Carbon Pricing and Firm-Level CO2 Abatement: Evidence from a Quarter of a Century-Long Panel

Gustav Martinsson, Royal Institute of Technology & SHoF
Laszlo Sajtos, SSE & SHoF
Per Strömberg, SSE, SHoF, & CEPR
Christian Thomann, Royal Institute of Technology & SSE

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)
  - Starting early 1990's, several countries have introduced carbon pricing schemes
  - Problem: CO_2 has same effect on climate, regardless of where it is emitted → need *global* carbon pricing.

- Burke et al (2016):
  - "Policies such as carbon pricing schemes, tradable obligations, fuel taxes, renewable portfolio standards, and energy effiency standards are already in use in different countries and will become more common […]. But there is often little empirical evidence on *individual- or market-level* responses to these policies."

- Existing schemes are far from ideal
  - Regional, not global
  - Cover only part of emissions
  - Differences in pricing across emitters
  - Levels lower than "optimal" (Nordhaus, Stern, Golosov et al)

→ Do they have any effect on emissions?

What we do

- Estimate the effect of the Swedish carbon tax on manufacturing firm CO_2 emissions
  - Comprehensive dataset tracking all CO_2 emissions from the Swedish manufacturing sector 1990-2015
- Calculate marginal cost of emitting CO_2 for every firm, given emissions and pricing scheme firm faces
  - Tax changes, exemptions, effects of EU-ETS inclusion
- Estimate the impact of carbon pricing on firm-level emissions.
  - 1% increase in CO_2 tax → 3-3.5% decrease in emissions per unit of sales
- Decompose aggregate change in manufacturing CO_2 emissions into scale, composition, and technology (Grossman & Krueger, 1993)
  - Decreasing emission intensities account for 18% out of the total CO2 reduction of 31%.
  - The effect of carbon pricing on emission intensities accounts for a 13 % decrease in total manufacturing emissions.

Closest work to ours

- Martin et al (2014): impact of 2001 UK manufacturing carbon tax
  - Negative effect on energy intensity and electricity use
  - No emissions data, only 3-year post-period.
- Brännlund et al (2014): impact of Swedish carbon tax 1990-2004
  - Firm level regressions of emission intensity on actual carbon taxes paid by subsectors. CO_2 taxes have significant effect on intensity; evidence of "decoupling"
    - But: insignificant for mining and iron/steel, two of highest-emitting sectors.
  - Our paper:
    - Account for huge within-sector differences in emission intensities
    - Consider marginal tax rates across firms and time
      - Important for marginal incentives
      - Important for econometric identification
    - Longer time period and allow for gradual adjustment

Figure 1.1: Environmental taxation system in Sweden

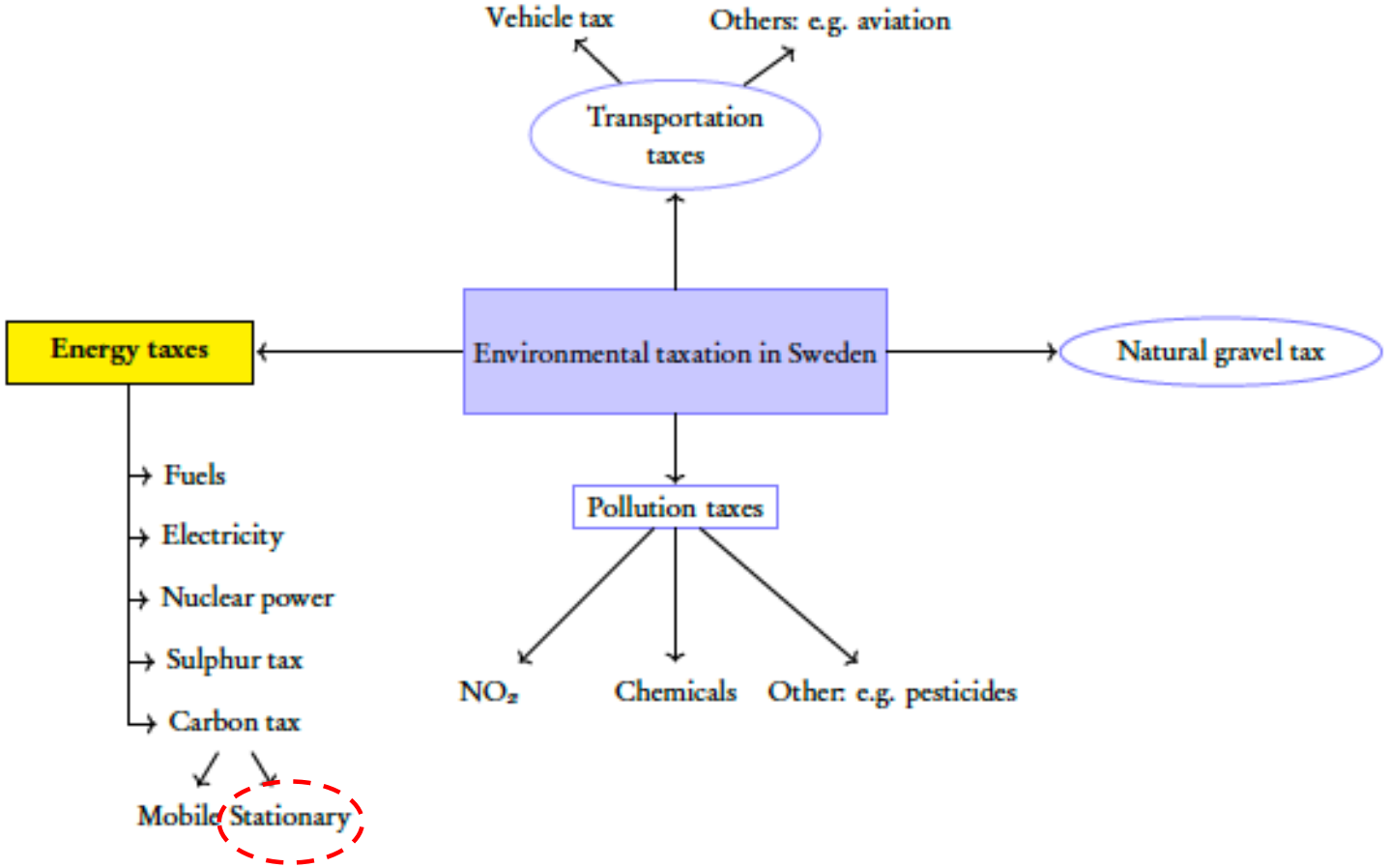
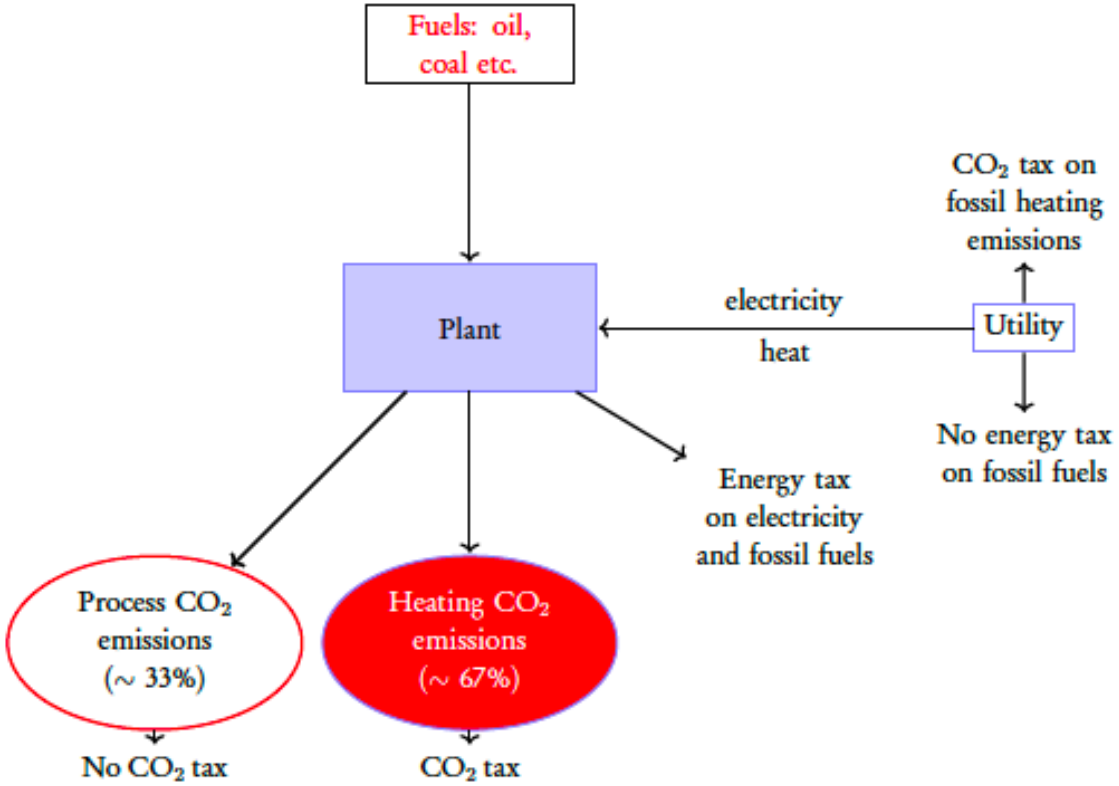


Figure 1.10: Carbon and energy taxation of an industrial plant



Data and sample: sources

- Emissions data from Swedish Environmental Protection Agency (SEPA and IVL): 1990-2016
- Accounting data for firms from UC (1990-1996) and Serrano (1997-2016)
- Data on tax rates and exemptions manually collected and used to infer tax payments for every firm.
  - Firm-level tax records unavailable.
- Prices are deflated using four-digit PPI series

Summary statistics

Table 2: Summary statistics

	All firm-years						Regression sample					
	OBS	Mean	Median	St.dev	Min	Max	OBS	Mean	Median	St.dev	Min	Max
CO_2 emissions (kt)	50,501	5	0.093	53	0	N/A	32,345	8	0.14	66	0	N/A
Sales (PPI, 2010, MSEK)	50,501	563	60	3,610	0	151,000	32,345	784	85	4,360	0	128,000
CO_2 emissions-to-sales	50,501	0.006	0.002	0.015	0	0.122	32,345	0.007	0.002	0.018	0	0.141
Carbon taxes paid (2010, MSEK)	50,501	0.589	0.016	7	0	394	32,345	0.886	0.025	8	0	394
EBIT (2010, MSEK)	50,501	32	2	543	-25,500	65,800	32,345	44	3	522	-6 880	29,800
Carbon taxes paid-to-EBIT	50,434	0.012	0.003	0.093	-0.439	0.561	32,301	0.015	0.003	0.107	-0.475	0.676
Marginal tax rate	50,501	0.192	0.191	0.122	0	0.702	32,345	0.2	0.212	0.128	0	0.702
Average tax rate	50,501	0.190	0.191	0.119	0	1	32,345	0.196	0.195	0.124	0	1
Nr of workers	50,080	168	33	732	0	22,460	32,209	221	43	868	0	21,305
PPE (2010, MSEK)-to-workers	49,741	0.504	0.277	0.758	0	5	31,976	0.519	0.316	0.87	0.003	6

Table 2 tabulates summary statistics over key variables in the overall and the regression sample. The regression sample consists of firms with at least five consecutive firm-year observations. Both *Marginal tax rate* and Average tax rate are expressed in SEK/kg emitted CO_2. *PPE* stands for Property, Plant, and Equipment.

Concentration of manufacturing CO2 emissions

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

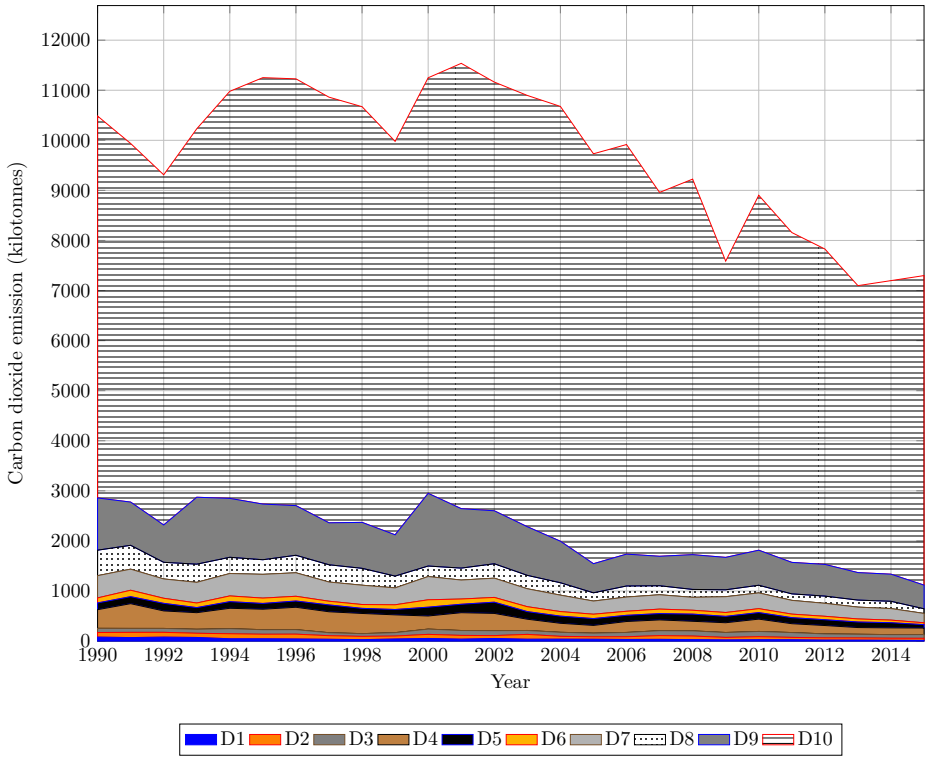


Figure 3 reports the distribution of CO_2 emissions in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Emissions by 4-digit NACS emissions decile

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

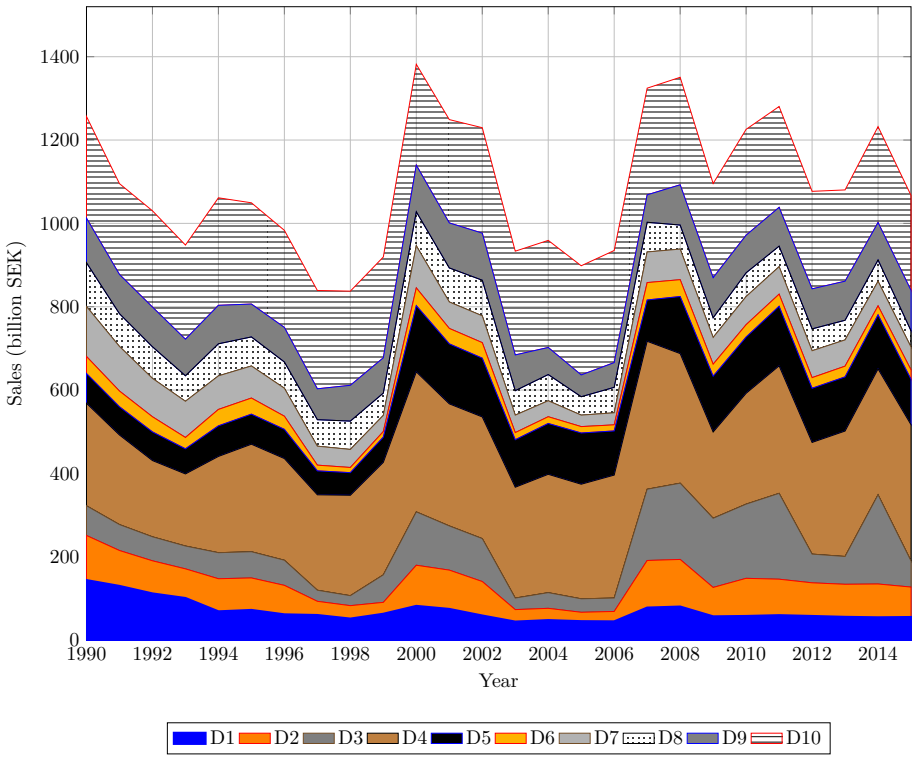


Figure 4 reports the distribution of PPI-adjusted sales in the Swedish manufacturing sector. The sample is divided into ten deciles based on the firms' carbon intensity (i.e. CO_2 emissions over sales) in 1990.

Sales by emission decile

The effect of tax rate changes and exemptions

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

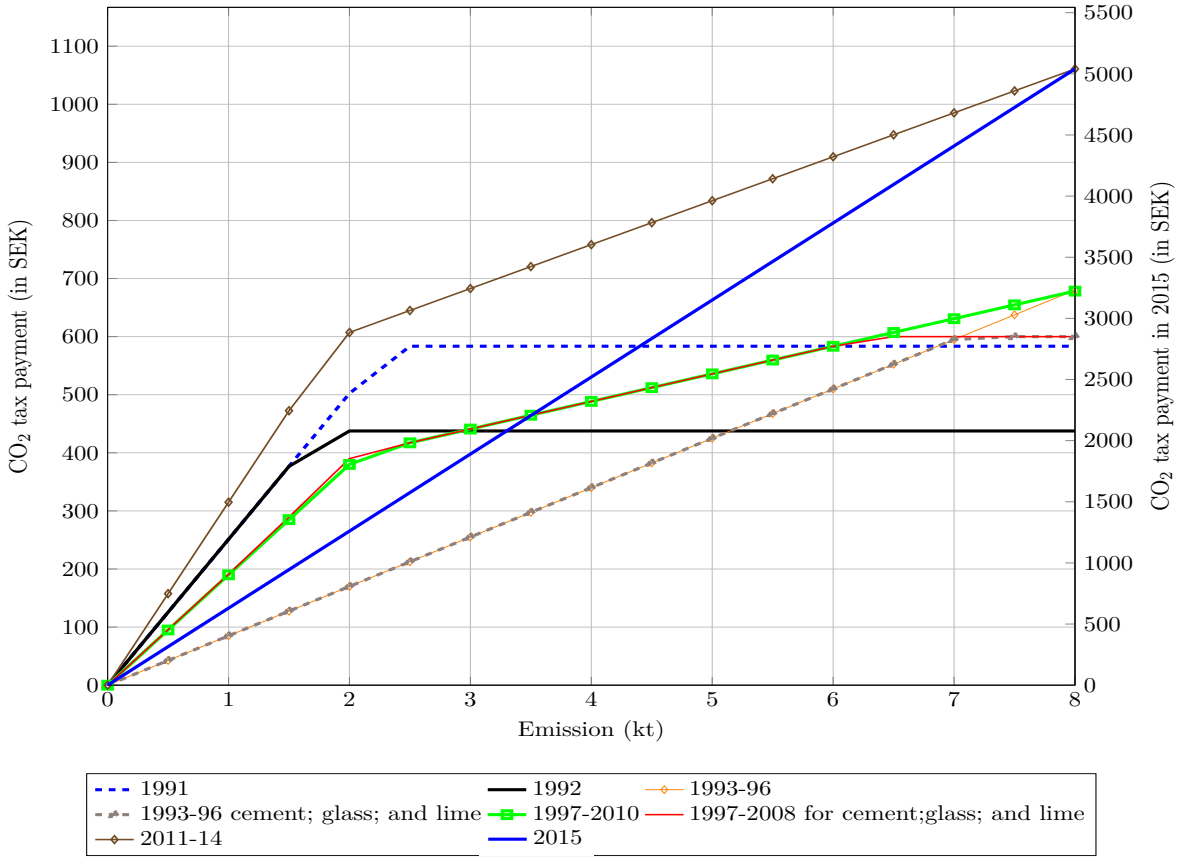


Figure 6 compares the carbon tax payments under the different regimes through a representative manufacturing firm. The hypothetical firm earns 50,000 SEK each year, and assumed to burn only coal in 1991 and 1992. All carbon tax payments with the exception of 2015 are shown on the vertical axis on the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

Differences in marginal tax across firms and time

- We compute each firm's marginal tax rate every year
  - Firm-specific exemptions and tax changes
  - For firms with establishments entering the EU ETS, we apply the emission price for those establishments

- Significant difference between marginal and average tax rates
  - During 1990's, decile 10 firms account for:

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

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

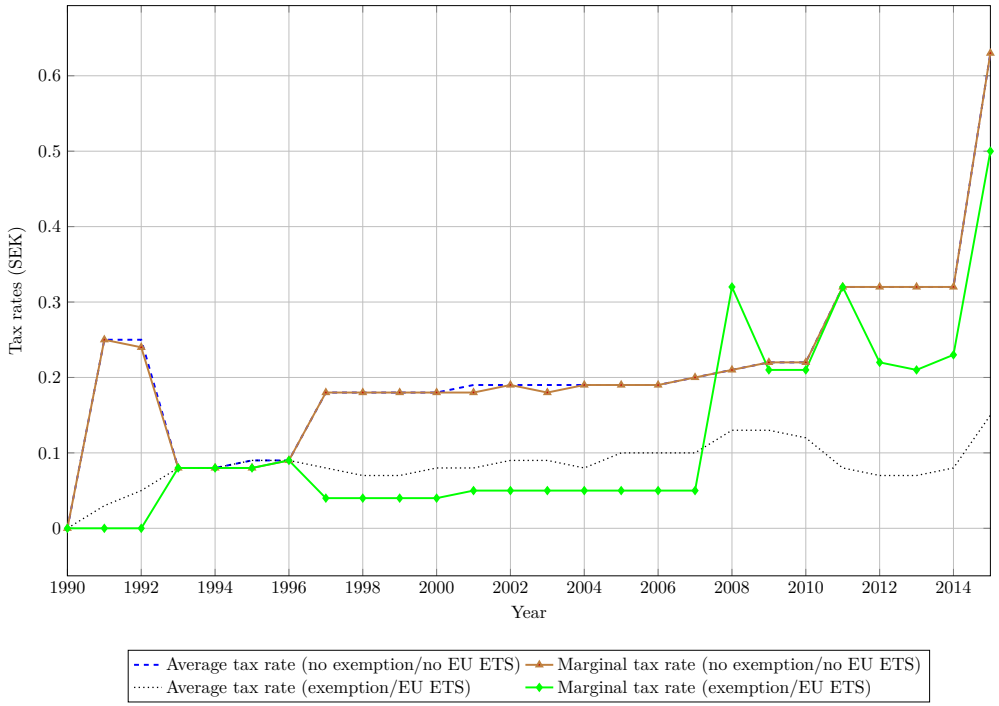


Figure 7 displays the average and marginal tax rates depending on whether the firm is eligible for carbon tax exemptions and covered by the EU ETS. *no exemption/no EU ETS* denotes firms that are not regulated by the EU ETS and are not entitled to carbon tax cut, *exemption/EU ETS* refers to the firms 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.

Illustration: Tax changes in early 1990's

Table 5: Difference-in-difference analysis around tax changes

	Firm exemptions (91-92)	**No firm exemptions**	**Relative change**
	Panel A: Marginal cost of emitting CO_2		
1990	0.000	0.000	
1991-1992	0.000	0.227	
1994-1996	0.086	0.086	
Change 90 to 91/92	0.000	0.227	-0.227
Change 91/92 to 94/96	0.086	-0.141	0.227
	Panel B: CO_2 emissions-to-sales		
1990	0.107	0.008	
1991-1992	0.113	0.009	
1994-1996	0.120	0.010	
Change 90 to 91/92	0.058	0.035	0.023
Change 91/92 to 94/96	0.060	0.120	-0.059
	Panel C: Summary statistics		
Nr of firms	9	225	
Total CO_2 (kt) 1990	2,244	4,323	
Total sales (1990, billion SEK)	21.2	538	
CO_2-to-sales	0.106	0.008	

Table 5 reports the change in marginal cost and emission intensity for firms with and without exemptions around the 1991 introduction of the carbon tax and the change in 1993. The sample is limited to a balanced sample of firms between 1990 and 2002. *Panel A* tabulates the marginal taxes for the manufacturing firms, *Panel B* reports the emission intensities, and *Panel C* provides a summary statistics about the sampled firms.

Estimating tax elasticities

- Regression specification:

$$ln\left(\frac{E_{\mathrm{i,t}}}{Y_{\mathrm{i,t}}}\right) = \omega + \sum_{s=0}^{q} \sigma_{\mathrm{s}} \cdot ln(\tau_{\mathrm{i,t\text{-}s}}) + \delta_{\mathrm{i}} + \delta_{\mathrm{t}} + \epsilon_{\mathrm{i,t}},$$

  - Dep variable: (log of) CO2-emissions (kg) divided by PPE-adjusted sales (SEK)
  - Firm-specific marginal tax rage (up to three lags)
  - Firm and time fixed-effects

- Identification from differences in firm marginal tax rates both in cross-section and time-series

Table 6: Baseline regression results

	(1)	(2)	(3)	(4)	(5)
	Dependent variable: log (CO_2/Y)(i,t)				
	All				D10
log (1 + marginal tax rate) (i,t)	-2.758	-2.244	-1.967	-1.859	-1.962
	(0.365)***	(0.320)***	(0.320)***	(0.359)***	(0.468)***
log (1 + marginal tax rate) (i,t-1)		-1.091	-0.848	-0.693	-1.146
		(0.275)***	(0.236)***	(0.251)***	(0.364)***
log (1 + marginal tax rate) (i,t-2)			-0.595	-0.366	-0.714
			(0.264)**	(0.236)	(0.331)**
log (1 + marginal tax rate) (i,t-3)				-0.485	-0.800
				(0.294)*	(0.407)*
Sum σ	-2.758	-3.335	-3.410	-3.403	-4.622
F-test	(0.000)***	(0.000)***	(0.000)***	(0.000)***	(0.000)***
Firm fixed effects	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y
OBS	32,345	28,387	24,355	20,296	2,026
Adjusted R^2	0.800	0.807	0.816	0.822	0.770

Table 6 tabulates our baseline regression results, i.e. the relationship between lagged marginal tax rates and emission intensities (CO_2/Y).

Robustness:

- EU-ETS
- Ln(workers) and capital/worker
- Get similar magnitudes
- Estimate by deciles:
  Even higher elasticities for D9 and D10

Abatement costs and asset mobility

Pollution Abatement Cost Expenditures (PACE)

- Use U.S. 4-digit industry estimates
- Sort firms on whether industry is above vs below median PACE/Sales

Asset mobility

(Ederington et al, 2005)

- Estimates of plant fixed costs for U.S. 4-digit industries
- Similar split.

Table 8: PACE and mobility

	(1)	(2)	(3)	(4)	(5)	(6)
	PACE		Low PACE		High PACE	
	Low	High	Low mobility	High mobility	Low mobility	High mobility
log (1 + marginal tax rate) (i,t)	-3.858	-1.686	-21.425	0.326	-2.812	-1.367
	(1.816)**	(0.663)***	(3.919)***	(1.491)	(1.258)**	(1.077)
log (1 + marginal tax rate) (i,t-1)	-1.385	-0.453	-5.802	-1.766	-0.556	-0.846
	(1.042)	(0.366)	(2.308)**	(1.294)	(0.618)	(0.645)
log (1 + marginal tax rate) (i,t-2)	-0.596	0.055	-2.797	-1.206	-0.102	0.424
	(0.914)	(0.361)	(1.942)	(2.091)	(0.691)	(0.602)
log (1 + marginal tax rate) (i,t-3)	-1.485	0.051	-4.853	-4.909	0.021	-0.241
	(1.217)	(0.403)	(1.343)***	(1.766)***	(0.718)	(0.563)
Sum σ	-7.324	-2.032	-34.877	-7.554	-3.448	-2.030
F-test	(0.034)**	(0.075)*	(0.000)***	(0.129)	(0.059)*	(0.335)
Firm fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
OBS	4,162	5,188	682	1,120	1,346	1,783
Adjusted R^2	0.801	0.834	0.829	0.791	0.820	0.838

Table 8 tabulates the effect of pollution abatement cost expenditures and geographic mobility of assets.

Grossman & Krueger decomposition

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

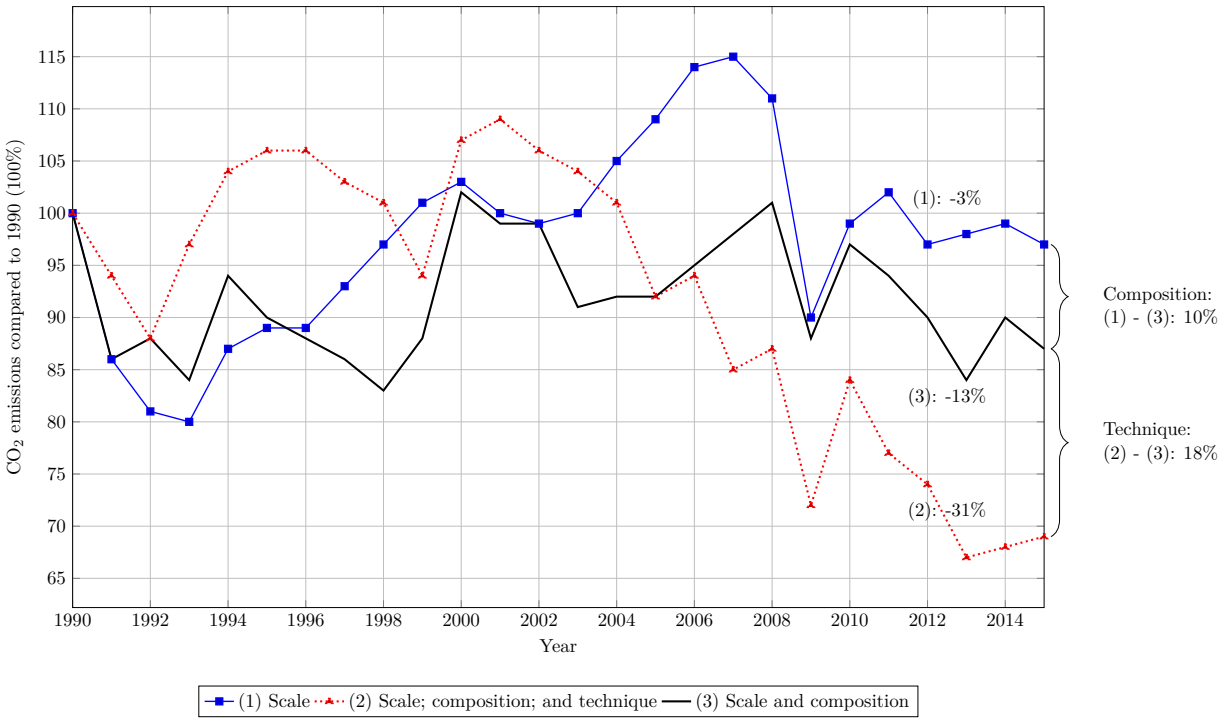
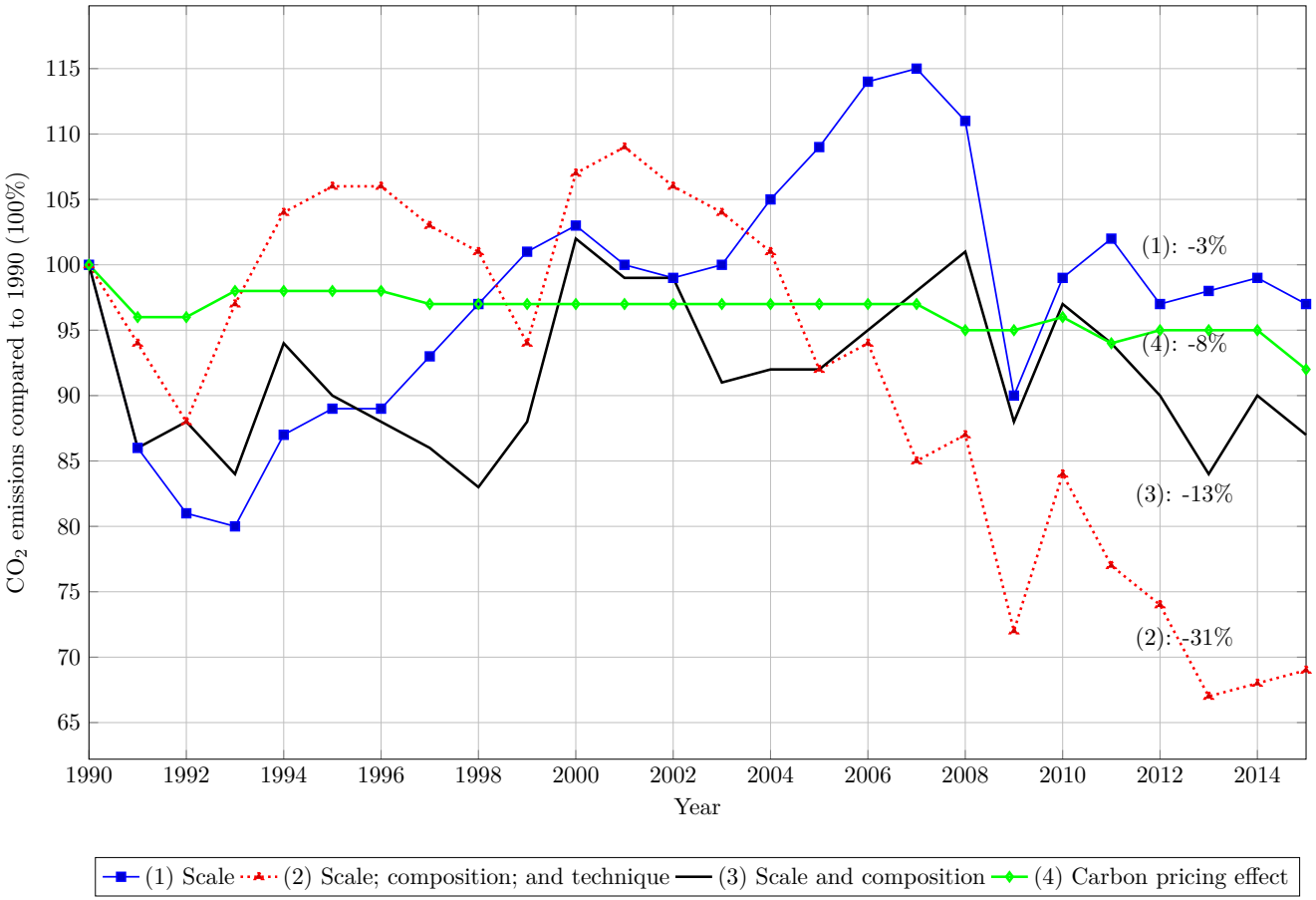


Figure 8 displays the decomposition of the Swedish carbon dioxide emission reduction. *Scale* captures how emissions would have evolved without tangible technological progress and structural changes in the manufacturing sector. *Composition* refers to the change in industry composition (e.g. booming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

Calibrated effect of marginal carbon pricing

Figure 9: Carbon dioxide emissions from Swedish manufacturing (1990-2015)



Conclusion

- Estimate effect of carbon tax on firm emissions over 25-year period
- 1% increase in marginal tax rate → 3-3.5% lower emission intensity
- Carbon pricing account for about 1/4 of decrease in carbon emissions

- Would have been higher if high-emitting subsectors had not faced substantial exemptions