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Carbon Pricing and Firm-Level CO_2 Abatement: Evidence from a Quarter of a Century-Long Panel

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Abstract

Sweden was one of the first countries to introduce a carbon tax in 1991. We assemble a unique dataset tracking all CO_2 emissions from the Swedish manufacturing sector to estimate the impact of carbon pricing on firm-level emission intensities. In panel regressions, spanning 26 years and around 4,000 firms, we find a statistically robust and economically meaningful negative relationship between emissions and marginal carbon pricing. We estimate an emission-to-pricing elasticity of around two, albeit with substantial heterogeneity across manufacturing subsectors. A simple calibration implies 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

JEL codes: H23, Q54, Q58

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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., Nordhaus 1993; Golosov et al. 2014; 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). Despite its importance, there is a shortage of comprehensive empirical evidence on the extent to which carbon taxation and pricing actually affects firm CO_2 emissions (Burke et al. 2016).

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.[1] We use this data set to explore four aspects of carbon pricing and firm-level CO_2 emissions. First, we document from where in the manufacturing sector the CO_2 emissions emanate and how these emissions are priced – on average and at the margin – across changing carbon pricing schemes, including the different Swedish carbon tax regimes and the EU Emissions Trading System (section 3). Second, we conduct event studies around major tax changes to assess the short-run responses of firms to changing marginal tax rates (section 4). Third, we run panel regressions to estimate the sensitivity of firm-level CO_2 emission intensity to the marginal carbon price over the longer run (section 5). Finally, we use our estimated marginal tax elasticities to quantify the impact of carbon pricing on aggregate manufacturing CO_2 emissions (section 6).

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,[2] levied on the heating emissions from manufacturing firms (see section 2 for details), and the Swedish carbon tax rate is currently the highest in the world (World Bank, 2022). In addition, several subsequent changes in tax rates, various exemptions, and the introduction of the EU ETS results in substantial variation in effective marginal tax rates in the cross-section and over time, which facilitates econometric identification. Our unique data

[1] See Brännlund et al. (2014) and Scharin, H and Wallström, J (2018) for overviews.

[2] Finland and the Netherlands were the first countries that introduced a carbon tax in 1990, followed by Sweden and Norway in 1991 (see Shah and Larsen (1992)).

contains information on both financials and CO_2 emissions for the universe of Swedish manufacturing firms over the period 1990-2015.

We first document that the vast majority of aggregate manufacturing CO_2 emissions can be attributed to a small fraction of narrowly defined manufacturing sectors, including steel, cement, and refineries. The decile of subsectors with highest CO_2 emission intensity (emissions relative to sales) represent as much as three quarters of aggregate manufacturing CO_2 emissions, despite only accounting for 15-20% of aggregate output. Soon after the initial introduction of the carbon tax, the Swedish government introduced various tax exemptions for the highest carbon-emitting firms, motivated by the need of mitigating "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 ended up having significantly lower (sometimes even zero) marginal tax rates, despite facing a high average tax rate that reduced their pre-tax margins by more than 6 percentage points on average. Consistent with the 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 had significantly higher reductions in their carbon intensity.

To measure short-term tax responses, we perform differences-in-differences analysis around the introduction and subsequent changes of the carbon tax regime, taking advantage of 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 find very similar results.

Next, we examine the longer-term relationship between emission intensity and the marginal carbon price a firm faces, including both the explicit CO_2 tax as well as the opportunity cost implied by the price of emission rights for firms included in 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 document a significant 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 document that a one percent increase in the marginal emissions cost share (to sales) reduces carbon emissions per unit of sales by roughly two percent over a three-year period. The estimate is stable over the introduction of the EU ETS in 2005 and robust to including various firm-level controls.

To better understand the association between carbon pricing and firm level emissions we consider the differential impact of abatement costs and carbon leakage risk. 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). Firms in low PACE sectors, i.e., where it is relatively cheaper and easier to reduce emissions, display a considerably higher carbon pricing elasticity relative to high PACE sectors. The estimated elasticity in low PACE sectors is around three compared to less than two in high PACE sectors. We then separate low and high PACE sectors based on the *ex ante* mobility of their assets.[3] The smallest elasticity point estimate is for firms in high PACE and low mobility sectors; these firms comprise between 80-90% of aggregate manufacturing CO_2 emissions.

Finally, we link carbon pricing to changes in aggregate manufacturing emissions of CO_2 during 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 to a decrease in aggregate manufacturing output ("scale") and 10 percentage points to the changing composition of the Swedish manufacturing sector away from CO_2 emitting industries to less emitting ones.[4] 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 reductions. These 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.

[3]Here we follow Ederington et al. (2005) and measure sectoral mobility by the real structures capital stock relative to sales. Sectors with high (low) ratio are relatively immobile (mobile). The PACE and mobility measures are highly correlated and as a result we do not uncover much statistically significant heterogeneity in the elasticities across the within PACE mobility sub-samples.

[4]In a related study using similar data, Forslid et al. (2021) show that imports actually reduce the emission intensity in Swedish firms and argue that this effect is not due to offshoring of dirty activities.

We believe our study contributes to the existing literature in several ways. First, thanks to a long time series and detailed micro-data on firm emissions and financials, we are able to provide more precise estimates of carbon pricing elasticities compared to earlier literature. As Burke et al. (2016) emphasize, there is a paucity of *ex-post* empirical analyses on the impact of carbon pricing.[5] Only a handful of countries have had carbon pricing regulation in place for any longer period of time and even fewer of them have the micro-level data needed for producing precise estimates.[6] Our micro-level estimates should be useful when calibrating macroeconomic models of optimal climate policy, such as Golosov et al. (2014) and Acemoglu et al. (2016).

Second, we aim to contribute to the literature on the effects of environmental and climate policy on firm behavior (e.g., Becker and Henderson 2000; Fowlie 2010; Greenstone et al. 2012; Fowlie et al. 2016; He et al. 2020; Brown et al. ming).[7] Two of the studies closest to ours are Martin et al. (2014), who analyze the effect of the 2001 UK carbon tax on manufacturing firms over the following three years, and show a significant negative effect on energy intensity, and Colmer et al. (2022), who document that French manufacturing firms reduce carbon emissions by 8-12% by being regulated under EU ETS. Compared to our study, these studies analyze smaller tax changes over a considerably shorter time period.

Our work should also be relevant for discussions on how to design optimal carbon taxation (e.g., Nordhaus 1993; Bovenberg and De Mooij 1994; Lans 1996; Pindyck 2013; Gillingham and Stock 2018; Stock 2020). While we acknowledge that our reduced-form estimates ignore important general equilibrium effects, they confirm that firms do respond to the marginal cost of emitting CO_2, consistent with economic theory. Our results also suggest that Sweden could have achieved significantly larger reductions in CO_2 absent the various exemptions that reduced marginal carbon tax rates for the highest-emitting firms.

Finally, this research relates to a growing literature on the connections between finance

[5]Recent exceptions are the studies by Metcalf and Stock (2020) studying aggregate data for 31 European countries and Andersson (2019) focusing on CO_2 emissions from the Swedish transportation sector.

[6]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 (Sweden, Finland, Denmark, Norway, Poland and Slovenia) and two-thirds of them were introduced after 2010.

[7]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., Newell et al. 1999; Popp 2002; Hassler et al. 2021.

and the environment (e.g., Hong et al. 2019; Krueger et al. 2020; Bolton and Kacperczyk 2021; Giglio et al. 2021a; Giglio et al. 2021b; Ilhan et al. 2021). More specifically, our study adds to the work considering the legal and financial determinants of environmental behavior more generally (e.g., Shive and Forster 2020; Akey and Appel 2021; Brown et al. ming; Xu and Kim 2022) by highlighting the particular role of carbon taxation on firm emissions.

2 Carbon Pricing in Sweden

Sweden introduced its carbon tax in 1991 along side a handful of countries.[8] The Swedish carbon tax is levied on fossil fuels used either in combustion engines ("mobile emissions") or for heating ("stationary emissions"). The carbon tax on mobile emissions primarily affects road transportation and is included in the after-tax price of fuel "at the pump". 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 (uniformly) on heating fuel inputs in proportion to the implied emissions of CO_2 during combustion. The manufacturing sector in Sweden uses about one third of its fossil fuel for production, generating so called process emissions, and the remainder for heating. As a result, about two thirds of the Swedish manufacturing sector's stationary CO_2 emissions are subject to carbon taxation. We summarize how the carbon tax affected the manufacturing sector in Figure 1.[9]

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 3.3.

In 2005, the European Union introduced a cap-and-trade scheme for CO_2 emissions,

[8] 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). We describe the historical background of the tax in Appendix A.

[9] See Statistics Sweden (2018) for how data has been collected.

[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.

the EU ETS (*European Union Emissions Trading System*), which had major implications for the Swedish carbon tax design. 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 also in the second trading phase (i.e., 2008-2012). In the third phase, starting in 2013, auctions of emission rights were introduced, although for manufacturing plants most emission rights were still distributed for free, motivated by concerns that manufacturing plants would otherwise move outside of the EU.

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 from *Bisnode Serrano* for 1998-2015.

In order to compute emission intensities we require our sample firms to have data on both 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, however, our sample consistently covers between 80-95% of aggregate manufacturing CO_2 emissions in any given year (Figure A.3). Our sample covers 85% of aggregate CO_2 heating emissions and 87% of total (process plus heating) CO_2 emissions (Figure A.4) from the Swedish manufacturing sector over our sample period.

Since historical firm-level records of actual carbon taxes paid could not be provided by the Swedish tax authority, we infer the effective marginal tax and 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. For the EU ETS period, we estimate the fraction of emissions subject to the Swedish carbon tax from the difference between emissions reported in SEPA and emissions according to the the European Union Transaction Log, the official registry of the EU ETS. Finally, for the regression analysis, we require firms to have at least four consecutive yearly observations to be included in the sample. Additional detail on the data and sample construction are provided in the appendix (subsection B.1 and subsection B.2) and in Sajtos (2020). We report summary statistics for our key variables in Table 2.

3.2 Swedish manufacturing CO_2 emissions 1990-2015

Next, 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 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. 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.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, which in turn include 82% of the 4-digit subsectors in deciles 9 and 10, jointly account for almost 88% of aggregate manufacturing CO_2 emissions in 1990.

Table 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).[11] In 1990, the emission intensity of the Swedish manufacturing

[11] We choose 2007 as a reference year because it is the last year when all Swedish manufacturing plants

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.[12] 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 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 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

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.

[12] 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.

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 3, Figure 4, and Figure 5 display the evolution of CO_2 emissions, output, and carbon tax payments, respectively, across emission deciles over time. Figure 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 4 shows that the shares of manufacturing output have been quite stable over our sample period. Finally, Figure 5 shows that decile 10's share of carbon tax payments decreased to below 40% once the heaviest emitters transitioned into the EU ETS.

3.3 The effect of changing carbon tax regimes

Our identification strategy relies on cross-sectional differences in marginal tax rates across firms, which allows us to control for time and firm fixed effects in order to isolate the effect of carbon pricing on emissions. This identification is made possible due to the various exemptions that high-emitting firms enjoyed at various points in our sample period. Figure 6 illustrates the tax rates a hypothetical firm would face across different regimes.[13]

When the tax was first introduced in 1991, CO_2 emissions were taxed at 0.25 SEK per kg, but with exemptions for the highest-emitting firms. Taxes were capped at 1.7% of sales, which was further reduced to 1.2% in 1992, with firms above the threshold facing a zero marginal tax rate on emissions. In 1993, the tax rate for manufacturing firms was reduced significantly in combination with the removal of the tax cap, so all firms (except for cement, glass and lime) were taxed at a constant rate of 0.08 SEK per kilogram. As a result, lower-emitting firms experienced a marginal tax decrease, while high-emitting firms (above the tax cap threshold) went from a zero to a positive marginal tax rate.

In 1997, the tax rate for manufacturing firms increased to 0.19 SEK per kg of CO_2

[13]We consider a firm with 50,000 SEK in sales. For 1991 and 1992, we assume that the firm only burns coal in order to avoid having to deal with energy taxation which manufacturing was exempted from in 1993 (see Table 1).

emitted.[14] At the same time, a new exemption was introduced for high-emitting firms, where the standard rate of 0.19 was paid until total payments reached 0.8% of sales, after which the marginal tax rate was reduced to 0.046 SEK per kg of CO_2 (or 25% of the standard rate). The manufacturing carbon tax rate was further raised in 2011, coupled with an increase in the exemption cutoff from 0.8% to 1.2% of sales. Finally, in 2015 all firm exemptions are removed and the manufacturing carbon tax rate is doubled to 0.63 SEK per kg CO_2 emissions. By this time, however, most high-emitting plants had transitioned into the EU ETS and were no longer subject to the Swedish carbon tax.

Importantly for our identification, the numerous changes in carbon taxation give rise to substantial variation in both the time-series and the cross-section. Figure 7 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 groups of firms. The first group comprises firms with emissions consistently below the thresholds for tax exemptions and that do not have any plants included in the EU ETS. For these firms, the average tax rate equals the marginal tax rate throughout the sample period. The second group consists of firms whose emissions consistently lie above the carbon tax exemption thresholds and whose plants later transition into the EU ETS. Prior to the EU ETS (and with the exception of 1993-1996), the average carbon tax rate exceeded the marginal tax rate for this group of firms. As EU ETS was introduced, their implicit marginal tax rate, reflected in the price of emission rights, increased considerably (subject to emission rights price movements), while their average tax rate stayed more or less constant (due to the free allocations of emission rights; see section 2).[15]

The significant differences in marginal and average tax rates across groups have important economic implications, as firms' incentives to reduce their CO_2 emissions depend on the former while their effective tax payments depend on the latter. For the most extreme

[14]This marginal tax increase was a result of a reduction in the tax discount for firms in the manufacturing sector. Upon the introduction in 1993, manufacturing firms paid only 25% of the nominal carbon tax rate (i.e., 0.32 x 0.25 = 0.08 SEK/kg in 1993). In 1997, this discount was changed to 50% (i.e., 0.37 x 0.50 = 0.185 SEK/kg).

[15]During the transition period between 2008 and 2011, 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 covered by the EU ETS were completely exempt from the carbon tax.

period in 1991-1992, the highest emitting group paid taxes amounting to 0.30-0.45 SEK per kg of emitted CO_2 on average, but had a marginal tax rate of zero on the next unit of emitted CO_2. 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 their tax payments decreased due to the free allowance of rights.

3.4 Decomposing Sweden's manufacturing CO_2 emissions

In Figure 8, we decompose the change in aggregate CO_2 emissions using the framework developed in Grossman and Krueger (1991) and Grossman and Krueger (1993).[16] 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.

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 8). 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 8 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

[16] 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.

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 8. 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 8. 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.

This "technique" effect captures the impact of carbon pricing on emission intensities and is the focus of our study. A few caveats are in order, however. First, it is likely that the scale and composition parts of emission changes were also at least partly due to carbon pricing. We believe that pricing elasticities with respect to total output are difficult to estimate reliably using the reduced-form approach we follow, however, which motivates our focus on emission intensities.[17] 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 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 adjust sales using each industry's 4-digit PPI, our estimates are still affected by relative price changes across firms over the sample period.[18] As a result, the "technique" effect also includes other strategic responses

[17]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.

[18]This problem is shared with much of the productivity literature (see Syverson 2011).

beyond just production technology, such as changes in pricing and product mix, and should thus be interpreted in a broad sense.

4 Short Term Effects of Carbon Pricing

We now examine the short-run response of firm-level emission intensities to changes in the Swedish carbon taxation. In particular, we investigate whether or not marginal pricing of carbon emissions is inversely related to firm emission intensity, as predicted by economic theory.

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. Given the political commitment to environmental taxation in Sweden after the tax reform of 1991 (Government Bill 1989/90:111 (1989)) and the strong reliance of the government on the revenue from environmental taxes (Tax Shift Commission (1997)) we believe it is plausible that firms at least did not anticipate any permanent cuts to carbon tax rates. In addition, to the extent firms expected a long-term tax rate different from the current one, the direct effect of carbon taxes on firms' cash flows is also likely to lead to an immediate response in and of itself (see Zwick and Mahon 2017).

The introduction of the Swedish carbon tax (in 1991) and its first revision (in 1993) provide reasonably clean events to analyze. As we discuss in subsection 3.3, there were caps in place in 1991 and 1992 preventing any firm from paying more than a certain percentage relative to its sales in carbon taxes. In 1993, these caps were removed and the statutory carbon tax rate was drastically reduced for all manufacturing firms. We analyze these two changes and divide firms into those who qualified for an exemption and those that did not. We report average marginal costs (panel A) and emissions-to-sales (panel B) in 1990, 1991-1992 and in 1993-1996 in Table 5. We focus on firms from decile 10 as most emissions are concentrated there and we have stable observation counts across the years for this group of firms. We exclude firms in the cement, lime and glass sectors from this test as they were not affected by these changes.[19]

[19]The cement, lime and glass sector was consistently subject to tax exemptions until the introduction of EU ETS in 2007.

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 price increase of 0.203 Swedish Krona (SEK) per kg of emitted CO_2, while firms with exemptions still faced a zero marginal tax (despite paying large amounts of carbon taxes, as previously discussed). In the 1993-1996 period, following the first change to the carbon tax, both groups were taxed similarly at the margin. This led to an increase of 0.084 in marginal carbon pricing for firms with exemptions in the 1993-1996 period, while the non-exemption group experienced a marginal cost decrease in 1993-1996 of -0.119. The difference-in-difference change 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). Firms in the non-exempt group display similar emissions-to-sales after the introduction of the tax in 1991-1992 (0.011) compared to 1990 (0.011). Firms in the exempt group, who still faced a zero marginal tax, experience an increase in emissions-to-sales from 0.087 to 0.103 during the same period. While the increase in the exemption group is not statistically significant, the diff-in-diff estimate of 0.016 relative to non-exempt firms is significant at the 1%-level. This suggests that a higher marginal carbon tax is associated with lower emission intensities. In the 1993-1996 period, when non-exempt firms experience a large cut in their marginal carbon tax rate, this group of firms saw a significant increase in their emissions-to-sales (from 0.011 to 0.016). In contrast, firms in the exempt group, whose marginal tax rate increased as exemptions were removed, decreased their emissions-to-sales ratios slightly from 0.103 to 0.100. The diff-in-diff estimate between groups between 1991-92 and 1993-96 is thus a negative -0.007, again consistent with firms responding to carbon taxes by reducing emission intensities (but just misses statistical significance at conventional levels). All difference in differences are robust to including four-digit industry dummies to control for difference in emission intensity across narrowly defined sectors (column (4)).

In Table 6 consider the period around the subsequent 1997 tax change. This period also provides a fairly clean event, since the preceding period (1993-96) was the only time period when all manufacturing firms (except for the cement, lime and glass, which we again exclude) 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) but at the same time re-introduced a tax exemption for firms whose tax payments exceeded 0.008 of sales, whose marginal tax was cut by 75% above this threshold. We again focus on firms from decile 10 sectors, and divide firms in to those qualifying for the exemption and those that did not. We balance the panel by requiring firms to be present during the entire period 1993-2000, to purge the estimates from changes in sample composition during this period.

Panel A reports evidence on marginal cost. 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 (non-significant), while non-exempt firms faced a large (and statistically significant) increase in their marginal tax cost (from 0.085 to 0.172). The difference in difference between exemption and non-exemption firms from the 1993-1996 to the 1997-2000 period is a highly significant -0.096. This effect is largely unchanged if we include a set of four-digit industry dummies (column 4).

Next, in panel B we evaluate whether the changes in marginal cost presented in panel A were associated with subsequent changes in firm level emission intensity. Again, by construction of the two groups, exemption firms have higher emissions-to-sales to start with (a significantly 0.054 higher level in 1993-1996). While we do note that the difference in periods for the two groups of firms are not statistically significant, they both evolve in line with our prediction. For exemption firms (with decreasing marginal cost) average emissions intensity increases slightly whereas non exemption firms display lower emissions intensity (with increasing marginal cost). Most importantly, the difference in difference is positive and statistically significant, again indicating a negative short-run relationship between marginal carbon tax and emission intensities.

To summarize: the early stages of the Swedish carbon tax relied on a system of capping maximum carbon tax payments to limit the amount paid by the highest polluting firms. This led to different marginal tax changes between different sets of firms, a feature we exploited in our short-term carbon pricing tests. The results show that carbon pricing was negatively associated with firm emission intensities around the events we considered. While suggestive, it provides a first indication that marginal carbon pricing matters for emission intensities even in the short run.

To obtain more precise estimates of longer-run tax elasticities, however, we next move to a panel regression framework that better allows us to account for delayed responses and heterogeneity across firms.

5 Estimation of Carbon Pricing Elasticities

5.1 Main specification

We now consider the longer-term impact of carbon pricing on firm-level CO_2 emissions. As it is the *marginal* (rather than the *average*) cost that should affect firm incentives (e.g., Cropper and Oates 1988), we model firm CO_2 emission intensity as a function of the marginal carbon tax rate. We have to tackle a few specification issues. First, some of the responses to carbon pricing involve significant investments and strategic changes that may take some 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 the lag length to differ across specifications.[20] 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 on the additional cost to their customers (which in turn depends on demand elasticities), costs of emissions abatement, and the ability to move production to jurisdictions without carbon pricing. Apart from including fixed effects, we will address such heterogeneity by estimating elasticities for various subsamples. It should be noted, however, 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.[21]

With these caveats in mind, we proceed with our baseline specification of the relationship between CO_2 emissions per unit of output and the marginal cost of emitting CO_2. Following Shapiro and Walker (2018) we estimate[22]

[20]Similar issues around lag length also comes up when modeling of the response of the capital-output ratio to changes in marginal corporate taxation, e.g., in Bond and Xing (2015).

[21]Exports make up about 70% of manufacturing value added in Sweden (over 80% in high emitting sectors such as basic metals, chemicals and paper and paper products) (Flam, 2021).

[22]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.

$$\Delta ln\left(\frac{E_{\text{i,t}}}{Y_{\text{i,t}}}\right) = \alpha + \sum_{s=0}^{q} \beta_{\text{s}} \cdot \Delta ln(1 - C_{\text{i,t-s}}) + \mu_{\text{i}} + \mu_{\text{t}} + \epsilon_{\text{i,t}}, \tag{1}$$

where E is kilograms (kg) of CO_2 heating emissions divided by producer price adjusted sales (PPI adjusted, in 2010 Swedish Krona (SEK)) of firm i in year t. C is the emissions cost share relative to sales for firm i in year t. For firms with plants covered under EU ETS we compute the marginal tax 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). $ln(1 - C_{i,t\text{-}s})$ captures the share of sales left after paying for one more unit of CO_2 emissions and makes it possible to take logs even for firms where $C_{i,t\text{-}s} = 0$. We thus expect $\sum_{s=0}^{q} \beta_{\text{s}} > 0$ if firms reduce emission intensities in response to marginal carbon pricing. μ_i accounts for any firm specific, time invariant factor that impacts the relation between CO_2 emissions and sales. μ_t captures specific changes in CO_2 emissions common to all manufacturing firms in Sweden in a given year. The lagged terms of C capture that changes in firm-level CO_2 emissions respond with some delay.

5.2 Baseline results

Table 7 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 discuss the economic magnitude of the elasticity estimates in more detail in section 6.) In the next three columns, we continue by adding additional lags and also present the sum of the β's and the joint significance. Adding $\Delta ln(1 - C_{\text{i,t-2}})$, as we do in column 3, leads to a larger estimate of the impact in *t-1* and a significant effect in *t-2*. The joint effect from including additional lags of the marginal cost of CO_2 emissions increases the estimated impact, with the magnitude increasing to a total elasticity above 2.0 with three lags (all being highly statistically significant).

In unreported regressions, we show that additional lags have small and a statistically insignificant coefficient, with the total estimated magnitude being largely unchanged. We therefore choose the specification which includes the marginal cost of CO_2 emissions at lags *t-1* to *t-3* as our baseline model.[23]

Since we have shown that the top deciles of emitters account for a disproportionately large fraction of total CO_2 emissions, it is particularly important to account for possible heterogeneity in this dimension. In the remaining three columns in Table 7, we therefore split the sample in to three bins according to 1990 emission deciles as in Table 3 and Table 4. Column 5 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 3 that firms from these sectors comprise under 6% of CO_2 emissions and emit at intensities relative to sales of between 0.0006-0.0015. In column 6 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 7, we consider firms from deciles 9 and 10, which account over 80% of CO_2 emissions in 1990 and have significantly higher carbon emissions-to-sales ratios compared to firms in other manufacturing subsectors. The joint carbon pricing effect in this sub-sample is considerably lower than in the other deciles (reported in columns 5-6) and also lower than the full sample effect from column 4. The results in the final three columns in Table 7 are consistent with firms in subsectors with production technologies associated with higher CO_2 emissions having the highest cost of abatement. We will carry out additional tests to shed more light on the mechanism behind these findings below.

We also carry out a set of additional robustness tests which are reported in Table B.4. 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, to account for the possibility that the cap-and-trade system leads to different carbon pricing elasticities. We report results for the full sample and for firms in deciles 9 and 10 (as the vast majority of all EU ETS regulated firms belong in these deciles). Following Brännlund et al. (2014), we also control for the size and capital intensity of the firms. The carbon pricing effect we find in

[23] 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.3).

Table 7 is essentially unchanged across these alternative specifications.

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 impact plant- and firm-level emissions and would be expected to affect a firm's response to carbon pricing: the marginal cost of reducing emissions and the geographic mobility of the firm's assets.

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 8. We retrieve a relatively larger carbon pricing elasticity among low-PACE sector firms compared to those in high PACE sectors. The elasticity for low PACE sector firms is three compared to in the high PACE firms which is below two. These results suggests that firms with lower abatement costs respond at a lower cost to a change in the marginal cost of emitting CO_2, as would be expected.

Second, we consider how the geographic mobility of assets impacts firms operating

[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).

in low- and high-PACE sectors. Firms with high mobility would be able to move their production facilities to other countries in order to avoid paying Swedish carbon tax. If firms move their most emission-intensive plants in response to an increase in carbon pricing, this might result in a higher estimated emission elasticity, since we now only observe emission-intensities for the lower-emitting plants. We follow Ederington et al. (2005) and measure the mobility of assets by plant fixed costs using data from the Swedish investment survey. Similarly as with the PACE measure above, we take the ratio of the sum of the real structures capital stock to aggregated industry sales for each four-digit industry and average over the sample years.[25] We define firms above (below) the median in plant fixed costs as having low (high) mobility.

Results for low- (high-) PACE industries divided by low versus high mobility are shown in columns 3 (5) and 4 (6) (in Table 8). 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 are noteworthy 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 $\Delta ln(1 - C)_{(i,t\text{-}s)}$ 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. This result should be interpreted with caution, however, as the sample size is smaller than for the other groups in Table 8 and the elasticity estimate is only marginally statistically significant.

5.3.2 EU leakage list

Next, we divide firms into those measured as being at a high risk of "carbon leakage by the EU" versus those who are not. In its effort to mitigate the risk that carbon pricing

[25]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 also robust to using US data from the NBER-CES Manufacturing Industry Database as in Ederington et al. (2005).

in the ETS would lead production to move outside of the European Union, EU sorts all industrial (four-digit) sectors in to those at risk of leakage and those not considered to be at risk. 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, iii) a combination of i) and ii).[26] Hence, in addition to partly capturing differences in production technology (similar to PACE and mobility), this classification also accounts for the competitive disadvantage resulting from carbon pricing, due to certain industries facing more price-sensitive demand which limits their ability to pass on the carbon pricing to their customers.

We report estimation results in Table 9. We first consider whether firms are in sectors on or outside the leakage list. It is noteworthy that about half of our sampled firms are operating in sectors on the list. The carbon pricing elasticity is around 2.6 for firms considered not be at risk of carbon leakage. For firms in sectors on the EU leakage list, we estimate a lower carbon pricing elasticity below two, although still statistically and economically significant. The lower elasticity for firms on the leakage list is consistent with those firms facing a larger difficulty in reducing emission-to-sales ratios, either by changing production technology or through increasing prices. While sample sizes are similar across groups, it is worth noting that over 90% of the aggregate manufacturing emissions in fact originate from firms on the carbon leakage list.

Finally, we further split firms into different categories considered by the EU for assessing the risk of carbon leakage. In column 3 we focus only on the sectors which are on the list due to trade concerns (based on criterion "C"). Firms in these sectors face high international competition (and thus would find it more difficult to pass on price increases to customers) but do not operate with very highly polluting production technologies. Interestingly, we retrieve a considerably higher carbon pricing elasticity for this group of firms (at 3.3), indicating that these firms, while having a limited ability to pass on tax costs to customers, are able to reduce emissions through technological means at a relatively low cost. In the final column, we report the carbon pricing elasticity of carbon leakage sectors with high emission intensities.[27] For this group we find a considerably lower elasticity (around 1.5),

[26] See European Commission (2009) for the initial carbon leakage list.

[27] These are all sectors outside those categorized as "C" in the EU classification, and is mutually exclusive to the sample in column (3). The sample in column (4) consists of firms categorized in group "A", sectors

similar in size to the results for firms in decile 9 and 10 sectors in Table 7 (around 1.3) and for those sorted in high PACE and low mobility sectors in Table 8 (around 1.7). This similarity is expected as there is considerable overlap with respect to sectors in these sub-samples.

6 Aggregate Effects: Quantifying the Economic Importance of Emission Elasticities

Now we turn to quantifying the estimation results from section 5. Our estimated carbon pricing elasticities imply that emission intensities would have been higher in the absence of carbon pricing. In the absence of a structural model, we instead perform a reduced form calibration which assumes that total output and entry and exit of firms had evolved as observed, hence ignoring equilibrium effects that would have led to a different "scale" and "composition" of the Swedish manufacturing sector. Since such effects are likely to be relevant, this should not be viewed as a proper counterfactual experiment, but rather a rough back-of-the-envelope assessment of the quantitative importance of our estimated carbon pricing elasticities. Still, we believe this exercise is informative in assessing the economic significance of the carbon pricing elasticity we have estimated.

Since we only perform this calibration with respect to emission intensities, the estimated aggregate effect will be dependent on the base year we choose, since overall output, industry composition, and carbon tax rates vary across years. We choose to focus on 2015, which is the year of the most recent change of the Swedish carbon pricing scheme (see Table 1 and Figure 7 for description and graphics of the events).

In particular, we use our estimated relationship to calculate the implied change in firm-level emission intensities to retrieve what the emissions intensity would have been in the absence of carbon pricing. Using our baseline estimates and actual 2015 carbon pricing we compare the difference in predicted emissions when $t = 2015$ compared to in 1990 for the sample of firms in question and the actual production technologies used in 2015 as follows:

with high emissions and some trade concerns and group "B", sectors with very high emissions and no trade concerns.

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

The top row in Table 10 evaluates the baseline elasticity which is retrieved from using variation across all firm-years (column 4 in Table 7) in Equation 2. The observed, average carbon intensity across all firms in 2015 is 0.0049. In the 2015 setting, the observed carbon intensity would have been 0.0071 (column 4) or 47% higher than the actual carbon intensity (column 5) without a carbon price in place.

The calibration based on the sample wide elasticity presented above does not account for the heterogeneity across sub-groups we document in Table 8. We present calibration results across PACE and mobility sub-samples in panel A. Here we compute Equation 2 separately for the four sub-groups in column 3-6 in Table 8. In the 2015 setting, we find that firms in low PACE sectors operating with low and high mobility assets respectively would have had 74% and 68% higher emissions intensity in the absence of carbon pricing. For high PACE firms the same is 27% and 38% higher emissions intensity in low and high mobility sectors. We then weight each sub-groups' implied emissions intensity with its share of CO_2 emissions. Based on our estimated elasticities, emissions intensity in Swedish manufacturing would have been almost 30% higher in the absence of carbon pricing. This effect is smaller than when we use the manufacturing sector wide elasticity in the top row. This is due to the differences across sub-groups in estimated elasticities, marginal cost shares and fraction of aggregate CO_2 emissions. Notably, firms in high PACE and low mobility sectors account for 90% of manufacturing CO_2 emissions is 2015.[28]

Panel B displays the implied carbon intensities for the other sub-samples used in our study. If the size and composition of manufacturing sales are constant over time our 30% effect on carbon intensity would translate in to an aggregate CO_2 emissions reduction of the same magnitude. Aggregate manufacturing emissions declined by 31% over the sample period (see subsection 3.4) which suggests the carbon pricing effect is indeed economically sizeable.

We re-calculate Equation 2 using the events of 1991, 1997, 2008 and 2011 and report the subsequent aggregate effect in Table B.5. Setting t to 2008 or 2011 yield similar calibration

[28]The fact that 90% of CO_2 emissions are concentrated to a set of sectors which have highly immobile assets and face high costs to abate is often side stepped in the literature and is a key finding.

results as in Table 10. However, if we instead base our calibration on 1991 and 1997 the implied emissions intensity is between 12-14% higher, i.e., only a third of the effect based on the 2008-2015 events.[29]

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. This would imply that the entire decline in emissions intensity could be attributed to carbon pricing. On the other hand, when we instead use the environment of the carbon tax prior to the EU ETS in the 1990s (often with marginal costs lower than average tax rates and occasionally zero for large emitters), the aggregate effect would instead account for around a third to half of the aggregate CO_2 emissions reduction in Swedish manufacturing since 1990.

7 Conclusions

As one of the first countries in the world, Sweden introduced a carbon tax in 1991, which remains the world's highest carbon price. We assemble a comprehensive dataset of Swedish manufacturing firms and track firm-level CO_2 emissions during 1990-2015. Our panel includes more than 4,000 firms and covers almost all CO_2 emissions in the Swedish manufacturing sector over this period. We document a statistically robust and economically meaningful inverse relationship between CO_2 emissions and the marginal cost of emitting CO_2. We estimate the CO_2 emissions-to-carbon pricing elasticity to be around two for the manufacturing sector. Aggregate Swedish manufacturing CO_2 emissions decreased by about 31% between 1990 and 2015, while total output of the Swedish manufacturing sector decreased by 3% over the same period. Finally, a back-of-the-envelope calculation using our estimated carbon pricing elasticities attributes between one third and up to most of the 31 percentage point decrease in aggregate manufacturing CO_2 emissions to carbon pricing.

[29] We report the share of CO_2 emissions and sales for each event year across sub-samples in Table B.6 and Table B.7.

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Figure 1: Carbon and energy taxation of an industrial plant

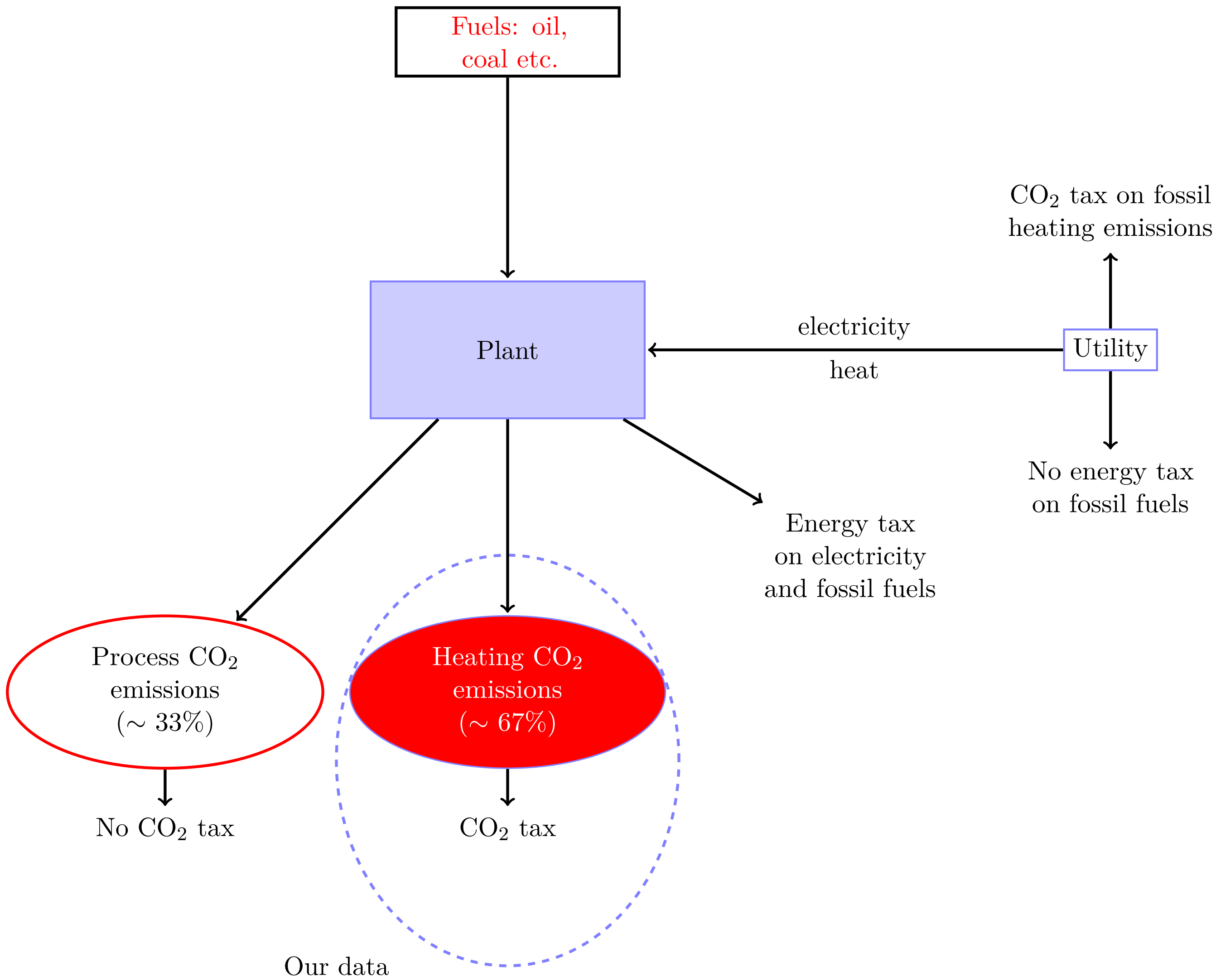

Figure 1 illustrates the carbon and energy taxation for a manufacturing plant in Sweden in 2019. *Heating CO_2 emissions* refers to the emissions released from the combustion of fossil fuels. *Process CO_2 emissions* refers to the carbon dioxide emissions released in the actual manufacturing process (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

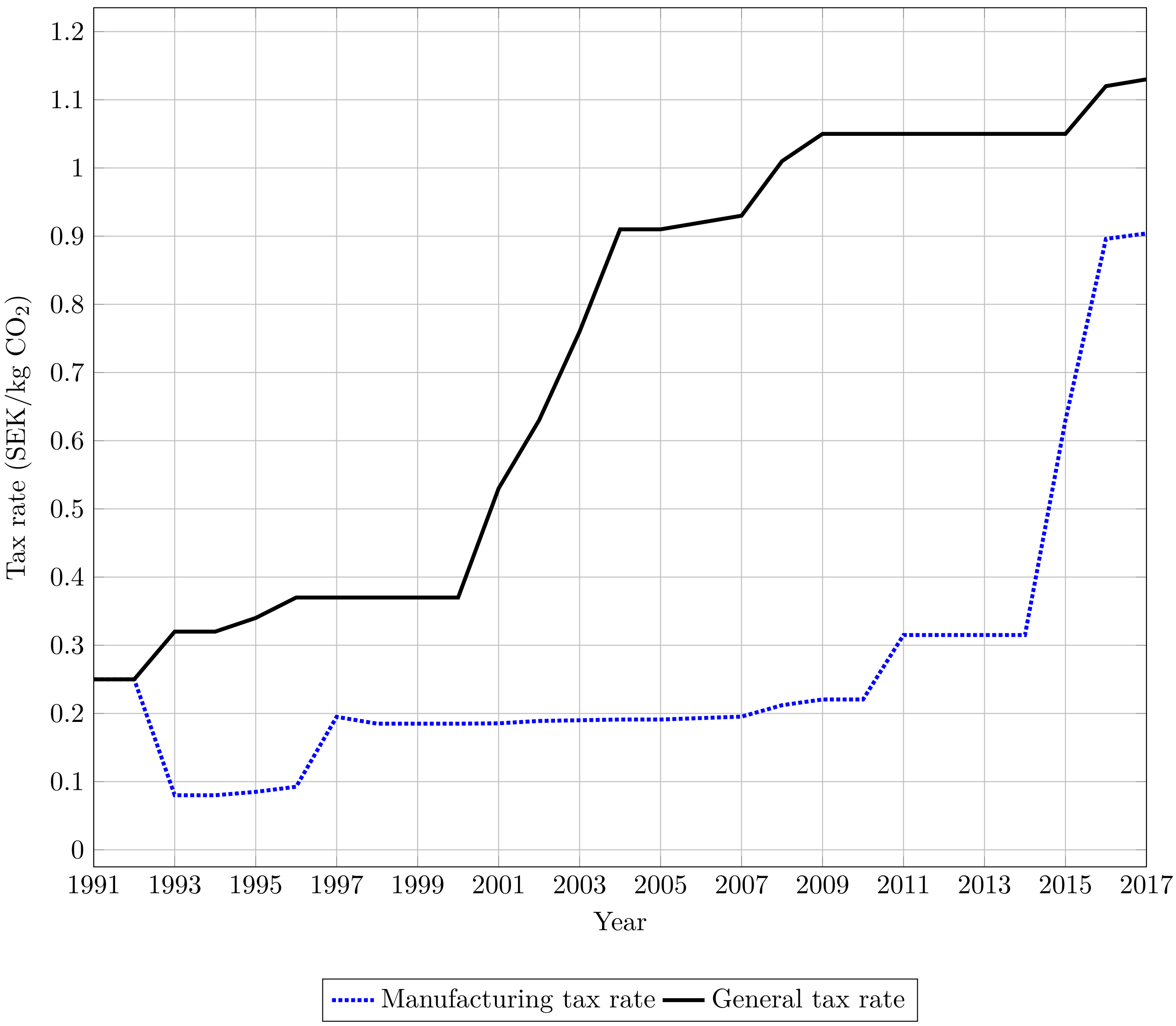

Figure 2 displays the nominal carbon tax rates (Swedish krona per kilogram of emitted carbon dioxide) for Sweden from 1991 to 2017. *Manufacturing tax rate* refers to the tax rate for the manufacturing sector (SNI 10-33 in the SNI2007 nomenclature), while *General tax rate* refers to the tax rate for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

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

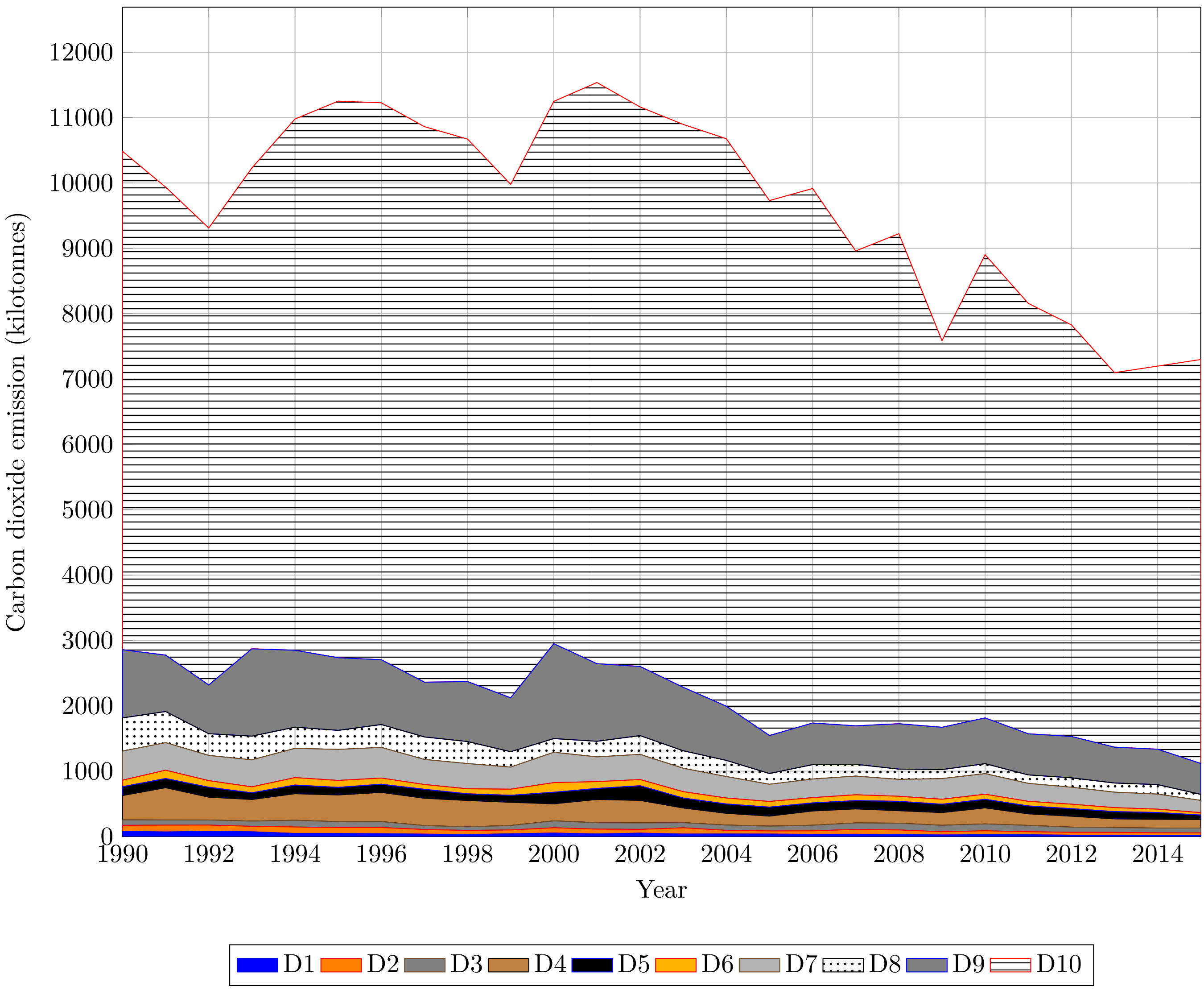

Figure 3 reports the distribution of CO_2 emissions in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

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

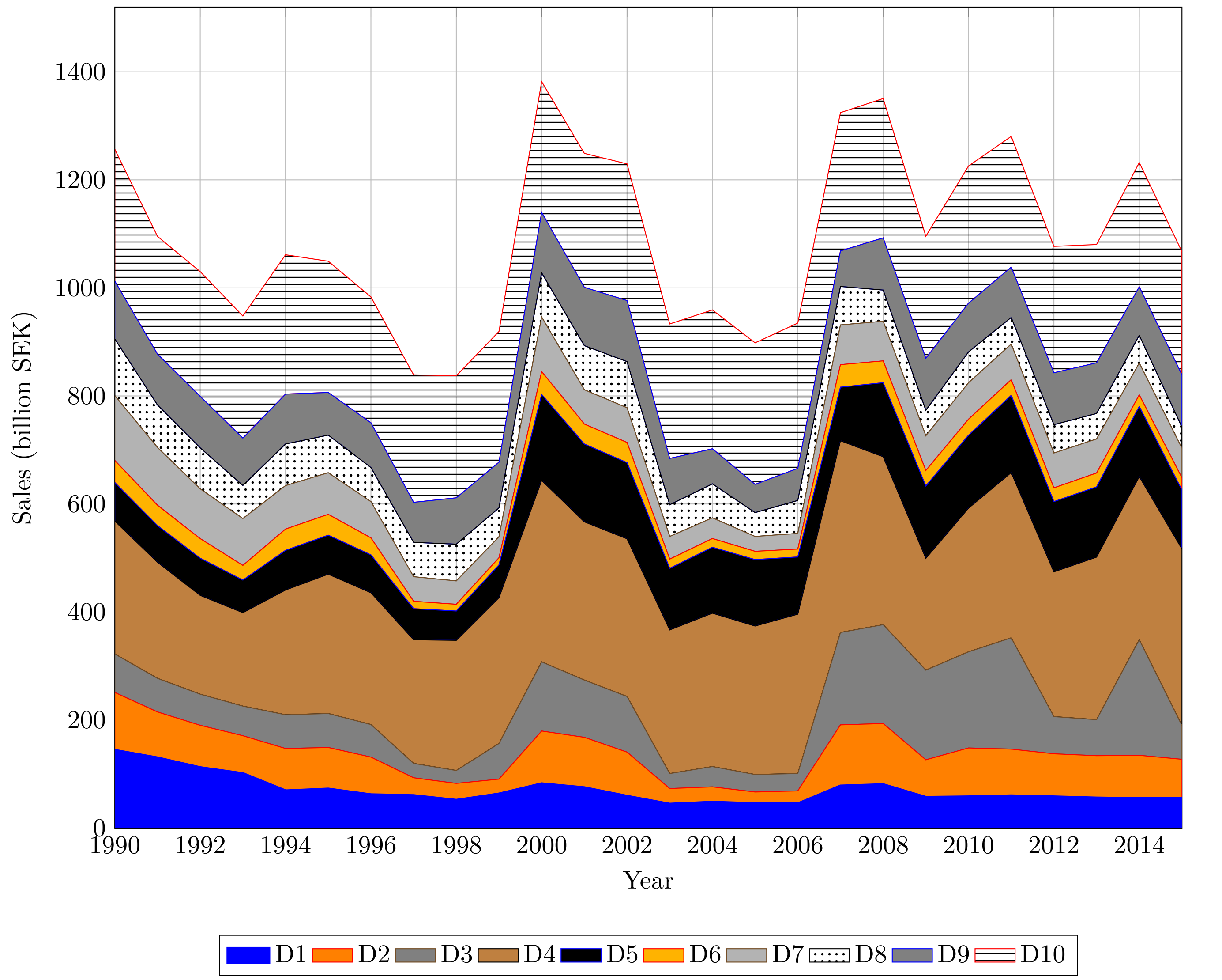

Figure 4 reports the distribution of PPI-adjusted sales in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

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

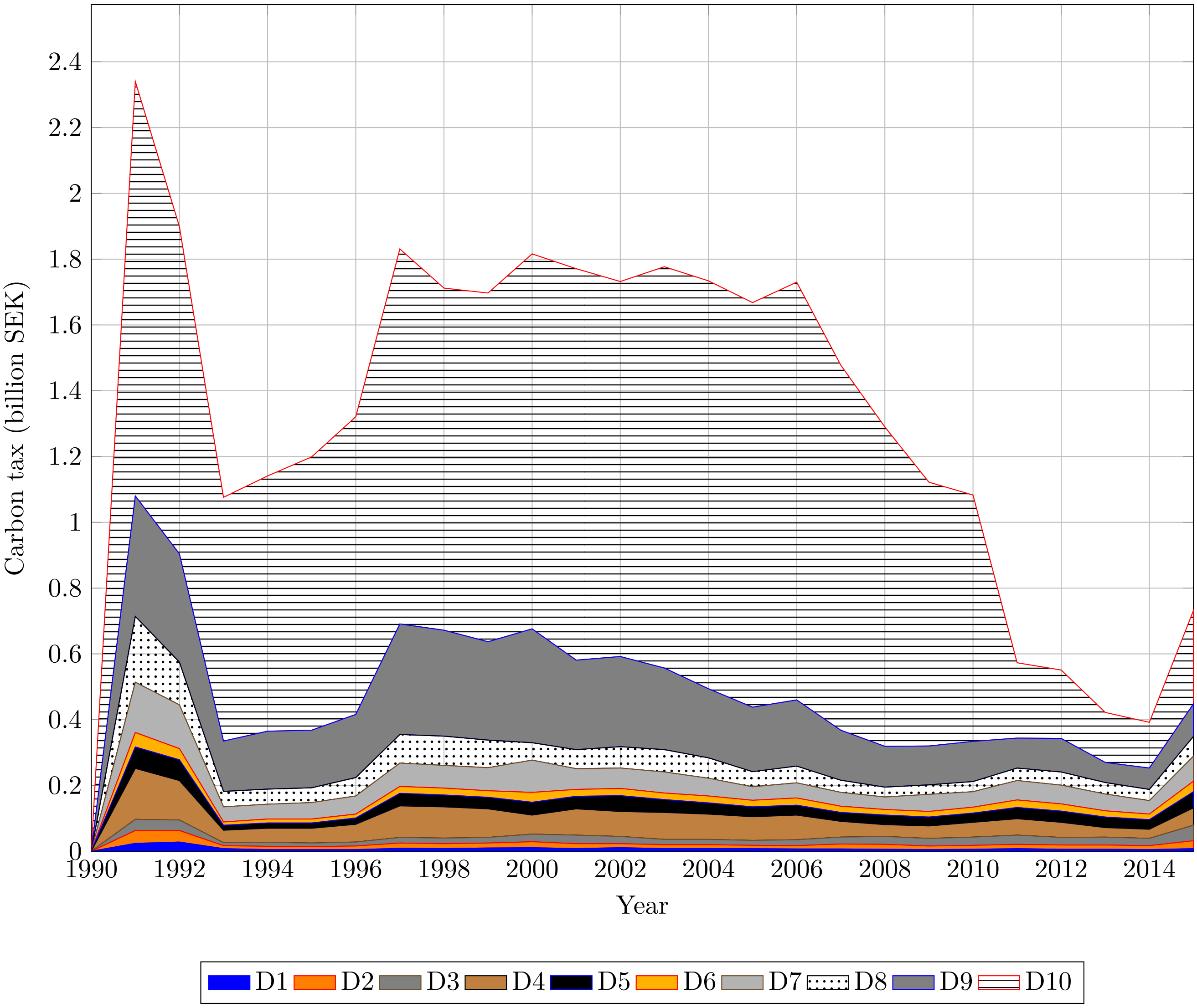

Figure 5 reports the distribution of carbon tax payments in the Swedish manufacturing sector. The sample is divided into deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Figure 6: Changes to the carbon tax: emissions and carbon tax payments by regime

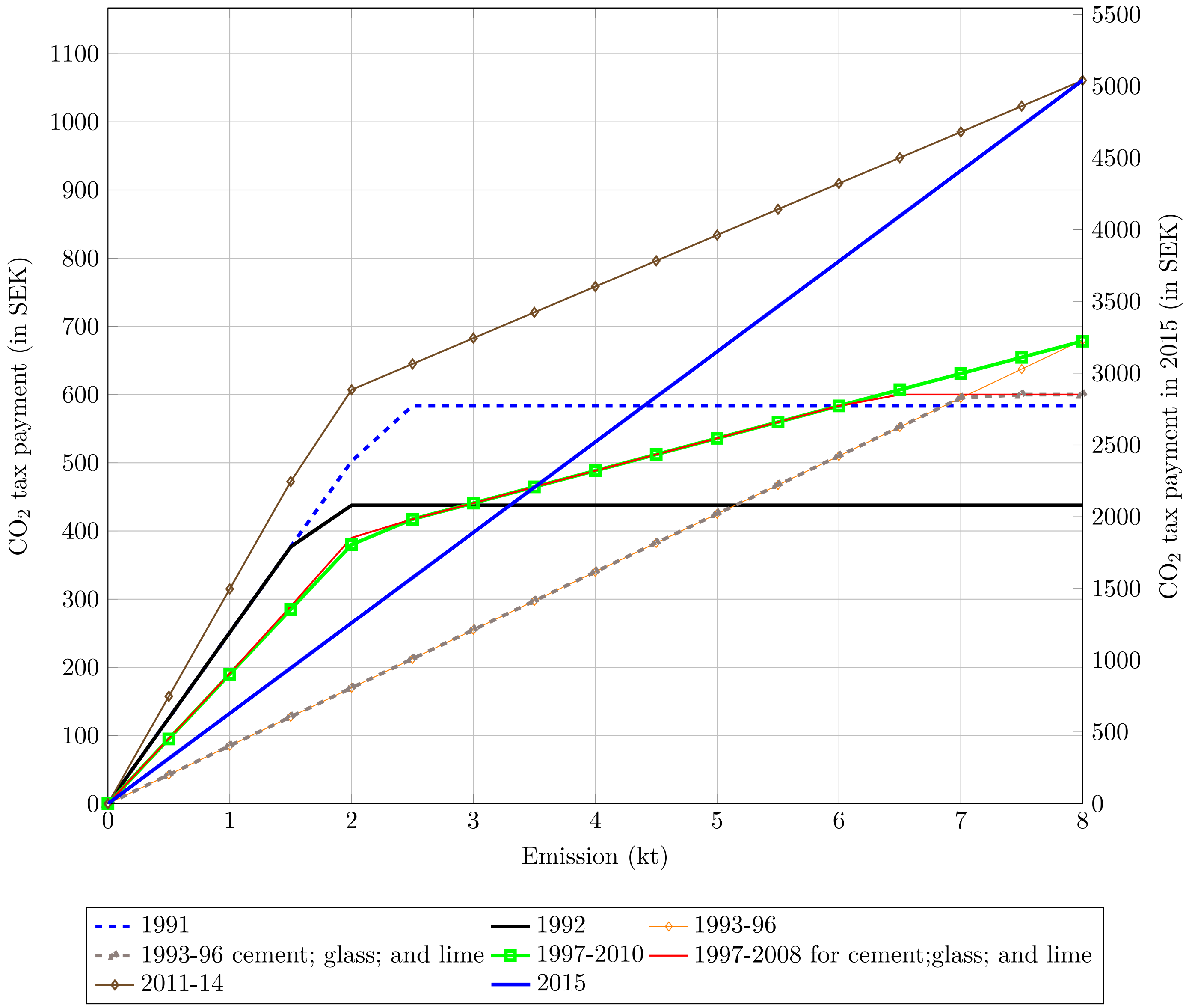

Figure 6 compares the carbon tax payments under the different regimes through a representative manufacturing firm. The hypothetical firm earns 50,000 SEK each year, and assumed to burn only coal in 1991 and 1992. All carbon tax payments with the exception of 2015 are shown on the vertical axis on the left side. Carbon tax payments in 2015 are shown on the vertical axis on the right side.

Figure 7: Average and marginal tax rates (1990-2015)

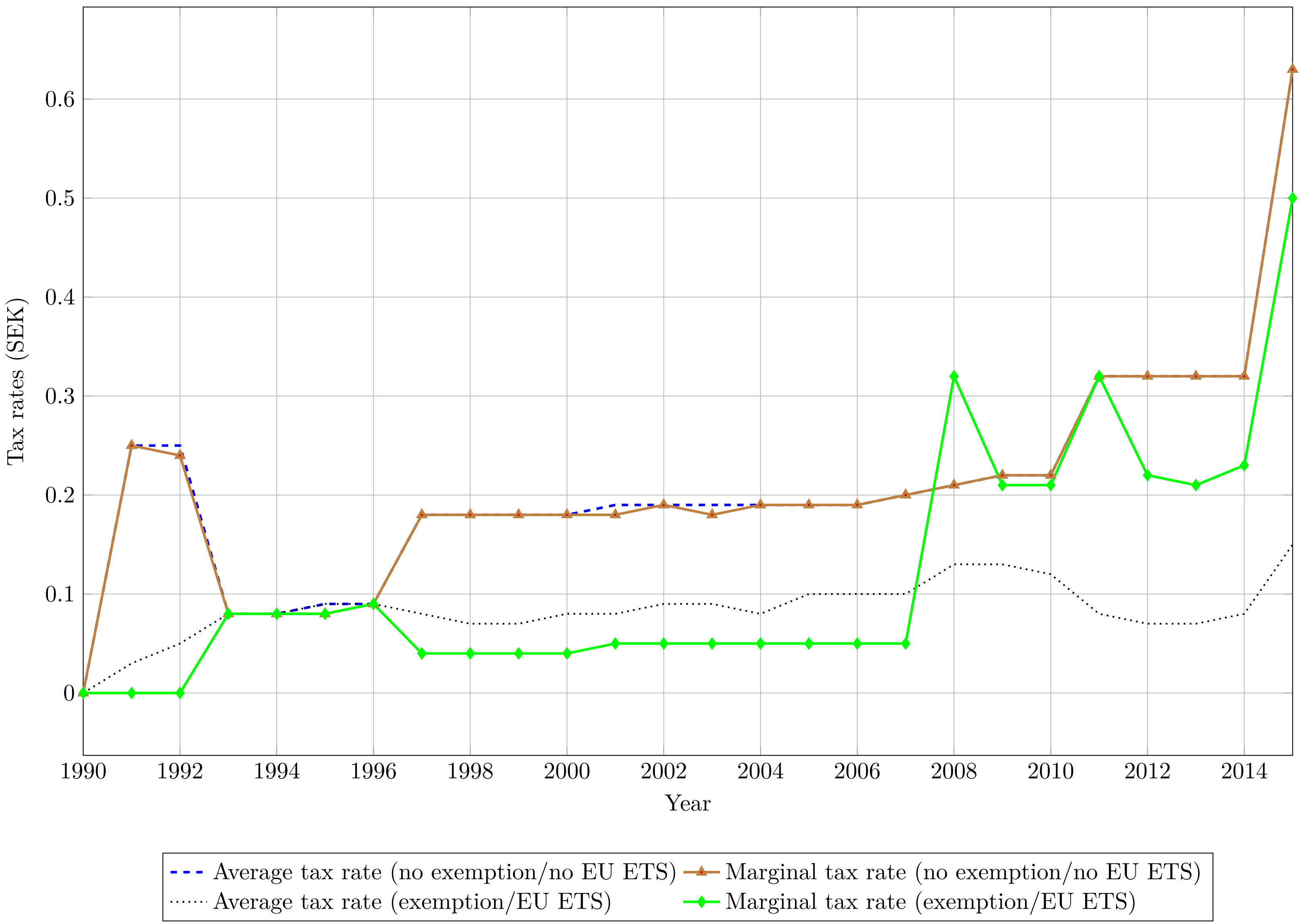

Figure 7 displays the average and marginal tax rates depending on whether the firm is eligible for carbon tax exemptions and covered by the EU ETS. *no exemption/no EU ETS* denotes firms that are not regulated by the EU ETS and are not entitled to carbon tax cut, *exemption/EU ETS* refers to the firms with available exemptions until they enter the emission trading scheme. Marginal tax rates for EU ETS are the price for emission rights.

Figure 8: Carbon dioxide emissions from Swedish manufacturing (1990-2015)

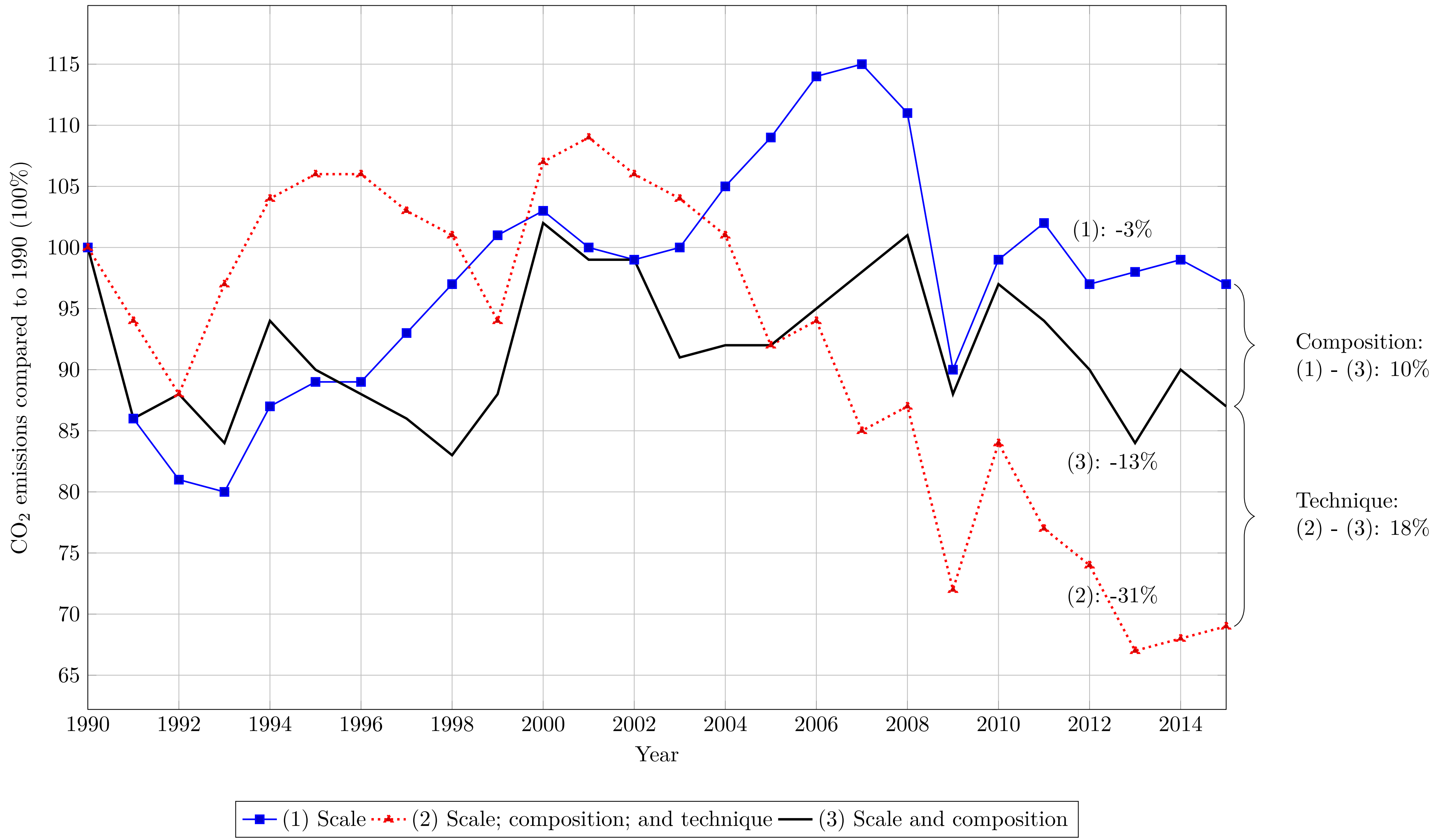

Figure 8 displays the decomposition of the Swedish carbon dioxide emission reduction. *Scale* captures how emissions would have evolved without tangible technological progress and structural changes in the manufacturing sector. *Composition* refers to the change in industry composition, *Technique* captures the technological progress in the industrial sector.

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

<table>
<tr><th></th><th colspan="5">Carbon tax rates (SEK/kg)</th></tr>
<tr><th>Year</th><th>Standard rate</th><th>Manufacturing rate</th><th>General exemptions</th><th>Cement, glass lime</th><th>Firms in EU ETS</th></tr>
<tr><td>1990</td><td>No tax</td><td>No tax</td><td>No tax</td><td>No tax</td><td rowspan="15">Before EU ETS</td></tr>
<tr><td>1991</td><td>0.25</td><td>0.25</td><td>Manufacturing rates if CO_2 + Energy tax<= 1.7% of sale, untaxed further emissions</td><td>Manufacturing rates if CO_2 + Energy tax<= 1.7% of sale, untaxed further emissions</td></tr>
<tr><td>1992</td><td>0.25</td><td>0.25</td><td>Manufacturing rates if CO_2 + Energy tax<= 1.2% of sale, untaxed further emissions</td><td>Manufacturing rates if CO_2 + Energy tax<= 1.2% of sale, untaxed further emissions</td></tr>
<tr><td>1993</td><td>0.32</td><td>0.08</td><td rowspan="4">Manufacturing rate</td><td rowspan="4">Industry rate up to 1.2 % of sales, untaxed further emissions (“1.2% rule”)</td></tr>
<tr><td>1994</td><td>0.32</td><td>0.08</td></tr>
<tr><td>1995</td><td>0.34</td><td>0.09</td></tr>
<tr><td>1996</td><td>0.37</td><td>0.09</td></tr>
<tr><td>1997</td><td>0.37</td><td>0.19</td><td rowspan="10">Manufacturing tax rate up to 0.8% of sales, exceeding emissions: 25 % of general manufacturing CO_2 tax rate (“0.8 % rule”)</td><td rowspan="10">0.8% rule is applied first, emissions exceeding 1.2 % of sales are untaxed</td></tr>
<tr><td>1998</td><td>0.37</td><td>0.19</td></tr>
<tr><td>1999</td><td>0.37</td><td>0.19</td></tr>
<tr><td>2000</td><td>0.37</td><td>0.19</td></tr>
<tr><td>2001</td><td>0.53</td><td>0.19</td></tr>
<tr><td>2002</td><td>0.63</td><td>0.19</td></tr>
<tr><td>2003</td><td>0.76</td><td>0.19</td></tr>
<tr><td>2004</td><td>0.91</td><td>0.19</td></tr>
<tr><td>2005</td><td>0.91</td><td>0.19</td><td rowspan="2">Manufacturing rate + exemptions where applicable</td></tr>
<tr><td>2006</td><td>0.92</td><td>0.19</td></tr>
</table>

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 five 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.

	OBS	**Mean**	**Median**	**St. Dev**	**Min**	**Max**
Emissions-to-sales	24,943	0.0072	0.0021	0.0184	0.0000	0.1393
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

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

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

Table 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 5: Firms with and without exemptions around 1991 and 1993 tax change

Table 5 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 the change in 1993. Column 4 reports the difference in difference controlling for four-digit industry fixed effects. The sample includes firms from decile 10 sectors. *Panel A* presents the marginal cost of emitting CO_2 for the manufacturing firms and *Panel B* 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: Marginal cost of CO_2 (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: 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)

Table 6: Firms with and without exemptions around 1997 tax change

Table 6 reports the change in marginal cost and emission intensity for firms with (column 1) and without exemptions (column (2) around the 1997 carbon tax change. Column 4 reports the difference in difference controlling for four-digit industry fixed effects. The sample includes firms from decile 10 sectors with observations each year during 1993-2000. *Panel A* presents the marginal cost of emitting CO_2 for the manufacturing firms and *Panel B* 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: Marginal cost of CO_2 (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 B: 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 7: Carbon pricing and firm level carbon emission intensity

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. 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). C is the emissions cost share relative to sales for firm i in year t. 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. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	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	2.828	1.246	0.838
	(0.146)***	(0.157)***	(0.229)***	(0.248)***	(0.884)***	(0.441)***	(0.284)***
$\Delta ln(1 - C)_{(i,t-2)}$			0.402	0.585	1.711	0.741	0.484
			(0.179)**	(0.210)***	(0.656)***	(0.440)*	(0.258)*
$\Delta ln(1 - C)_{(i,t-3)}$				0.377	2.184	0.747	-0.025
				(0.159)**	(0.482)***	(0.349)**	(0.168)
$\sum \Delta ln(1 - C)$	0.751	0.968	1.572	2.077	6.722	2.733	1.297
	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.002)***	(0.013)**	(0.007)***
Firm fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	24,943	24,757	19,485	15,001	5,529	6,284	3,130
Adjusted R^2	0.019	0.022	0.000	0.000	0.098	0.000	0.022

Table 8: Carbon pricing and carbon emission intensity: PACE and mobility

Table 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 comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least five 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)	(5)	(6)
	PACE		Low PACE		High PACE	
	Low	High	Low mobility	High mobility	Low mobility	High mobility
$\Delta\ln(1 - C)_{(i,t-1)}$	1.320	1.088	1.375	1.288	0.942	1.685
	(0.394)***	(0.297)***	(0.586)**	(0.491)***	(0.335)***	(0.651)***
$\Delta\ln(1 - C)_{(i,t-2)}$	0.849	0.527	1.100	0.614	0.552	0.368
	(0.298)***	(0.261)**	(0.346)***	(0.425)	(0.296)*	(0.533)
$\Delta\ln(1 - C)_{(i,t-3)}$	0.832	0.281	0.304	1.027	0.228	0.399
	(0.213)***	(0.202)	(0.279)	(0.267)***	(0.199)	(0.598)
$\sum \Delta\ln(1 - C)$	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
Adjusted R^2	0.012	0.016	0.074	0.000	0.007	0.081

Table 9: Carbon pricing and carbon emission intensity: Carbon leakage

Table 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 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
$\Delta\ln(1 - C)_{(i,t-1)}$	1.257	1.062	1.605	0.956
	(0.457)***	(0.301)***	(0.645)**	(0.329)***
$\Delta\ln(1 - C)_{(i,t-2)}$	0.565	0.609	0.793	0.644
	(0.419)	(0.247)**	(0.504)	(0.303)**
$\Delta\ln(1 - C)_{(i,t-3)}$	0.764	0.214	0.950	-0.057
	(0.332)**	(0.170)	(0.308)***	(0.193)
$\sum \Delta\ln(1 - C)$	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
Adjusted R^2	0.025	0.000	0.038	0.004

Table 10: Economic magnitude based on 2015 carbon pricing change and emissions intensities

Table 10 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, 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	6.7223	0.0025	0.0069	175%
Deciles 5-8	0.0591	2.7333	0.0039	0.0069	78%
Deciles 9-10	0.9099	1.2973	0.0142	0.0174	23%

Appendices

A The Political Process Behind the Carbon Tax

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, H and Wallström, J (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, H and Wallström, J (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)).

The proposed taxonomy was enacted in 1991, followed by subsequent reforms. 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 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)).

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.[30] 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.[31] 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.3, we are able to match the vast majority of firms from step 3 with sales data. The top line in Figure A.3 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,

[30] 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.

[31] 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.

manufacturing CO_2 heating emissions. We also note that there is no systematic difference between the top and bottom lines. In Figure A.4 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 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.[32] 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 major challenge in the analysis is handling the revisions of the industrial classification systems in force, which occurred three times in our sample period. NACE[33] 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[34]) 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

[32] 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.

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

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

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 to the sample until its exit. We benefited from the following steps to address the multiple classifications:

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.

Figure A.1: Distribution of total environmental taxes in the overall economy

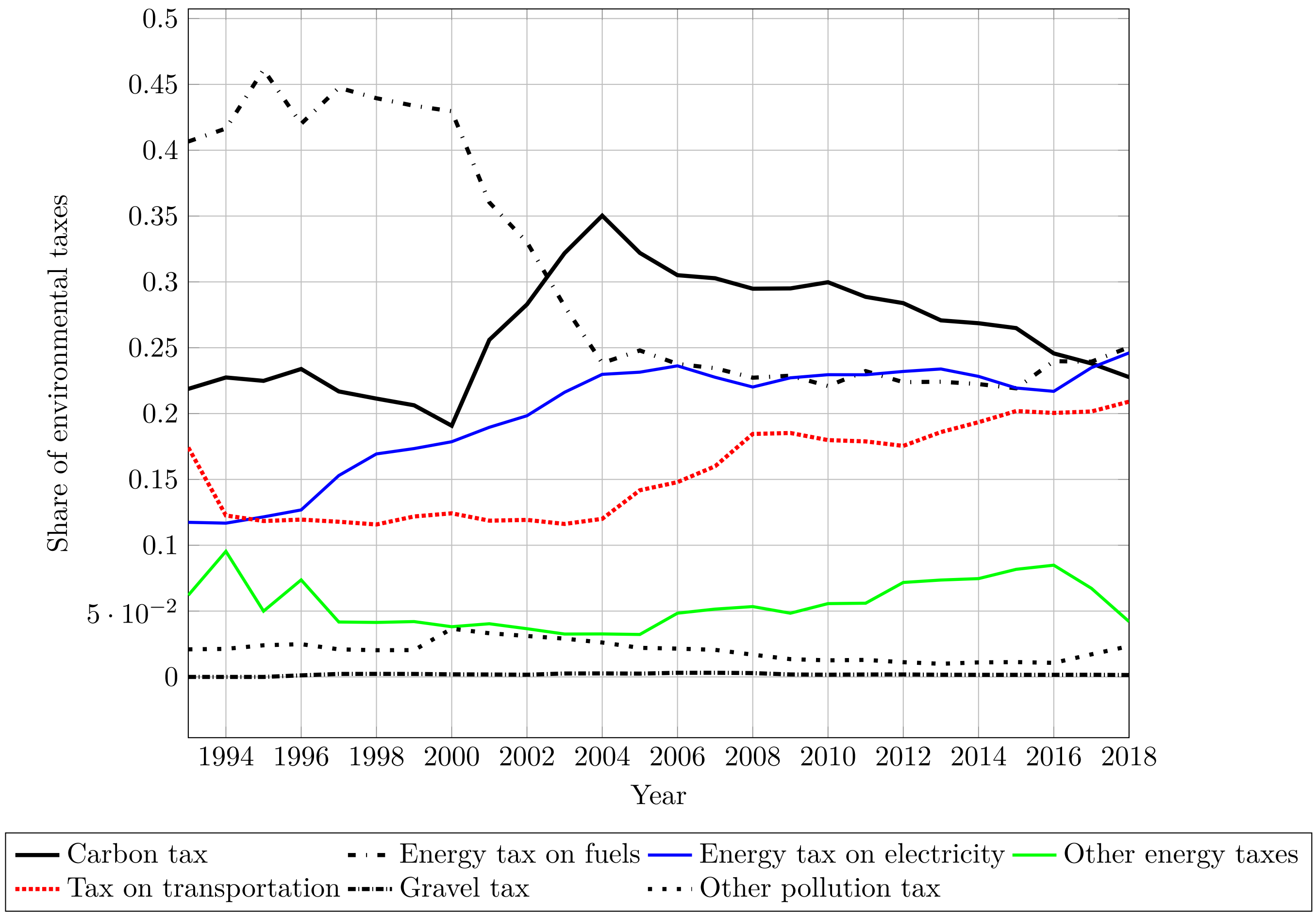

Figure A.1 displays distribution of the Swedish environmental tax payments in the overall economy (including households) from 1993 to 2018.

Figure A.2: Distribution of environmental taxes in the manufacturing sector

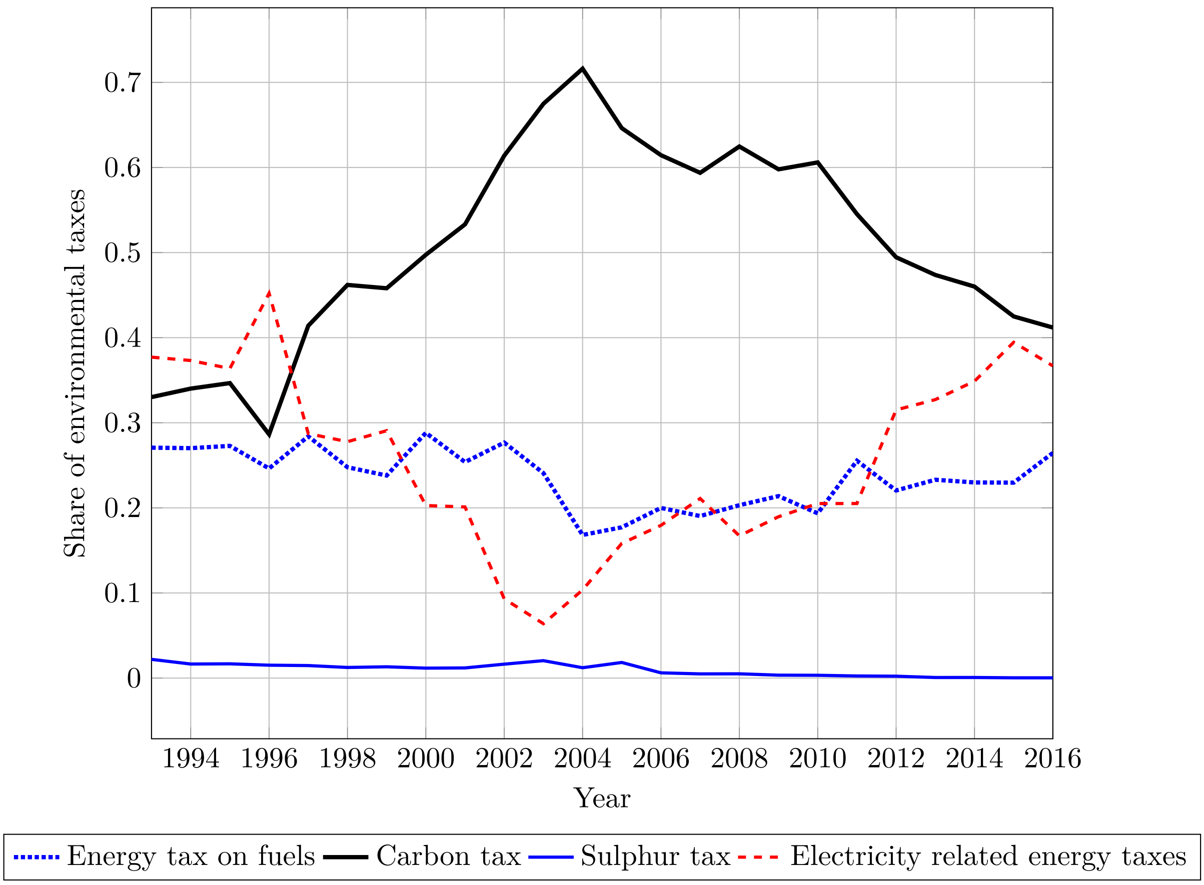

Figure A.2 displays the distribution of the Swedish environmental tax payments in the manufacturing sector (i.e. SNI 10-33 in the SNI2007 nomenclature) from 1993 to 2016.

Figure A.3: Coverage of heating emissions data in our sample

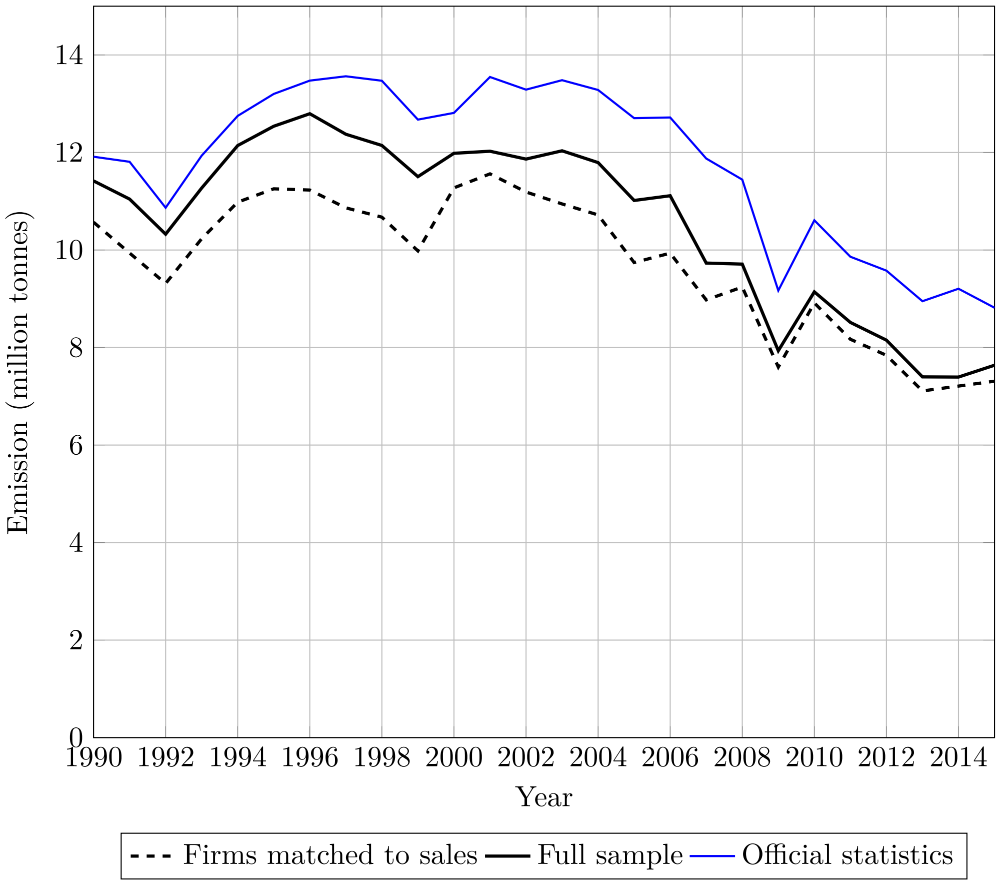

Figure A.3 compares heating emissions calculated from our full sample (*Full sample*) with the official tax payments registered by the responsible authorities and government agencies (*Official statistics*) and with that subsample that has observable sales (*Firms matched to sales*).

Figure A.4: Coverage of total emissions (heating plus process) data in our sample

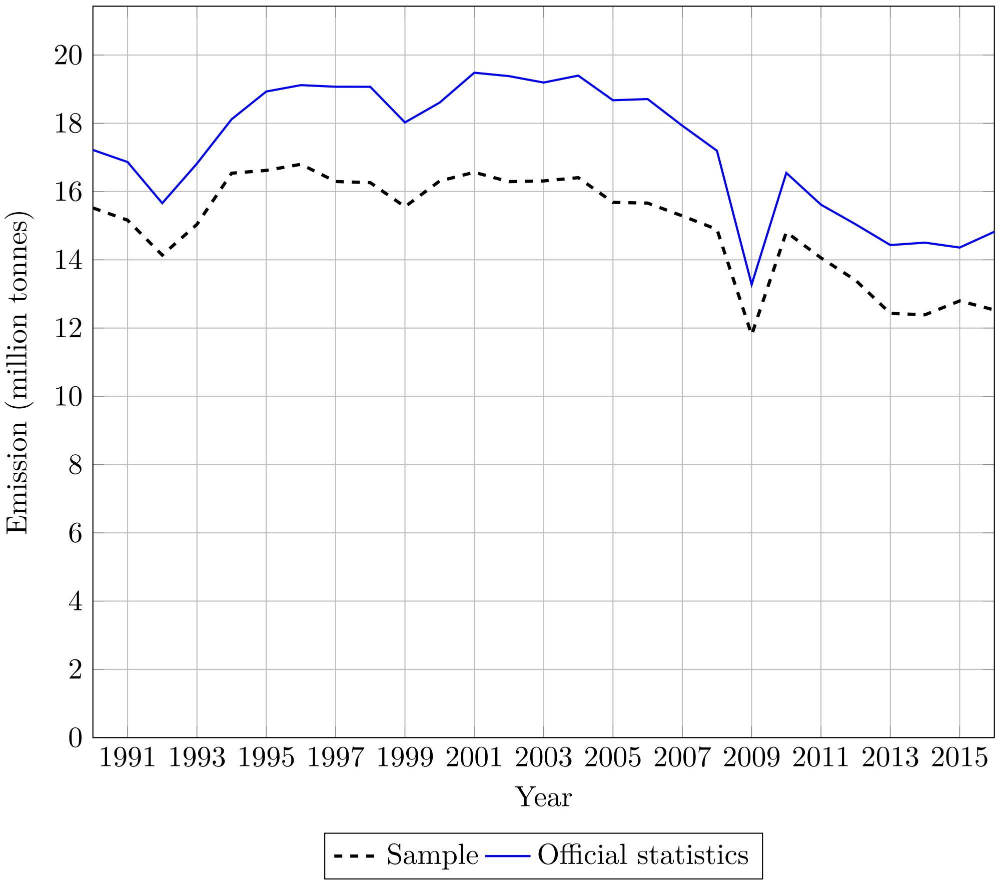

Figure A.4 compares the total emissions (i.e. heating plus process) calculated from our sample (*Sample*) with the official tax payments registered by the responsible authorities and government agencies (*Official statistics*).

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.

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
12	Tobacco products	4	0.000	0.000	0.008	0.004	0.0003	0.0002	0.000	0.000
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: Carbon pricing and carbon emission intensity: EU ETS, Firm size and capital intensity

Table B.3 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. *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)**
Δln(1 - C)$_{(i,t-1)}$	0.698	0.892	1.028
	(0.191)***	(0.198)***	(0.247)***
Δln(1 - C)$_{(i,t-2)}$			0.431
			(0.210)**
$\sum$ Δln(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
Adjusted R^2	0.020	0.000	0.000

Table B.4: Carbon pricing and carbon emission intensity: EU ETS, Firm size and capital intensity

Table B.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. 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. *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)
	All	**D9-D10**	**All**	**All**	**All**
$\Delta\ln(1 - C)_{(i,t-1)}$	1.414	1.025	1.008	1.012	1.011
	(0.327)***	(0.392)***	(0.253)***	(0.252)***	(0.253)***
$\Delta\ln(1 - C)_{(i,t-2)}$	0.684	0.508	0.512	0.514	0.515
	(0.246)***	(0.329)	(0.205)**	(0.205)**	(0.205)**
$\Delta\ln(1 - C)_{(i,t-3)}$	0.351	-0.208	0.245	0.243	0.245
	(0.188)*	(0.218)	(0.137)*	(0.137)*	(0.138)*
EU ETS	0.000	0.000			
	(0.001)	(0.001)			
$\Delta\ln(1 - C)_{(i,t-1)}$ x EU ETS	-0.953	-0.470			
	(0.390)**	(0.407)			
$\Delta\ln(1 - C)_{(i,t-2)}$ x EU ETS	-0.317	0.008			
	(0.308)	(0.392)			
$\Delta\ln(1 - C)_{(i,t-3)}$ x EU ETS	0.180	0.630			
	(0.303)	(0.378)*			
$\ln(EMP)_{i,t}$			-0.002		-0.002
			(0.001)***		(0.001)***
$\Delta\ln(CAP/EMP)_{i,t}$				0.001	0.001
				(0.000)***	(0.000)***
$\sum$ Δln(1 - C)	1.359	1.493	1.765	1.769	1.770
	(0.017)**	(0.030)**	(0.000)***	(0.000)***	(0.000)***
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	15,001	3,130	14,828	14,789	14,789
Adjusted R^2	0.000	0.025	0.000	0.000	0.000

Table B.5: Economic magnitude based on 1991, 1997, 2008, 2011 and 2015 carbon pricing changes and emissions intensities

Table B.5 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%	19%	83%	55%	78%
Deciles 9-10	7%	10%	20%	21%	23%

Table B.6: Share of CO_2 emissions by sub-sample and event year

Table B.6 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

Table B.7: Share of sales by sub-sample and event year

Table B.7 reports reports the distribution of aggregate PPI-adjusted sales 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	0.2291	0.2687	0.2794	0.2780	0.2965
Low pace & High mobility	0.2364	0.2191	0.2332	0.2469	0.2461
High pace & Low mobility	0.4338	0.4012	0.3879	0.3779	0.3635
High pace & High mobility	0.1007	0.1110	0.0995	0.0972	0.0939
Low pace sectors	0.4473	0.4701	0.4928	0.5045	0.5211
High pace sectors	0.5527	0.5299	0.5072	0.4955	0.4789
Not on Leakage list	0.3719	0.3421	0.2861	0.2790	0.2619
On Leakage list	0.6281	0.6579	0.7139	0.7210	0.7381
Deciles 1-4	0.6216	0.6602	0.7132	0.7221	0.7151
Deciles 5-8	0.1739	0.1326	0.1092	0.1094	0.1073
Deciles 9-10	0.2045	0.2072	0.1776	0.1685	0.1777