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Mind the emission gap

Policy stringency matters

L. Bortolan[1]   L. Prosperi[2]   L. Taschini[3]   L. Zanin[2]
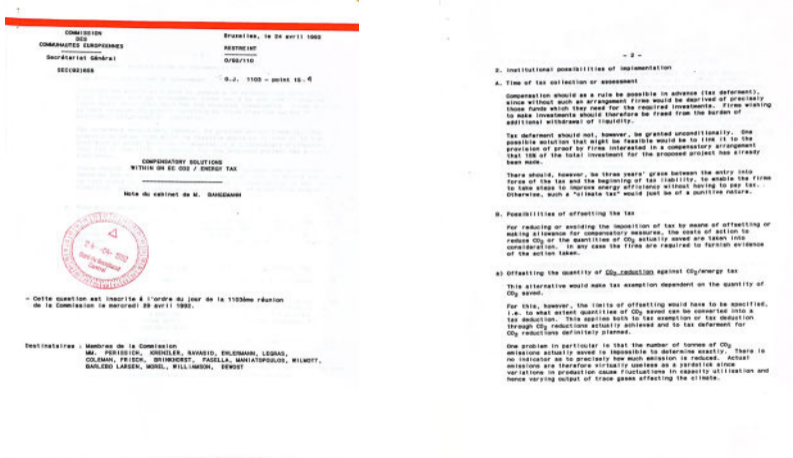
[1]Eni Plentitude

[2]Prometeia

[3]University of Edinburgh Business School

[4]University of Bologna
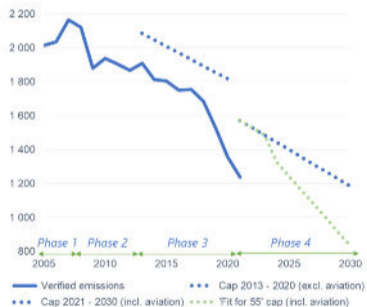
European University Institute – November 2024

Motivation
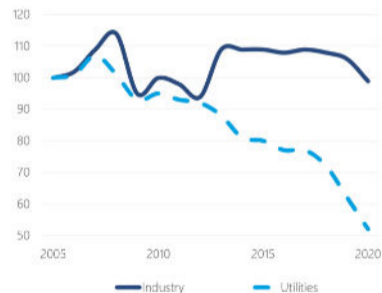
Policy stringency in the archive

Limited emissions reductions in non-electricity sector

EU ETS emissions
(in million tCO$_2$-eq)

Phase 1   Phase 2   Phase 3   Phase 4

— Verified emissions   ••• Cap 2013 - 2020 (excl. aviation)
••• Cap 2021 - 2030 (incl. aviation)   •••• 'Fit for 55' cap (incl. aviation)

Relative evolution of emissions
(2005 = 100)

— Industry   –– Utilities

Emissions reductions in the EU ETS: stylized facts 1/3

Average Carbon Emissions (tons)

2013 2014 2015 2016 2017 2018 2019 2020 2021

◆ Manufacturing & Construction   ▲ Mining   ■ Transportation   + Utilities
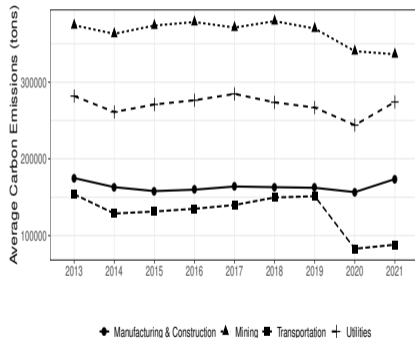
- Verified emissions: most reductions from electricity sector.
- Emissions stable in sectors like manufacturing, construction, transportation.
- Combustion-related emissions decreasing due to fuel switching, reducing emissions/unit electricity.
- Process-related emissions remain stable due to technical complexities and costs.

Differences in regulatory stringency: stylized facts 2/3

Manufacturing & Construction   Mining   Transportation   Utilities
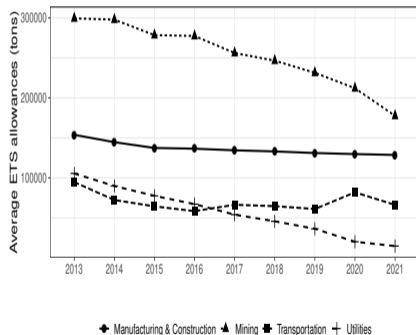
- Emission reduction disparities across sectors not solely driven by industry characteristics.
- Differential regulatory pressure plays a significant role.
- Electricity sector experiences the highest *regulatory stringency* due to the no free allowances.
- Sectors receiving free allocations face less stringency to achieve emission reductions.

Substantial differences within sectors: stylized facts 3/3

Density distributions
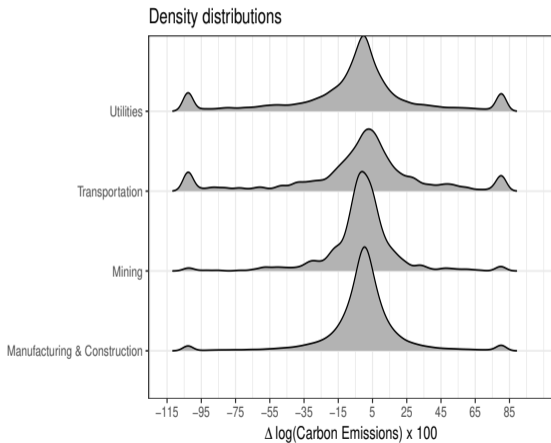
- Technological barriers and industry nature
- Organizational constraints (ability to access external funding)

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Research questions

Research question and sketch of the approach

What question are we aiming to address?

- Does carbon policy stringency matter?
- Is current policy stringency sufficient to achieve Net Zero targets in EU?

Contribution:

- Theoretically-founded definition of policy stringency
- Examine determinants of change in emissions
    - firm-specific financial variables (leverage, ROA, cash-holding)
    - characteristics of the scale of operations (sales, total assets, inst., age)
- Simulate firm-level emissions under varying policy stringency to assess whether current levels are sufficient to achieve net-zero.

Main findings

What do we find?

- Policy stringency and sales are main determinants of change in emissions.
- Results not driven by firms operating in specific sectors.
- Results robust to alternative definitions of policy stringency.
- Forward-looking component most relevant part of policy stringency.
- Counterfactual analysis illustrates relevance of policy stringency pressure to get to net-zero.

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Data

Data - EU firms subject to EU ETS scheme (2013-2021)

- Installation-level Verified Emissions and Allocated Allowances (source: EU-ETL):
- Firm-Level Financial Data and Characteristics (Source: Orbis Bvd):
  - NACE sectoral classification
  - Matching installations to firms (Letout (2021))
  - Total assets, fixed assets ratio
  - Return on assets (ROA)
  - Firm cash holding, debt-to-asset ratio, listing status
  - Firm age, changes in number of installations, geographical location
- Macro variable (Source: LSEG):
  - European Union Allowances carbon price futures (yearly average)

Policy stringency

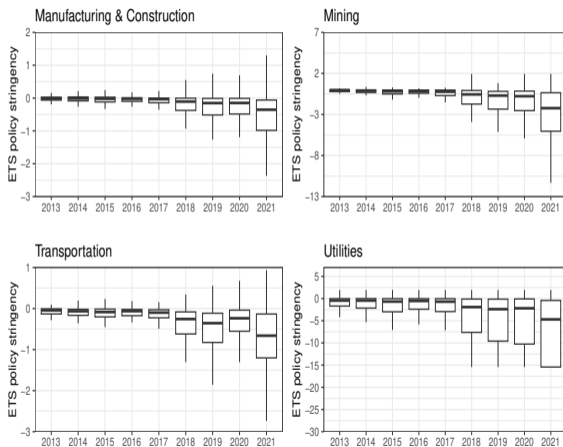# Mind the compliance gap: Policy stringency

- Firm's compliance problem:

$$\min_{\alpha, \beta} \mathbb{E} \left[\sum_{t=0}^{T} C(\bar{e}_t - e_t(p_t, \bar{e}_t)) + p_t \cdot \beta_t \right]$$

$$\text{s.t. } E_T - A_T = \sum_{t=0}^{T} \alpha_t + \sum_{t=0}^{T} \beta_t$$

- Solving $\rightarrow C'(\alpha_t) = p_t$ i.e. the per-unit cost of compliance at each instant t.
- At year $t = 0$ the total expected compliance cost for the firm is

$$\sum_{t=0}^{T} \left(\alpha_t + \beta_t \right) \cdot p_t = \sum_{t=0}^{T} (e_t - a_t) \cdot p_t$$

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Mind the compliance gap: Policy stringency (an illustration)

Policy stringency:

$$\frac{1}{10} \sum_{k=1}^{10} \left[\frac{(a_{t+k} - e_t) \times P_t}{\text{Sales}_t} \right]$$

average annual expected compliance cost over the next 10 years

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Analysis

The model

$$\Delta\log \mathrm{E}_{i,t} = \ \beta_1' X_{1i,t-1} + \boldsymbol{\beta_2}' \boldsymbol{X}_{2i,t-1} + \boldsymbol{\beta_3}' \boldsymbol{X}_{3i,t} + \mu_t + \gamma_s + \zeta_c + \gamma_s \times \mu_t + \varepsilon_{i,t}$$

Firm-specific variables:

- Policy stringency: $1/10 \sum_{k=1}^{10} [(a_{t+k} - e_t) \times P_t/\mathsf{Sales}_t]$
- Financial (lagged): leverage, fixed assets, ROA, and cash holding
- Characteristics determining scale of operations: change in sales, total assets, change nr. installations, age, listed dummy
- μ_t and ζ_c time and country fixed effects.
- γ_s NACE two-digit sector fixed effects
- $\gamma_s \times \mu_t$ NACE two-digit sector-time interaction fixed effects

Full sample analysis

Variables	Model 1	Model 2	Model 3	Model 4
	Dependent variable: Δlog Emissions			
lag(Debt/Total Assets)	0.04*	0.03	1.03*	0.86
	(0.02)	(0.02)	(0.60)	(0.60)
lag(Debt/Total Assets)^2	-0.00**	-0.00**	-0.61**	-0.61**
	(0.00)	(0.00)	(0.27)	(0.27)
lag(Fixed Assets)	0.80**	0.64**	0.80**	0.64**
	(0.32)	(0.33)	(0.32)	(0.33)
lag(Cash holding)	0.04**	0.04**	0.45**	0.46**
	(0.02)	(0.02)	(0.20)	(0.20)
lag(ROA)	0.07***	0.06***	0.66***	0.55***
	(0.02)	(0.02)	(0.20)	(0.20)
lag(ROA^2)	-0.00***	-0.00**	-0.24***	-0.22**
	(0.00)	(0.00)	(0.09)	(0.09)
log(Age of firm)	0.05	-0.02	0.05	-0.02
	(0.16)	(0.16)	(0.16)	(0.16)
Listed firm (Yes)	-0.92	-0.90	-0.14	-0.14
	(1.10)	(1.11)	(0.17)	(0.17)
log(Assets)	-0.52	-0.34	-9.47	-6.27
	(0.35)	(0.35)	(6.30)	(6.36)
Change N. Installations	4.93***	4.97***	1.87***	1.88***
	(1.81)	(1.82)	(0.69)	(0.69)
Change in Sales	29.26***	29.67***	5.41***	5.48***
	(1.48)	(1.48)	(0.27)	(0.27)
Policy stringency		0.62***		2.19***
		(0.08)		(0.27)
Fixed effects				
Country	Y	Y	Y	Y
NACE two-digits	Y	Y	Y	Y
Year	Y	Y	Y	Y
NACE two-digits $\times Year$	Y	Y	Y	Y
Num. obs.	27,177	27,177	27,177	27,177
R^2 (full model)	0.12	0.12	0.12	0.12
AIC	259,019.79	258,947.39	259,019.79	258,947.39
BIC	262,369.52	262,305.33	262,369.52	262,305.33

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$

Sectorial analysis

Variables	Dependent variable: Δlog Emissions				
	Full sample	Mining (B)	Industry (C + F)	Utilities (D+E)	Transportation (H)
lag(Debt/Total Assets)	0.86	-4.76	0.20	1.34	5.74
	(0.60)	(4.85)	(0.64)	(1.31)	(4.61)
lag(Debt/Total Assets)^2	-0.61**	2.21	-0.13	-1.02**	-1.88
	(0.27)	(2.66)	(0.31)	(0.51)	(1.61)
lag(Fixed Assets)	0.64**	-1.00	1.39***	0.31	-1.58
	(0.33)	(3.59)	(0.35)	(0.81)	(1.62)
lag(Cash holding)	0.46**	2.95**	0.27	1.11**	1.09
	(0.20)	(1.36)	(0.22)	(0.45)	(1.14)
lag(ROA)	0.55***	0.37	0.66***	0.66	1.16
	(0.20)	(1.50)	(0.22)	(0.50)	(1.03)
lag(ROA)^2	-0.22**	0.25	-0.28***	-0.24	-0.19
	(0.09)	(0.56)	(0.09)	(0.23)	(0.37)
log(Age of firms)	-0.02	-0.18	-0.04	0.09	-2.77**
	(0.16)	(1.94)	(0.18)	(0.40)	(1.25)
Listed firm (Yes)	-0.14	1.38**	-0.22	-0.51	0.80
	(0.17)	(0.65)	(0.18)	(0.64)	(1.11)
log(Assets)	-6.27	22.67	-22.09***	4.20	29.61
	(6.36)	(78.90)	(6.87)	(15.68)	(33.44)
Change N. Installations	1.88***	2.64***	1.76*	2.29***	0.88
	(0.69)	(0.63)	(0.92)	(0.55)	(1.20)
Change in Sales	5.48***	4.78***	4.99***	6.20***	8.22***
	(0.27)	(1.60)	(0.29)	(0.61)	(1.53)
Policy stringency	2.19***	5.77***	5.65***	1.99***	4.71*
	(0.27)	(1.74)	(0.82)	(0.34)	(2.61)
Fixed effects					
Country	Y	Y	Y	Y	Y
NACE two-digits	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y
NACE two-digits $\times Year$	Y	Y	Y	Y	Y
Num. obs.	27,177	27,177	27,177	27,177	27,177
R^2 (full model)	0.12	0.27	0.11	0.10	0.34
Adj. R^2 (full model)	0.10	0.12	0.09	0.09	0.28

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$

Robustness analysis: alternative stringency definition

- **NGFS policy stringency (NPS):** assume the allowance price follows the NGFS scenario consistent with Fit for 55.

$$\text{NPS}_{i,t} = \frac{1}{10} \sum_{k=1}^{10} \left[\frac{(a_{i,t+k} - e_{i,t}) \times P_{t+k}}{\text{Sales}_{it}} \right]$$

- **Full foresight policy stringency (FFPS):** Firms have foresight on all future factors

$$\text{FFPS}_{i,t} = \frac{1}{10} \sum_{k=1}^{10} \left[\frac{(a_{i,t+k} - e_{i,t+k}) \times P_{t+k}}{\text{Sales}_{it}} \right]$$

- **Banking policy stringency (BPS):** Incorporate the banking of allowances from 2005

Robustness analysis

Variables	Policy stringency	Dependent variable: Δlog Emissions			
		CPS	FFPS	NPS	BPS
lag(Debt/Total Assets)	0.86	1.00*	1.07*	0.74	0.99*
	(0.60)	(0.60)	(0.60)	(0.61)	(0.60)
lag(Debt/Total Assets)²	−0.61**	−0.63**	−0.62**	−0.60**	−0.63**
	(0.27)	(0.27)	(0.27)	(0.27)	(0.27)
lag(Fixed Assets)	0.64**	0.68**	0.84***	0.63*	0.66**
	(0.33)	(0.33)	(0.32)	(0.33)	(0.33)
lag(Cash holding)	0.46**	0.47**	0.45**	0.44**	0.46**
	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
lag(ROA)	0.55***	0.64***	0.70***	0.48**	0.62***
	(0.20)	(0.20)	(0.20)	(0.20)	(0.20)
lag(ROA)²	−0.22**	−0.22**	−0.25***	−0.21**	−0.23***
	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
log(Age of firm)	−0.02	0.02	0.05	−0.06	0.02
	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)
Listed firm (Yes)	−0.14	−0.15	−0.14	−0.12	−0.14
	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)
log(Assets)	−6.27	−6.22	−10.33	−7.15	−5.86
	(6.36)	(6.43)	(6.31)	(6.35)	(6.41)
Change N. Installations	1.88***	1.87***	1.86***	1.88***	1.88***
	(0.69)	(0.69)	(0.68)	(0.69)	(0.69)
Change in Sales	5.48***	5.43***	5.36***	5.51***	5.43***
	(0.27)	(0.27)	(0.27)	(0.27)	(0.27)
Policy stringency	2.19***				
	(0.27)				
CPS		1.38***			
		(0.25)			
FFPS			−0.76**		
			(0.31)		
NPS				2.78***	
				(0.26)	
BPS					1.40***
					(0.26)
Fixed effects					
Country	Y	Y	Y	Y	Y
NACE two-digits	Y	Y	Y	Y	Y
Year	Y	Y	Y	Y	Y
NACE two-digits $\times Year$	Y	Y	Y	Y	Y
Num. obs.	27,177	27,177	27,177	27,177	27,177
R^2 (full model)	0.12	0.12	0.12	0.12	0.12
Adj. R^2 (full model)	0.10	0.10	0.10	0.11	0.10
AIC	258,947.39	258,985.04	259,004.37	258,886.64	258984.19
BIC	262,305.33	262,342.98	262,362.31	262,244.58	262,342.13
Log Lik.	−129,064.70	−129,083.52	−129,093.18	−129,034.32	−129,083.09

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

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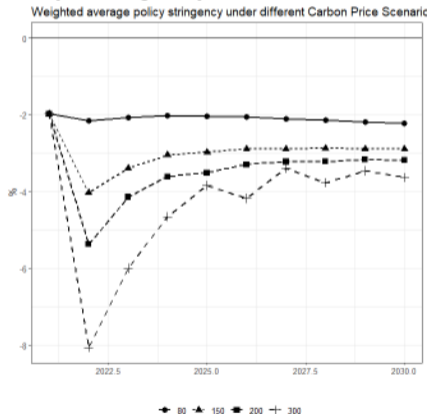
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Counterfactual Analysis

Counterfactual Analysis: emissions

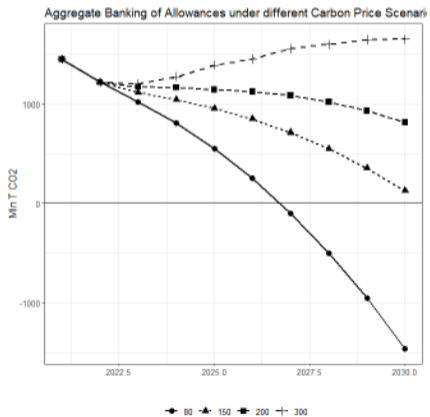Simulation of emission under alternative carbon price level and freely allocated allowances

emissions (CP=80) emissions (CP=150) emissions (CP=200) emissions (CP=300) free
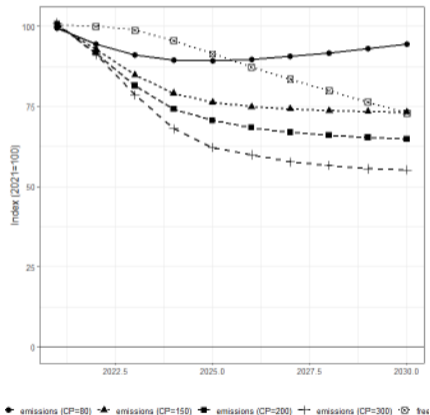
Counterfactual Analysis: policy stringency

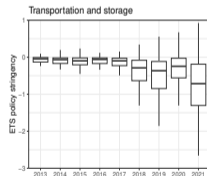Simulation of expected policy stringency under alternative carbon price level

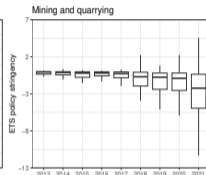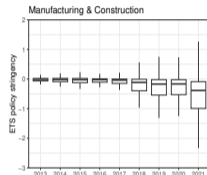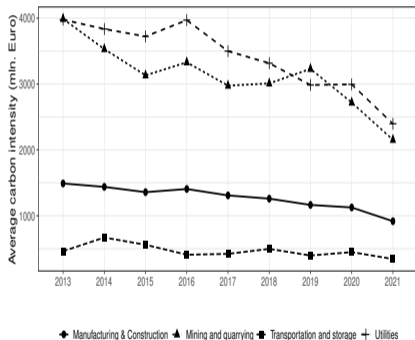Weighted average policy stringency under different Carbon Price Scenario

Counterfactual Analysis: bank of allowances

Simulation of Total Number of Allowances in Circulation under alternative carbon price level

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Emissions intensity based figures

Data - EU firms subject to EU ETS scheme (2013-2021)

- Installation-level Verified Emissions and Allocated Allowances (source: EU-ETL):
- Firm-Level Financial Data and Characteristics (Source: Orbis Bvd):
  - NACE sectoral classification
  - Matching installations to firms (Letout (2021))
  - Total assets, fixed assets ratio
  - Return on assets (ROA)
  - Firm cash holding, debt-to-asset ratio, listing status
  - Firm age, changes in number of installations, geographical location
- Macro variable (Source: LSEG):
  - European Union Allowances carbon price futures (yearly average)