Carbon Pricing and Investment

James R. Brown[Texas A&M], Gustav Martinsson[SU], Per Strömberg[SSE] and Christian Thomann[KTH]

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Is carbon pricing effective?

- Carbon pricing is a potentially important policy tool
  - Nordhaus (1993); Aghion et al. (2012); Golosov et al. (2014); Rockström et al. (2017); Sterner et al. (2019)
- Extensive focus on carbon pricing and emissions
  - Martinsson et al. (2024, Sweden); Colmer et al. (2024, ETS); Dechezlepretre et al. (2023, ETS); Ahmadi et al. (2022, BC)
- How do carbon prices affect firm investment decisions?
  - The response in dirty firms is particularly important
    - where most of the pollution is located
    - requires substantial capx to materially reduce pollution
  - Evidence is mixed
    - Colmer et al. (2024, RES); Jacob and Zerwer (2024, TAR)

Recent example

SSAB continues the transformation with a fossil-free mini-mill in Luleå, Sweden

Luleå, Strategy, Fossil-free steel

April 02, 2024 7:30 CEST

SSAB's Board of Directors have today taken the decision to proceed with the next step in SSABs transition, building a state-of-the-art fossil-free mini-mill in Luleå, Sweden. When completed SSAB will close the current blast furnace-based production system. This will reduce Sweden's CO2 emissions with 7% in addition to the 3% from the Oxelösund mill conversion.

Microsoft

The new Luleå mill will have a capacity of 2.5 mton/year and consist of two electric arc furnaces, advanced secondary metallurgy, a direct strip rolling mill to produce SSABs specialty products, and a cold rolling complex to serve the mobility segment with a broader offering of premium products. The new mill will be supplied with a mix of fossil free sponge iron from the Hybrit demonstration plant in Gällivare and recycled scrap.

"The transformation of Luleå is a major step on our journey to fossil-free steel production. We will remove 7% of Sweden's carbon dioxide emissions, strengthen our competitive position and safeguard jobs with the most cost-effective and sustainable strip production in Europe," says SSAB's President and CEO **Martin Lindqvist**.

The total mini-mill investment is estimated to EUR 4.5 billion including contingencies. By investing in new technologies, SSAB is avoiding investments otherwise required in existing plant and equipment of EUR 2 billion during the next 10 years. The plan is to fund the investment with own cash flows and within SSAB's financial targets.

The investment will result in significant value creation. Compared to the current system the yearly EBITDA improvement is estimated to be more than SEK 5 billion/year at current commodity forecasts. The new mini-mill will have a better cost position with lower fixed costs, higher efficiency, shorter lead times and eliminated CO_2 costs. The mill design includes a production increase of 0.5 mton/year, a mix improvement with 1 mton/year increase of special and premium steel grades.

Startup of the new mill is planned at the end of 2028 with full capacity one year later. Environmental permits are expected at the end of 2024. The investment is an important step in SSAB's strategy to establish a leading position in emission free special and premium steels. To date SSAB has entered 55 partnerships with leading customers for our fossil free and zero steels.

This paper

- Carbon prices and firm-level investment in Sweden, 2000-2019
- Attractive setting
  - Can directly relate firm-level investment to firm-specific cost of emissions
  - Can identify investments focused specifically on pollution abatement
  - Sharp increase in carbon prices after 2014 (phase out of manufacturing exemptions)
    - large capital investments not positive NPV unless carbon price is sufficiently high (Bolton et al, 2023)

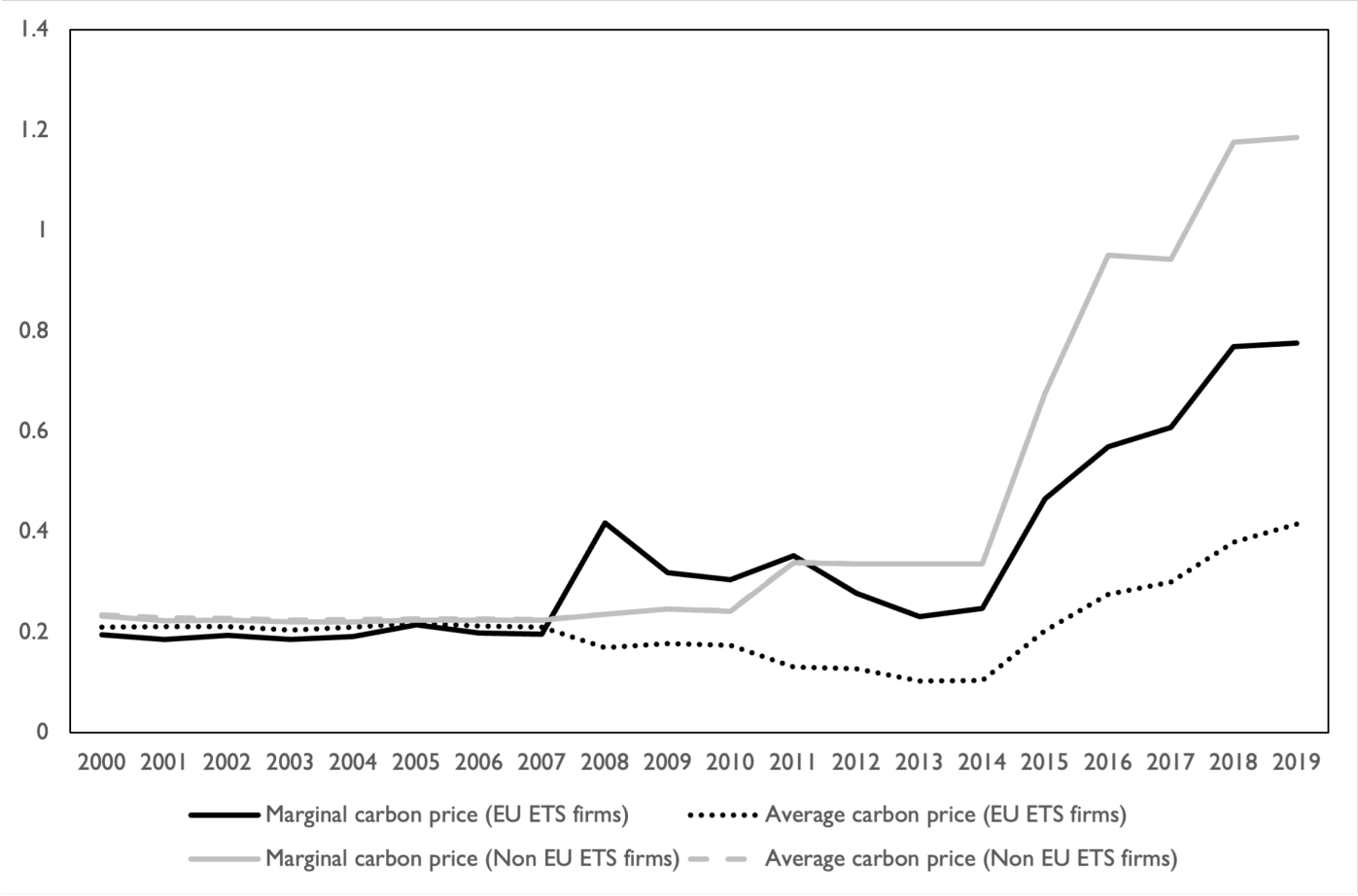
Findings

- Carbon pricing associated with significant investment response in high-emitting firms
  - 10% increase in MC of emissions associated with 2% increase in investment spending
  - No significant investment response in low-emitting firms
  - New capx is (green) abatement investment
  - No response until carbon price is sufficiently high
  - Internal resources matter
    - firms in EU ETS with surplus emission rights invested more
    - larger investment response in firms with high internal cash flow

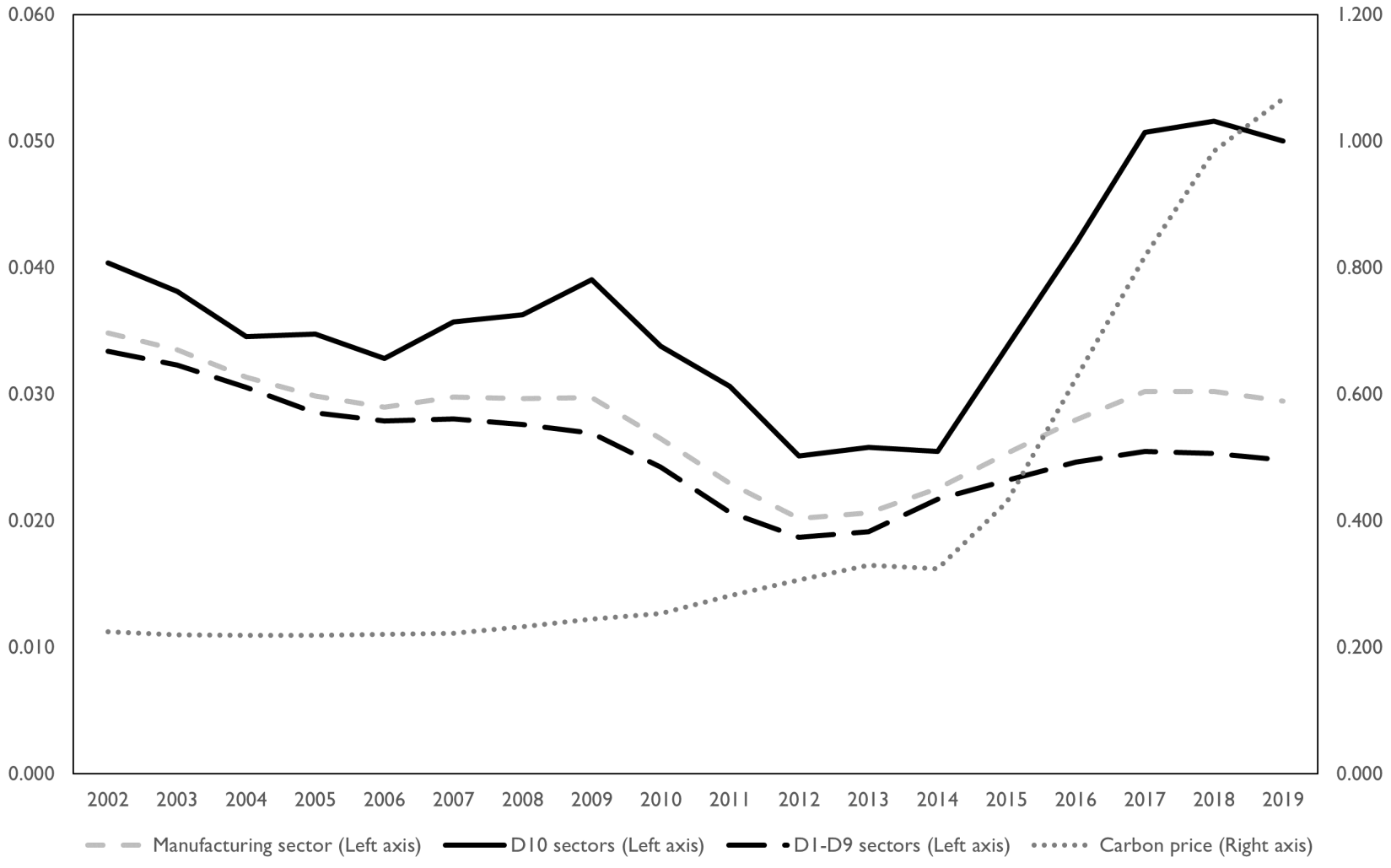
Data and samples

- Primary data sources
  - Annual capital investment survey 2000-2019 (Statistics Sweden)
  - Firm CO_2 emissions (Swedish Environmental Protection Agency)
  - Abatement investment 2002-2019 (Environmental Protection Expenditure Survey)
  - Investment in research and development (R&D) (Statistics Sweden)
  - Firm balance sheet and income statement information (Serrano dataset)
- Final samples
  - Main sample: intersection of capital investment, CO_2 emissions, and firm fundamentals (9,839 firm-years)
  - Abatement investment sample (2,046 firm-years)
  - R&D sample (5,267 firm-years)

Carbon pricing in Sweden 2000–2019



Capital investment in the Swedish manufacturing sector



Aggregate patterns in emissions and investment

- Highest emitting industries (D10) account for 85-90% of CO_2 emissions throughout the sample period
- Comparing 2000-2002 with 2017-2019
  - D10 share of manufacturing output falls from 21.8% to 16.8%
  - D10 share of investment increases from 23.5% to 31.3%
  - Investment-to-cash flow in D10 increases from 32.7% to 52.1% (while declining in rest of manufacturing)
  - Absolute change in manufacturing investment: +11 billion SEK
    - D10 accounts for 60% of this increase (7 billion SEK)

Baseline empirical specification

$$ln(Inv)_{i,t} = \alpha + \sum_{s=0}^{q} \beta_s \cdot ln(C)_{i,t-s} + \gamma X_{i,t-1} + \eta_i + \eta_{j,t} + \epsilon_{i,t}. \quad (1)$$

- *Inv*: Capx-to-sales (or R&D-to-sales) in year t
- C: marginal cost of emitting a unit of CO_2 in year t-s
- X: firm-year control variables
- Firm- and 4-digit industry-year fixed effects

Carbon pricing and operating margins

	(1)	(2)	(3)	(4)	(5)
	ALL	**D1-D4**	**D5-D8**	**D9-D10**	**D10**
$\ln(C_{i,t})$	-0.003***	-0.001	-0.005***	-0.008**	-0.009**
	(0.001)	(0.001)	(0.002)	(0.003)	(0.004)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Industry x Year effects	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes
Observations	6,234	2,690	2,453	1,083	642
Adjusted R^2	0.456	0.575	0.486	0.171	0.219

Carbon pricing and firm level capital investment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln(C_{i,t})$	0.111***	0.046***	0.061***	0.059**	0.080***	0.087***	0.075**
	(0.013)	(0.016)	(0.022)	(0.025)	(0.029)	(0.030)	(0.035)
$\ln(C_{i,t-1})$					0.000	0.005	0.019
					(0.029)	(0.033)	(0.038)
$\ln(C_{i,t-2})$						0.020	0.029
						(0.028)	(0.032)
$\ln(C_{i,t-3})$							0.007
							(0.035)
Cash $\text{flow}_{i,t-1}$				0.488***	0.641***	1.336***	1.508***
				(0.165)	(0.205)	(0.371)	(0.368)
$\ln(\text{Total assets}_{i,t-1})$				0.018	0.021	-0.009	0.063
				(0.043)	(0.075)	(0.073)	(0.084)
Long term $\text{debt}_{i,t-1}$				-0.762***	-0.809***	-0.710***	-0.803***
				(0.208)	(0.218)	(0.223)	(0.495)
$\ln(\text{Age}_{i,t-1})$				-0.736**	-0.576	-0.497	-0.727
				(0.352)	(0.378)	(0.393)	(0.495)
Sales $\text{gwth}_{i,t-1}$				-0.026	-0.050*	-0.053	-0.155***
				(0.021)	(0.027)	(0.064)	(0.059)
$\sum \ln(C)$					0.080**	0.112***	0.130**
					(0.015)	(0.006)	(0.021)
Firm fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	No	No	No	No
Industry x Year effects	No	No	Yes	Yes	Yes	Yes	Yes
Firm controls	No	No	No	Yes	Yes	Yes	Yes
Observations	9,839	9,043	7,869	6,242	5,477	4,681	3,653
Adjusted R^2	0.040	0.453	0.443	0.449	0.459	0.478	0.481

Robustness

Carbon pricing and firm level capital investment: By decile

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	D1-D4	**D1-D4**	**D5–D8**	**D5–D8**	**D9–D10**	**D9–D10**	**D10**	**D10**
$\ln(C_{i,t})$	0.046	0.066	0.018	-0.002	0.149***	0.200***	0.189***	0.186***
	(0.036)	(0.047)	(0.040)	(0.058)	(0.056)	(0.065)	(0.056)	(0.070)
$\ln(C_{i,t-1})$		-0.004		0.034		0.066		0.018
		(0.056)		(0.050)		(0.082)		(0.085)
$\ln(C_{i,t-2})$		0.026		-0.019		0.082**		0.085**
		(0.053)		(0.067)		(0.036)		(0.034)
$\ln(C_{i,t-3})$		-0.032		0.075		-0.043		-0.038
		(0.058)		(0.054)		(0.069)		(0.082)
Cash $\text{flow}_{i,t-1}$	0.876***	3.166***	0.161	0.958**	0.259	0.959	-0.261	0.694
	(0.276)	(0.603)	(0.257)	(0.463)	(0.320)	(0.843)	(0.498)	(0.863)
$\ln(\text{Total assets}_{i,t-1})$	-0.015	-0.182	-0.007	0.295**	0.120	-0.015	0.124	-0.003
	(0.077)	(0.165)	(0.055)	(0.127)	(0.104)	(0.158)	(0.150)	(0.177)
Long term $\text{dbt}_{i,t-1}$	-1.100***	-1.294**	-0.529*	-0.264	-0.586	-0.946	-0.714	-0.896
	(0.370)	(0.521)	(0.274)	(0.264)	(0.603)	(0.591)	(0.601)	(0.692)
$\ln(\text{Age}_{i,t-1})$	-1.737***	-0.987	-0.083	-0.398	-0.623	-1.162	-1.228	-1.892
	(0.556)	(1.054)	(0.397)	(0.602)	(0.953)	(1.191)	(1.218)	(1.309)
Sales $\text{gwth}_{i,t-1}$	-0.076**	-0.405***	0.028	-0.047	-0.047	-0.135	0.025	-0.155
	(0.038)	(0.125)	(0.033)	(0.048)	(0.039)	(0.122)	(0.066)	(0.117)
$\sum \ln(C)$		0.056		0.088		0.305***		0.251**
		(0.569)		(0.252)		(0.002)		(0.023)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry x Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,693	1,495	2,457	1,401	1,084	757	643	481
Adjusted R^2	0.419	0.437	0.474	0.502	0.480	0.548	0.486	0.513

Carbon pricing and firm level abatement investment

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Abate Inv		Share Abate Inv		Non Abate Inv	
$\ln(C_{i,t})$	0.220**	0.297***	0.039	0.175	-0.121	0.137***	0.091
	(0.088)	(0.101)	(0.112)	(0.107)	(0.136)	(0.044)	(0.060)
$\ln(C) \times$ D10			0.578***		0.550***		0.085
			(0.158)		(0.179)		(0.087)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry x Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	No	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,239	1,025	1,025	815	815	795	795
Adjusted R^2	0.369	0.375	0.389	0.260	0.272	0.477	0.477

Carbon pricing and R&D investment

	(1)	(2)	(3)	(4)	(5)	(6)
		R&D Inv			Abate R&D Inv	
$\ln(C_{i,t})$	-0.033	0.034	-0.007	0.485**	0.496	-0.197
	(0.049)	(0.048)	(0.048)	(0.237)	(0.304)	(0.271)
$\ln(C) \times$ D10			0.364***			0.890**
			(0.108)			(0.478)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry x Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	No	Yes	Yes	Yes	Yes	Yes
Observations	1,200	830	830	181	152	152
Adjusted R^2	0.771	0.834	0.838	0.761	0.720	0.730

Carbon pricing and firm level capital investment: Value of EU ETS allowances

	(1)	(2)	(3)	(4)	(5)	(6)
	ALL	**D10**	**ALL**	**D10**	**ALL**	**D10**
$\ln(C_i)$	0.096**	0.099*			0.099**	0.096
	(0.037)	(0.058)			(0.039)	(0.063)
$\ln(\text{Value allowances}_{i,t})$			0.214***	0.260***	0.218***	0.258***
			(0.062)	(0.079)	(0.059)	(0.071)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	479	302	479	302	479	302
Adjusted R^2	0.538	0.500	0.545	0.514	0.551	0.517

Event (diff-in-diff) tests

$$Inv_{i,t} = \sigma + \omega \cdot D10\ firm_i + \kappa \cdot Post_t + \phi(D10\ firm_i \cdot Post_t) + \epsilon_{i,t}. \quad (2)$$

- Sample: 2010-2019
- *D10 firm* equal 1 if firm is in a high-emitting industry
- *Post* equal 1 if 2015–2019
- Firm and year fixed effects
- Additional diffs based on *ex ante* measures of access to internal cash flow and debt

Carbon pricing and firm level capital investment: Event results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
					HFP: Cash flow			HFP: Credit ratings	
D10 Firm	0.005			0.008**			0.007		
	(0.003)			(0.004)			(0.005)		
Post	0.003***	0.001		0.003*	0.002		0.002	0.001	
	(0.001)	(0.001)		(0.002)	(0.002)		(0.002)	(0.002)	
D10 Firm × *Post*	0.014***	0.014***	0.014***	0.005	0.004	0.004	0.013**	0.012*	0.012*
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)
HFP				0.009***			0.004**		
				(0.002)			(0.002)		
D10 Firm × *HFP*				-0.002			0.000		
				(0.007)			(0.006)		
Post × *HFP*				-0.001	-0.002	-0.002	0.003	0.002	0.002
				(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
D10 Firm × *Post* × *HFP*				0.018*	0.021**	0.021**	0.000	0.004	0.004
				(0.010)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)
Firm fixed effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year effects	No	No	Yes	No	No	Yes	No	No	Yes
Observations	8,597	8,108	8,108	5,199	5,026	5,026	5,199	5,026	5,026
Adjusted R^2	0.009	0.397	0.397	0.015	0.368	0.368	0.018	0.367	0.368

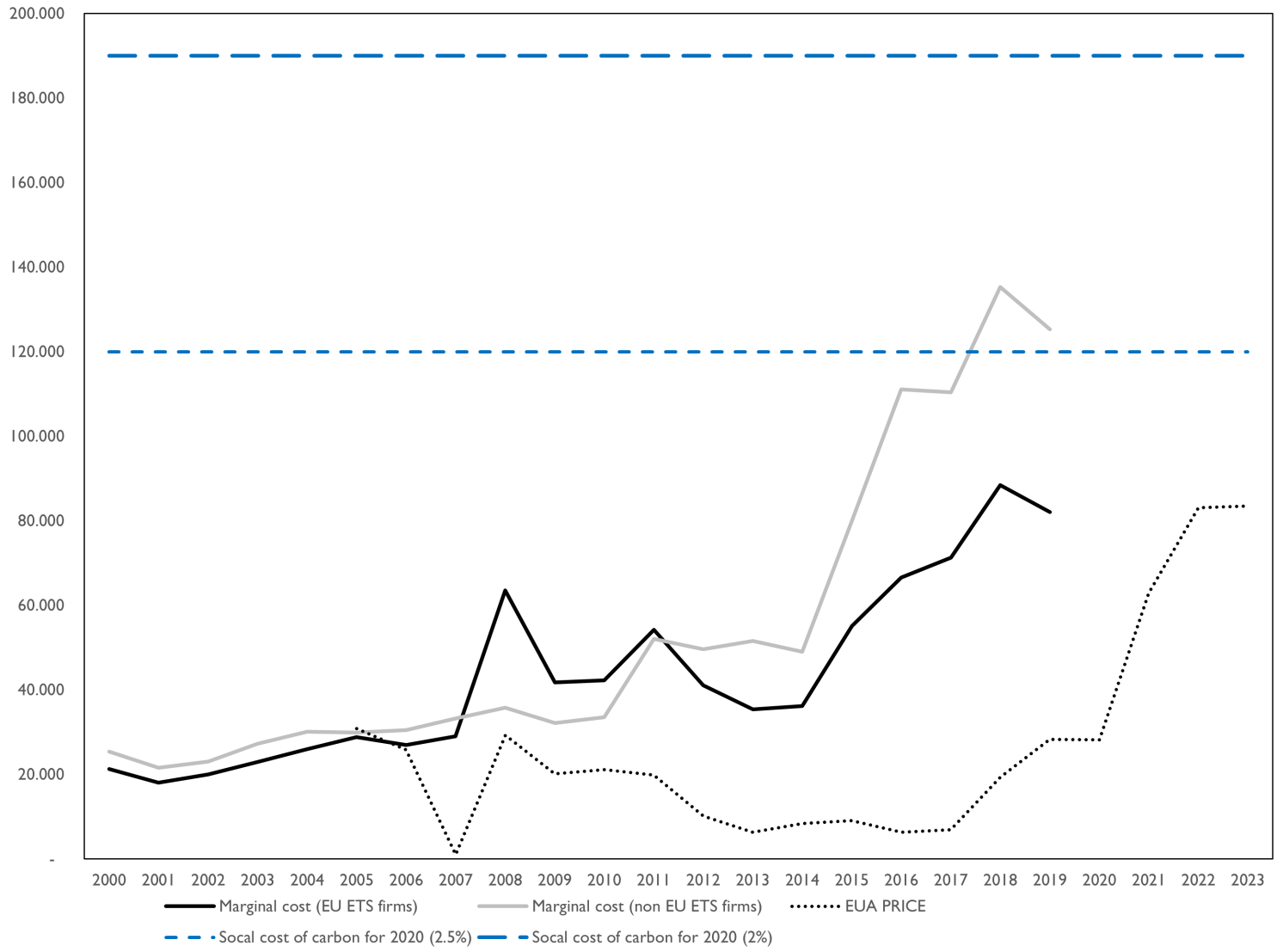
Robustness

Quantification of estimation results

	(1)	(2)	(3)	(4)	(5)	(6)
	Percent change in marginal cost		Predicted percent change		Predicted change to actual change	
	2000-2010	2011-2019	D10	D1–D9	D10	D1–D9
Actual marginal cost for average sample firm	8%	239%	45%	9%	72%	44%
Marginal cost had all firms faced Swedish carbon tax	4%	250%	47%	9%	75%	46%
Marginal cost had all firms faced carbon price as EU ETS firms	56%	120%	23%	4%	36%	22%

- Increase in carbon prices account for 75% of increase in investment in D10 firms

Swedish carbon prices and social cost of carbon estimates



Conclusion

- Sharp increase in carbon price in Sweden after 2014
- A positive investment-to-carbon price elasticity in Swedish manufacturing firms
- Differentially stronger effects in the dirty firms most affected by higher carbon pricing
- Significant increase in investments (Capx and R&D) focused specifically on pollution abatement

Stats across deciles over time: Levels

	D1–D10	D1–D9	D10
	Panel A: Levels 2000-2002		
CO_2	9,745	1,473	8,272
Output	1,313	1,027	286
INV	42	32	10
Cash flow	117	87	30
	Panel B: Levels 2017-2019		
CO_2	5,392	661	4,731
Output	1,830	1,522	308
INV	54	37	17
Cash flow	181	149	32
	Panel C: Change levels		
CO_2	-4,354	-812	-3,541
Output	517	495	22
INV	11	4	7
Cash flow	64	62	2

Return

Baseline regression: Some robustness

	(1)	(2)	(3)	(4)	(5)
		Inv	Inv Scaled TA	Inv unscaled	Uncons-olidated
ln($C_{i,t}$ - Sales weighted)	0.065***				
	(0.023)				
ln($C_{i,t}$ - Fixed assets weighted)		0.072***			
		(0.021)			
ln($C_{i,t}$ - Scaled by Total assets)			0.063**		
			(0.025)		
ln($C_{i,t}$)				0.050*	
				(0.029)	
ln($C_{i,t}$ - Unconsolidated)					0.044***
					(0.017)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Industry x Year effects	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes
Observations	6,242	6,154	6,242	6,242	10,621
Adjusted R2	0.450	0.435	0.461	0.802	0.401

Return

Event results: robustness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Collapsed	Firm-years with emissions data			HFP: Cash flow			HFP: Dividend			HFP: Long term dbt		
D10 Firm	0.004	0.009**			0.011**			0.001			0.009		
	(0.004)	(0.004)			(0.005)			(0.004)			(0.005)		
Post	0.000	0.004***	0.002		0.004**	0.002		0.003	0.001		0.002	0.002	
	(0.001)	(0.001)	(0.001)		(0.002)	(0.002)		(0.002)	(0.002)		(0.002)	(0.001)	
D10 Firm × *Post*	0.011**	0.014***	0.015***	0.015***	0.008	0.009	0.009	0.003	0.003	0.003	0.017**	0.019**	0.019***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)	(0.007)	(0.007)	(0.005)	(0.004)	(0.004)	(0.008)	(0.008)	(0.004)
HFP					0.008***			0.000			0.001		
					(0.002)			(0.002)			(0.002)		
D10 Firm × *HFP*					0.000			0.011**			-0.004		
					(0.007)			(0.006)			(0.007)		
Post × *HFP*					0.000	-0.002	-0.002	0.001	0.002	0.002	0.002	-0.001	-0.001
					(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
D10 Firm × *Post* × *HFP*					0.021**	0.025**	0.025**	0.020**	0.022**	0.022**	-0.009	-0.011	-0.011
					(0.009)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
HGP					0.005***								
					(0.002)								
D10 Firm × *HGP*					-0.008								
					(0.007)								
Post × *HGP*					-0.002	0.000	0.000						
					(0.003)	(0.003)	(0.003)						
D10 Firm × *Post* × *HGP*					-0.009	-0.013	-0.013						
					(0.009)	(0.010)	(0.010)						
Firm fixed effects	No	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year effects	No	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Observations	2,144	5,594	5,096	5,096	5,199	5,026	5,026	5,199	5,026	5,026	5,199	5,026	5,026
Adjusted R^2	0.007	0.019	0.445	0.445	0.035	0.369	0.370	0.022	0.370	0.371	0.015	0.368	0.368

Return