| Motivation 000000 | Research questions | Main findings | Data 00 | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendi: 000 |
|----------------------|--------------------|---------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Mind the emission gap

Policy stringency matters

L. Bortolan¹ L. Prosperi² L. Taschini³ L. Zanin²

¹Eni Plentitude

²Prometeia

³University of Edinburgh Business School

⁴University of Bologna

European University Institute - November 2024

| Motivation ●00000 | Research questions | Main findings | Data 00 | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------|---------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Motivation

▲□▶▲圖▶▲≣▶▲≣▶ ≣ めぬぐ

| Motivation | |
|------------|--|
| 00000 | |

Policy stringency

Analysis

Counterfactual Analysis

Appendix

Policy stringency in the archive

| DES DES CLASPENALES | Bruzalian, in 24 avril 1965 Adatus int |
|--|--|
| Secretarial General | 0/88/110 |
| 502(42)468 | 0.J. 2103 - point 15.4 |
| | |
| | |
| COMPLEX WITHIN ON | ATORY BOLUTIONS EC 002 / ENERGY TAX |
| Note du cabi | net de M. DANCEAURA |
| | |
| lle question est inscrite à l'orde la Commission le mercredi 29 avri | e du joer de la 1103ème réunion 1 1982. |
| Instaires : Mambres de la Comeles MA. PERISSICH, KREM COLUMA, FRISCH, BRIS | ICO LER, RAVASID, EMLEMMANN, LEGRAS, BICEST, FASELLA, MANIATOPORAS, MILWOFT, |

....

2. Institutional possibilities of instamentation

4. Time of tax satissiion or assessment

Compensation should as a rule be possible in advance (tax deforment). since without such as arrangement firms would be deprived of precisely those funds which they need for the needined investments. Firms wishing to make investments should therefore be freed from the burden of additional withdrawal of liquidity.

Tax deferment should not, however, be granted unconditionally. One possible solution that wight be feasible would be to first it to the possible solution that might be reacted in a compensatory arrangement that 16% of the total investment for the proposed project has already have made

There should, however, be three years' grace between the entry into force of the tax and the beginning of tax liability, to enable the firms force of the tax and the beginning of tax trability, to ensure the first to take steps to improve energy efficiency without having to pay tax... Otherwise, such a "simula tax" would put be of a punitive rature.

B. Possibilities of offsetting the las

For reducing or avaiding the imposition of tax by means of offsetting or Per remaining or assisting the imposition of tax by manual or orfineting) making allowance for compensatory measures, the cents of action to restance OD, or the quantities of OD, actually maved are latent into correldentiation. In any case the fiftee are required to furtain or identee. of the solles lakes.

at offeatting the questity of COs reduction equinat COs/energy tax

This alternative would make tax exemption dependent on the quantity of CDs arout.

For this, bosover, the limits of offsetting would have to be specified. For this, however, the limits of offsetting would make to be specify i.e. to shat extent quantities of CDy saved can be converted into a tax deduction. This applies both to tax exemption or tax deduction through Cog reductions actually achieved and to tax deforment for COg reductions definitely planned.

One problem in perticular is that the number of tonnes of COg * -here in one problem in perticular is that the number of conves of coon indicator as to provide to impossible to ontermine statity. Then emissions are therefore virtually useless as a yardstick since variations in predation cause fluctuations in capacity utilization and house varying output of trace games affecting the climate.

C.coninanter'





Limited emissions reductions in non-electricity sector



Relative evolution of emissions (2005 = 100)





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



+ 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.

< ロ > < 同 > < 回 > < 回 >

Differences in regulatory stringency: stylized facts 2/3

Policy stringency



Motivation

◆ Manufacturing & Construction ▲ Mining ➡ Transportation + Utilities

• Emission reduction disparities across sectors not solely driven by industry characteristics.

Counterfactual Analysis

- 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 Utilities Transportation Mining Manufacturing & Construction -115 -95 -75 -55 -35 25 45 65 85 ∆ log(Carbon Emissions) x 100

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

| Motivation 000000 | Research questions ●0 | Main findings 00 | Data 00 | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------------|---------------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

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?

Policy stringency

Contribution:

Research questions

- 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.

Counterfactual Analysis

| Motivation 000000 | Research questions | Main findings ●○ | Data oo | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------|---------------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Main findings

▲□▶ ▲□▶ ▲目▶ ▲目▶ 目 のへで



- 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.

| Motivation 000000 | Research questions 00 | Main findings 00 | Data ●0 | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------------|---------------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Data

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

Data

00

• Installation-level Verified Emissions and Allocated Allowances (source: EU-ETL):

Policy stringency

Analysis

Counterfactual Analysis

- 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)

| Motivation 000000 | Research questions | Main findings | Data 00 | Policy stringency ●00 | Analysis 000000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------|---------------|------------|--------------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Policy stringency

▲□▶ ▲□▶ ▲目▶ ▲目▶ 目 のへで

Mind the compliance gap: Policy stringency

Main findings

• Firm's compliance problem:

$$\begin{split} \min_{\alpha,\beta} \mathbb{E} \Bigg[\sum_{t=0}^{T} C(\bar{e}_t - e_t(p_t, \bar{e}_t)) + p_t \cdot \beta_t \Bigg] \\ \text{s.t.} \ E_T - A_T = \sum_{t=0}^{T} \alpha_t + \sum_{t=0}^{T} \beta_t \end{split}$$

Policy stringency

000

Analysis

Solving → C'(α_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

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

・ロ・・母・・ヨ・・ヨ・ ヨー うへぐ

Counterfactual Analysis

Appendix

Motivation Notivation Notivation



Policy stringency:

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

average annual expected compliance cost over the next 10 years

| Motivation 000000 | Research questions | Main findings 00 | Data 00 | Policy stringency | Analysis •00000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------|---------------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Analysis

▲□▶ ▲□▶ ▲ 臣▶ ▲ 臣▶ ─ 臣 ─ のへぐ

| Motivation 000000 | Research questions | Main findings | Data 00 | Policy stringency | Analysis 0●0000 | Counterfactual Analysis | Appendix 000 |
|----------------------|--------------------|---------------|------------|-------------------|--------------------|-------------------------|-----------------|
| The m | odel | | | | | | |

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

Firm-specific variables:

- Policy stringency: $1/10 \sum_{k=1}^{10} \left[(a_{t+k} e_t) \times P_t / \text{Sales}_t \right]$
- 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.
- $\gamma_{\rm s}~{\rm NACE}$ two-digit sector fixed effects
- $\gamma_{\rm s} imes \mu_t$ NACE two-digit sector-time interaction fixed effects

| Motivation | Research questions | Main findir |
|------------|--------------------|-------------|
| 000000 | 00 | 00 |

indings

Policy stringency

Data 00 Analysis 00●000 Counterfactual Analysis

(4回) (4回) (4回)

Appendix 000

Full sample analysis

| | Dependent variable: $\Delta \log Emissions$ | | | | | | | |
|-------------------------------------|---|------------|------------|-----------|--|--|--|--|
| Variables | Model 1 | Model 2 | Model 3 | Model 4 | | | | |
| 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** | | | | |
| 25.20 | (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*** | | | | |
| 9 | (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 × 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 | 258,947.3 | | | | |
| BIC | 262,369.52 | 262.305.33 | 262,369.52 | 262,305.3 | | | | |

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

19 / 29

э

| 5.4. | | | |
|------|------|-----|---|
| | עודנ | | n |
| | | | |
| OC | | 000 | |

Main findings

Policy stringency

Data 00

Analysis

Counterfactual Analysis

▲□ ▶ ▲ □ ▶ ▲ □ ▶

Appendix 000

Sectorial analysis

| | Dependent variable: $\Delta \log Emissions$ | | | | | | | |
|-------------------------------------|---|------------|------------------|-----------------|--------------------|--|--|--|
| Variables | 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) | | | |
| Fized effects | | | | | | | | |
| Country | Y | Y | Y | Y | Y | | | |
| NACE two-digits | Y | Y | Y | Y | Y | | | |
| Year | Y | Y | Y | Y | Y | | | |
| NACE two-digits ×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

3

Robustness analysis: alternative stringency definition

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

$$\mathsf{NPS}_{i,t} = rac{1}{10} \sum_{k=1}^{10} \left[rac{(a_{i,t+k} - e_{i,t}) imes P_{t+k}}{\mathsf{Sales}_{it}}
ight]$$

Policy stringency

Analysis

Counterfactual Analysis

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

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

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

Appendix

| Motivation | Rese |
|------------|------|
| 000000 | 00 |

Policy stringency

Analysis 00000● Counterfactual Analysis

米田 と 米 ヨ と 米 ヨ と

Appendix 000

Robustness analysis

| | Dependent variable: $\Delta \log$ Emissions | | | | | | |
|-------------------------------------|---|-------------|-------------|-------------|-------------|--|--|
| Variables | Policy stringency | 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) | | |
| lac(Fixed Assets) | 0.64** | 0.68** | 0.84*** | 0.63* | 0.66* | | |
| and a second second second | (0.33) | (0.33) | (0.32) | (0.33) | (0.33) | | |
| log(Cash holding) | 0.46** | 0.47** | 0.45** | 0.44** | 0.46* | | |
| Provident House (P) | (0.20) | (0.20) | (0.20) | (0.20) | (0.20) | | |
| lag(ROA) | 0.55*** | 0.64*** | 0.70*** | 0.48** | 0.62 | | |
| mg(recort) | (0.90) | (0.20) | (0.20) | (0.20) | (0.20) | | |
| ROAV? | -0.30** | -0.99** | -0.95*** | -0.21** | -0.225 | | |
| ing(nora) | (0.00) | (0.00) | (0.00) | 10.000 | (0.00) | | |
| load A ma of finne) | (0.09) | (0.09) | (0.05) | (0.09) | (0.09) | | |
| og(age of nem) | -0.02 | (0.10) | (0.05 | -0.06 | 0.02 | | |
| Internet Barrow (March) | (0.10) | (0.10) | (0.10) | (0.10) | (0.10) | | |
| Listed firm (Yes) | -0.14 | -0.15 | -0.14 | -0.12 | -0.14 | | |
| | (0.17) | (0.17) | (0.17) | (0.17) | (0.17) | | |
| og(Assets) | -6.27 | -6.22 | -10.33 | -7.15 | -5.80 | | |
| | (6.30) | (0.43) | (0.31) | (0.35) | (0.41) | | |
| 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 | | | | 10.00 | 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 ×Year | Ŷ | 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

э

| Motivation 000000 | Research questions | Main findings | Data 00 | Policy stringency | Analysis 000000 | Counterfactual Analysis •000 | Appendix 000 |
|----------------------|--------------------|---------------|------------|-------------------|--------------------|---------------------------------|-----------------|
| | | | | | | | |

Counterfactual Analysis

・ロト・日本・モート モー シック



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) 🙁 tree



Counterfactual Analysis: policy stringency

Simulation of expected policy stringency under alternative carbon price level



◆ B0 -▲ 150 ● 200 + 300



Counterfactual Analysis: bank of allowances

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



🛨 80 📥 150 🖶 200 🕂 300

| Motivation 000000 | Research questions 00 | Main findings | Data 00 | Policy stringency | Analysis 000000 | Counterfactual Analysis | Appendix ●00 |
|----------------------|--------------------------|---------------|------------|-------------------|--------------------|-------------------------|-----------------|
| | | | | | | | |

Appendix

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 のへで



Emissions intensity based figures



+ Manufacturing & Construction + Mining and guarrying + Transportation and storage + Utilities



イロト イヨト イヨト イヨト 二日

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

• Installation-level Verified Emissions and Allocated Allowances (source: EU-ETL):

Policy stringency

Analysis

Counterfactual Analysis

人口区 人間区 人居区 人居区

- 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)

Appendix