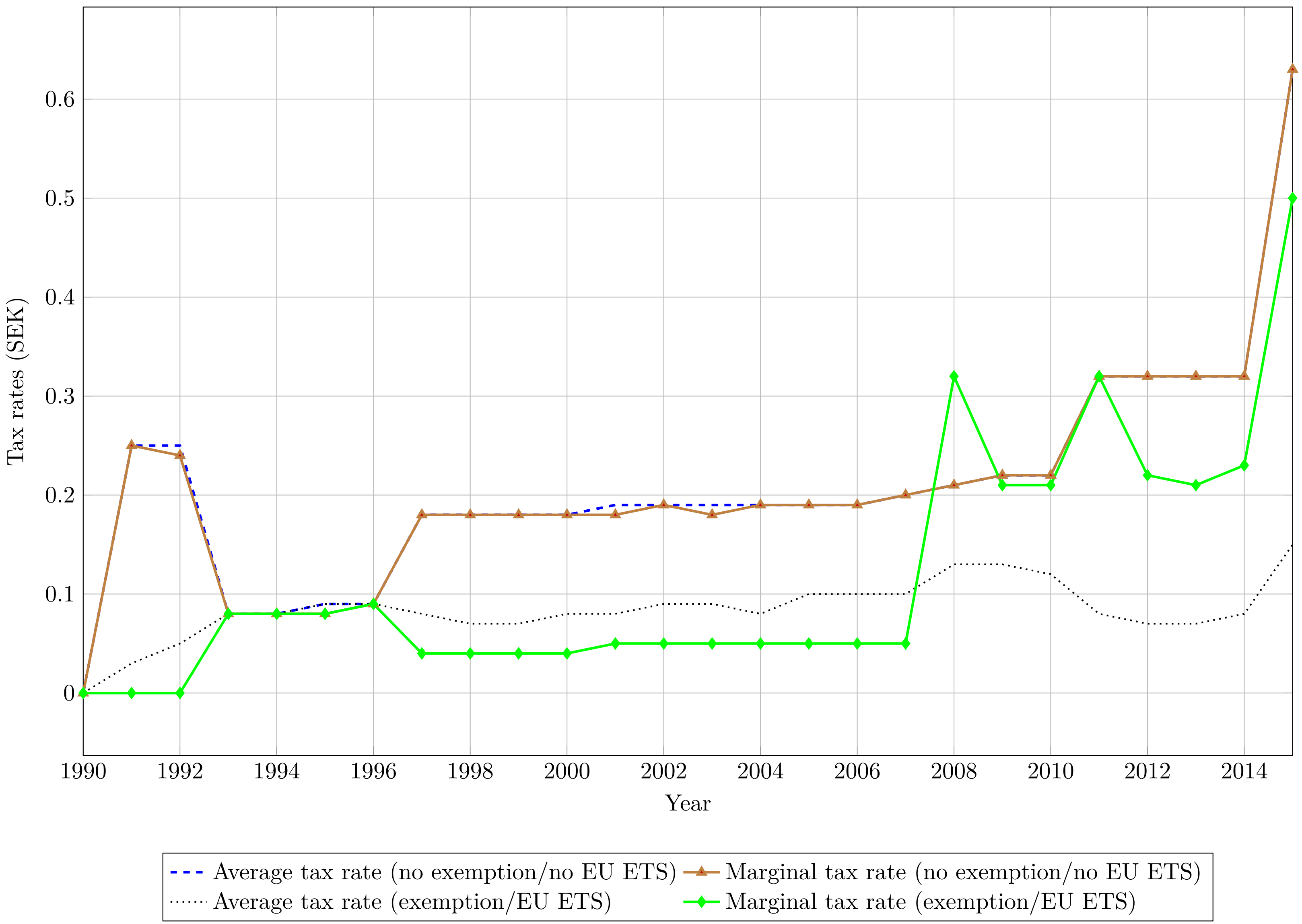

Figure 4 displays the average and marginal tax rates depending on whether the firm is eligible for carbon tax exemptions and covered by the EU ETS. *no exemption/no EU ETS* denotes firms that are not regulated by the EU ETS and are not entitled to carbon tax cut, *exemption/EU ETS* refers to the firms with available exemptions until they enter the emission trading scheme. Marginal tax rates for EU ETS are the price for emission rights.

Figure 5: Carbon dioxide emissions from Swedish manufacturing (1990-2015)

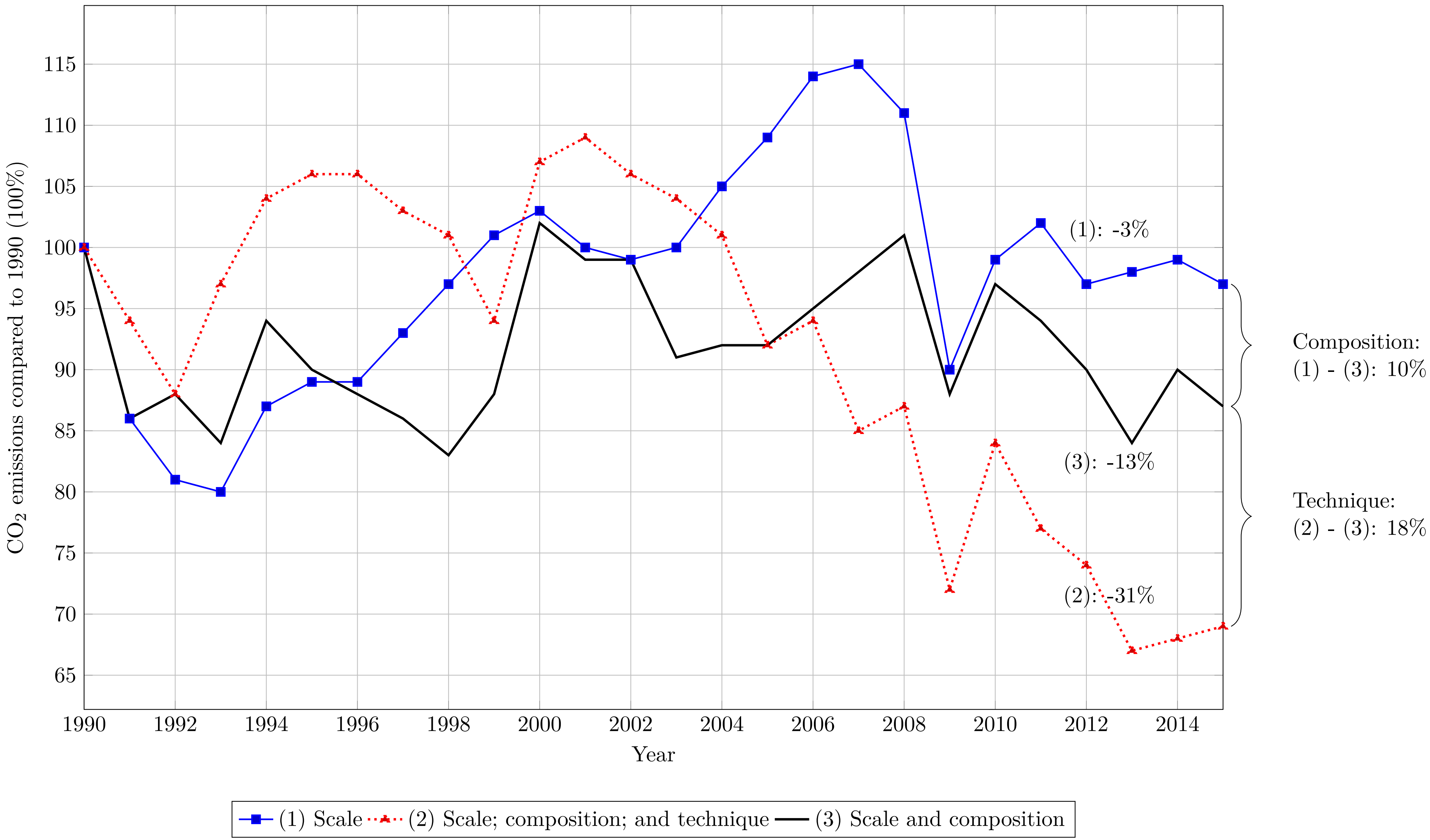

Figure 5 displays the decomposition of the Swedish carbon dioxide emission reduction. *Scale* captures how emissions would have evolved without tangible technological progress and structural changes in the manufacturing sector. *Composition* refers to the change in industry composition, *Technique* captures the technological progress in the industrial sector.

Table 1: Summary of the rates in the Swedish carbon tax system.

Carbon tax rates (SEK/kg)					
Year	Standard rate	Manufacturing rate	General exemptions	Cement, glass lime	Firms in EU ETS
1990	No tax	No tax	No tax	No tax	Before EU ETS
1991	0.25	0.25	Manufacturing rates if CO_2 + Energy tax<= 1.7% of sale, untaxed further emissions	Manufacturing rates if CO_2 + Energy tax<= 1.7% of sale, untaxed further emissions	
1992	0.25	0.25	Manufacturing rates if CO_2 + Energy tax<= 1.2% of sale, untaxed further emissions	Manufacturing rates if CO_2 + Energy tax<= 1.2% of sale, untaxed further emissions	
1993	0.32	0.08	Manufacturing rate	Industry rate up to 1.2 % of sales, untaxed further emissions (“1.2% rule”)	
1994	0.32	0.08			
1995	0.34	0.09			
1996	0.37	0.09			
1997	0.37	0.19	Manufacturing tax rate up to 0.8% of sales, exceeding emissions: 25 % of general manufacturing CO_2 tax rate (“0.8 % rule”)	0.8% rule is applied first, emissions exceeding 1.2 % of sales are untaxed	
1998	0.37	0.19			
1999	0.37	0.19			
2000	0.37	0.19			
2001	0.53	0.19			
2002	0.63	0.19			
2003	0.76	0.19			
2004	0.91	0.19			
2005	0.91	0.19			Manufacturing rate + exemptions where applicable
2006	0.92	0.19			

Carbon tax rates (SEK/kg)

Year	Standard rate	Manufacturing rate	General exemptions	Cement, glass lime	Firms in EU ETS
2007	0.93	0.20		Special exemption removed	
2008	1.01	0.21			EU ETS+15% of standard rate for plants under EU ETS
2009	1.05	0.22			
2010	1.05	0.22			
2011	1.05	0.315	Manufacturing rate up to 1.2%: Exceeding: 24% of manufacturing rate		No CO_2 tax for installations covered by EU ETS
2012	1.05	0.32			
2013	1.05	0.32			
2014	1.05	0.32			
2015	1.05	0.63	Special exemption removed		

Table 1 summarizes the special provisions that enacted tax reliefs for certain industrial enterprises. *Standard rate* applies for households and non-industrial firms, *Manufacturing rate* is the applicable rate for manufacturing enterprises (SNI10-33 under SNI2007 nomenclature), the exemptions in *Manufacturing rate + exemptions where applicable* are the 0.8% and the 1.2% rules.

Table 2: Summary statistics

Table 2 reports summary statistics in the key variables included in this study. The firm-level data are from UC and Bisnode and consist of CO_2-emitting firms with at least four consecutive observations during 1990-2015 and a primary NACE industry classification between 10-33. Monetary values are adjusted and expressed in constant 2010 Swedish Krona (SEK). CO_2 emissions are expressed in kilograms (kg). *MC of emissions-to-sales* is the emissions cost (marginal cost multiplied by emissions) share relative to sales for firm i in year t. *MC of emissions-to-EBIT* is relative to earnings before interest and taxes. *Capital intensity* is the ratio between fixed assets and workers. *EU ETS* is an indicator variable taking on the value one if the firm is regulated under EU ETS some time during the sample period, and zero otherwise. *Low (High) Pace* (pollution abatement costs and expenditure) is an indicator variable taking on the value one if the firm is located in an industry below (above) the median in terms of air pollution abatement costs and expenditures relative to sales, and zero otherwise. *Low (High) Mobility* is an indicator variable taking on the value one if the firm is located in an industry above (below) the median in terms of the real structures capital stock to sales, and zero otherwise. *Not on leakage list* and *On leakage list* are indicator variables taking on the value one if the sector the firm is operating in is either not on or on the EU's Carbon leakage list. *D1-D4* is an indicator variable taking on the value one if the firm is located in an industry in the first to fourth decile in terms of CO_2 emission to sales in 1990, and zero otherwise. *D5-D8* and *D9-D10* are based on firms from deciles 5-8 and 9-10 respectively. Decile 1 (10) means lowest (highest) emission intensity. The firm ownership and financing variables are available during 1996-2015. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm is considered publicly listed if at least one firm in the corporate group is publicly listed at least once during the sample period. *Large (Small) firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *High (Low) dividend firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in dividend payout divided by book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *Mature (Young) firm* is an indicator variable taking on the value one (zero) if the firm's founding year (measured at the corporate group level) is below (above) the median within its four digit NACE industry.

	OBS	Mean	Median	St. Dev	Min	Max
Emissions-to-sales	24,943	0.0072	0.0021	0.0184	0.0000	>0.100
MC of emissions-to-sales	24,943	0.0010	0.0004	0.0017	0.0000	0.0104
MC of emissions-to-EBIT	24,904	0.0143	0.0034	0.0995	-0.4164	0.5900
Nr of workers	24,884	234	45	908	0	n/a
Capital intensity	24,682	0.6083	0.3255	0.9010	0.0022	5.6367
EU ETS	24,943	0.0673	0.0000	0.2505	0.0000	1.0000
Low pace	24,943	0.4658	1.0000	0.4988	0.0000	1.0000
High pace	24,943	0.4788	0.0000	0.4996	0.0000	1.0000
Low pace & Low mobility	24,943	0.2064	0.0000	0.4047	0.0000	1.0000
Low pace & High mobility	24,943	0.2547	0.0000	0.4357	0.0000	1.0000
High pace & Low mobility	24,943	0.2927	0.0000	0.4550	0.0000	1.0000
High pace & High mobility	24,943	0.1780	0.0000	0.3825	0.0000	1.0000
Not on leakage list	24,943	0.5043	1.0000	0.5000	0.0000	1.0000
On leakage list	24,943	0.4931	0.0000	0.5000	0.0000	1.0000
D1-D4	24,943	0.3969	0.0000	0.4893	0.0000	1.0000
D5-D8	24,943	0.4265	0.0000	0.4946	0.0000	1.0000
D9-D10	24,943	0.1725	0.0000	0.3778	0.0000	1.0000
Public firm	16,328	0.2257	0.0000	0.4181	0.0000	1.0000
Private firm	16,328	0.7743	1.0000	0.4181	0.0000	1.0000
Large firm	16,328	0.4789	0.0000	0.4996	0.0000	1.0000
Small firm	16,328	0.5211	1.0000	0.4996	0.0000	1.0000
High dividend firm	16,328	0.5137	1.0000	0.4998	0.0000	1.0000
Low dividend firm	16,328	0.4863	0.0000	0.4998	0.0000	1.0000
Mature firm	16,328	0.4995	0.0000	0.5000	0.0000	1.0000
Young firm	16,328	0.5005	1.0000	0.5000	0.0000	1.0000

Table 3: Firms with and without exemptions around the 1991, 1993 and 1997 tax changes

Table 3 reports the change in marginal cost and emission intensity for firms with (column 1) and without exemptions (column 2) around the 1991 introduction of the carbon tax and subsequent change in 1993 (panels A and B) and the 1997 event (panels C and D). Column 4 reports the difference in difference controlling for four-digit industry fixed effects. The sample includes firms from decile 10 sectors in panels A and D and is restricted to firms with observations each year during 1993-2000 in panels C and D. Panels A and C present the marginal cost of emitting CO_2 for the manufacturing firms and panels B and D the emission intensities. Standard errors are displayed in parenthesis.

	Exemption	**No exemption**	**Diff in groups**	**w Ind. F.E.**
	(1)	**(2)**	**(3)**	**(4)**
Panel A: 1991 and 1993 events – Marginal cost of CO2 (SEK/Kg)				
Period 1: 1990	0.0000	0.0000	0.0000	
			(1.0000)	
Period 2: 1991-1992	0.0000	0.2034	-0.2034	
			(0.0168)	
Period 3: 1993-1996	0.0842	0.0844	-0.0001	
			(0.0006)	
Difference periods: 2-1	0.0000	0.2034	-0.2034	-0.2036
	(1.0000)	(0.0096)	(0.0242)	(0.0239)
Difference periods: 3-2	0.0842	-0.1191	0.2033	0.2029
	(0.0009)	(0.0047)	(0.0118)	(0.0118)
Panel B: 1991 and 1993 events – Emissions-to-sales				
Period 1: 1990	0.0865	0.0106	0.0759	
			(0.0053)	
Period 2: 1991-1992	0.1027	0.0110	0.0917	
			(0.0032)	
Period 3: 1993-1996	0.1005	0.0162	0.0843	
			(0.0032)	
Difference periods: 2-1	0.0162	0.0004	0.0158	0.0165
	(0.0115)	(0.0015)	(0.0060)	(0.0057)
Difference periods: 3-2	-0.0022	0.0052	-0.0074	-0.0071
	(0.0084)	(0.0015)	(0.0050)	(0.0047)
Panel C: 1997 event – Marginal cost of CO2 (SEK/Kg)				
Period 1: 1993-1996	0.0844	0.0845	-0.0001	
			(0.0008)	
Period 2: 1997-2000	0.0756	0.1721	-0.0964	
			(0.0068)	
Difference in periods	-0.0087	0.0876	-0.0964	-0.0968
	(0.0074)	(0.0031)	(0.0068)	(0.0065)
Panel D: 1997 event – Emissions-to-sales				
Period 1: 1993-1996	0.0706	0.0170	0.0536	
			(0.0036)	
Period 2: 1997-2000	0.0784	0.0151	0.0633	
			(0.0038)	
Difference in periods	0.0078	-0.0019	0.0098	0.0100
	(0.0077)	(0.0014)	(0.0052)	(0.0047)

Table 4: Carbon pricing and firm level carbon emission intensity

Table 4 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. D1-D4 include firms from the four-digit industries with emissions to sales in 1990 in the lowest 40%, D5-D8 from four-digit industries from the 5th to the 8th decile in terms of emissions intensity, and D9-D10 include firms from the highest 20% (i.e., the two highest deciles). All regressions include firm fixed effects. Regressions in columns 1-4 and 6-8 include year fixed effects and column 5 includes industry (four-digit NACE) by year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All	**All**	**All**	**All**	**All**	**D1-D4**	**D5-D8**	**D9-D10**
$\Delta\ln(1 - C)_{(i,t-1)}$	0.751***	0.968***	1.170***	1.115***	1.171***	2.828***	1.246***	0.838***
	(0.146)	(0.157)	(0.229)	(0.248)	(0.276)	(0.884)	(0.441)	(0.284)
$\Delta\ln(1 - C)_{(i,t-2)}$			0.402**	0.585***	0.732***	1.711***	0.741*	0.484*
			(0.179)	(0.210)	(0.231)	(0.656)	(0.440)	(0.258)
$\Delta\ln(1 - C)_{(i,t-3)}$				0.377**	0.289*	2.184***	0.747**	-0.025
				(0.159)	(0.153)	(0.482)	(0.349)	(0.168)
$\sum \Delta\ln(1 - C)$	0.751***	0.968***	1.572***	2.077***	2.193***	6.722***	2.733**	1.297***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.013)	(0.007)
Firm fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Industry-year fixed effects	No	No	No	No	Yes	No	No	No
Observations	24,943	24,757	19,485	15,001	13,948	5,529	6,284	3,130
Within R^2	0.007	0.014	0.019	0.017	0.020	0.076	0.016	0.015

Table 5: Carbon pricing and carbon emission intensity: EU ETS, Firm size and capital intensity

Table 5 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. In column 2 (D9-10), we only include firms from the four-digit industries with emissions to sales in 1990 in the highest 20% (i.e., the two highest deciles). All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. T is the share of corporate income taxes (CIT) relative to sales for firm i in year t in column 3 and the share of labor taxes (Labor) to sales for firm i in year t in column 4. Labor tax data ends in 2013 so the sample in column 4 is 1990-2013. *EU ETS* is an indicator variable taking on the value one when a firm-year has at least one plant regulated under EU ETS. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	All	**D9-D10**	**CIT**	**Labor**	**All**	**All**	**All**
$\Delta\ln(1 - C)_{(i,t-1)}$	1.414***	1.025***	1.115***	1.134***	1.008***	1.012***	1.011***
	(0.327)	(0.392)	(0.247)	(0.265)	(0.253)	(0.252)	(0.253)
$\Delta\ln(1 - C)_{(i,t-2)}$	0.684***	0.508	0.586***	0.610***	0.512**	0.514**	0.515**
	(0.246)	(0.329)	(0.210)	(0.224)	(0.205)	(0.205)	(0.205)
$\Delta\ln(1 - C)_{(i,t-3)}$	0.351*	-0.208	0.374**	0.387**	0.245*	0.243*	0.245*
	(0.188)	(0.218)	(0.160)	(0.169)	(0.137)	(0.137)	(0.138)
EU ETS	0.000	0.000					
	(0.001)	(0.001)					
x $\Delta\ln(1 - C)_{(i,t-1)}$	-0.953**	-0.470					
	(0.390)	(0.407)					
x $\Delta\ln(1 - C)_{(i,t-2)}$	-0.317	0.008					
	(0.308)	(0.392)					
x $\Delta\ln(1 - C)_{(i,t-3)}$	0.180	0.630*					
	(0.303)	(0.378)					
$\Delta\ln(1 - T)_{(i,t-1)}$			0.004	0.006			
			(0.010)	(0.004)			
$\Delta\ln(1 - T)_{(i,t-2)}$			-0.011	0.006			
			(0.009)	(0.006)			
$\Delta\ln(1 - T)_{(i,t-3)}$			-0.004	0.005			
			(0.006)	(0.004)			
$\ln(EMP)_{(i,t)}$					-0.002***		-0.002***
					(0.001)		(0.001)
$\ln(CAP/EMP)_{(i,t)}$						0.001***	0.001***
						(0.000)	(0.000)
$\sum \Delta\ln(1 - C)$	1.359**	1.493**	2.075***	2.131***	1.765***	1.769***	1.770***
	(0.017)	(0.030)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15,001	3,130	15,001	13,952	14,828	14,789	14,789
Within R^2	0.021	0.019	0.018	0.018	0.027	0.023	0.030

Table 6: Carbon pricing and carbon emission intensity: PACE and mobility

Table 6 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta\text{ln}(1 - \text{C})$ present an F-test of joint significance. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)
	PACE		**Low PACE**		**High PACE**	
	Low	High	Low mobility	High mobility	Low mobility	High mobility
$\Delta\text{ln}(1 - \text{C})_{(i,t-1)}$	1.320***	1.088***	1.375**	1.288***	0.942***	1.685***
	(0.394)	(0.297)	(0.586)	(0.491)	(0.335)	(0.651)
$\Delta\text{ln}(1 - \text{C})_{(i,t-2)}$	0.849***	0.527**	1.100***	0.614	0.552*	0.368
	(0.298)	(0.261)	(0.346)	(0.425)	(0.296)	(0.533)
$\Delta\text{ln}(1 - \text{C})_{(i,t-3)}$	0.832***	0.281	0.304	1.027***	0.228	0.399
	(0.213)	(0.202)	(0.279)	(0.267)	(0.199)	(0.598)
$\sum \Delta\text{ln}(1 - \text{C})$	3.000***	1.895***	2.779***	2.928***	1.721***	2.452*
	(0.000)	(0.001)	(0.006)	(0.003)	(0.006)	(0.059)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,671	7,568	3,023	3,591	4,773	2,673
Within R^2	0.024	0.016	0.034	0.023	0.013	0.035

Table 7: Carbon pricing and carbon emission intensity: Carbon leakage

Table 7 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta$ln(1 - C) present an F-test of joint significance. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)
	Leakage list		**Leakage list Yes**	
	No	Yes	Trade only	Emission
Δln(1 - C)$_{(i,t-1)}$	1.257***	1.062***	1.605**	0.956***
	(0.457)	(0.301)	(0.645)	(0.329)
Δln(1 - C)$_{(i,t-2)}$	0.565	0.609**	0.793	0.644**
	(0.419)	(0.247)	(0.504)	(0.303)
Δln(1 - C)$_{(i,t-3)}$	0.764**	0.214	0.950***	-0.057
	(0.332)	(0.170)	(0.308)	(0.193)
Within R^2	2.585***	1.885***	3.348***	1.543***
	(0.009)	(0.000)	(0.008)	(0.007)
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	7,228	7,737	5,805	1,932
Within R^2	0.015	0.021	0.039	0.021

Table 8: Carbon pricing and carbon emission intensity: Financing constraints

Table 8 reports $\sum \Delta \ln(1 - C)$ and the corresponding F-test based on OLS estimates of Equation 1 where $\Delta ln(E/Y)_{i,t}$ is the dependent variable. See Table B.6, Table B.7, Table B.8 and Table B.9 for detailed regression results for each panel. The sample period is 1996-2015. All regressions include firm and year fixed effects. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm is considered publicly listed if at least one firm in the corporate group is listed at least once during the sample period. *Large (Small) firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *High (Low) dividend firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in dividend payout divided by book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *Mature (Young) firm* is an indicator variable taking on the value one (zero) if the firm's founding year (measured at the corporate group level) is below (above) the median within its four digit NACE industry. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All Sectors		**D1-D4 Sectors**		**D9-D10 Sectors**		**Low PACE**		**High PACE**	
	Panel A: Publicly listed									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
$\sum \Delta \ln(1 - C)$	2.220***	0.959	7.478***	3.902***	2.323***	0.401	3.173	2.659**	2.525***	0.739
	(0.001)	(0.206)	(0.002)	(0.000)	(0.004)	(0.628)	(0.277)	(0.019)	(0.001)	(0.408)
Observations	2,107	6,535	595	2,531	736	1,307	464	2,083	1,567	4,207
	Panel B: Large firm									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
$\sum \Delta \ln(1 - C)$	2.115***	0.585	4.100***	4.607***	1.948*	0.680	1.920*	3.811**	2.066**	0.494
	(0.009)	(0.296)	(0.000)	(0.000)	(0.076)	(0.266)	(0.097)	(0.031)	(0.027)	(0.446)
Observations	4,138	4,504	1,581	1,545	886	1,157	1,254	1,293	2,801	2,973
	Panel C: High dividend payer									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
$\sum \Delta \ln(1 - C)$	2.699***	0.743	4.053**	4.243***	3.641***	-0.024	2.872	2.441**	2.671***	0.659
	(0.000)	(0.301)	(0.015)	(0.000)	(0.000)	(0.971)	(0.113)	(0.042)	(0.002)	(0.450)
Observations	4,209	4,433	1,558	1,568	930	1,113	1,273	1,274	2,822	2,952
	Panel D: Mature firm									
	Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
$\sum \Delta \ln(1 - C)$	2.934***	0.562	4.457***	3.907***	3.072***	0.184	4.654***	1.615	2.838***	0.435
	(0.000)	(0.450)	(0.000)	(0.000)	(0.000)	(0.793)	(0.004)	(0.144)	(0.002)	(0.632)
Observations	3,814	4,779	1,489	1,613	799	1,232	1,167	1,365	2,549	3,194

Table 9: Economic magnitude based on the 2015 carbon pricing change and emissions intensities

Table 9 reports the share of aggregate CO_2 emissions across sub-samples in 2015 (in column 1), the estimated elasticity (in column 2), the actual CO_2-to-sales in 2015 for each sub-sample (in column 3), the value from subtracting the product of the elasticity and actual carbon pricing change in 2015 to the actual CO_2-to-sales (in column 4), and the ratio of column 4 and column 3 (in column 5).

	(1)	(2)	(3)	(4)	(5)
	Share CO_2	Elasticity	CO_2 intensity	Without tax	Relative
Panel A: PACE, mobility and aggregate emissions					
All	1.0000	2.0769	0.0049	0.0071	47%
Low pace & Low mobility	0.0415	2.7789	0.0033	0.0057	74%
Low pace & High mobility	0.0125	2.9284	0.0025	0.0042	68%
High pace & Low mobility	0.9021	1.7213	0.0077	0.0098	27%
High pace & High mobility	0.0438	2.4516	0.0049	0.0068	38%
Aggregate emissions					30%
Panel B: PACE, Leakage list and deciles					
Low pace sectors	0.0541	3.0003	0.0029	0.0054	83%
High pace sectors	0.9459	1.8948	0.0067	0.0087	31%
Not on Leakage list	0.0758	2.5853	0.0039	0.0060	52%
On Leakage list	0.9242	1.8850	0.0058	0.0078	33%
Deciles 1-4	0.0310	6.7230	0.0025	0.0069	175%
Deciles 5-8	0.0591	2.7340	0.0039	0.0069	78%
Deciles 9-10	0.9099	1.2970	0.0142	0.0174	23%
Panel C: Ownership, size, dividend payout and age					
Public firm	0.4684	2.2195	0.0074	0.0103	39%
Private firm	0.5316	0.9591	0.0044	0.0050	14%
Large firm	0.7077	2.1150	0.0047	0.0065	38%
Small firm	0.2923	0.5854	0.0049	0.0056	12%
High dividend firm	0.4110	2.6990	0.0047	0.0071	51%
Low dividend firm	0.5890	0.7429	0.0050	0.0050	0%
Mature firm	0.6616	2.9335	0.0045	0.0076	69%
Young firm	0.3384	0.5620	0.0051	0.0057	13%

Appendices

A Historical Background of Carbon Taxation in Sweden

Sweden has taxed the use of fossil fuels for a long time, initially motivated by the desirability of fuel as a tax base. The government started collecting an excise tax (the energy tax) on gasoline in 1924, originally intended to finance road construction and the electrification of rural areas (Swedish Tax Authority, 2012), but extended the scope of the taxation to other fuels in the following decades. During the oil crisis in the 1970's the energy tax was also seen as an instrument to reduce oil dependence (Scharin and Wallström, 2018).

In 1988, the *Environmental Charges Commission* was formed (comprising representatives of different stakeholders, including political parties, economists, and industry representatives) to explore the possibilities of using economic instruments in environmental policy. A first report on fees and taxes on sulphur and chlorine was published in July 1989. In the same year, the Swedish Parliament decided to request a program to reduce CO_2 emissions (Scharin and Wallström, 2018). The Commission's final report proposed the introduction of a carbon tax on fossil fuels, and a 50% reduction in the general energy tax (Environmental Charges Commission, 1989). When the carbon tax was enacted in 1991, it was part of a comprehensive tax reform package (e.g., Jonsson et al., 2020). The tax reform implemented so called tax shifting practices. As taxation on carbon emissions was implemented, taxes on corporate income and labor related taxes were subsequently lowered.[39]

The implementation and reforms of taxes are tied to a parliamentary legislation process, which can take at least half a year. Stakeholders, therefore, can be aware of the upcoming changes in taxation in advance. In order to assess this possibility, we retrieved not only official reports of government agencies but also newspaper articles that reflected societal sentiment between 1988 and 2010. Our goal was to study stakeholders' sentiment, the political environment, and to measure the length of time between the dissemination and implementation of the new tax rates.

The evidence suggests that the government disclosed the new tax rates during the budget process up to 1993 and after 2000. Hence, the firms had only a few months to prepare for the anticipated new rates in this period. However, due to Sweden joining the European Union (EU) in 1995 it took longer time, creating some uncertainty about increasing the manufacturing carbon tax rate (which came in effect in 1997). The government motivated the tax increase as a way to have more ambitious environmental policy both in Sweden and in the European Union. However, the tax increase did not apply to the most energy-intensive manufacturing firms (i.e., the firm exemptions were re-introduced). It is evident

[39] This practice is consistent with academic evidence placing great weight on the importance of recycling carbon tax revenues in a locally and constructive way (e.g., Conte et al., 2022; Timilsina, 2022).

from the contemporaneous newspaper articles that there was considerable policy uncertainty due to a lacking political will to raise the tax. The tax change was initially planned for 1996 but due to the above cited uncertainties, the proposed tax schedule could not enter into effect until 1997 as the EU did not endorse the re-introduction of the special tax relief for energy-intensive firms. In other words, the EU wanted all manufacturing firms to pay the same tax rates. After several rounds of negotiations, Sweden could adopt the carbon tax change in 1997.

The introduction of the EU ETS in 2005 would further change Swedish carbon pricing policy (see Sajtos (2020) for a detailed description). With respect to the Swedish carbon tax, the Swedish parliament passed a reform package in 2009 to further encourage the use of renewable energy resources and increase energy efficiency. An acknowledged goal of the package was to levy a more uniform national price on carbon emissions by phasing out existing exemptions (Hammar and Åkerfeldt, 2011).

Sweden was among the pioneer countries introducing a carbon tax in the early 1990s. The political sentiment around environmental and climate regulation is in general agreement in Sweden and the electorate ranks these issues highly (see e.g., European Commission, 2021). Also, the lack of a fossil fuel based lobby in Sweden (due to no significant fossil fuel deposits) removes much of the resistance to carbon taxation. As Meckling et al. (2017) write on p. 919: "*It is symptomatic that the world leader in carbon taxation, Sweden, has no significant fossil resources or companies that would provide significant lobbying resistance against such taxes.*" This perspective is also found in Sterner (2020) and his description of the background to the Swedish carbon tax (on p. 62): "*There are, however, no fossil-fuel resources. Apart from some peat, Sweden simply does not have any coal deposits, oil or natural gas worth exploiting and thus also does not have any major companies in these industries. This means that there is a notable absence of the anti-climate lobbying that is frequently found in economies with rich fossil endowments.*"

Related to the discussion above, firms' expectations of future climate policy are therefore likely to be reasonably unaffected by fossil fuel industry-based lobbying. A paper by Ramadorai and Zeni (2021) finds an important role for beliefs about future climate regulation for firm level carbon abatement in the US (expecting tighter regulations in 2015 following the Paris Climate Accord and subsequent reversal due to the US exit from the agreement). The setting studied in Ramadorai and Zeni (2021) differs from the Swedish context. Carbon taxation is yet to be introduced in the US (see e.g., Metcalf, 2019), in part due to it being a politically divisive issue. In Sweden, the broad rails of climate policy are less controversial.[40] Indeed, Sweden stands out as a country with stringent climate policy but with low variation over time (Benincasa et al., 2022). Overall, based on the

[40]Out of the five carbon tax increases in our sample period three were under a centre-left government (1991, 1997 and 2015) and two with a centre-right government (2008 and 2011).

discussion above, Swedish firms are likely to view carbon pricing as a long-term, stable policy instrument which is unlikely to be reversed as a result of changing majorities in the parliament.

B Data and Sample Construction

B.1 Road map

We construct our sample in several steps. First, we begin with the harmonization of the industry classification codes and use micro-level workplace data to obtain a coherent classification using the most recent classification across time.[41] Second, we aggregate our workplace-level data to the level of the firm (since the emissions data is administered at firm-level). For firms with only one workplace or whose workplaces all are classified the same, we simply take the industry classification of the workplace. But, if several installations (with different industry codes) belong to the same firm, we determine the primary one based on the number of employees that belong to the installations under the different codes.[42] We keep all firms which we can assign to a coherent industry classification over the full time period 1990-2015. Third, we merge CO_2 emissions data to firms with consistent industry classification as reported above. We report the firm count after this step by year in the *"Surveyed firm"* column Table B.1.

Fourth, we only include firms with available sales data as we scale CO_2 emissions with sales in many of the tests. We display the annual firm count after this step in the *"Matched with sales"* column in Table B.1. We also deflate sales to 2010 prices using producer price indices at the four-digit industry level. As seen from Figure A.1, we are able to match the vast majority of firms from step 3 with sales data. The top line in Figure A.1 represents the total CO_2 heating emissions for Swedish manufacturing. The middle line represents the total CO_2 heating emissions from the original data supplied by SEPA, and the bottom line (dashed line) represents the aggregate annual CO_2 heating emissions for the firms in our sample. Our sample firms cover, on average during 1990-2015, around 85% of the total, manufacturing CO_2 heating emissions. We also note that there is no systematic difference between the top and bottom lines. In Figure A.2 we also consider process emissions (which were not covered by the tax) and again we can see that our sample covers the vast majority of all manufacturing CO_2 emissions in Sweden over our sample period.

Fifth, and finally, since official firm-level tax records of actual carbon taxes paid are not available, we infer the tax payments from the CO_2 heating emissions using the carbon

[41] As we work with anonymized data, it is unfeasible to unveil the reason for any change in the industry affiliation; therefore, we limit our sample to firms with consistent industry codes. This cut, however, has only a small effect on our final sample.

[42] The amount of information available at the workplace level is somewhat limited in Swedish data. For instance, sales are not reported at the workplace level.

tax schedule (including exemptions) in place for each year of our sample (we infer the official tax rates and exemptions from government bills, and laws). Between 2008 and 2010, when firms are covered also by the EU ETS, we work with the exemptions and carbon tax rates in force as all emissions are also taxed. From 2011, emissions under the trading systems are not taxed in the Swedish system. We approximate carbon tax payments from the comparison of reported EU ETS emissions and total emissions in several steps. As our emissions data report carbon dioxide and other greenhouse gas emissions separately, we can easily isolate emissions from the other sources. Although, we can also observe process and heating emissions under EU ETS separately for each firm, it is not reported in any official sources what fraction of these heating emissions are taxed in Sweden.[43] Therefore, we assume that all heating emissions above the reported EU ETS heating emissions are subject to the Swedish carbon tax.

B.2 Handling the different industrial classification systems

A significant challenge in the analysis is handling the revisions of the industrial classification systems in force, which occurred three times in our sample period. NACE[44] is the statistical classification of economic activities in the European Community (Eurostat, 2016), hence implemented in the entire European Union. As Sweden joined the block in 1995, the country had to harmonize its applicable system (SNI69[45]) to NACE Rev.1 (SNI92 in Sweden). The new nomenclature entered into effect in 1993 in Sweden. A minor update in the standard became effective in 2003 (Statistics Sweden, 2003), called NACE Rev 1.1 (SNI2002 in Sweden). A major revision of the international integrated system of economic classifications resulted in the presently used NACE Rev. 2 (Eurostat, 2008). The new classification came into effect in 2008.

The most recent nomenclature comprises more subgroups than the previous standards. For example, SNI2002 used 776 groups while SNI2007 classifies industrial enterprises into 821 different categories. The refinement of the classification imposes a significant challenge on longitudinal studies since there is no unique key that maps all firms' classifications. For example, the 01111 (which is cereal cultivation in SNI2002) is separated into seven further categories in SNI2007 (01110, 01120, 01160, 01199, 01302, 01640, 02200). However, correct industrial classification is necessary to draw inferences on the environmental regulation's effects. Our goal was identifying the five-digit identification number that represents the firm's activity between entering the sample until its exit. We took the following steps to address the multiple classifications:

[43] The European Union Transaction Log, the official registry of the EU ETS, reports only that fraction of the total EU ETS emissions that are covered by purchased emission rights.

[44] NACE is the acronym for "Nomenclature statistique des activités économiques dans la Communauté Européenne"

[45] SNI is the acronym for "Standard för svensk näringsgrensindelning"

1. We embarked on the harmonization based on our workplace-level data, due to several reasons. First, the database spans the entire sample horizon, and it is our most complete dataset for the unification purpose. We can trace most of the plant's classification numbers in the entire horizon of the operation. The key feature of this database is that industry affiliation codes are available in multiple nomenclatures in some transitional years. For example, the implementation of SNI2002 formally started in 2003 but the system was applied to data reported between 2000 and 2008 (Swedish National Audit Office (2013)). This generated four overlapping years with the SNI92 classification (i.e. 2000-2003), and one with the SNI2007 (in 2008).

   Hence, we first harmonize the classification on the plant-level. The codes are located in three different columns (one for SNI92, one for SNI2002, and SNI2007), depending on the incumbent nomenclature in a given year. If a plant operates under several standards, the codes are available in both systems in the overlapping years.

   a, The first step was to harmonize the classification in the SNI92 and the SNI2002 systems that we carried out in two steps. We started our inspection with the plants that operate both in the SNI92 and in the SNI2002 standards as their operations are classified in both nomenclatures. We used the corresponding SNI2002 codes for all observed earlier years. For example, if the associated SNI2002 code is 15120 in year t for a given plant, we apply this number for the same plant for all the years when the plant is in the sample.

   b, If a firm's operation is tracked only in one industry standard, we rely on the official keys published by Statistics Sweden (Statistics Sweden). As the first revision of the NACE Rev.1 system was minor, the key between SNI92 and SNI2002 provides an almost unique matching between the two standards. When an identifier in SNI92 corresponds to several different SNI2002 codes, we kept the first one. Since the codes are relatively close to each other, we believe this simple selection does not bring much uncertainty into our analyses.

   c, The next step reconciles the observed SNI2002 and SNI2007 industry codes. As in point a, we started our work with the firms that have overlapping classification numbers. Since our primary objective is to obtain the structuring in the most recent nomenclature, we replaced all SNI2002 codes with the corresponding SNI2007 identification numbers. This step provides the internal consistency of the categorization in time.

   d, We also need to link the SNI2002 and the SNI2007 codes for those enterprises that are categorized only in one system. We address this challenge by keeping the most frequent SNI2007 subgroup that belongs to the same SNI2002 identification number. Similarly to the previous point, we finish this step with copying the obtained SNI2007 codes throughout the sample.

C Swedish manufacturing CO_2 emissions 1990-2015

Here, we document how CO_2 emissions evolve over our sample period across different manufacturing sub-sectors. Since firms enter and exit the sample over time, we divide firms into four-digit industries and track the evolution of industry emissions from 1990 and onward. Specifically, we sum up all (heating) CO_2 emissions as well as Producer Price Index (PPI) deflated sales across all firms in each four-digit industry each year. For deflating sales, we use 2010 as the base year and deflate using the Swedish PPI at the four-digit NACE code level. We then rank the industries depending on the ratio between aggregate emissions divided by aggregate sales in 1990 (the year before the introduction of the carbon tax) from highest to lowest and divide them into deciles. This results in 10 bins of about 20 four-digit industries each.

Table B.3 presents summary statistics of emissions-to-sales ratios, shares of CO_2 emissions and shares of carbon tax payments by decile bin for the years 1990 (panel A), 2007 (panel B), and 2015 (panel C).[46] In 1990, the emission intensity of the Swedish manufacturing sector as a whole was 0.0084, i.e., for every SEK of sales (in 2010 prices), 0.0084 kg (or 8.4 grams) of CO_2 was emitted. The heterogeneity across manufacturing firms is substantial, however, with a large concentration of emissions in decile 10, with an emissions intensity of 0.0313 compared to 0.0019 in decile 5.

Firms in decile 10 accounted for 72% of aggregate CO_2 emissions in 1990, and decile 9 for another 10%. The remaining eight deciles combined thus comprised only 18% of aggregate CO_2 emissions in 1990, despite accounting for more than 75% of manufacturing sales. We also present the share of total carbon tax payments in 1991 in panel A. Since carbon tax payments were capped at 1.7% of sales when the tax was introduced in 1991, a large fraction of the CO_2 emissions for high-emitting firms was effectively exempt from taxes. As a consequence, decile 10 firms only made up 54% of the carbon tax payments in 1991 despite emitting 72% of aggregate CO_2. In contrast, the share of tax payments exceeded the share of CO_2 emissions for the other nine deciles.

Panels B and C show that aggregate CO_2 emissions-to-sales decreased from 0.0084 to 0.0067 between 1990 and 2007 and remained at a similar level thereafter.[47] In 2007, changes in the tax system (described above) made the share of CO_2 emissions and carbon tax payments more similar across groups: decile 10's share of CO_2 emissions is 81% while the share of carbon tax payments is 75%. In 2015, the majority of high-emitting plants

[46]We choose 2007 as a reference year because it is the last year when all Swedish manufacturing plants were subject to the domestic carbon tax. Following the introduction of EU ETS, plants entering the emissions trading system were gradually phased out of the Swedish carbon tax system.

[47]Since firms enter and exit the sample over time, these changes reflect a combination of technological and compositional changes, which we will later try to decompose.

had transitioned into the EU ETS, leading to a sharp reduction in decile 10's share of carbon tax payments from 2007 to 2015.

We report additional emission statistics across deciles in Table B.4. Panel A reports averages over 1991-1995, to smooth out the volatility in manufacturing sales and profitability stemming from the deep recession Sweden experienced in the early 1990s (and the subsequent rebound). The fraction of carbon tax payments-to-sales was 0.0018 for the total manufacturing sector in the early years, ranging from a high of 0.0055 in decile 10 to a low of 0.0002 in decile 1. We also relate carbon tax payments to firm operating profits, measured by Earnings Before Interest and Taxes (EBIT). Tax payments amounted to 3.2% of EBIT for the manufacturing sector as a whole. In decile 10, however, carbon tax payments reduced firms' pre-tax margins by more than 6 percentage points. To put this in perspective, the corporate tax rate was 28-30% over the same period (calculated on earnings *after* interest), implying that the carbon tax led to a significant increase in the overall tax level of high-emitting firms.

Figure A.3, Figure A.4, and Figure A.5 display the evolution of CO_2 emissions, output, and carbon tax payments, respectively, across emission deciles over time. Figure A.3, illustrates that CO_2 emissions in the Swedish manufacturing sector have decreased over the sample period together with a contemporaneous increase in the concentration of emissions to the firms in decile 10. In contrast, Figure A.4 shows that the shares of manufacturing output by decile have been – to a large extent – quite stable over our sample period (although aggregate manufacturing sales have fluctuated). Finally, Figure A.5 shows that decile 10's share of carbon tax payments decreased to below 40% once the heaviest emitters transitioned into the EU ETS.

D Decomposing Sweden's manufacturing CO_2 emissions

Here we describe in detail how we construct Figure 5 using the framework developed in Grossman and Krueger (1991) and Grossman and Krueger (1993).[48] The decomposition separates the change in emissions into three parts. The first part is a "scale" effect, which captures how CO_2 emissions would have developed if the composition of the manufacturing sector and production technologies had remained at their 1990 level. The second part is a "composition" effect, which captures to what extent the mix of sub-sectors making up the manufacturing sector changes over time and how that affects aggregate CO_2 emissions. The third part is a "technique" effect and captures the effect of changing production technologies on CO_2 emissions per unit of output produced.

[48]This approach is formalized in Copeland and Taylor (1994) and discussed in light of the broader trade and environment literature in Copeland and Taylor (2004). We follow the approach of Levinson (2009), who applies this decomposition to understand the evolution of sulphur dioxide emissions from the U.S. manufacturing sector in 1987-2001. See section I of that article for a more detailed description of this methodology.

We compute the scale effect by plotting hypothetical emissions by multiplying the average 1990 emission intensity with PPI-adjusted, total sales for Swedish manufacturing, normalized to 100 in 1990 (Line (1) in Figure 5). If the composition and production technologies had remained constant since 1990, CO_2 emissions from Swedish manufacturing would have decreased by 3% in 2015 compared to 1990 levels. Line (2) in Figure 5 plots the actual aggregate CO_2 (heating) emissions over the same period. The level of CO_2 emissions in 2015 was 31% lower than in 1990, representing the combined scale, composition and technique effects. Finally, line (3) captures the scale and composition effects, holding technology constant, measured as the emission intensity (aggregate CO_2 emissions divided by aggregate PPI-adjusted sales) in each four digit industry in 1990 multiplied by the annual PPI-adjusted sales of that industry. Line (3) thus represents what total CO_2 emissions would have been each year if each manufacturing sub-sector would have kept their 1990 emission intensities while their output shares would have evolved as in the data. Swedish manufacturing CO_2 emissions would have been 13% lower given the changes in scale and composition but holding emission intensities constant.

The composition effect is obtained by the difference between line (1) and line (3) in Figure 5. Since the scale effect can account for a 3% reduction and the scale and composition effects combined for a 13% (line (3)) reduction, the composition effect accounts for a 10% drop in CO_2 emissions relative to 1990 levels. Hence, changes in the composition of the Swedish manufacturing industry towards less carbon-intensive sub-sectors explains slightly more than a third of the 28 percentage point gap between total manufacturing sales and total CO_2 emissions.

Finally, the technique effect, defined as the residual, is the difference between lines (2) and (3) in Figure 5. Out of a total reduction in CO_2 emissions of 31%, scale and composition (line (3)) accounted for 13%. Accordingly, the technique effect accounts to an 18% drop in CO_2 emissions, almost two thirds of the total reduction.

Figure A.1: Coverage of heating emissions data in our sample

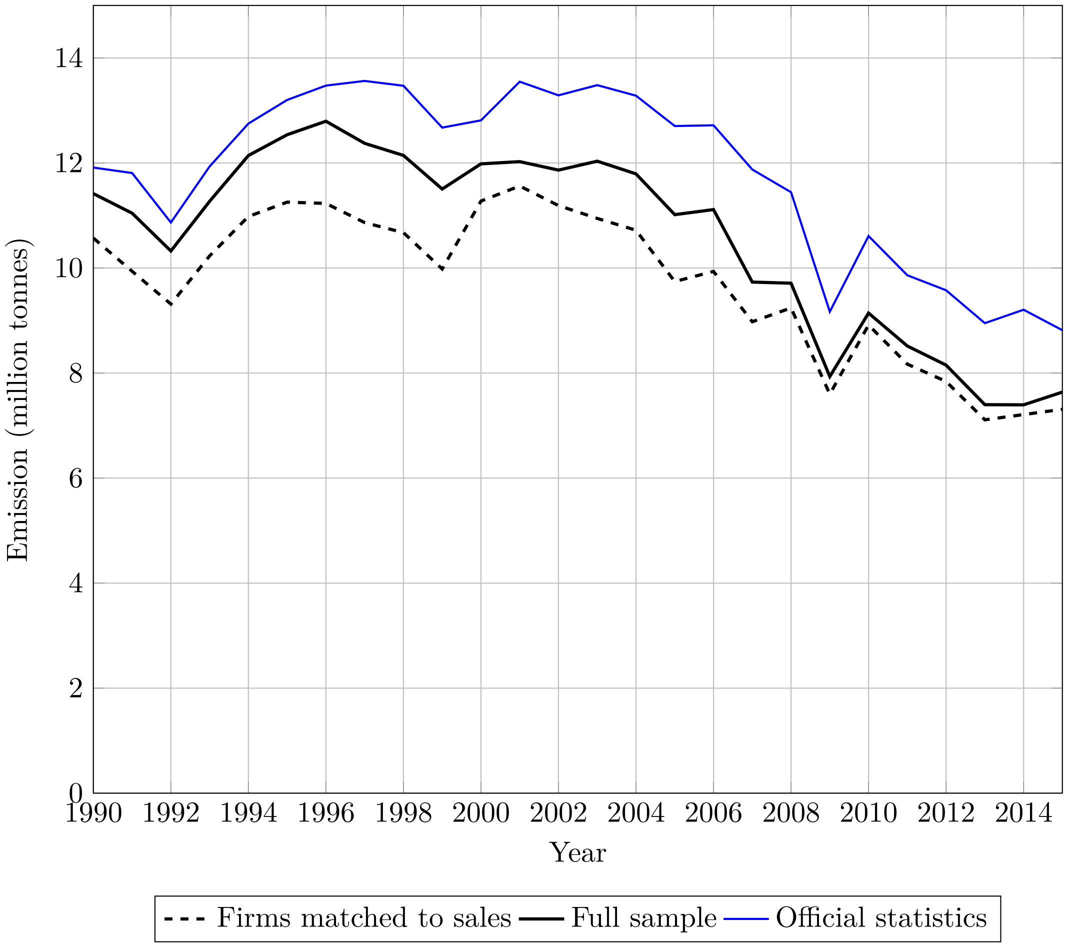

Figure A.1 compares heating emissions calculated from our full sample (*Full sample*) with the official tax payments registered by the responsible authorities and government agencies (*Official statistics*) and with that subsample that has observable sales (*Firms matched to sales*).

Figure A.2: Coverage of total emissions (heating plus process) data in our sample

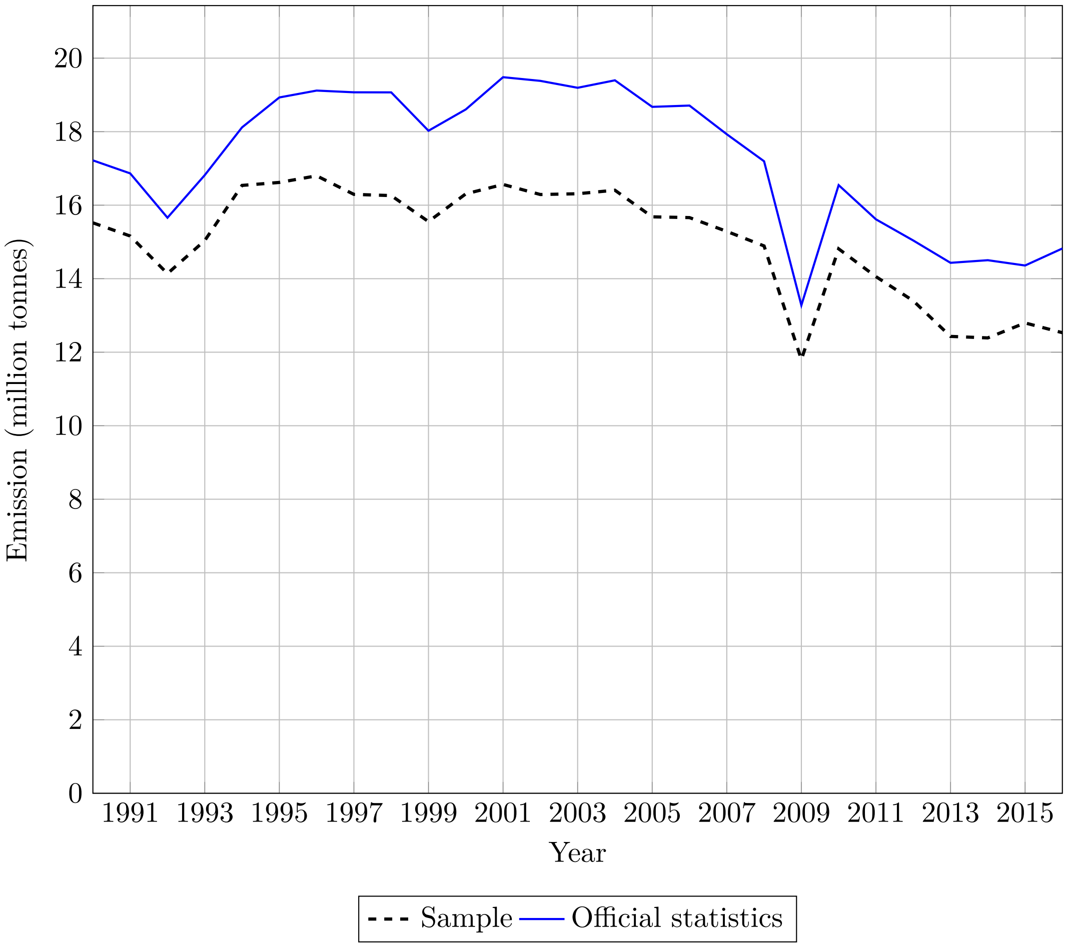

Figure A.2 compares the total emissions (i.e. heating plus process) calculated from our sample (*Sample*) with the official tax payments registered by the responsible authorities and government agencies (*Official statistics*).

Figure A.3: Distribution of CO_2 emissions from Swedish manufacturing (1990-2015)

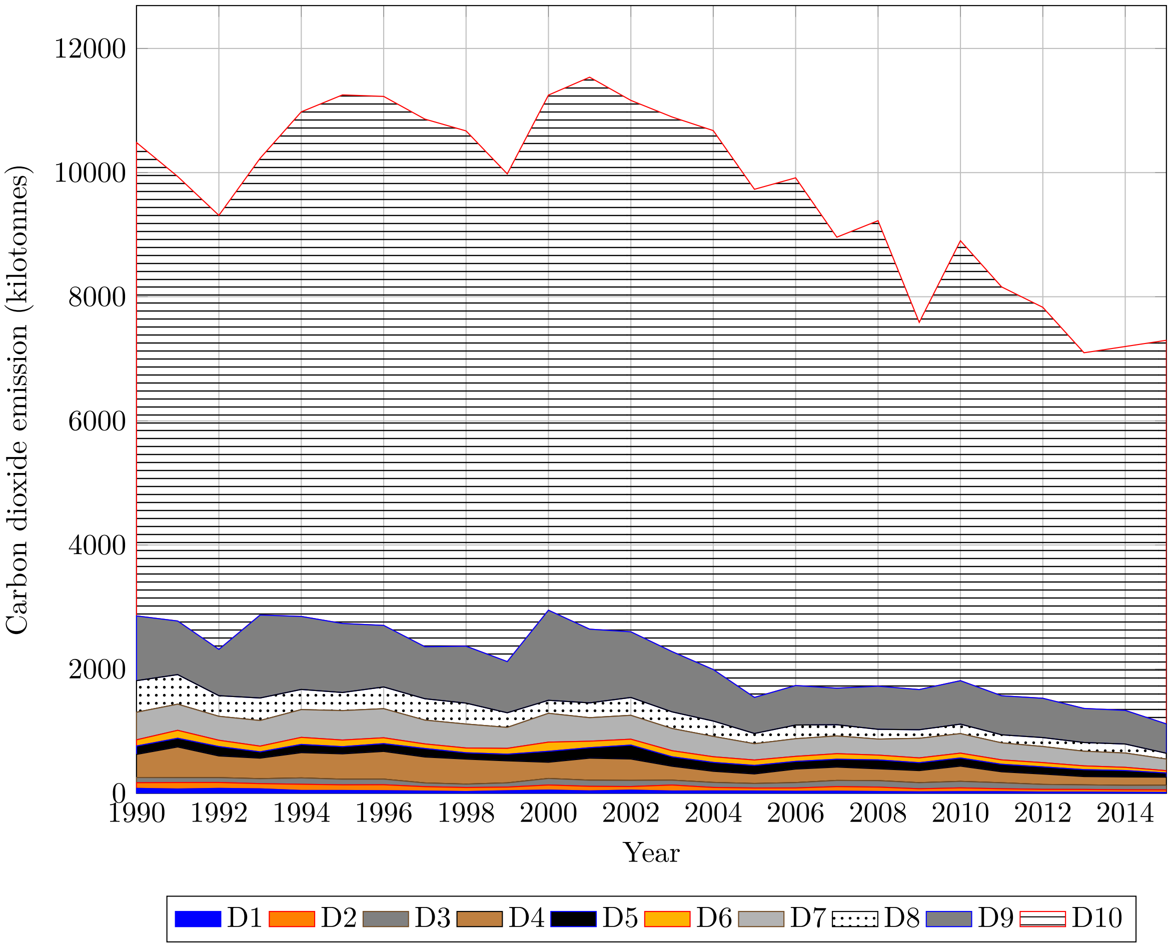

Figure A.3 reports the distribution of CO_2 emissions in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Figure A.4: Distribution of sales in the Swedish manufacturing sector (1990-2015)

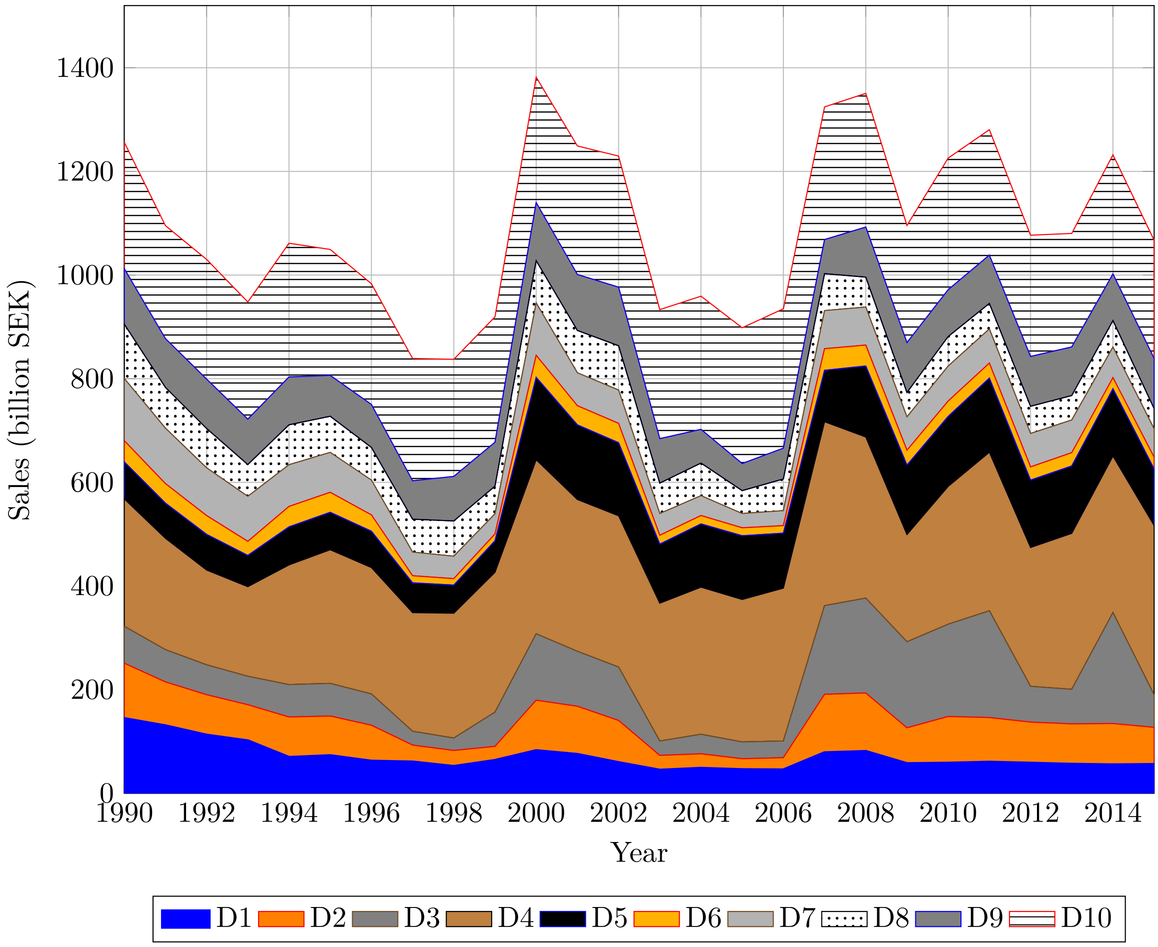

Figure A.4 reports the distribution of PPI-adjusted sales in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Figure A.5: Carbon tax payments from Swedish manufacturing (1990-2015)

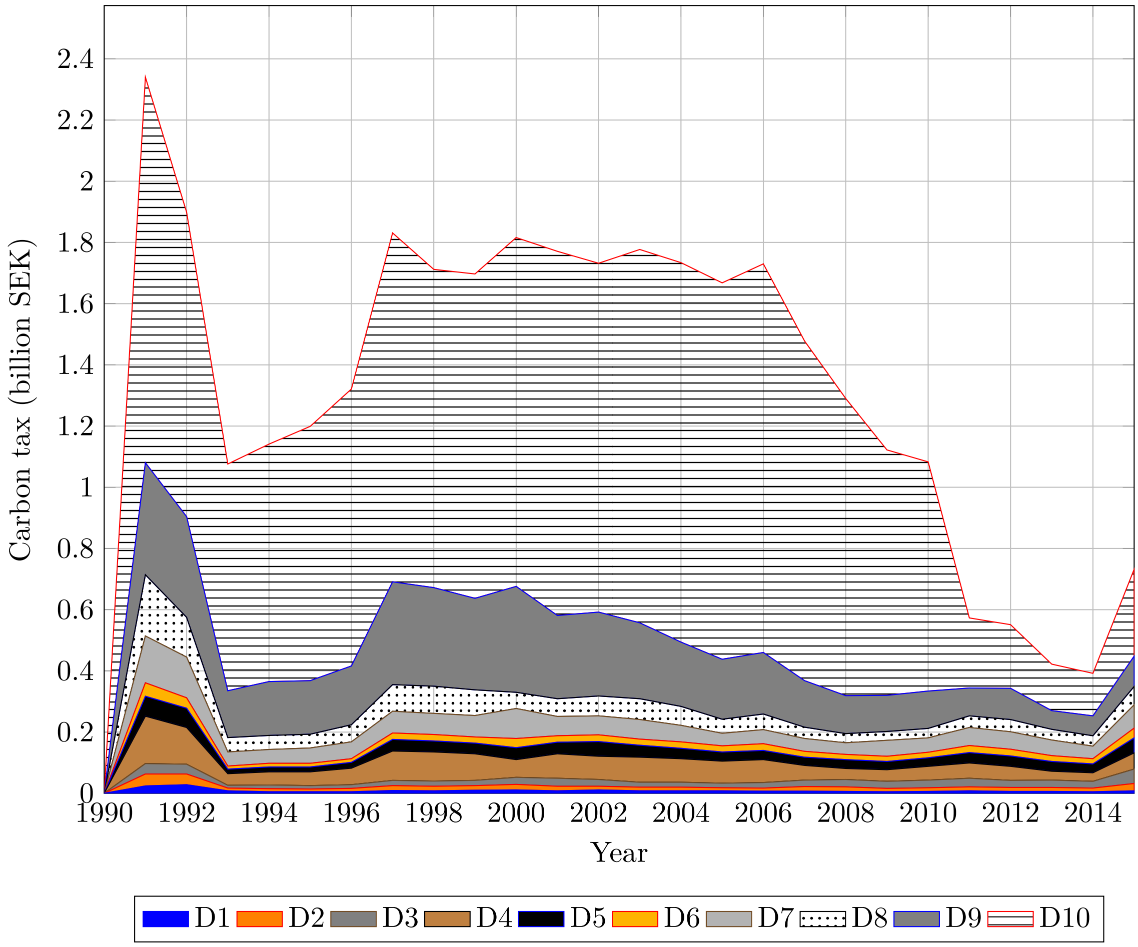

Figure A.5 reports the distribution of carbon tax payments in the Swedish manufacturing sector. The sample is divided into deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Table B.1: Sample size by year

Table B.1 reports the size of the Swedish manufacturing emission data. *All surveyed firms in manufacturing* is the number of firms with observable emissions in the data. *Matched to firm-level identifier with sales* is our working sample; i.e. the number of firms with observable emissions and sales.

Year	Surveyed firm	Matched with sales	Year	Surveyed firm	Matched with sales
1990	4,239	3,702	2003	583	498
1991	4,475	3,554	2004	564	477
1992	4,255	3,407	2005	485	401
1993	3,551	2,819	2006	511	426
1994	3,794	3,457	2007	2,799	2,651
1995	3,419	3,066	2008	2,794	2,633
1996	3,170	2,776	2009	2,622	2,502
1997	545	465	2010	2,452	2,335
1998	506	421	2011	2,385	2,260
1999	575	462	2012	2,351	2,210
2000	4,004	3,773	2013	2,232	2,128
2001	1,856	1,738	2014	2,130	2,043
2002	1,687	1,575	2015	1,995	1,718

Table B.2: Statistics by two-digit NACE sector level

Table B.2 reports statistics across two-digit NACE sectors. Tobacco products (NACE code 12) is excluded from this table due to low observation count and subsequent potential of data confidentiality concerns.

NACE	Industry	N	Share CO_2 1990	Share CO_2 2015	Share Sales 1990	Share Sales 2015	CO_2 -to-sales 1990	CO_2 -to-sales 2015	Share Deciles 9–10 CO_2	Share D9–10 Sub-sectors
10	Food products	392	0.067	0.040	0.078	0.068	0.0052	0.0024	0.053	0.130
11	Beverages	19	0.010	0.004	0.017	0.007	0.0035	0.0023	0.005	0.065
13	Textiles	144	0.016	0.002	0.009	0.003	0.0115	0.0026	0.016	0.065
14	Wearing apparel	55	0.001	0.000	0.003	0.002	0.0011	0.0001	0.000	0.000
15	Leather and related products	19	0.000	0.000	0.001	0.001	0.0016	0.0004	0.000	0.000
16	Wood and of products of wood and cork	329	0.012	0.005	0.064	0.039	0.0011	0.0005	0.009	0.022
17	Paper and paper products	209	0.191	0.080	0.094	0.076	0.0124	0.0044	0.210	0.065
18	Printing and reprod. of recorded media	112	0.001	0.001	0.013	0.009	0.0006	0.0003	0.000	0.000
19	Coke and refined petroleum products	15	0.196	0.281	0.046	0.060	0.0261	0.0195	0.232	0.043
20	Chemicals and chemical products	104	0.081	0.133	0.048	0.042	0.0103	0.0132	0.091	0.130
21	Basic pharmaceutical products	8	0.002	0.002	0.019	0.034	0.0007	0.0002	0.000	0.000
22	Rubber and plastic products	136	0.004	0.005	0.027	0.024	0.0009	0.0009	0.000	0.000
23	Other non-metallic mineral products	181	0.149	0.141	0.034	0.022	0.0268	0.0268	0.167	0.261
24	Basic metals	279	0.178	0.272	0.095	0.078	0.0113	0.0145	0.186	0.130
25	Fabricated metal products	735	0.032	0.010	0.064	0.050	0.0030	0.0008	0.030	0.087
26	Computer, electronic and optical products	58	0.002	0.000	0.021	0.101	0.0006	0.0000	0.000	0.000
27	Electrical equipment	127	0.007	0.002	0.034	0.049	0.0013	0.0001	0.000	0.000
28	Machinery and equipment n.e.c.	471	0.015	0.007	0.101	0.106	0.0009	0.0003	0.000	0.000
29	Motor vehicles, trailers and semi-trailers	125	0.017	0.014	0.077	0.171	0.0013	0.0003	0.000	0.000
30	Other transport equipment	102	0.006	0.000	0.055	0.018	0.0006	0.0001	0.000	0.000
31	Furniture	168	0.002	0.001	0.016	0.011	0.0007	0.0004	0.000	0.000
32	Other manufacturing	38	0.001	0.000	0.008	0.012	0.0004	0.0001	0.000	0.000
33	Repair and installation	378	0.011	0.000	0.077	0.015	0.0008	0.0001	0.000	0.000

Table B.3: Emission intensity and the distribution of CO_2 emissions and carbon tax payments in 1990, 2007 and 2015

Table B.3 reports emission intensities as well as the distribution of carbon dioxide emissions and carbon tax payments in 1990, 2007, and 2015. The sample is divided into ten deciles, based on the sampled firms' carbon intensities in 1990. *Share of fossil CO_2 emissions* and *Share of CO_2 tax payments* report the average contribution of each decile to the overall fossil carbon dioxide emissions and carbon tax payments of the manufacturing sector, respectively. Average contribution is defined as total tax payments (emissions) in a decile relative to the number of firms.

	All	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1
	Panel A: 1990										
Emissions-to-sales	0.0084	0.0313	0.0097	0.0048	0.0037	0.0024	0.0019	0.0015	0.0012	0.0008	0.0006
Share of fossil CO_2 emissions	1.0000	0.7216	0.0987	0.0481	0.0421	0.0094	0.0128	0.0353	0.0079	0.0086	0.0075
Share of CO_2 tax payments (1991)	1.0000	0.5385	0.1564	0.0855	0.0654	0.0188	0.0279	0.0662	0.0145	0.0165	0.0104
	Panel B: 2007										
Emissions-to-sales	0.0067	0.0284	0.0089	0.0025	0.0039	0.0021	0.0013	0.0006	0.0006	0.0007	0.0004
Share of fossil CO_2 emissions	1.0000	0.8094	0.0656	0.0201	0.0319	0.0100	0.0141	0.0240	0.0110	0.0083	0.0038
Share of CO_2 tax payments	1.0000	0.7500	0.1027	0.0248	0.0283	0.0129	0.0182	0.0325	0.0141	0.0101	0.0049
	Panel C: 2015										
Emissions-to-sales	0.0068	0.0271	0.0049	0.0024	0.0034	0.0016	0.0006	0.0004	0.0012	0.0006	0.0002
Share of fossil CO_2 emissions	1.0000	0.8457	0.0647	0.0127	0.0256	0.0050	0.0093	0.0179	0.0101	0.0057	0.0018
Share of CO_2 tax payments	1.0000	0.3869	0.1349	0.0813	0.1035	0.0433	0.0670	0.0715	0.0644	0.0332	0.0112

Table B.4: Emission intensity and carbon taxes paid ratios in 1991-1995, 2007 and 2011-2015

Table B.4 reports average emission intensities as well as the distribution of carbon dioxide emissions and carbon tax payments over 1991-1995, in 2007, and over 2011-2015. The sample is divided into ten deciles, based on the sampled firms' carbon intensities in 1990. *Share of manufacturing sales* reports the contribution of each decile to the overall sales of the manufacturing sector, defined as the average of average sales per decile over 1991-1995 in Panel A, and over 2011-2015 in Panel C. *CO_2 tax payments-to-sales* and *CO_2 tax payments-to-EBIT* report the average carbon tax over sales (EBIT) per decile (defined as total carbon tax over total sales or EBIT).

	All	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1
	Panel A: Average 1991-1995										
Emissions-to-sales	0.0100	0.0324	0.0117	0.0063	0.0048	0.0030	0.0019	0.0019	0.0014	0.0012	0.0006
CO_2 tax payments-to-sales	0.0018	0.0055	0.0035	0.0017	0.0011	0.0007	0.0006	0.0004	0.0003	0.0004	0.0002
CO_2 tax payments-to-EBIT	0.0324	0.0647	0.0404	0.0261	0.0200	0.0113	0.0083	0.0294	0.0081	0.0055	0.0033
Share of manufacturing sales	1.0000	0.1611	0.0866	0.0700	0.0856	0.0346	0.0661	0.2047	0.0579	0.0759	0.0926
	Panel B: 2007										
Emissions-to-sales	0.0067	0.0284	0.0089	0.0025	0.0039	0.0021	0.0013	0.0006	0.0006	0.0007	0.0004
CO_2 tax payments-to-sales	0.0011	0.0042	0.0025	0.0005	0.0006	0.0005	0.0003	0.0001	0.0001	0.0001	0.0001
CO_2 tax payments-to-EBIT	0.0161	0.0455	0.0539	0.0088	0.0116	0.0112	0.0027	0.0035	0.0013	0.0016	0.0014
Share of manufacturing sales	1.0000	0.1925	0.0495	0.0536	0.0553	0.0314	0.0746	0.2669	0.1286	0.0857	0.0579
	Panel C: 2011-2015										
Emissions-to-sales	0.0065	0.0266	0.0060	0.0027	0.0039	0.0023	0.0008	0.0005	0.0006	0.0005	0.0003
CO_2 tax payments-to-sales	0.0005	0.0009	0.0009	0.0009	0.0009	0.0009	0.0003	0.0001	0.0003	0.0002	0.0001
CO_2 tax payments-to-EBIT	0.0072	0.0338	0.0041	0.0199	0.0194	0.0176	0.0014	0.0119	0.0068	0.0028	0.0017
Share of manufacturing sales	1.0000	0.1998	0.0814	0.0814	0.0532	0.0215	0.1113	0.2607	0.1071	0.0694	0.0483

Table B.5: Carbon pricing and carbon emission intensity: Robustness

Table B.5 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. All regressions include year fixed effects. Regressions (2) and (3) include firm fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta\ln(1 - C)$ present an F-test of joint significance. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)
$\Delta\ln(1 - C)_{(i,t-1)}$	0.698***	0.892***	1.028***
	(0.191)	(0.198)	(0.247)
$\Delta\ln(1 - C)_{(i,t-2)}$			0.431**
			(0.210)
$\sum \Delta\ln(1 - C)$	0.698***	0.892***	1.459***
	(0.000)	(0.000)	(0.000)
Firm fixed effects	No	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	15,447	15,001	15,001
Within R^2	0.007	0.013	0.015

Table B.6: Carbon pricing and financing constraints: Ownership

Table B.6 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm is considered publicly listed if at least one firm in the corporate group is publicly listed at least once during the sample period. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All sectors		**D1-D4 sectors**		**D9-D10 sectors**		**Low PACE**		**High PACE**	
	Public	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**
$\Delta\ln(1 - C)_{(i,t-1)}$	1.056***	0.445	3.809**	1.483***	1.059**	0.184	2.936*	0.944*	1.101***	0.439
	(0.342)	(0.285)	(1.574)	(0.376)	(0.414)	(0.310)	(1.554)	(0.484)	(0.381)	(0.330)
$\Delta\ln(1 - C)_{(i,t-2)}$	0.531*	-0.014	1.418*	0.587	0.650*	-0.062	0.923	0.712*	0.643**	-0.179
	(0.276)	(0.360)	(0.833)	(0.406)	(0.328)	(0.492)	(2.149)	(0.394)	(0.316)	(0.441)
$\Delta\ln(1 - C)_{(i,t-3)}$	0.633**	0.529*	2.251***	1.832***	0.614*	0.279	-0.686	1.003**	0.781**	0.479
	(0.283)	(0.281)	(0.628)	(0.312)	(0.320)	(0.286)	(0.851)	(0.474)	(0.303)	(0.323)
$\sum \Delta\ln(1 - C)$	2.220***	0.959	7.478***	3.902***	2.323***	0.401	3.173	2.659**	2.525***	0.739
	(0.001)	(0.206)	(0.002)	(0.000)	(0.004)	(0.628)	(0.277)	(0.019)	(0.001)	(0.408)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,107	6,535	595	2,531	736	1,307	464	2,083	1,567	4,207
Within R^2	0.026	0.009	0.174	0.074	0.026	0.003	0.060	0.013	0.031	0.012

Table B.7: Carbon pricing and financing constraints: Firm size

Table B.7 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. *Large (Small) firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
	All Sectors		**D1-D4 Sectors**		**D9-D10 Sectors**		**Low PACE**		**High PACE**	
	Large	**Small**	**Large**	**Small**	**Large**	**Small**	**Large**	**Small**	**Large**	**Small**
Δln(1 - C)$_{(i,t-1)}$	1.138***	0.051	1.602***	1.844***	1.226***	-0.028	0.849	1.755***	1.190***	0.010
	(0.279)	(0.241)	(0.385)	(0.406)	(0.392)	(0.259)	(0.564)	(0.581)	(0.298)	(0.275)
Δln(1 - C)$_{(i,t-2)}$	0.340	0.039	0.562	1.730***	0.441	0.104	0.497	1.129***	0.281	-0.055
	(0.307)	(0.416)	(0.420)	(0.281)	(0.434)	(0.462)	(0.472)	(0.278)	(0.365)	(0.501)
Δln(1 - C)$_{(i,t-3)}$	0.637*	0.496	1.936***	1.033	0.281	0.604***	0.574	0.928	0.595	0.539**
	(0.349)	(0.192)**	(0.295)	(0.266)***	(0.451)	(0.225)	(0.538)	(1.030)	(0.401)	(0.209)
$\sum$ Δln(1 - C)	2.115***	0.585	4.100***	4.607***	1.948*	0.680	1.920*	3.811**	2.066**	0.494
	(0.009)	(0.296)	(0.000)	(0.000)	(0.076)	(0.266)	(0.097)	(0.031)	(0.027)	(0.446)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,138	4,504	1,581	1,545	886	1,157	1,254	1,293	2,801	2,973
Within R^2	0.027	0.005	0.081	0.165	0.037	0.008	0.009	0.022	0.033	0.007

Table B.8: Carbon pricing and financing constraints: Dividend payout ratio

Table B.8 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta \ln(1 - C)$ present an F-test of joint significance. *High (Low) dividend firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in dividend payout divided by book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All Sectors		**D1-D4 Sectors**		**D9-D10 Sectors**		**Low PACE**		**High PACE**	
	High	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
$\Delta \ln(1 - C)_{(i,t-1)}$	1.268***	0.371	2.026*	1.594***	1.658***	0.027	1.344*	0.947	1.294***	0.381
	(0.340)	(0.282)	(1.048)	(0.412)	(0.472)	(0.273)	(0.758)	(0.618)	(0.381)	(0.331)
$\Delta \ln(1 - C)_{(i,t-2)}$	0.347	0.065	0.440	0.737	0.609	0.021	0.866*	0.649	0.254	-0.024
	(0.425)	(0.317)	(0.458)	(0.482)	(0.565)	(0.382)	(0.504)	(0.557)	(0.495)	(0.391)
$\Delta \ln(1 - C)_{(i,t-3)}$	1.084***	0.307	1.587*	1.913***	1.375***	-0.071	0.663	0.846	1.123***	0.302
	(0.267)	(0.280)	(0.809)	(0.184)	(0.296)	(0.228)	(0.756)	(0.585)	(0.286)	(0.327)
$\sum \Delta \ln(1 - C)$	2.699***	0.743	4.053**	4.243***	3.641***	-0.024	2.872	2.441**	2.671***	0.659
	(0.000)	(0.301)	(0.015)	(0.000)	(0.000)	(0.971)	(0.113)	(0.042)	(0.002)	(0.450)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,209	4,433	1,558	1,568	930	1,113	1,273	1,274	2,822	2,952
Within R^2	0.026	0.007	0.038	0.117	0.053	0.000	0.011	0.023	0.032	0.008

Table B.9: Carbon pricing and financing constraints: Firm age

Table B.9 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. *Mature (Young) firm* is an indicator variable taking on the value one (zero) if the firm's founding year (measured at the corporate group level) is below (above) the median within its four digit NACE industry. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All Sectors		**D1-D4 Sectors**		**D9-D10 Sectors**		**Low PACE**		**High PACE**	
	Mature	**Young**	**Mature**	**Young**	**Mature**	**Young**	**Mature**	**Young**	**Mature**	**Young**
$\Delta\ln(1 - C)_{(i,t-1)}$	1.389***	0.242	2.619***	1.117***	1.374***	0.054	2.416***	0.478	1.312***	0.265
	(0.278)	(0.288)	(0.417)	(0.412)	(0.372)	(0.279)	(0.901)	(0.413)	(0.296)	(0.348)
$\Delta\ln(1 - C)_{(i,t-2)}$	0.842***	-0.228	0.644	0.578	1.066***	-0.259	1.661***	0.257	0.799***	-0.369
	(0.269)	(0.346)	(0.419)	(0.448)	(0.316)	(0.422)	(0.581)	(0.428)	(0.300)	(0.430)
$\Delta\ln(1 - C)_{(i,t-3)}$	0.703***	0.548**	1.194**	2.212***	0.633**	0.389	0.578	0.881*	0.728***	0.540
	(0.246)	(0.278)	(0.482)	(0.231)	(0.296)	(0.265)	(0.846)	(0.491)	(0.255)	(0.329)
$\sum \Delta\ln(1 - C)$	2.934***	0.562	4.457***	3.907***	3.072***	0.184	4.654***	1.615	2.838***	0.435
	(0.000)	(0.450)	(0.000)	(0.000)	(0.000)	(0.793)	(0.004)	(0.144)	(0.002)	(0.632)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,814	4,779	1,489	1,613	799	1,232	1,167	1,365	2,549	3,194
Within R^2	0.033	0.013	0.209	0.067	0.049	0.008	0.030	0.011	0.040	0.016

Table B.10: Carbon pricing and financing constraints: Size-Age and Whited-Wu

Table B.10 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta \ln(1 - C)$ present an F-test of joint significance. *SA* and *WW* is the Size-Age (Hadlock and Pierce, 2010) and Whited-Wu (Whited and Wu, 2006) index respectively for each firm. *Low (High)* in each measure is an indicator variable taking on the value one (zero) if the firm's SA or WW index value is below the median. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All sectors		D9-D10 sectors		All sectors		D9-D10 sectors	
	Low SA	High SA	Low SA	High SA	Low WW	High WW	Low WW	High WW
$\Delta\ln(1 - C)_{(i,t-1)}$	0.818**	0.599**	1.091**	0.456*	0.724***	0.191	0.646***	-0.358
	(0.339)	(0.249)	(0.473)	(0.275)	(0.211)	(0.737)	(0.234)	(1.000)
$\Delta\ln(1 - C)_{(i,t-2)}$	0.789**	0.063	0.793	0.171	0.218	-0.212	0.341	-0.699
	(0.364)	(0.297)	(0.569)	(0.358)	(0.250)	(0.935)	(0.313)	(1.234)
$\Delta\ln(1 - C)_{(i,t-13)}$	0.514*	0.544**	0.445	0.403	0.515**	0.622**	0.344	0.430
	(0.304)	(0.245)	(0.374)	(0.250)	(0.244)	(0.308)	(0.253)	(0.370)
$\sum \Delta\ln(1 - C)$	2.121***	1.206*	2.329***	1.030	1.457***	0.601	1.331**	-0.627
	(0.000)	(0.061)	(0.001)	(0.131)	(0.009)	(0.742)	(0.026)	(0.798)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,891	4,751	632	1,411	4,848	3,794	1,489	554
Within R^2	0.014	0.013	0.028	0.007	0.014	0.009	0.011	0.017

Table B.11: Carbon pricing and financing constraints: Drop firms switching ownership status

Table B.11 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum \Delta\text{ln}(1 - \text{C})$ present an F-test of joint significance. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm is considered publicly listed if at least one firm in the corporate group is publicly listed all years it is present in the sample. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**
	All sectors		**D1-D4 sectors**		**D9-D10 sectors**		**Low PACE**		**High PACE**	
	Public	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**	**Public**	**Private**
$\Delta\text{ln}(1 - \text{C})_{(\text{i,t-1})}$	1.340***	0.445	12.021**	1.483***	0.693*	0.184	10.339***	0.944*	1.089***	0.439
	(0.349)	(0.285)	(4.833)	(0.376)	(0.379)	(0.310)	(3.354)	(0.484)	(0.282)	(0.330)
$\Delta\text{ln}(1 - \text{C})_{(\text{i,t-2})}$	0.612	-0.014	-2.413**	0.587	1.488	-0.062	8.171***	0.712*	0.577	-0.179
	(0.729)	(0.360)	(0.905)	(0.406)	(0.973)	(0.492)	(2.739)	(0.394)	(0.831)	(0.441)
$\Delta\text{ln}(1 - \text{C})_{(\text{i,t-3})}$	0.966	0.529*	5.309***	1.832***	0.805	0.279	0.846	1.003**	1.345	0.479
	(0.816)	(0.281)	(1.482)	(0.312)	(0.869)	(0.286)	(1.331)	(0.474)	(0.814)	(0.323)
$\sum \Delta\text{ln}(1 - \text{C})$	2.917***	0.959	14.917**	3.902***	2.986***	0.401	19.356**	2.659**	3.011***	0.739
	(0.000)	(0.206)	(0.030)	(0.000)	(0.001)	(0.628)	(0.013)	(0.019)	(0.000)	(0.408)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	639	6,535	252	2,531	194	1,307	168	2,083	450	4,207
Within R^2	0.035	0.009	0.523	0.074	0.035	0.003	0.444	0.013	0.039	0.012

Table B.12: Carbon pricing and financing constraints: Allow firms switching ownership status

Table B.12 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm-year is considered publicly listed if at least one firm in the corporate group is publicly listed at least once during the sample period. The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All sectors		D1-D4 sectors		D9-D10 sectors		Low PACE		High PACE	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
Δln(1 - C)$_{(i,t-1)}$	0.995**	0.594**	4.978*	1.506***	0.741	0.479*	5.956**	0.887**	0.772*	0.629**
	(0.414)	(0.245)	(2.546)	(0.369)	(0.479)	(0.288)	(2.420)	(0.440)	(0.404)	(0.288)
Δln(1 - C)$_{(i,t-2)}$	0.421	0.136	1.141	0.607	0.716	0.151	4.510**	0.542	0.312	0.060
	(0.572)	(0.292)	(0.843)	(0.389)	(0.783)	(0.373)	(2.215)	(0.369)	(0.640)	(0.358)
Δln(1 - C)$_{(i,t-3)}$	0.434	0.590**	3.171***	1.832***	0.319	0.436*	-0.455	0.916**	0.555	0.588**
	(0.356)	(0.233)	(0.893)	(0.312)	(0.600)	(0.240)	(0.563)	(0.458)	(0.566)	(0.271)
$\sum$ Δln(1 - C)	1.850***	1.320**	9.290***	3.945***	1.776**	1.066	10.011**	2.345**	1.639**	1.277*
	(0.005)	(0.038)	(0.001)	(0.000)	(0.047)	(0.137)	(0.025)	(0.023)	(0.036)	(0.095)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,060	7,533	373	2,731	303	1,729	256	2,279	757	4,908
Within R^2	0.019	0.012	0.245	0.075	0.013	0.009	0.303	0.011	0.015	0.015

Table B.13: Carbon pricing and carbon emission intensity: Banking crisis, access to finance and CO_2 emissions

Table B.13 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample period is 1996-2015. All regressions include firm and year fixed effects. C is the emissions cost share relative to sales for firm i in year t. The standard errors are clustered at the firm level. $\sum$ Δln(1 - C) present an F-test of joint significance. *Public (Private) firm* is an indicator variable taking on the value one (zero) if the firm is (not) listed on a Swedish stock exchange. A firm is considered publicly listed if at least one firm in the corporate group is publicly listed at least once during the sample period. *Large (Small) firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *High (Low) dividend firm* is an indicator variable taking on the value one (zero) if the firm is above (below) the median in dividend payout divided by book value of total assets (averaged over the sample period and measured at the corporate group level) within its four digit NACE industry. *Mature (Young) firm* is an indicator variable taking on the value one (zero) if the firm's founding year (measured at the corporate group level) is below (above) the median within its four digit NACE industry. *Banking crisis* is an indicator variable taking on the value one if the year is coded as having a banking crisis in Laeven and Valencia (2018). The standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Public	**Private**	**Large**	**Small**	**High**	**Low**	**Mature**	**Young**
$\Delta\ln(1 - C)_{(i,t-1)}$	1.239***	0.594**	1.325***	0.199	1.414***	0.531*	1.558***	0.362
	(0.394)	(0.274)	(0.346)	(0.208)	(0.367)	(0.282)	(0.308)	(0.294)
$\Delta\ln(1 - C)_{(i,t-2)}$	0.735**	-0.009	0.495	0.049	0.407	0.135	0.862***	-0.133
	(0.301)	(0.338)	(0.317)	(0.377)	(0.416)	(0.298)	(0.249)	(0.346)
$\Delta\ln(1 - C)_{(i,t-3)}$	0.600**	0.592**	0.629**	0.510**	1.038***	0.381	0.739***	0.583**
	(0.285)	(0.241)	(0.290)	(0.197)	(0.256)	(0.254)	(0.241)	(0.254)
$\Delta\ln(1 - C)_{(i,t-1)}$	-0.611**	-0.804**	-0.734**	-0.669*	-0.634***	-0.762*	-0.874**	-0.501
x Banking crisis	(0.288)	(0.361)	(0.320)	(0.389)	(0.238)	(0.415)	(0.409)	(0.315)
$\Delta\ln(1 - C)_{(i,t-2)}$	-0.354	-0.163	-0.454	-0.003	-0.229	-0.161	-0.171	-0.257
x Banking crisis	(0.332)	(0.286)	(0.375)	(0.244)	(0.271)	(0.331)	(0.499)	(0.244)
$\Delta\ln(1 - C)_{(i,t-3)}$	-0.020	-0.508***	-0.222	-0.352**	-0.155	-0.481***	-0.323	-0.259*
x Banking crisis	(0.198)	(0.169)	(0.205)	(0.178)	(0.179)	(0.163)	(0.241)	(0.138)
$\sum \Delta\ln(1 - C)$	2.574***	1.177	2.449***	0.757	2.859***	1.047	3.158***	0.812
	(0.001)	(0.113)	(0.004)	(0.159)	(0.000)	(0.148)	(0.000)	(0.289)
$\sum \Delta\ln(1 - C)$	-0.985*	-1.475***	-1.410***	-1.024*	-1.018**	-1.404**	-1.368*	-1.016**
x Banking crisis	(0.064)	(0.006)	(0.001)	(0.092)	(0.014)	(0.024)	(0.095)	(0.026)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,107	6,534	4,138	4,504	4,209	4,433	3,814	4,779
Within R^2	0.034	0.016	0.034	0.011	0.030	0.015	0.040	0.017

Table B.14: Economic magnitude based on 1991, 1997, 2008, 2011 and 2015 carbon pricing changes and emissions intensities

Table B.14 reports the ratio of i) the value from subtracting the product of the elasticity and the actual carbon pricing change in the event year to ii) the actual CO_2-to-sales in the event year for each of the reform years 1991, 1997, 2008, 2011 and 2015.

	1991	1997	2008	2011	2015
Panel A: PACE, mobility and aggregate emissions					
All	18%	15%	57%	41%	47%
Low pace & Low mobility	32%	20%	87%	58%	74%
Low pace & High mobility	27%	17%	89%	47%	68%
High pace & Low mobility	11%	11%	30%	27%	27%
High pace & High mobility	29%	15%	22%	31%	38%
Aggregate emissions	14%	12%	34%	30%	30%
Panel B: PACE, Leakage list and deciles					
Low pace sectors	28%	22%	125%	65%	83%
High pace sectors	14%	12%	32%	29%	31%
Not on Leakage list	25%	14%	54%	43%	52%
On Leakage list	15%	13%	41%	30%	33%
Deciles 1-4	69%	45%	205%	158%	175%
Deciles 5-8	28%	20%	83%	55%	78%
Deciles 9-10	7%	10%	20%	21%	23%
Panel C: Ownership, size, dividend status and age					
Public firm			40%	35%	39%
Private firm			26%	10%	14%
Large firm			40%	40%	38%
Small firm			25%	9%	12%
High dividend firm			69%	45%	51%
Low dividend firm			0%	0%	0%
Mature firm			82%	60%	69%
Young firm			26%	10%	13%

Table B.15: Share of CO_2 emissions by sub-sample and event year

Table B.15 reports the distribution of aggregate CO_2 emissions across the different sub-samples across the different reform years.

	1991	1997	2008	2011	2015
All	1.0000	1.0000	1.0000	1.0000	1.0000
Low pace & Low mobility	0.0616	0.0518	0.0513	0.0532	0.0415
Low pace & High mobility	0.0441	0.0518	0.0157	0.0144	0.0125
High pace & Low mobility	0.8276	0.8502	0.8865	0.8850	0.9021
High pace & High mobility	0.0667	0.0462	0.0465	0.0474	0.0438
Low pace sectors	0.1064	0.1036	0.0670	0.0676	0.0541
High pace sectors	0.8936	0.8964	0.9330	0.9324	0.9459
Not on Leakage list	0.1286	0.1008	0.0792	0.0855	0.0758
On Leakage list	0.8714	0.8992	0.9208	0.9145	0.9242
Deciles 1-4	0.0429	0.0378	0.0356	0.0444	0.0310
Deciles 5-8	0.1181	0.1138	0.0672	0.0680	0.0591
Deciles 9-10	0.8390	0.8484	0.8972	0.8876	0.9099
Public firm		0.5289	0.4889	0.4562	0.4684
Private firm		0.4711	0.5111	0.5438	0.5316
Large firm		0.7588	0.7126	0.6857	0.7077
Small firm		0.2412	0.2874	0.3143	0.2923
High dividend firm		0.5218	0.4247	0.3858	0.4110
Low dividend firm		0.4782	0.5753	0.6142	0.5890
Mature firm		0.7785	0.6795	0.6420	0.6616
Young firm		0.2215	0.3205	0.3580	0.3384