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

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Motivation

- Carbon tax a key climate policy tool to make firms internalize the costs of their emissions
  - Nordhaus (1993) ; Golosov et al. (2014); Rockström et al. (2017); Sterner et al. (2019)
  - In early 1990's, several European countries introduced carbon pricing schemes
  - EU Emission Trading System (ETS) introduced in 2007
  - More recently, CA cap-and-trade, BC carbon tax

- Existing schemes are far from theoretical 1st best
  - Regional, not global
    - CO2 has same effect on climate regardless of where it is emitted
  - Tax rates are too low (Nordhaus, Stern, Golosov et al)
  - Taxes do not cover all CO_2 emissions and differ across emitters (exemptions etc)
  - Taxes are not revenue-neutral
    - Can reduce firms' financial capacity to invest in abatement

→Do they have any effect on emissions?

Figure 2: Carbon tax rate, in nominal values

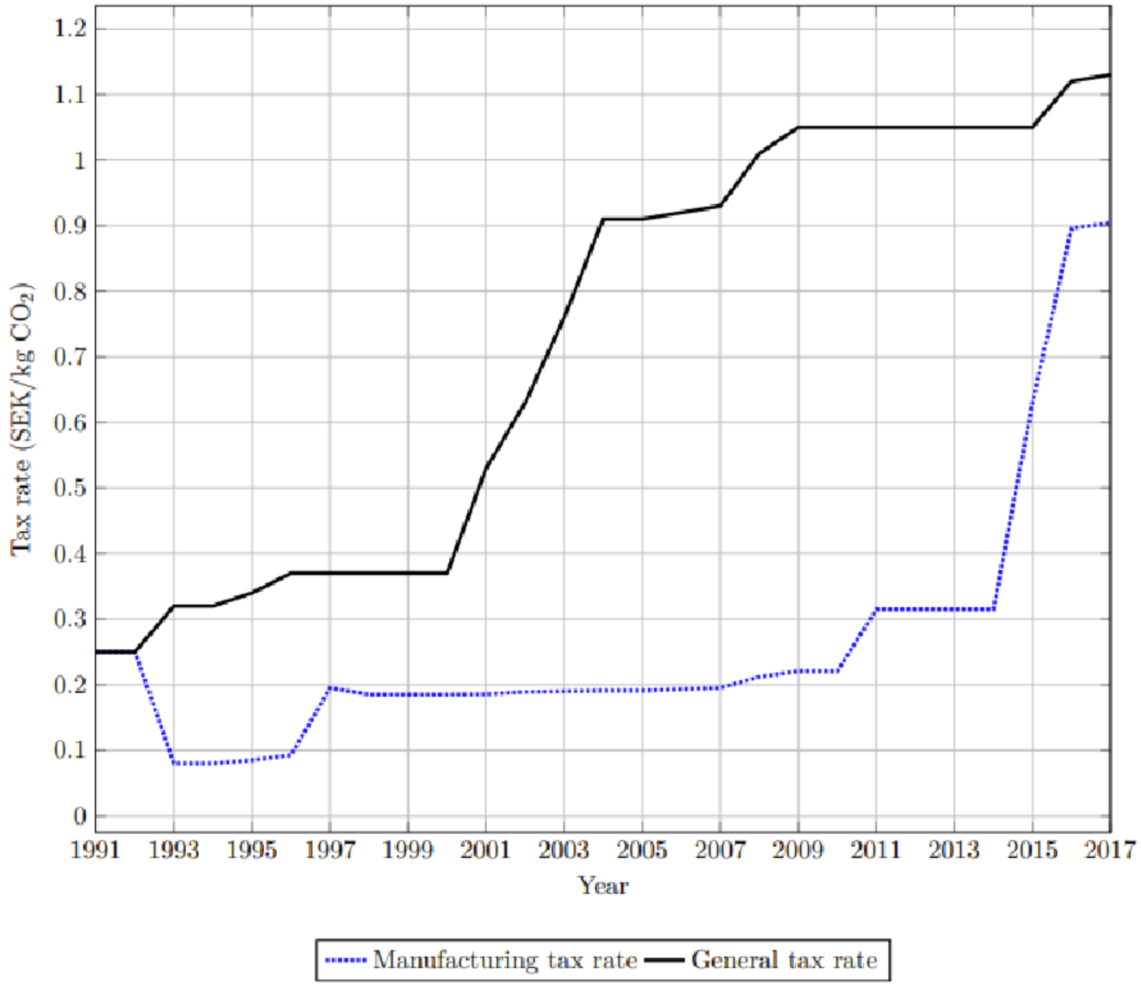

Figure 2 displays the nominal carbon tax rates (Swedish krona per kilogram of emitted carbon dioxide) for Sweden from 1991 to 2017. *Manufacturing tax rate* refers to the tax rate for the manufacturing sector (SNI 10-33 in the SNI2007 nomenclature), while *General tax rate* refers to the tax rate for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

Our paper

- Previous literature estimate DiD (→ATEs) around introduction of carbon pricing scheme (EU ETS, CA, BC, Swe, Ger, Fra)
  - Mostly aggregate/sector-level, some on microdata
  - Very mixed results across methodologies and schemes (Rafaty et al, 2021)

- Firms will invest in abatement as long as MC<=MB
  - MB = carbon tax savings from reducing a unit of CO2
    - Depends on carbon pricing scheme and (marginal) tax rates over time
  - MC = cost of reducing one a unit of CO2
    - Depends on technology, price elasticity of demand, cost of funds, and time to adapt

  → Change in emissions depends on tax level, time to adjust, & differs across sectors / firms

- What we do:
  - Estimate carbon pricing elasticities using long panel of micro-data on firms
  - Account for dynamic response and heterogeneity across sectors, firms

Related work

- Studies of effects from carbon pricing schemes
  - *Country / Sector-level data*: Lin and Li (2011, EU), Rafaty et al (2021, 39 countries), Pretis (2022, BC), Andersson (2019, transportation in Swe vs synth panel), Metcalf & Stock (forthc., EU)
  - *Microdata*: Martin et al (2004, UK utilities), Bartram et al (2022, CA), Colmer et al (2022, EUETS), Dechezlepetre et al (2023, EUETS), Ahmadi et al (2022, BC)
  - *Swedish carbon tax*: Brännlund et al (2014), Forslid et al (2019), Andersson (2019)
  - *Elasticities:* Germeshausen (2022, German power plants), Dussaux (2022, French manuf, elast to energy price)

- Closest paper is Colmer et al (2022): impact of EU-ETS on French manufacturing firms
  - Inclusion in EUETS leads firms to lower emissions by 8-12%; DiD, do not estimate elasticities, no heterogeneity wrt technology or financial constraints.

- Our paper:
  - Micro data on firms and establishments 1990-2015
  - Consider marginal tax rates across firms and time
  - Estimate short- and long-run responses to carbon taxation
  - Assess importance of technological and financial heterogeneity
  - Calibrate aggregate effect

Data and sample: sources

- Emissions data from Swedish Environmental Protection Agency (SEPA and IVL): 1990-2015 (plus European Union Transaction Log for EUETS plants)
- Accounting data for firms from UC (1990-1996) and Serrano (1997-2015)
- Firm-level environmental protection expenditure
- Data on tax rates and exemptions manually collected and used to infer tax payments for every firm.
- Prices are deflated using four-digit PPI series
  - Effectively adjusting for industry-level output price changes
- Sort 4-digit industries into deciles according to their emission intensity in 1990

Table B.1: Sample size by year

Year	All surveyed firms in manufacturing	Matched to firm-level identifier with sales	Year	All surveyed firms in manufacturing	Matched to firm-level identifier 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.1 tabulates 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.

Even in years with fewer firms covered, cover 80-95% of aggregate emissions.

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

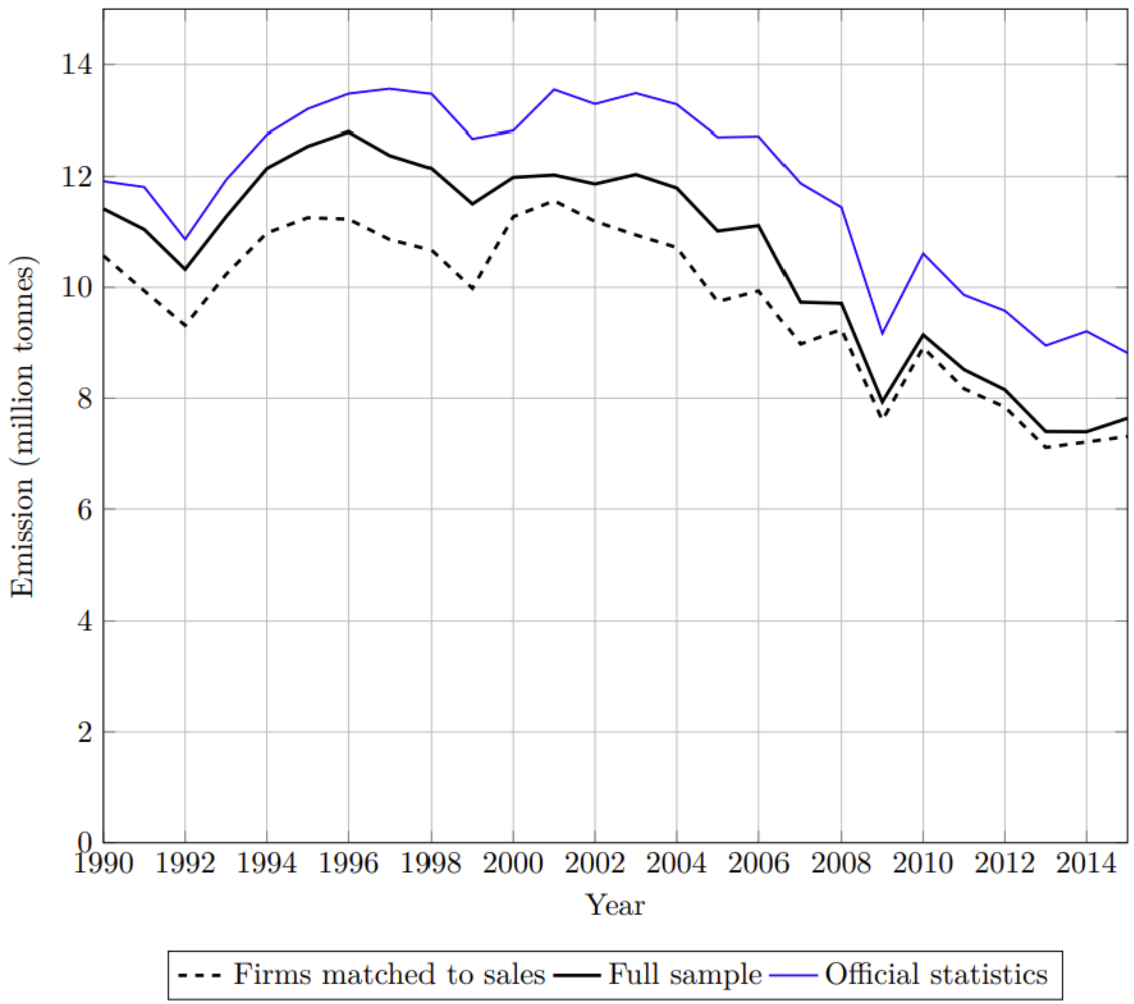

Figure A.1 compares heating emissions calculated from our full sample (*Full sample*) with the official tax payments registered by the responsible authorities and government agencies (*Official statistics*) and with that subsample that has observable sales (*Firms matched to sales*).

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
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

Concentration of manufacturing CO2 emissions

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

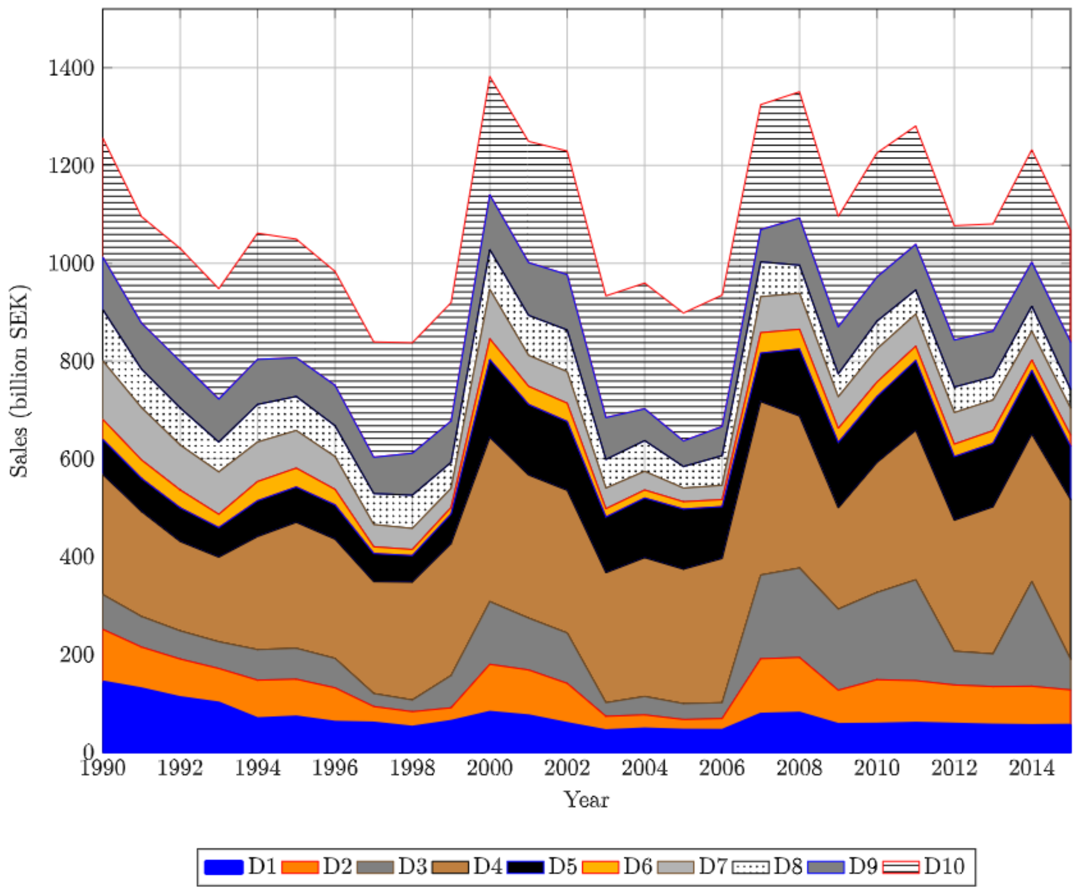

Figure 4 reports the distribution of PPI-adjusted sales in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Sales by 4-digit NACS emission decile

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

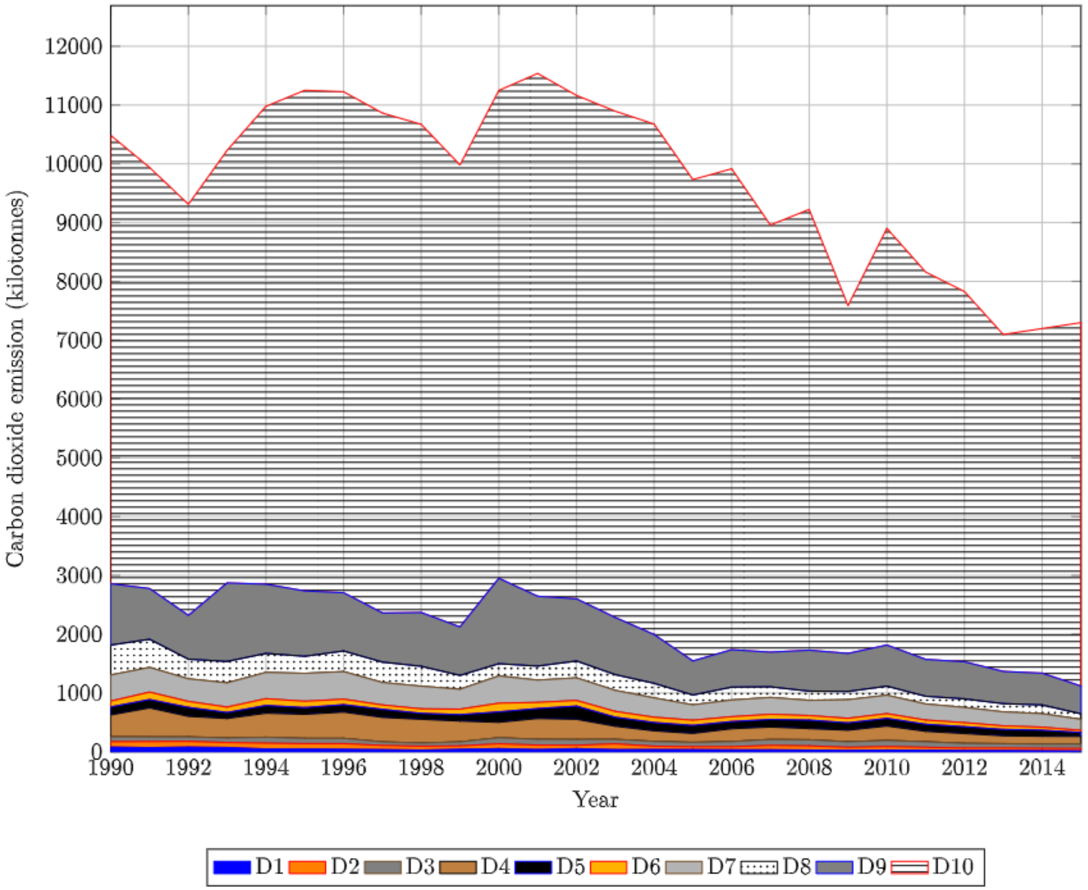

Figure 3 reports the distribution of CO_2 emissions in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Emissions by 4-digit NACS emissions decile

Differences in marginal tax across firms and time

- Compute each firm's tax rate every year
  - For firms with establishments entering the EU ETS, we apply the emission price for those establishments

- Before EU-ETS, marginal tax < average tax for high emitters due to exemptions

- After 2007, marginal tax > average tax for firms with installations in EU-ETS
  - Free allocation of emission rights
  - Tax paid for installations not in EU-ETS

- During 1990's, decile 10 accounts for:

  <20% of manufacturing sales
  >70% of CO2 emissions
  ~ 50% of CO2 tax payments

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

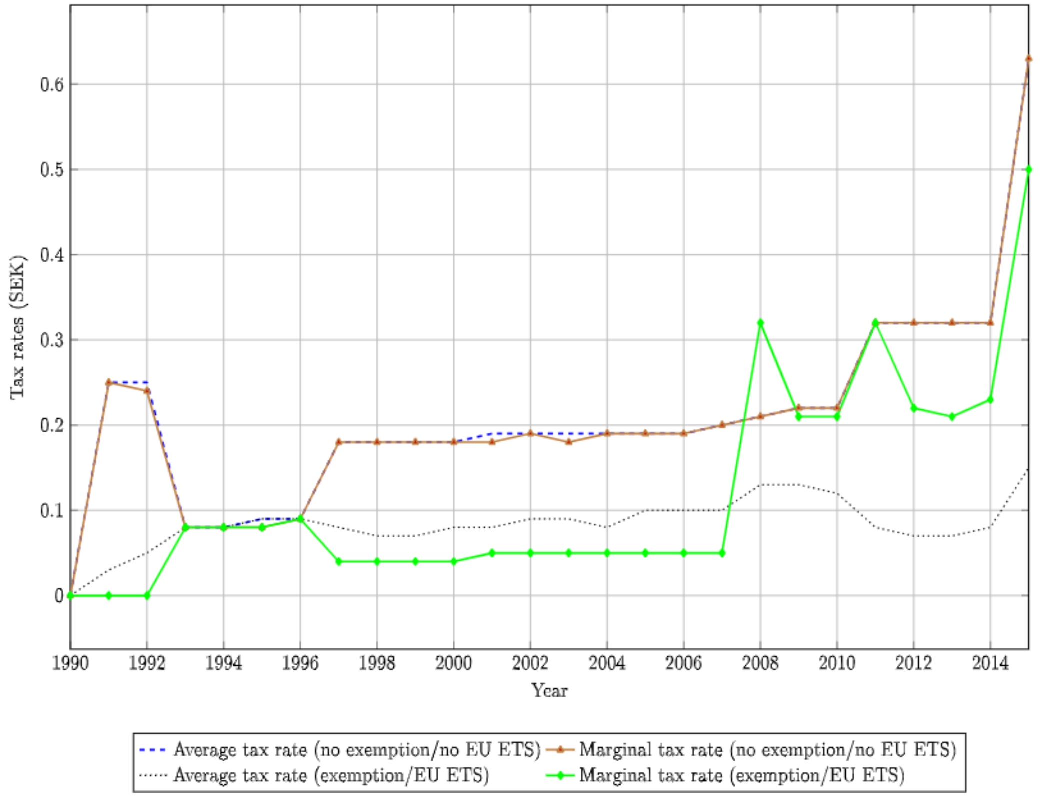

Figure 7 displays the average and marginal tax rates depending on whether the firm is eligible for carbon tax exemptions and covered by the EU ETS. *no exemption/no EU ETS* denotes firms that are not regulated by the EU ETS and are not entitled to carbon tax cut, *exemption/EU ETS* refers to the firms with available exemptions until they enter the emission trading scheme. Average tax rates are backward-looking effective tax rates. Marginal tax rates are obtained as forward-looking effective tax rates. Marginal tax rates for EU ETS are the price for emission rights. Average tax rates for EU ETS are backward-looking. consider historical prices and free distribution of emission rights.

Estimating long-run tax elasticities

- Regression specification (following Shapiro & Walker, 2018):

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

  - Dep variable: (log of) CO_2-emissions (kg) divided by output
  - $C_{i,t\text{-}s}$ is marginal tax payments over sales ($\tau_{i,t}/Y_{i,t}$)

  - $\Delta ln(1 - C_{\mathrm{i,t\text{-}s}})$ = the change in profit margin from change in marginal tax
  - Firm and year / sector-year fixed effects

- Identification from different marginal tax rates across firms and time:
  (1) Exemptions and tax rate changes
  (2) Tax represent a different fraction of sales (tax is levied on tons of emissions)

Baseline estimates

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

	(1)	(2)	(3)	(4)	(5)	(6)
	All	**All**	**All**	**D1-D4**	**D5-D8**	**D9-D10**
Δln(1 - C)$_{(i,t-1)}$	0.957 (0.159)***	1.178 (0.231)***	1.123 (0.249)***	2.310 (0.999)**	1.676 (0.443)***	0.855 (0.286)***
Δln(1 - C)$_{(i,t-2)}$		0.398 (0.181)**	0.591 (0.213)***	1.321 (0.692)*	0.970 (0.429)**	0.509 (0.262)*
Δln(1 - C)$_{(i,t-3)}$			0.379 (0.160)***	1.739 (0.481)***	0.950 (0.343)***	0.004 (0.170)
$\sum$ Δln(1 - C)		1.576 (0.000)***	2.092 (0.000)***	5.369 (0.035)**	3.596 (0.003)***	1.368 (0.015)**
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	23,594	19,366	15,001	11,228	5,745	6,216
Adjusted R^2	0.000	0.000	0.000	0.000	0.101	0.012

Table 7: Carbon pricing and carbon emission intensity: Financing constraints

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

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

Access to finance and reduction of CO_2/sales

Overall firms that have better access to finance react more

- Public firms
- Large firms
- High dividend payer
- Mature firm

But not in low PACE sectors

Effect of PACE and mobility on emission elasticities

Table 5: Carbon pricing and carbon emission intensity: PACE and mobility

Table 5 reports OLS estimates of Equation 1. $\Delta ln(E/Y)_{i,t}$ is the dependent variable. E is firm-level CO_2 emissions in kilograms (kg) and Y is firm-level, PPI-adjusted sales in Swedish Krona (SEK). The sample comprises manufacturing firms in Sweden with both CO_2 emissions and sales data and with at least four consecutive observations during 1990-2015. 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)
	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
Within R^2	0.024	0.016	0.034	0.023	0.013	0.035

PACE:
pollution abatement
costs expenditures

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

Short-run response around tax changes

- Diff-in-diff estimate, similar to previous literature
  - 1991 introduction
  - Changes in tax rates and exemptions 1993 and 1997
    - 2011 and 2015 changes were post-ETS
- While introduction was anticipated, subsequent changes plausibly unexpected.
  - Tax had considerable bipartisan support
  - To the extent changes were expected, should bias towards no effect
- Focus on firms in Decile 10 (highest-emitting sectors)
  - Account for >70% of emissions
  - Stable observation count (firms continuously sampled by SEPA)
  - Exclude cement, glass & lime (always exempted, monopoly)

Short-run response: 1991 and 1993 tax changes

	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	
Period 2: 1991-1992	0.0000	0.2032	-0.2032	
			(0.0170)***	
Period 3: 1993-1996	0.0845	0.0844	0.0001	
			(0.9508)	
Difference periods: 2-1	0.0000	0.2032	-0.2032	-0.2047
		(0.0110)***	(0.0236)***	(0.0236)***
Difference periods: 3-2	0.0845	-0.1188	0.2033	0.2033
	(0.0012)***	(0.0058)***	(0.0114)***	(0.0115)***
Panel B: Emissions-to-sales				
Period 1: 1990	0.0806	0.0100	0.0705	
			(0.0055)***	
Period 2: 1991-1992	0.0984	0.0115	0.0870	
			(0.0036)***	
Period 3: 1993-1996	0.0903	0.0172	0.0730	
			(0.0042)***	
Difference periods: 2-1	0.0178	0.0014	0.0164	0.0141
	(0.1398)	(0.3721)	(0.0065)**	(0.0056)**
Difference periods: 3-2	-0.0081	0.0058	-0.0139	-0.0099
	(0.0098)	(0.0019)***	(0.0056)**	(0.0052)*

Conclusion

- Carbon taxation works:
  - 1% increase in marginal tax cost → 2% lower emission intensity
  - Economic significance: Swedish manufacturing emissions of CO_2 would have been roughly 30% higher without carbon pricing
- Sector heterogeneity important:
  - Large emitters have lower elasticities due to higher abatement costs
  - Access to financing matters the most for these firms
- Swedish carbon tax was suboptimally designed:
  - Highest emitters paid significant carbon tax - making them less competitive and more financially constrained - but had lowest marginal benefit of reducing emissions