EUROPEAN CENTRAL BANK

EUROSYSTEM

Working Paper Series

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Financing the low-carbon transition in Europe

No 2813

Abstract

Using evidence from the EU emissions trading system, we collect verified emissions of close to 4000 highly polluting and mostly non-listed firms responsible for 26% of EU's emissions. Over the period 2013 - 2019, we find a non-linear relationship between leverage and emissions. A firm with higher leverage has lower emissions in subsequent years. However, when leverage exceeds 50%, a further increase is associated with higher emissions. Our difference-in-differences approach sheds light on the existence of a group of firms that are too indebted to successfully accomplish the low-carbon transition, even when they face a steep increase in the cost of their emissions.

JEL classification: C58, E58, G32, Q51, Q56, Q58
Keywords: low-carbon transition; climate change; debt finance; transition finance; EU ETS

Non-technical summary

With the *Fit for 55* plan and the *European Green Deal*, the European Commission set the goal to reduce greenhouse gas emissions by 55% by 2030 and to reach carbon neutrality by 2050. To direct European firms toward the path of the low-carbon transition, the EU introduced in 2005 an economic mechanism of carbon pricing based on an emissions trading system. This system imposes a cap on emissions of fossil-fuel-intensive businesses in Europe, in particular covering firms that are active in industries such as aviation, electricity supply, and manufacturing of chemicals and metals. The system encourages emissions reduction by decreasing the cap every year and by putting a price on tradable emissions. Firms subject to such a cap-and-trade mechanism need adequate financing to adopt clean technologies and reduce their emissions without constraining their economic activity. The EU's 2019 *Green Deal* acknowledges that financing is central to achieving emission reduction. In particular, European firms subject to a cap on their emissions are mostly non-listed and heavily reliant on debt financing. Therefore, the development of debt markets and the understanding of the debt-emissions nexus is crucial to efficiently reaching carbon neutrality.

We rely on evidence from a sample of almost 4000 firms subject to the EU emissions trading system (EU ETS) that are responsible for approximately one-third of the EU's greenhouse gas emissions to study how European firms' debt finance relates to changes in emission. We find that firms' leverage matters for their ability to reduce their emissions. Firms with higher leverage produce significantly lower emissions without constraining their economic activity. In fact, they reduce their carbon footprint through cleaner production. Moreover, when firms increase their leverage, their transition performance improves overall. Relying on existing theory and previous findings, we explain that firms with adequate debt financing can reduce their emissions through investments in the adoption of green technologies. Although this holds true up to a certain level of leverage, we find that when leverage is too high, firms produce significantly higher emissions. This is consistent with theoretical models showing that high indebtedness constraints firms' capacity to undertake profitable — and in our case green— investment opportunities.

In particular, we investigate firms' reaction to the steep increase in the cost of their emissions caused by a tightening of the regulatory framework of the EU ETS. We find that

highly indebted firms did not reduce their emissions even when exposed to this growing constraint on their emissions, while other firms successfully did so. The study sheds light on the existence of a group of European firms that are too indebted for transition. We show that such firms do not employ their debt financing to improve their transition performance, even when they are exposed to an increasingly constraining cost of emissions.

Our study highlights debt financing as a valid channel to enable the low-carbon transition of firms subject to the EU ETS while sustaining their economic activity. The findings indicate that the availability of suitable debt financing is key to ensuring the effectiveness of the EU ETS to prompt firms to reduce emissions. After an increase in the cost of emissions in the system, this policy instrument has proven its ability to effectively encourage firms to reduce their emissions, but this held true only for firms with suitable leverage levels. Similarly, we show that the EU ETS is not a self-sufficient tool to push firms on the path of the low-carbon transition if they are excessively indebted. Finally, we document that firms subject to the EU ETS generally do not rely on green debt financing. Therefore, we pose that the development of green debt markets, including transition finance, could allow those firms that are highly indebted, yet have high growth potential, to obtain financing by committing to a green use of proceeds, in turn, allowing them to reduce their emissions.

1 Introduction

Reducing drastically greenhouse gas emissions is key for mitigating climate change (IPCC, 2021). Firms generally do not internalize in their decision-making the considerable social cost related to the greenhouse gases that they generate, which is described as a negative externality[1] (Common and Stagl, 2005; Perman, Ma, Common, Maddison, and McGilvray, 2011). Correcting for this negative externality can be achieved through economic mechanisms of carbon pricing such as carbon tax or a cap-and-trade policy. Subject to such constraints and provided with adequate financing opportunities, firms can be enabled to direct their corporate investments toward the adoption of cleaner technologies. The European Union's 2019 *Green Deal* acknowledges that financing is central to achieving emission reduction. Literature shows that finance can have a key role in the low-carbon transition as, through the pressure of stock markets, equity can be reallocated towards greener firms (De Haas and Popov, 2023; Bolton and Kacperczyk, 2021b). However, in the EU, most firms are not exposed to the stock market. Indeed, the vast majority of European firms are non-listed and debt finance is the primary source of non-financial corporations' external financing[2]. Given the relevance of debt finance in Europe, leverage could affect the (path of) low-carbon transition of European firms (Alogoskoufis, Dunz, Emambakhsh, Hennig, Kaijser, Kouratzoglou, Muñoz, Parisi, and Salleo, 2021).

In this paper, using historical data for close to 4000 European firms subject to the EU Emissions Trading System (EU ETS), which is the EU's cap-and-trade policy instrument, we study how European firms' debt finance relates to changes in emissions. Specifically, we ask whether pre-existing leverage hinders firms' response to carbon price shocks. Our sample covers mostly non-listed firms and includes a large share of small and medium enterprises. Particularly, our analysis focuses on the financing structure of the firm, while accounting for the role of other financing-related indirect factors such as carbon permits, fossil fuels subsidies, green debt, carbon price, and energy mix.

The EU ETS regulates emissions produced by most fossil-fuel-intensive economic activities. Its main goal is to reduce the aggregate level of emissions under the cap-and-trade

[1] A negative externality exists when the production or consumption of a product result in a cost to a third party.

[2] The euro area financial structure is characterized by non-marketable financing instruments, i.e., loans and unlisted shares, while listed shares represent a very small part. See e.g., ECB (2020).

policy, while its longer-term goal is to foster innovation and adoption of clean technologies (Martin, Muûls, and Wagner, 2020). For this purpose, each installation subject to the EU ETS is allocated yearly a limited amount of allowances (EUAs) to emit for free a given amount of CO2 equivalents. If an installation's yearly emissions exceed its total amount of free EUAs, it will have to purchase additional EUAs to cover its excess of emissions. Conversely, operators with a surplus of EUAs may store them or trade them in a system of auctions with those with a deficit of EUAs. Where a firm fails to provide EUAs covering the amount of its verified emissions for the past year, it has to pay a penalty[3].

Based on a set of EU ETS-regulated firms, we find that a firm's leverage matters for its ability to reduce emissions. A firm with higher leverage has lower emissions and better emission efficiency in the following years, as measured by the revenues per unit of emission. The relation is non-linear: when leverage is below 50%, higher leverage is associated with better ETS transition performance, but not pass this threshold. We investigate firms' reaction to the introduction of the March 2018 ETS directive that imposed a more stringent cap on emissions and was accompanied by a steep rise in emission allowances prices. Highly indebted firms exposed to the price increase did not succeed in reducing their emissions, while other firms successfully did so. Our interpretation of such findings builds upon the economic mechanism of carbon pricing in the EU ETS, investments, and emissions: the EU ETS may encourage the use of debt to invest in the adoption of green technologies that enable firms to achieve their low-carbon transition unless firms are highly indebted (potentially constrained). The study sheds light on the existence of a group of firms that are too indebted for transition, although subject to a constraint on their emissions and even when such constraints become more binding. Our analysis further shows that the improvement observed in emission efficiency after an increase in leverage is attributable to a reduction in firm-level absolute emissions. This result discards the possibility that the firm improves its emission efficiency purely by increasing its revenues without actually investing in the adoption of green technologies that allow for cleaner production. While our results are consistent with the narrative that firms invest in the adoption of green technologies to reduce their emissions, they

[3] See for instance Ellerman, Marcantonini, and Zaklan (2020) for a history of EU ETS, its functioning with respect to emissions, allowance prices, and the use of offsets, and overall performance for reducing emissions.

may also align with the narrative that carbon pricing encourages firms to relocate emissions or investments outside the EU ETS (carbon leakage). Relying on existing evidence, we argue that the former channel significantly prevails and we discuss the robustness of our analysis.

In addition to leverage, we account for firms' revenues, profitability, and age, but also firm-specific environmental factors, such as the number of plants with carbon-intensive activities, and country-specific environmental factors, such as fossil fuel subsidies, as possible determinants of firms' low-carbon transition. Only a very limited number of firms in the sample relied on green debt between 2013 and 2019, suggesting that debt financing of ETS active firms has been driven so far foremost by means of traditional debt instruments. The channel that we describe is particularly significant for non-listed firms and it is relevant for firms belonging to all sectors regulated by the EU ETS. Finally, the source of debt financing of European firms is predominantly bank-based and the share of market-based debt finance does not seem to affect these findings.

We test our hypotheses about the existence of a non-linear relationship between debt finance and emission reduction using a difference-in-differences approach based on the findings of a panel regression analysis. Potential endogeneity concerns are addressed in our empirical design as well as through robustness analysis. We construct a novel dataset covering yearly verified emissions and debt finance data of close to 4000 non-financial firms subject to the EU ETS from 2013 to 2019. The emissions of each installation subject to the EU ETS are verified by a third party and they are made available yearly on the public website of the European Union Transaction Log (EUTL). We identify the firm corresponding to each operator that owns installations within the EUTL and we aggregate the ETS verified emissions at the firm level. We further collect firm-specific financial and economic factors, firm-specific environmental factors, and country-specific environmental factors. This dataset represents close to one-third of EU total emissions. The emission data collected only refers to firms that can be attributed as being subject to the cap-and-trade climate policy instrument and herewith cap-and-trade-constrained[4].

[4]See Section 3 for a detailed description of the ETS emissions data. ETS emissions relate to the Scope 1 emissions of the firm. To date, there are no EU-wide mandatory reporting requirements in place for firms to report both their ETS emissions and Scope 1 emissions. Under the EU CSRD, firms shall be required to report the share of ETS emissions in Scope 1 emissions. Methodological variations in the computation of Scope 1 emissions and ETS emissions of a firm make these two metrics not easily comparable (e.g. different set of greenhouse gases, use of different organizational-boundary-setting methodologies equity-based approach or control approach — operational control or financial control —

This paper contributes to three strands of the climate economics literature: (i) the EU ETS as a determinant of firms' emissions reduction and energy efficiency improvement, (ii) the role of firms' financial structure, financing opportunities, and financial constraints in reducing emissions and (iii) the role of debt in the low-carbon transition.

The first stream of literature assesses empirically the role of the EU ETS for regulated firms' low-carbon transition. Albeit sorting out the effects of the EU ETS on emissions reduction from other factors is not trivial, particularly in the light of concomitant use of other climate policy instruments (e.g. feed-in tariffs, renewable energy obligations), there is robust evidence that EU ETS had a negative effect on emissions (Ellerman and McGuinness, 2008; Anderson and Di Maria, 2011; Wagner, Muûls, Martin, and Colmer, 2013; Petrick and Wagner, 2014; Ellerman, Marcantonini, and Zaklan, 2020). The literature on clean production documents that clean innovation has increased since the launch of the EU ETS in 2005 (Martin, Muûls, and Wagner, 2020). Furthermore, ETS-regulated firms showed a larger increase in low-carbon patents compared with non–regulated firms (Calel and Dechezleprêtre, 2016), suggesting that carbon pricing is related to an uptick in green innovation (Känzig, 2021; Martin, Muûls, and Wagner, 2013; Borghesi, Cainelli, and Mazzanti, 2015). Our contribution is to show that the emissions cap of the EU ETS, strengthened across Phase 3, has pushed regulated firms to reduce their emissions. However, we show that the system alone is not a sufficient tool to achieve the transition if not paired with suitable financing opportunities.

The literature on the role of firms' financial structure, financing opportunities and financial constraints in the low-carbon transition is still in its infancy. Macroeconomic literature suggests that economies that are relatively more equity-funded are greener (De Haas and Popov, 2023). Theoretically, under different carbon regulations, the investment decisions of emissions-intensive firms result in a change of the production cost structure and/or production quantity (Jiang and Klabjan, 2012). Furthermore, factors such as credit constraints and green managerial constraints may affect a firm's green investment decisions as documented by De Haas, Martin, Muûls, and Schweiger (2022). Howell (2017) shows that relief of financial constraints is associated with more patents, especially for firms in industries related to clean energy and clean production. Moreover, financially constrained firms experience higher emissions as they face either the cost of the

in carbon accounting).

transition or possible legal costs of their pollution (Xu and Kim, 2022). Overall, whilst preliminary analysis suggests that more indebted firms in Europe tend to invest less in energy efficiency and reduce less their emissions (Maurin, Barci, Davradakis, Gereben, Tueske, and Wolski, 2021), the microeconomic effect of debt finance on emission reduction received little attention. Firstly, we contribute to the literature on green finance by showing that debt financing is a determinant of the transition of European non-listed firms subject to the EU ETS. Secondly, we also highlight the existence of a group of firms that are too indebted to abate their emissions and improve their clean production. While highly indebted firms with low growth prospects may have to leave the market to more emission-efficient firms, highly indebted firms with high growth prospects require suitable transition finance solutions to enable them to reduce emissions.

Finally, the literature on green finance is very heterogeneous ranging from traditional bank and market-based finance to ESG investing and green bonds. The literature that studies debt as a source of external financing for the low-carbon transition has focused so far on the providers of debt finance (bank-based vs bond-based) and the role of green bonds. Beyene, De Greiff, Delis, and Ongena (2021) show that fossil fuel firms source debt from banks that price the risk of stranded assets whilst the bond market already does. Kacperczyk and Peydró (2021) find that after making an SBTi commitment, banks reduce loans to brown firms and increase loans to green firms, while not being able to encourage brown firms to reduce their emissions. Degryse, Goncharenko, Theunisz, and Vadasz (2021) find that after the Paris Agreement, firms are rewarded for being green in the form of cheaper loans only when borrowing from banks that adhere to greenness. The evidence on green bonds' role in reducing emissions on firm-level is inconclusive. Some studies find that firms that issue green bonds reduce their GHG emissions (Flammer, 2021; Fatica and Panzica, 2021), while another study does not confirm this relationship (Ehlers, Mojon, and Packer, 2020). Empirical research on green loans' role in reducing emissions in Europe is scarce (see e.g., Gilchrist, Yu, and Zhong, 2021 for a literature review). We contribute to this literature by examining the propensity of firms to use debt financing to improve their transition performance, and how this changes for highly indebted firms. Additionally, we document the scarce use of green debt among firms subject to the EU ETS. Finally, our analysis provides insights on a wide sample of carbon-intensive firms that is still mostly unexplored in the strand of literature on green finance.

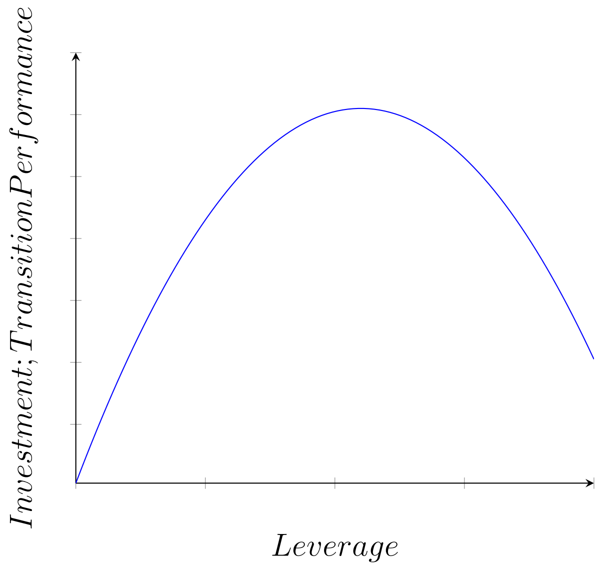
From an empirical design perspective, this study has three distinctive features relative to existing literature. First, we analyze the low-carbon transition of firms that are subject to an explicit constraint on their emissions as they are subject to the EU ETS. Second, whereas existing studies focus on listed firms or large firms only, we assess both listed and unlisted firms, large as well as small and medium enterprises. Third, we move beyond inferred or non-verified measures of emissions to develop a novel firm-level dataset with verified disclosed emissions. This feature reduces the risk of greenwashing that characterizes self-reported or inferred emissions data (Busch, Johnson, and Pioch, 2020; Kalesnik, Wilkens, and Zink, 2020). By comparison, most existing studies on green finance use non-verified emissions, focus on listed firms, and do not account for an explicit climate policy constraint. From a policy perspective, our work provides valuable insights on the effectiveness of the EU ETS, on firms' access to transition finance and contributes to the discussions related to the role of debt financing within this framework.
The rest of the paper is organized as follows. Section 2 presents the theoretical background and the set of hypotheses as well as the empirical strategy. Section 3 describes the dataset and presents stylized facts. Section 4 discusses the main results including robustness tests. Section 5 concludes and discusses policy implications.

2 Theoretical background and empirical predictions

The stream of literature on corporate debt and investments documents two opposing forces descriptive of the relationship between leverage and investment. Firms can benefit from corporate debt financing throughout tax advantages and reduced agency costs (Modigliani and Miller, 1958, 1963; Ross, 1977; Grossman and Hart, 1982). This allows firms to channel a higher share of debt financing towards profitable investment opportunities. However, high indebtedness may hold back investment. Accounting for supply-side constraints, firms may face higher barriers to raising new external financing. On the demand side, they may need to direct a higher share of their debt financing towards the coverage of rising servicing costs (Myers, 1977). Given the two opposing forces, the static trade-off theory on debt and investment hints at a non-linear relationship between debt financing and investment (as in Figure 1). Empirically, Gebauer, Setzer, and Westphal (2018) provide evidence of the concave relationship between debt and investment for a set of European firms and further empirical literature provides suggestive evidence that high corporate leverage may negatively affect investment (Barbiero, Popov, and Wolski, 2020; Kalemli-Özcan, Laeven, and Moreno, 2018; Gebauer, Setzer, and Westphal, 2018; Hernando and Martínez-Carrascal, 2008; Martinez-Carrascal and Ferrando, 2008).

Figure 1: Theoretical relation between leverage and investment of a corporate firm

Notes: The figure provides an illustration of the theoretical non-linear relationship between leverage and investment as well as between leverage and transition performance as measured by emission efficiency.

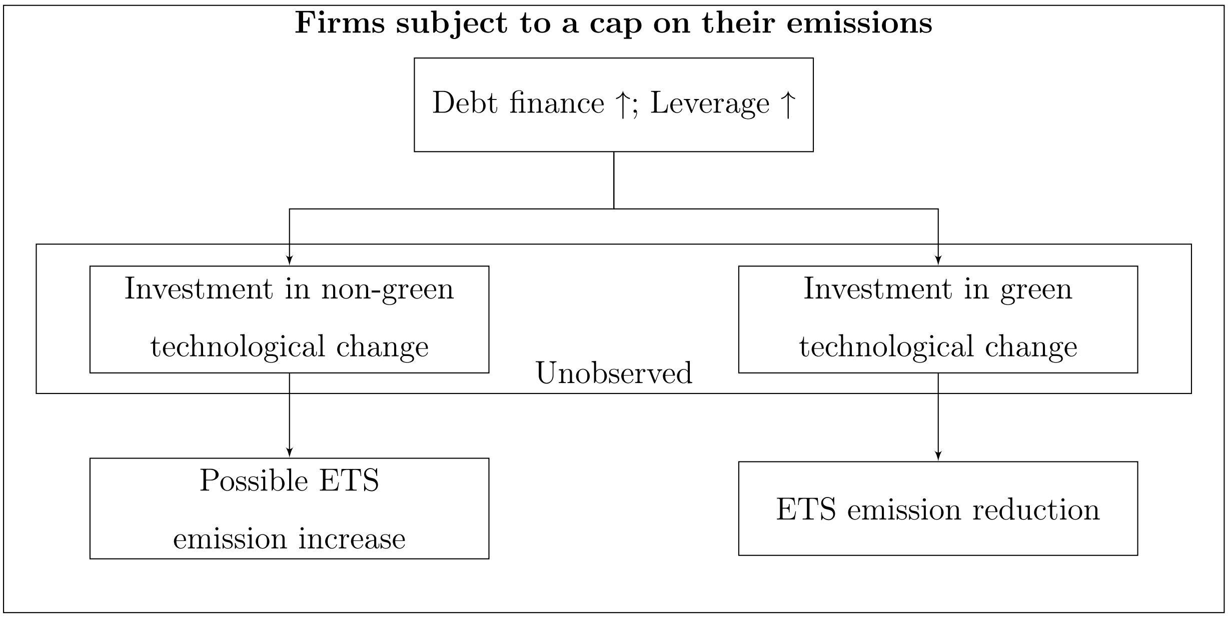


This study relies on corporate finance literature on firms' capital structure and environmental economics literature to disentangle the role of corporate debt in financing firms' investments in the adoption of technological change needed to achieve the low-carbon transition.

The literature on environmental economics clarifies that greenhouse gas emissions are a negative externality (Nordhaus, 1991). If firms' decisions are primarily based on financial gains and do not include considerations related to externalities, greater economic activity could imply higher GHG emissions (Helbling, 2017). In this paradigm, to comply with the EU ETS cap, a firm would need to produce less and / or invest in substituting its emissions-intensive technologies with less polluting ones. Financing is central to enabling firms subject to a cap on their emissions to invest in their low-carbon transition, without reducing their economic activity. The ECB economy-wide stress test describes that "under the transition scenarios we assume that firms at the onset of transition [corporate firms] take out debt to invest in green technologies that will allow them to achieve the necessary emission reductions" as debt finance is the primary source of external financing of non-financial firms in Europe (Alogoskoufis, Dunz, Emambakhsh, Hennig, Kaijser, Kouratzoglou, Muñoz, Parisi, and Salleo, 2021). In a simplified illustration of debt-investment links (Figure 2), firms that are subject to a cap on their emissions may use their debt financing to invest in the adoption of clean technologies or for any other purpose (e.g., debt servicing and other types of investment). Eventually, an investment in green technological change allows firms to approach low-carbon transition goals. Whereas generally firms' leverage and firms' emissions are observed, the choice of the firm to invest in the adoption of green or non-green technologies is unobserved.

Figure 2: Link between debt finance, investment, and transition performance

Notes: The Figure illustrates the theoretical link between external financing, investments and emissions for firms subject to the EU ETS.



Building upon the link between leverage, investment, and emissions and on the theoretical characterization of the non-linear relationship between leverage and investment, we pose that there is a non-linear relationship between ETS firms' leverage and their transition performance (see Figure 1)[5]. Our empirical prediction is that firms subject to the EU

[5] The idea to estimate debt overhang through a non-linear, quadratic relationship between leverage and investment was developed by Mosk and Pietsch (2023). We thank the authors for sharing their ideas at an early stage.

ETS and having a relatively low leverage ratio are less constrained by debt, more flexible to raise external finance to invest in adopting the technologies needed in order to accomplish their low-carbon transition, and ultimately display better transition performance. However, when these firms' leverage is relatively high, they can channel a lower share of financing towards investments in technological change. High leverage reduces firms' opportunities to raise external finance to achieve better transition performance.

The assumption of our analysis is that firms do not use investments to shift emissions outside the cap-and-trade system (discussed in Section 4.4).

Empirically, our research asks whether firms' leverage, as measured by their debt-to-assets ratio, constraints their ability to reduce their future emissions. Therefore, as a first step, we test whether a relationship between firms' leverage and transition performance exists.

H1. There is an inverse U-shaped relationship between the level of transition performance of a firm within the EU ETS and its leverage.

H2. A leverage increase is associated with an increase in transition performance when leverage does not exceed a certain level.

As a second step, we examine the relationship between the two variables in the context of the entry into force of the March 2018 EU ETS Directive[6]. The event is considered as the reason for the strengthened credibility of the EU ETS and offers the opportunity to exploit the variation in firms' behavior in relation to a steep increase in emission prices, which translates into increased pressure on their emission reduction efforts (Ampudia, Bua, Kapp, and Salakhova, 2022).

H3. Highly leveraged firms exposed to rising EUAs price are unable to reduce their emissions. Instead, other firms successfully do so.

To test our main hypotheses, we rely on a panel regression (for hypotheses 1 and 2) and a difference-in-differences approach (for hypothesis 3). We consider two possible measures of transition performance for a given firm: emissions and emission efficiency (as in De Jonghe, Mulier, and Schepens, 2020). The two measures reflect different yet both im-

[6]Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814 (OJ L 76, 19.3.2018, p. 3).

portant and complementary aspects of a firm's low-carbon transition and are consistent with the targeted metrics of the EU ETS: reducing aggregate emissions and improving emission efficiency. Firm-level emissions reflect firms' contribution to the economy-wide level of greenhouse gases; therefore emissions reduction is key in the perspective of achieving the economy-wide low-carbon transition. Emission efficiency expresses how many units of revenues the firm generates for each unit of emissions[7]. The higher the level of emission efficiency, the cleaner the production technology of the firm. Appendix B.1 provides technical input supporting this rationale. We measure leverage using total debt divided by total assets (as in Gebauer, Setzer, and Westphal, 2018).

The following equation is exploited to test hypothesis one:

$$\begin{aligned} TransitionPerformance_{i,t} = {} & \alpha + \beta_1 debttoassets_{i,t-1} + \beta_2 debttoassets^2_{i,t-1} + \\ & \beta_3' X_{i,t-1} + \gamma_{i,t} + \rho_i + \epsilon_{i,t} \end{aligned} \tag{1}$$

Equation 1 is quadratic in Debt-to-assets. This allows testing the non-linearity of the relationship between leverage and transition performance. $X_{i,t-1}$ is the vector of controls. In our preferred specification, we include $\gamma_{i,t}$ sector-time and ρ_i country fixed-effects. The coefficients resulting from Equation 1 allow us to compute the implied leverage threshold above which the relationship between Debt-to-assets and $TransitionPerformance$ inverts, in line with the economic mechanism that we aim at capturing. We obtain:

$$threshold = \frac{-\beta_1}{2\beta_2} \tag{2}$$

Equation 3 tests hypothesis 2 studying the relationship between first differences of transition performance and leverage depending on the firm's initial leverage being below or above the implied leverage threshold (computed in Equation 2).

$$\begin{aligned} \Delta TransitionPerformance_{i,t} = {} & \alpha + \beta_1 \Delta debttoassets_{i,t-1} X threshold_{i,t-1} + \beta_2 threshold_{i,t-1} \\ & \beta_3 \Delta debttoassets_{i,t-1} + \beta_4' \Delta X_{i,t-1} + \eta_t + \epsilon_{i,t} \end{aligned} \tag{3}$$

Where $\Delta X_{i,t-1}$ is the vector of the first-differences of the time-varying controls and η_t is

[7] Emission efficiency is the inverse of emissions intensity.

the time fixed effect. To confirm hypothesis 2, the coefficient should be negative when leverage is below the threshold and positive when leverage is above the threshold and transition performance is measured through emissions; vice versa should hold when transition performance is measured through emissions efficiency.

Finally, to test hypothesis 3, the following equation is exploited by the means of a difference-in-differences approach.

$$\begin{aligned} TransitionPerformance_{i,t} =& \alpha + \beta_1 treatmentXpostevent + \beta_2 treatment + \\ & \beta_3 postevent + \beta_4' \Delta X_{i,t-1} + \gamma_{i,t} + \theta_{i,t} + \epsilon_{i,t} \end{aligned} \tag{4}$$

In Equation 4 the coefficient of interest is β_1 which captures the average relative difference in emissions after the event for the treated firms, relative to control firms. In our preferred specification, the treatment dummy is equal to 1 for firms with a leverage above the implied leverage threshold (computed in Equation 2) and with a EUA balance below zero, i.e., firms that need to purchase additional EUAs to cover for their emissions in excess of their free EUAs, in the year prior the event (2017). The variable allows capturing firms that are highly indebted and exposed to rising EUAs prices. The dummy is equal to 0 for the remaining firms. We conduct robustness tests for alternative constructions of the treatment and control samples.

To address concerns related to omitted variable bias, we use a rich set of controls in addition to fixed effects: (i) firm-specific economic variables, (ii) firm-specific environmental variables, and (iii) country-specific environmental variables. The firm-specific economic variables are defined based on the limited literature on the determinants of emissions reduction. They include revenues, profitability, and the age of the firm (as in Xu and Kim, 2022; De Jonghe, Mulier, and Schepens, 2020; Bolton and Kacperczyk, 2021a; De Haas, Martin, Muûls, and Schweiger, 2022). Market-to-book is also a widely used control in literature. However, we exclude it from our regressions as 96% of the firms in our sample are non-listed. Firm-specific environmental variables are the balance and the cumulative balance of free allowances to emit net of ETS emissions and the number of ETS-regulated installations of a firm. We cumulate the EUAs balance of a firm to proxy its total number of EUAs in a given year accounting for the fact that firms can bank their EUAs. Country-specific environmental variables are the level of fossil fuel subsidies and a carbon tax indicator variable. This set of controls allows addressing endogeneity concerns by including common factors which may explain both leverage and transition performance, as documented in the literature (see for instance Gebauer, Setzer, and Westphal, 2018 for the literature on leverage and De Jonghe, Mulier, and Schepens, 2020 for literature on transition performance). Additionally, independent variables in our models are lagged relative to transition performance. We apply a lag of one year as well as of a lag of three years to reflect that certain technological changes may result in an improvement in transition performance in the next year (e.g., thermal insulation of a firm's building), while other technological changes are more time-intensive and would result in an improvement in transition performance over a longer time horizon (e.g., changing to clean cement production). Unobserved variation is captured in Equation 1 through country fixed effects and sector-time fixed effects. Country fixed effects are included to absorb unobserved and time-invariant country-specific characteristics (e.g., country-specific debt financing policies, potential economy-wide climate policies), while country-specific time-varying factors that might affect significantly firms' transition are included in the set of control variable as explained above. Sector-time fixed effects are included to account for unobservable macroeconomic factors on the sector level in given years and / or sector-level policy changes that may affect firms' transition performance (e.g., sector specific differences in debt financing policies, sector-specific energy policies). Sectors are defined using Nace 2-digits codes. The choice of country, industry, and time fixed effects is aligned with literature that aims at estimating the determinants of firm-level emissions (see e.g., Bolton and Kacperczyk, 2021a). As shown in Figure B3, firm-level emissions change little over time, but they vary substantially across firms. Therefore, we show in Section 4 that the inclusion of firm fixed effects within this panel regression on levels would absorb the effect of leverage, while differences in variability are more systematically related to country and sector (i.e., across firms). In Equation 3, unobserved variation is captured through year fixed effects, since time-invariant characteristics are differenced out in a first-difference estimation set-up. All standard errors are clustered on the firm level to account for serial correlation in error terms. In Equation 4, unobserved variation is captured through sector-year, country, and firm fixed effects (as in De Haas, Martin, Muûls, and Schweiger, 2022 among others).

We conduct additional robustness tests in Section 4.5.

3 Data

We construct a firm-level dataset based on observations of the EUTL on the verified greenhouse gas emissions of installations subject to the European Carbon Market (EU ETS), which reflects approximately 40% of the EU's CO2 emissions. The EUTL dataset allows mapping installations to their owners through national identification and trade registry numbers. Our mapping approach follows closely De Jonghe, Mulier, and Schepens (2020). Throughout Bureau van Dijk's Orbis database, we identify the non-financial corporations that own most of the installations in the EUTL and we retrieve financial and economic factors that may explain their transition performance. We also obtain further firm and country-level environmental factors as explained in Section 3.2. To construct our key variables, we compute firm-level verified ETS emissions and ETS emission efficiency, measured as revenues relative to emissions[8] as explained in Section 3.1. We obtain a dataset covering 3,724 firms over the period from 2013 to 2019. The period observed is the third phase of emissions trading in the EUTL, which is characterized by a homogeneous ETS regulation. The dataset is descriptive of 26% of the greenhouse gas emissions produced in the EU on average between 2013 and 2019. In Figure 3, we show a map of the installations that are owned by the firms in our sample and that produce verified greenhouse emissions within the EU ETS. In the dataset, most observations describe firms with legal registration in the European Economic Area, particularly Germany, France, Spain, and Poland, and entities in the Nace sectors of manufacturing and electricity, gas, and air conditioning supply, metals, manufacturing, and chemicals. The dataset includes small and medium European enterprises (SMEs), which we identify as entities with total assets below 43 million EUR[9] and represent approximately 40% of firms in our sample and non-listed companies. Overall, the sample is representative of the structure of the fossil-fuel-intensive section of the European real economy.

The sample composition by year, country, and Nace 1-digit sector can be found in the Online Appendix B.

[8]Data on the share revenues that are attributable to ETS emissions are not available. Therefore, to obtain emission efficiency, we divide ETS emissions by the firm's operating revenues from Bureau van Dijk's Orbis.

[9]We approximate the European Commission's classification of firms into small and medium enterprises (European Commission, 2021).

Figure 3: Map of installations active within the EU ETS in 2019

Notes: The Figure illustrates the installations owned by the firms in our EU ETS sample in 2019. Each dot represents one installation. Green dots are installations with free EUAs in excess of their emissions, vice versa for orange and red dots.

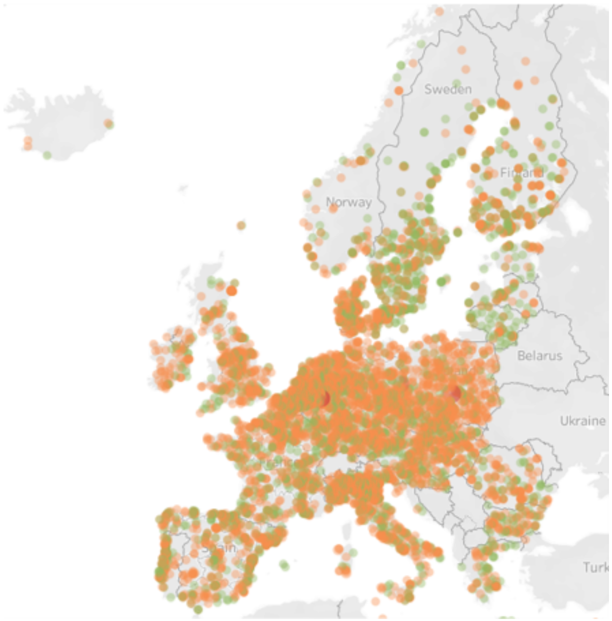
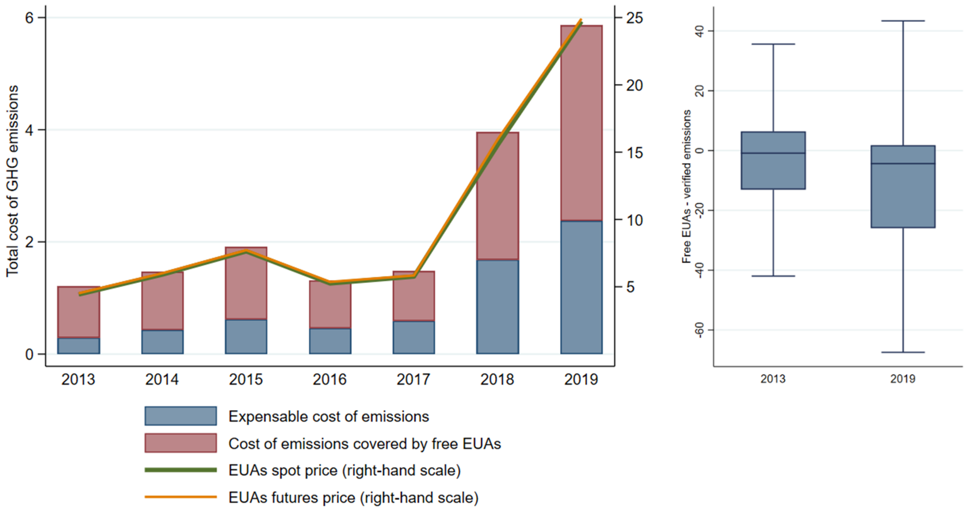


Figure 4: Cost of ETS emissions, EUA prices and distribution of EUA balance over time.

Notes: Left panel: cost of emissions faced by an average firm in the sample (in million euros, as shown in the left-hand side scale) and the level of EUA prices over time in phase three of EU ETS trading (in euros, as shown in the right-hand side scales). EUA futures prices reflect 12-month futures' prices. Right panel: distribution of firm-level EUA balance in 2013 and 2019.



Crucially, the sample includes only firms that own installations that are regulated by the EU ETS. Therefore, all firms in our sample are subject to a constraint on their emissions. Figure 4 left panel describes the magnitude of such constraint for the sample covered by our analysis. It shows the cost of emissions of the average firm in our sample, including a breakdown between the expensable cost of emissions and the cost of emissions covered by free EUAs. During the sample period, from 2013 to 2019, the total cost and expensable cost of emissions of the firms in our sample increased across time and especially from 2018. This was driven by the increase in the price of EUAs. The right panel of Figure 4 shows that comparing the distribution of EUA balances between 2013 and 2019, many more firms were experiencing a deficit of free EUAs in the latter year compared to the former. Therefore, our data suggest that the framework of our study is an increasing constraint on firms' emissions from the ETS.

In the following section, we describe the variables employed for the measurement of transition performance as well as the set of economic and environmental controls that we employ in the empirical analysis.

3.1 Measures of transition performance

Two measures of transition performance are analyzed. Consistently with the literature on the topic (see e.g., De Jonghe, Mulier, and Schepens, 2020), we rely on firm-level EU ETS verified greenhouse gas emissions and on emission efficiency, which we compute as the ratio of firm-level revenues on verified ETS emissions of their plants subject to the EU ETS[10]. To conduct our empirical analyses, we consider the log-transformation of the two measures of transition performance, which allows decreasing the skew in their distribution. Firm-level ETS emissions are the sum of the ETS emissions of the firm's installations that are subject to the EU ETS. ETS emissions are disclosed by firms at the installation level and verified by a third party. They compare to Scope 1 emissions of a firm as defined under the GHG protocol, albeit excluding methane (European Parliament and the Council, 2003) and excluding non-ETS eligible installations.

During the sample period, the firms in the sample have broadly experienced a limited reduction in the levels of their ETS emissions (Figure B3 in the Online Appendix B.2, left panel). Across the same period, firms have generally experienced an increase in their emission efficiency (Figure B3 in the Online Appendix B.2, middle panel). The

[10] An ideal metric would be revenues generated by the ETS plants relative to their ETS emissions, but plant-level financial data is not disclosed as ETS plants are not a legal entity, but an asset.

average firm in our sample has emissions of order of 250 thousand tonnes eCO2, emissions efficiency of 540 thousand EUR/eCO2, leverage of 18%, and total assets of 700 million EUR.

3.2 Determinants of transition performance

We collect entities' reference data (e.g., Nace Revision 2 codes and country of legal registration) and their yearly financial accounts (including total debt, total assets, return on assets, revenues) from Bureau van Dijk's Orbis. We select financials at an unconsolidated level. This allows to provide economic information at the level of the firm that is direct owner of the installations that produce and trade their emissions within the EU ETS. The description of the economic variables used in the analysis is found in Table 1. Our main variable of interest is leverage measured as debt-to-assets ratio and winsorized at 99% level. Total assets is equivalent to liabilities and equity, where the latter includes retained earnings; thus, it accounts for other sources of external and internal financing of the firm. We also collect data on whether the firm holds green debt. We find that out of our sample of almost 4000 firms, only a few have taken a green loan or issued green bonds. This is discussed in Section 3.3.

The dataset is enriched with firm and country-specific environmental variables. Relying on the EUTL database, we compute the number of installations subject to the EU ETS owned by each firm and the balance of emission allowances allocated to the firms in the sample. The balance is the difference between the EUAs allocated for free to the firm and its verified emissions. We also compute the cumulative sum of this variable to account for firms' possibility to store EUAs across years. Relying on the EUTL regulation, we also build a dummy indicating whether a firm is included within the carbon-leakage list by the European Commission (European Commission, 2009). These firms are deemed to be at risk of reallocating their production activity outside the EU, area of coverage of the EU ETS (this topic is further explored in Section 4.4).

At the country level, the dataset includes data on fossil fuel subsidies and carbon taxes. Data on fossil fuel subsidies is retrieved from Vernon, Parry, and Black (2021) and includes both explicit and implicit subsidies. The former undercharge supply costs and producer subsidies, while the latter undercharge environmental costs and consumption taxes. These are taken as a ratio of the GDP of the country. The variable is available from 2015, therefore the first available observation is carried back to the beginning of our time frame of interest, 2013. The country-level carbon tax flag is retrieved from Laeven and Popov (2021). The flag is equal to one in the years following the introduction of any type of explicit carbon tax by a given country. Carbon taxes are heterogeneous across the countries in the sample (e.g., taxes on transport and heating, on thermal energy, on fluorinated gases). The description of the firm and country-level environmental variables used in the analysis is found in Table 1. Summary statistics of our variables of interest are provided in the Online Appendix B.2.

Table 1: List of variables

Variable	Description	Source
Economic Variables		
Debt-to-assets	Ratio of total debt on total assets winsorized at 99% level.	Constructed
(Debt-to-assets)^2	Squared debt to assets.	Constructed
Total debt	Total debt at unconsolidated level.	Orbis
Total assets	Total assets at unconsolidated level.	Orbis
ln(Revenues)	Natural logarithm of sales and other operating revenues.	Orbis
ROA	Ratio of net income on total assets.	Orbis
Green debt	Dummy indicating whether the company has issued green bonds or taken green loans.	Bloomberg
Age	Difference between a given year and year of incorporation.	Orbis
Sector	Sector of economic activity (NACE Revision 2) of the company.	Orbis
Country	Country where the firm is registered and is primarily conducting business.	Orbis
Emission Variables		
ln(Rev./Em.)	Natural logarithm of the ratio of total revenues on ETS emissions of the company.	Constructed
ln(Emissions)	Natural logarithm of the total ETS emissions of the company.	Constructed
ETS emissions	Sum of ETS emissions of the installations owned by the company.	EUTL
EUA balance	Difference between EUAs allocated to the company and its verified emissions.	Constructed
EUA balance cumul.	Difference between EUAs allocated to the company and its verified emissions (cumulative).	Constructed
EUA	Sum of free EU ETS allowances allocated to the installations owned by the company.	EUTL
Installations	Number of EU ETS installations owned by the company.	Constructed - EUTL
Carbon leakage list	Dummy indicating whether the company operates in a sector included within the carbon leakage list in a given year.	EUTL
Carbon tax flag	Dummy indicating whether the company's country of legal registration has a carbon tax.	Laeven and Popov (2021)
Fossil fuel subsidies	Implicit and explicit fossil fuel subsidies divided by the GDP of the country of legal registration of the company.	Vernon, Parry, and Black (2021)

3.3 Data on green debt

Since 2015, the green debt market has demonstrated fast growth with only green bonds market exceeding USD 1 trillion of cumulative issuance worldwide in 2020 (Pietsch and Salakhova, 2022). Fatica and Panzica (2021) and Flammer (2021) show that issuance of green bonds by NFCs is associated with an emission reduction in the following years. However, they argue that the size of the market is still too small to finance green projects, rather an issuance of green bonds serves as a signal of a firm's commitment to climate objectives and attracts new investors.

We are interested in controlling for the use of green debt as it might determine the firm's transition performance. Using data on the issuance of green debt, we find that a negligible number of firms in our sample have relied on green bonds and loans. Only 18 EU ETS firms directly benefited from green debt, while 37 firms have benefited from it through their consolidated group structure[11]. The EU ETS regulates highly polluting industries, and it is possible that polluting firms may find it difficult to convince investors of the greenness of their projects in the absence of a common regulatory standard for green bonds. Findings by Pietsch and Salakhova (2022) and Fatica and Panzica (2021) hint in this direction, as they show that only green bonds from credible investors trade at a lower spread than comparable conventional bonds from the same issuer. Another potential explanation is that the majority of firms in our sample are small and medium enterprises that likely do not use bond markets to raise funding, while green loans market is still developing. All in all, we conclude that use of different forms of green debt does not explain firms' transition performance in EU ETS between 2013 and 2019.

4 Results

First, we present the baseline results of the regression analysis testing hypothesis 1 and 2. Afterwards, building on such results, we present the difference-in-differences analysis testing hypothesis 3. Throughout this section, we show consistently the results for the two

[11] Table B7 does not include sustainability-linked bonds, albeit only few sustainability-linked bonds have been issued according to our data during the time period of interest.

chosen metrics of transition performance - emissions and emission efficiency[12] - introduced in section 2.

4.1 Baseline results

We start our analyses using the specification presented in Equation 1 to address the relationship between firms' leverage and transition performance. Results are in Table 2. Firm-level emissions change little over time (Online Appendix, Figure B3)), but they vary substantially across firms. Henceforth, we will focus on the results in columns (1) and (2), which do not include firm fixed effects. Indeed, Table 2 shows that the inclusion of firm fixed effects absorbs the effect of leverage and confirms that differences in variability are more systematically related to country and industry. Overall, the inclusion of firm fixed effects would not allow to observe the non-linearity of the theorized relationship between leverage and emissions, as this is visible across firms, rather than at the firm-level.

Results are consistent with a significant convex relationship between leverage and greenhouse gas emission levels. This suggests that on average, firms with a leverage ratio below 55% are associated with lower emissions, while firms levels of leverage above this threshold are associated with higher emissions. The implied leverage threshold of 55% is the minimum of the regression's equation, computed as explained in Equation 2. Additionally, results are consistent with a significant concave relationship between leverage and emission efficiency. This suggests that on average, firms with a leverage ratio below 45% are associated with high emission efficiency, while firms with higher levels of leverage are associated with low emission efficiency. These results are aligned with hypothesis 1.

[12]Our metric of choice is emission efficiency, i.e., Revenues / Emissions, rather than emissions intensity, i.e., Emissions / Revenues. This choice is in line with the practice in the literature on clean production - see for instance De Jonghe, Mulier, and Schepens (2020). Nevertheless, our results can be interpreted also for emissions intensity. Regressions tables using Emissions / Revenues (instead of Revenues / Emissions) are available per the request of the interested reader.

Table 2: Panel regression for transition performance and leverage, from 2013 to 2019

Notes: The table shows the result of the panel regression relevant for H1 for the two metrics of transition performance: emissions and emissions efficiency. The relationship between transition performance and leverage is tested for the full data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses, they are clustered at the firm level. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. All independent variables are lagged by one year (i.e., taken at time $t-1$, apart from $ln(Revenues)$ which is taken at time t.

VARIABLES	(1) ln(Emissions)	(2) ln(Rev./Em.)	(3) ln(Emissions)	(4) ln(Rev./Em.)
Debt-to-assets	-1.39***	2.60***	-0.053	1.15***
	(0.32)	(0.36)	(0.12)	(0.28)
(Debt-to-assets)^2	1.26***	-2.86***	0.10	-0.98***
	(0.48)	(0.50)	(0.20)	(0.37)
ln(Revenues)	0.31***		0.029***	
	(0.039)		(0.0081)	
ROA	-0.00041	0.016***	0.0019**	0.0060***
	(0.0021)	(0.0028)	(0.00081)	(0.0020)
Age	0.0018	0.0041***		
	(0.0011)	(0.0012)		
Installations	0.19***	-0.039**	0.13***	-0.038
	(0.023)	(0.016)	(0.023)	(0.037)
EUA balance cumul.	-0.073**	0.035*	-0.0080***	0.0087***
	(0.036)	(0.018)	(0.0022)	(0.0032)
Carbon tax flag	0.0049	0.096	0.023	0.17**
	(0.043)	(0.089)	(0.026)	(0.086)
Fossil fuel subsidies	6.81**	-12.0**	2.50*	-14.0***
	(2.72)	(5.02)	(1.51)	(4.46)
Constant	4.12***	7.64***	9.31***	7.91***
	(0.67)	(0.14)	(0.15)	(0.12)
Sector-Time FE	Y	Y	Y	Y
Country FE	Y	Y	N	N
Firm FE	N	N	Y	Y
Observations	20,903	20,903	20,663	20,663
R-squared	0.393	0.310	0.964	0.847

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We analyze the differential effect of leverage on transition performance for firms that have and those that do not have access to the public equity market. As shown by De Haas and Popov (2023), public equity markets reallocate investment towards less emitting firms and they push them to improve their transition performance. Therefore, such firms' adoption of green technologies might be driven by an economic mechanism that differs from the one discussed in Section 2. In Table 3 columns (2) and (4), we find that the convex (concave) relationship between leverage and emission levels (emission efficiency) is particularly driven by non-listed firms, which constitute 96% of our sample. While the result has an economic meaning, it might also be driven by the smaller size of the sub-sample of listed firms. To avoid confounding effects, henceforth, we focus on this sample of firms.

Table 3: Panel regressions on sub-samples for firms with listed versus non-listed equity

Notes: The table shows the result of the fixed effect regression relevant for H1 for sub-samples of listed or non-listed firms. The entire data sample covering the period from 2013 to 2019 is used. Standard errors are indicated in parentheses, they are clustered at the firm-level. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) Listed ln(Emissions)	(2) Non-listed ln(Emissions)	(3) Listed ln(Rev./Em.)	(4) Non-listed ln(Rev./Em.)
Debt-to-assets	0.71	-1.45***	1.23	2.61***
	(1.76)	(0.33)	(1.94)	(0.37)
(Debt-to-assets)^2	-2.72	1.39***	0.78	-2.92***
	(3.12)	(0.48)	(3.45)	(0.51)
Controls	Y	Y	Y	Y
Sector-Time FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Observations	813	20,060	813	20,060
R-squared	0.755	0.384	0.653	0.309

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Next, we test hypothesis 2 using first-differenced estimators, as described in Equation 3. In this test, a firm is highly indebted when the leverage ratio in time $t-2$ is above the implied leverage thresholds computed using Equation 2 with the values obtained in Table 2. Results are in Table 4. Firstly, in columns (1) and (2), we use 50% as an implied threshold. A possible concern with these results is that the use of the implied threshold of 50% might introduce in the regression a confounding effect caused by firms with a leverage ratio that is very close to the implied threshold, or that such firms might drive the results. Therefore, we further test the relationship by excluding firms with a leverage ratio between 25% (approximately one standard deviation below the implied threshold) and 75% (approximately one standard deviation above the implied threshold) from our first-differences analysis.

The results in Table 4 suggest that there is a non-linear relationship between leverage changes and transition performance changes. When leverage is already above 50%, a further increase is associated with a worsening of the transition performance. Interestingly, when removing the noisy effect of firms with leverage that is too close to the implied threshold, we obtain that results are slightly less significant, while qualitatively unchanged relative to the first specification. The results are also significant when selecting the samples according to the two different implied thresholds of 55% and 45% for emissions and emission efficiency respectively. These results are in Table 8, in the Appendix.

Table 4: First-differences regression for transition performance and leverage, from 2013 to 2019

Notes: The table shows the result of the first-differences regression relevant for H1. The relationship between transition performance and leverage is tested for the full data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. In columns (1) and (2) $d(Leverage > 50\%)$ is equal to one if the leverage ratio in time $t-2$ is above 50% and 0 otherwise. In columns (3) and (4) it is equal to one if the leverage ratio in time $t-2$ is above 75% and 0 if it is below 25%.

VARIABLES	(1) fdln(Em.)	(2) fdln(Rev./Em.)	(3) fdln(Em.)	(4) fdln(Rev./Em.)
d(Leverage $>$ 50%) X fd(Debt-to-assets)	0.17**	-0.21*		
	(0.085)	(0.12)		
d(Leverage $\leq$ 50%) X fd(Debt-to-assets)	-0.068	0.19***		
	(0.043)	(0.062)		
d(Leverage $>$ 50%)	-0.018	0.0089		
	(0.016)	(0.018)		
d(Leverage $\geq$ 75%) X fd(Debt-to-assets)			0.26**	-0.13
			(0.13)	(0.23)
d(Leverage $\leq$ 25%) X fd(Debt-to-assets)			-0.11**	0.22***
			(0.054)	(0.082)
d(Leverage $\geq$ 75%)			-0.028	0.023
			(0.037)	(0.044)
Controls	Y	Y	Y	Y
Time FE	Y	Y	Y	Y
Observations	17,056	17,056	12,443	12,443
R-squared	0.022	0.006	0.027	0.007

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2 Difference-in-differences approach

In the analyses so far, we have shown a non-linear relationship between leverage and transition performance. High leverage is correlated with relatively low ETS emissions as long as it is below an implied threshold of approximately 50% (Table 2). An increase in leverage is correlated with a reduction in emissions as long as it is below the same implied threshold (Table 4). Assuming that our baseline results are not affected by omitted variable bias given our rich set of controls and fixed effects, a further possible concern is that firms' transition performance might be entirely endogenously determined. For example, this could occur if the relationship observed is determined by firms' preferences for green investments. To mitigate these concerns, we use the specification of Equation 4 to test hypothesis 3 and investigate firms' emissions following the introduction of the March 2018 amendment of the EU ETS Directive[13] that set the ground for phase 4

[13]Directive (EU) 2018/410 of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814 (OJ L 76, 19.3.2018, p. 3).

of the ETS (2021 to 2030). This regulation has introduced a more stringent cap on emissions and it has increased the credibility of the EU ETS, in turn accompanying a steep increase in EUA prices. EUA prices reacted promptly to the 2018 event, while they remained close to their medium-term average levels until the beginning of 2018 (Ampudia, Bua, Kapp, and Salakhova, 2022). This evidence supports the assumption that the event chosen is sufficiently exogenous to the firms' behavior. Within our preferred specification, the treatment group includes firms, which prior to the event (2017) have a leverage above 50% and a negative cumulative EUA balance (i.e., firms that need to buy additional EUAs in 2018 to cover for their excess emissions). In columns (1) and (4) of Table 5 the control group includes all other firms (treatment dummy $D1$). In an alternative specification of the treatment, the control group includes all other firms that have a negative cumulative EUA balance, but a debt-to-asset ratio below 50% (treatment dummy $D2$). This alternative specification isolates the effect of leverage on firms' transition performance. The results are in columns (2) and (5). The analysis is performed on a sample covering the years 2016 to 2019. Descriptive evidence of the mean and standard deviation of the treatment variables (leverage, EUA balance) in the year prior to the event (2017, base year) within and across firms' country and Nace 2 sector are in the Appendix (Table 6 and 7, respectively). The coefficients show that the introduction of a more stringent regulation on emissions within the EU ETS is associated with an increase in emissions for firms that are highly indebted and exposed to the rising EUA prices, relative to the control group. These results are aligned with hypothesis 3: while ETS firms on average reduce their emissions following a steep increase in the cost of EUAs, highly indebted firms do not experience such emission reduction. The results on emission efficiency in columns (4) and (5) are not as significant across specifications. Firms facing the sudden EUA price increase might react by forcing a decrease in emissions through a reduction in their economic activity, while not being able to benefit from the introduction of green technologies on a short time horizon.

The possible concern with the results reported in columns (1), (2), (4), and (5) is that the use of the implied threshold of 50% might introduce in the regression a confounding effect caused by firms with a leverage ratio that is very close to the implied threshold, or that such firms might drive the results. Therefore, in columns (3) and (6), we further test the relationship by introducing treatment $D3$ that excludes firms with a leverage ratio between 25% (approximately one standard deviation below the implied threshold) and 75% (approximately one standard deviation above the implied threshold).

The results of this analysis suggest that the increased EUA price has led to different levels of pollution of treated firms following 2018, relative to the control group, while the effect is mostly non-significant when considering emission efficiency. Interestingly, results are particularly significant when excluding the confounding effect of firms with leverage close to the implied threshold of 50%.

Table 5: Difference-in-differences on emissions and emissions efficiency

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a sample covering the years 2016 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) ln(Emissions)	(2) ln(Emissions)	(3) ln(Emissions)	(4) ln(Rev./Em.)	(5) ln(Rev./Em.)	(6) ln(Rev./Em.)
D1(Treated) X Post	0.100*			-0.090		
	(0.056)			(0.065)		
D2(Treated) X Post		0.101**			-0.097	
		(0.047)			(0.061)	
D3(Treated) X Post			0.24**			-0.32**
			(0.11)			(0.15)
Controls	Y	Y	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	10,464	6,472	4,725	10,472	6,232	4,725
R-squared	0.982	0.987	0.989	0.913	0.913	0.902

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.3 Economic significance

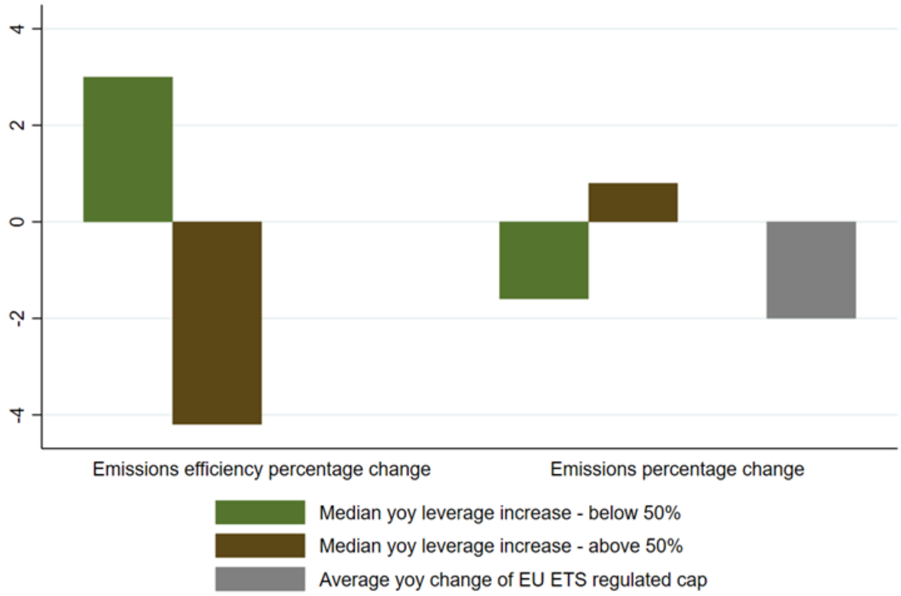
In the previous section, we documented the relationship between leverage and transition performance. We now aim to provide quantitative indications of the economic significance of the estimated coefficients. We study the magnitude separately for firms with leverage above 50% and below this threshold. To do so, formally, we compute the percentage change in transition performance (TP) as follows:

$$\%TP_s = \frac{TP(MED(debttoassets)_s) - TP(MED(debttoassets)_s + \Delta)}{TP(MED(debttoassets)_s)} \tag{5}$$

$TP(MED(debttoassets)_s)$ is the level of emissions or emission efficiency obtained when inputting the median leverage of sample s (i.e., $s = 0$ for firms with leverage below 50% and $s = 1$ for firms with leverage above 50%) into Equation 1 with the coefficients obtained in Table 2. $MED(debttoassets)_s + \Delta$ is the median leverage of sample s considering an increase in leverage. Δ is set equal to the median yearly leverage change. In a second specification, we use the mean absolute change instead. The median debt-to-assets across samples s, is 6.5% for firms with leverage below 50% and 59.9% for firms with leverage above this threshold. The median yearly leverage change is 1.4% for firms with leverage below 50% and it is 4.5% for firms with leverage above this threshold. As a result of this increase, emissions of firms in the former sample s would decrease by 1.6% and those of firms in the latter sample would increase by 0.8%. Vice versa, emission efficiency of firms with leverage below 50% would improve by 3.0% and that of firms with leverage above 50% would drop by 4.2% on average. The results are illustrated in Figure 5. For comparison, the figure also shows the yearly average change of the EU ETS cap. As an additional exercise, we observe the economic magnitude of the effect when the leverage of the median firm increases by the mean of the yearly leverage change. This value is 4.5% for firms with leverage below 50% and it is 11.0% for firms with leverage above this threshold. As a result of this increase, we obtain that emissions of firms in the former sample s would decrease by 5.0% and those of firms in the latter sample would increase by 2.8%. Vice versa, emission efficiency of firms with leverage below 50% would improve by 9.8% on average and that of firms with leverage above 50% would drop by 11.9% on average. The results for the mean yearly leverage change are larger than those observed in Figure 5.

Figure 5: Magnitude of the impact of an increase in leverage on transition performance

Notes: Economic magnitude of the relationship between leverage and transition performance of the median firm (in brown, the highly indebted median firm, and in green the median firm with leverage below 50%) vis-a-vis the yearly average reduction in the emissions' cap imposed by the EU ETS (in grey).



4.4 Robustness

Carbon pricing in a cap-and-trade system such as the ETS may encourage investment in the adoption of green technologies or may rather encourage relocation of emissions or relocation of investment. Literature recognizes two types of EU ETS related carbon leakage practices. Firstly, firms could shut down their active plants to relocate them outside the EU ETS, to avoid facing the cost of EUAs. In Section 4, we control for such type of carbon leakage using the *Installations* variable that controls for the number of EU ETS active plants held by the firms in the sample across time. Secondly, firms could maintain their EU ETS plants, while increasing their economic activity outside the ETS (Martin, Muûls, De Preux, and Wagner, 2014). Our results could be consistent with such forms of regulatory arbitrage. In fact, the use of debt for investments in the adoption of green technologies is not the only possible interpretation of the non-linear relationship between leverage and transition performance proposed in Section 4, as debt could also be used to finance carbon leakage practices. A limitation of the available data is that we cannot fully mitigate these concerns throughout empirical analyses because information on plants that are active outside the coverage of the EU ETS is unavailable.

However, it is reassuring that empirical research has not corroborated theoretical models that predict a high risk of carbon leakage within the EU ETS. Empirical findings of prior literature allow us to argue that the economic mechanism that we capture describes firms' improvement of their low-carbon transition performance throughout the adoption of clean technologies. Naegele and Zaklan (2019) do not find evidence that the EU ETS has induced firms belonging to the manufacturing sector to carbon leakage in the initial years of emissions trading (consistently with Koch and Mama, 2019, whose focus is the German manufacturing sector; Branger, Quirion, and Chevallier, 2016, whose focus are the cement and steel sectors; Dechezleprêtre, Gennaioli, Martin, Muûls, and Stoerk, 2022; whose focus are multinational firms). Using more recent confidential plant-level data, Colmer, Martin, Muûls, and Wagner (2022) show that the emission reduction achieved by manufacturing firms active within the EU ETS and registered in France is inconsistent with carbon leakage. Instead, they prove that the main driver of EU ETS active firms' emission reduction is their investment in facilities that enable clean production. De Beule, Schoubben, and Struyfs (2022) focus on Phase 3 of the EU ETS. Using foreign direct investment data, the analysis provides evidence for significant risk of shifting economic activities outside the EU ETS only for those firms that are in the NACE 4-digits sectors that are deemed to be at risk of carbon leakage by the European Commission. Instead, the authors do not find evidence of carbon leakage for firms that are not on the carbon leakage list.

To summarise, the empirical literature on carbon leakage in the EU ETS suggests that, while the overall risk of carbon leakage is limited, it is more likely to occur for firms that are active in sectors deemed to be at risk of carbon leakage. Therefore, it could be less likely that the results presented in Section 4 capture improved ETS transition performance due to carbon leakage, rather than due to green investments if they hold in the sub-sample of firms that are not on the carbon leakage list provided by the European Commission (European Commission, 2009, 2014). In the Appendix Table 9, we repeat our empirical test of hypothesis 1 on a sub-sample of firms that belong to sectors included or excluded by the carbon leakage list. Results remain significant. They show that there is not a significant difference in the relationship between leverage and transition performance across the two sub-samples. The implied thresholds in these regressions remains close to 50%.

Similarly, we repeat the diff-in-diff analysis. Results are in Appendix Table 10. In column (1), the treatment group includes firms that are on the carbon leakage list, which prior the event (2017) have leverage including and above 75% and a negative EUA balance. The control group includes all other firms that are on the carbon leakage list and have leverage equal to or lower than 25% (as in treatment dummy $D3$ defined in Section 4.2). In column (2) of Table 10, the treatment group is selected similarly, but including firms that are not on the carbon leakage list prior to the event (2017). As mentioned in Section 4.2, this removes the noisy effect of firms with leverage that is too close to the implied threshold of 50%. The method is especially appropriate when dealing with implied thresholds that are close, but not equal to 50%, as in the case of Table 9. The diff-in-diff results obtained for the sub-sample of firms that are not on the carbon-leakage list are consistent with the findings obtained for the entire sample. The coefficient of interest is positive and significant in the emissions regression, and it is negative and not significant in the emission efficiency regression. Subject to a stringent cap on their emissions, highly indebted firms that are not on the carbon leakage list do not reduce their emissions, while the effect is not significant for firms on the carbon leakage list. Economically, this hints at the possibility that these firms, even if highly indebted, managed to reduce their emissions through the practice of carbon leakage as soon as EUAs prices started increasing. Results of the carbon leakage test are not significant when splitting the sample according to the relatively noisier treatment dummies $D1, D2$ defined in Section 4.2. This may be caused by the smaller sample size.

4.5 Additional robustness tests

Robustness of the difference-in-differences analysis: Firstly, we inspect the validity of the parallel trend assumption that underlies the empirical methodology used estimating the dynamic coefficient of the treatment effect on emission levels and emission efficiency across time. We rely on the following regression specification:

$$\begin{aligned} TransitionPerformance_{i,t} = & \alpha + \beta_1 treatmentXyears + \beta_2 treatment + \\ & \beta_3 years + \beta_5' \Delta X_{i,t-1} + \gamma_{i,t} + \theta_{i,t} + \epsilon_{i,t} \end{aligned} \tag{6}$$

Our inspection, in Figure 6 and 7 shows that prior to the event treated and non-treated firms are non-distinguishable based on their emissions. In fact, the coefficient for the years prior to the event is not statistically different from zero, while it is statistically different from zero at conventional levels afterwards. Secondly, to further test the validity of the parallel trend assumption we estimate the following regression specification:

$$\begin{aligned} TransitionPerformance_{i,t} = &\alpha + \beta_1 treatmentXpostevent + \beta_2 treatment + \beta_3 postevent + \\ &\beta_4 posteventXpretrend_t + \beta_5' \Delta X_{i,t-1} + \gamma_{i,t} + \theta_{i,t} + \epsilon_{i,t} \end{aligned} \tag{7}$$

The methodology is aligned with Laeven and Popov (2021), *pretrend* is equal to 1 in 2016, 2 in 2017, and constant at 3 afterward. The coefficient β_4 tests the existence of a long term trend of increasing emissions which would imply that the effect observed in Section 4.2 is independent of the timing of the event. The results in Table 11 show that, if anything, we can observe a trend of decreasing emissions prior to the event. This further confirms the empirical validity of the parallel trend assumption in our analysis. Thirdly, we conduct placebo tests on our results shifting the event date to 2017. The diff-in-diff coefficient is not statistically significant at conventional levels (Table 12). This test also allows us to rule out that firms react to the 2018 event in advance (e.g., around the 2017 MSR reform).

Time lag from investment till emission reduction: A further concern of our analysis is that we test the relationship between leverage and emissions over a short time interval of one year. To capture the financing of technological changes that extend over several years, we regress transition performance over the third lag of leverage. The results are in Appendix Table 13. The findings in columns (1) and (2) support hypothesis 1 and the coefficients on the variables of interest are highly significant. Instead, the results of the first-differences analysis on emission changes do not support the findings obtained in Table 4, showing that a leverage increase in year $t-4$ is not associated with significantly lower emissions after four years for firms that are initially not highly leveraged, nor higher emissions for firms that are highly leveraged. In this case, separating the sample into highly leveraged firms and others based on their leverage 4 years prior to the measurement of their transition performance might produce unrealistic results as leverage might have changed largely across the 3 years. Therefore, the first differences analysis results in being less appropriate in the context of this robustness test. Similarly, a limitation of our study is that we cannot conduct the same test on our diff-in-diff analysis due to the unavailability of a sufficiently long time series.

Sector: Prior literature has shown that the implications of indebtedness may vary with firms' features, for instance, it might be linked to their sector (Rajan and Zingales, 1996). We test whether the relationship between leverage and transition performance levels of Equation 1 is driven by firms that are active within a specific sector; acknowledging that the difference in the need for external financing as well as the level above which leverage represents a financial constraint may differ across sectors. In Table 14, we show that the hypothesis of a convex relationship between leverage and emissions is particularly driven by firms in the sectors of electricity, gas, steam, and air conditioning supply (Nace 2-digits 35) and manufacturing of metals, non-metals, chemicals, and petroleum products (Nace 2-digits 19 to 25). These constitute 63% of the observations in the sample. Coefficients are qualitatively unchanged for firms in other manufacturing sectors (e.g., paper and food production), construction, mining and quarrying, and air transport (Nace 1-digits C, excluding Nace 2-digits 19 to 25, Nace 1-digits B, F, G, and H), albeit only the coefficient on the linear term of leverage is significant. In Table 15 we repeat the difference-in-differences analysis employing a specification with a triple moderation term as follows:

$$\begin{aligned} TransitionPerformance_{i,t} = &\alpha + \beta_1 treatmentXposteventXsector + \beta_2' X_{i,t-1} \\ &+ \gamma_{i,t} + \rho_t + \epsilon_{i,t} \end{aligned} \tag{8}$$

Where $X_{i,t-1}$ interaction terms between *postevent* and *sector*, *postevent* and *treatment*, and *sector* and *treatment*, in addition to controls. This specification allows to discern how the treated firms react to the increase in EUAs prices by sector. The results observed in Table 15 are aligned with those observed in Section 4 and do not highlight a pronounced heterogeneity of the effect across sectors.

Market versus bank-based debt: Differences in firms' source of debt financing, i.e., bank-based through bank loans versus market-based through bonds, might affect the results of our difference-in-differences analysis. As firm-level data on this split is unavailable for our sample, we attempt an approximation by using country-level aggregates.

The debt financing of NFCs is predominantly bank-based in all countries in our sample as the share of market-based debt finance did not exceed 20% throughout the period of our sample (see Appendix figure B4)[14]. We employ a difference-in-differences regression in which the treatment effect is moderated by country or by the ratio of NFCs' market-based debt financing on total debt financing at the country and year level. Results do not point at any significant difference across this dimension and are scarcely significant when considering countries separately due to the excessive fragmentation of the dataset. Tables are available upon request.

Alternative dependent variable: For comparability with other studies in the literature, all analyses performed on the variable emission efficiency, i.e., revenues on emissions, are repeated for (i) total assets on emissions and (ii) total sales on emissions. As shown in Table 16, the results testing hypothesis 1 and 2 hold when using total assets on emissions, while column (4) shows that results on the first-differences regression are not significant when using total sales on emissions. A possible reason is that sales, by comparison with revenues, include also the costs incurred by the firm, and therefore capture a different relationship to leverage. Results of the difference-in-differences analysis for these alternative specifications of the dependent variable are reported in Table 17. The relation becomes more significant when using total assets on emissions compared to the main results that employ revenues on emissions, but they are not significant when using total sales on emissions.

Low or high-emissions firms: A further concern is that firms producing very low or very high emissions might drive our main results. Therefore, we run our baseline regression specification in Equation 1 on a sub-sample of firms excluding the ones with emissions higher than 75% of the entire sample, in columns (1) and (3), and lower than 75% of the sample, in columns (2) and (4) of Table 18. We find that the non-linear relationship between transition performance and leverage is most robust to the sub-sample analysis.

Large firms or SMEs: Lastly, on a similar note, we examine the differential effect of

[14]For a discussion of the Eurozone market-based debt market see for instance Darmouni and Papoutsi (2022). In the past, most large listed firms were observed in the European bond market. Bond financing increased over the past two decades as new firms entered the market. New issuers are noticeably smaller and more leveraged than historical issuers.

leverage on transition performance across firm size, particularly large firms by comparison with small-and-medium enterprises (SMEs). We test hypotheses 1 and 2 on these sub-samples to investigate whether larger firms' higher reliance on external finance affects the relationship between leverage and transition performance. In Table 19, we show that while the results are qualitatively consistent with the hypothesis of a non-linear relationship between leverage and transition performance, the coefficient on the squared term of leverage is significant only for SMEs. A possible interpretation of this result is that while leverage-induced constraints are not biting for large firms, they represent an obstacle to the achievement of low-carbon transition goals for SMEs.

5 Conclusion and policy relevance

We study the role of debt as a source of transition finance supporting the low-carbon transition of non-financial corporations in Europe. Particularly, we focus on the emissions of firms that are subject to the EU ETS. Using historical data on verified emissions of close to 4000 firms and accounting for 26% of the total emissions in the EU, we show that higher debt financing of firms subject to a cap on their emissions contributes to emissions reduction and cleaner production (higher emission efficiency) as long as leverage is not above a given threshold. We find that this inverse U-shaped relationship between debt financing and low-carbon transition is especially robust when accounting for the subsample of non-listed firms subject to the EU ETS. Crucially, our study highlights the existence of a group of firms that are too indebted for the transition, although subject to a constraint on their emissions and even when such constraints become more binding. Indeed, we show that on average firms reduced their emissions in response to the introduction of the March 2018 EU ETS Directive that tightened the ETS emission cap going forward. However, highly indebted firms in the sample did not respond with an emission reduction. Rather, the increased cost of emission allowances that was triggered by the event was followed by a further increase in the emissions produced by such firms. The result is robust to a large set of economic and environmental controls and it is unaffected by the prevalence of bank rather than market-based debt financing in the countries of residence of most firms in our sample.

Our analyses show that the non-linear leverage-emissions relation holds true for the sub-sample of firms that are not at risk of carbon leakage. This mitigates the concern that our results are driven by carbon-leakage firms that are exposed to the risk of relocating their plants outside the EU ETS, rather than investing in the adoption of green technologies to improve their transition performance. While this does not rule out that firms in our sample shift their polluting activity outside the EU ETS, previous literature discards such concerns as it only provides scarce evidence of the materialization of carbon leakage risks.

These results contribute to two policy discussions. First, in line with previous literature, we show that in the context of rising EUA prices, the EU ETS as a cap-and-trade policy instrument effectively encourages firms with adequate leverage to reduce emissions, on average. Therefore, to achieve emissions reduction in Europe at a more sustained pace, strengthening the mechanism is indispensable.

Second, together with policy instruments such as the EU ETS, debt as a source of transition finance is a necessary tool to allow for firms' convergence towards a low-carbon economy. We document a scarce use of green debt instruments in the sample analyzed. However, the development of green debt markets, and in particular of the implementation of standards and labels for green bonds and green loans, might be important for the transition of highly indebted European NFCs. While firms with high leverage and low growth prospects may have to leave the market to more emission-efficient firms, firms with high leverage and high growth prospects could access green financing conditionally on their commitment to a green use of proceeds.

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A Appendix

Table 6: Descriptive statistics of treatment variables across countries

Notes: Mean and standard deviation of EUA balance and leverage (treatment variables) in the base year (2017, year prior to the event) across most represented countries in the sample. Sorted by mean treatment effect.

Country	Mean EUABalance	Std	Country	Mean Leverage	Std
Sweden	0.118737	1.231112	Portugal	0.236907	0.229649
Belgium	0.065574	1.508878	Finland	0.218871	0.225261
Spain	-0.05128	1.003392	Spain	0.198323	0.202974
Portugal	-0.06892	1.053862	Belgium	0.197676	0.215914
France	-0.12532	0.863398	Germany	0.19441	0.200031
Finland	-0.31768	1.146637	Italy	0.167867	0.196409
Hungary	-0.4307	3.534284	Sweden	0.161966	0.2518
Germany	-0.64849	1.815591	France	0.158962	0.192693
Poland	-0.90728	5.575338	Poland	0.101398	0.14751
Czech Republic	-1.01973	3.384129	Czech Republic	0.098348	0.159191
Italy	-2.44629	18.4702	Hungary	0.083441	0.158944

Table 7: Descriptive statistics of treatment variables across Nace 2 sectors

Notes: Mean and standard deviation of EUA balance and leverage (treatment variables) in the base year (2017, year prior to the event) across most represented Nace 2 sectors in the sample. Sorted by mean treatment effect.

Nace2	Mean EUAbalance	Std	Nace 2	Mean Leverage	Std
24	0.263546	3.275266	13	0.287349	0.203984
16	0.171979	0.296167	16	0.272102	0.230356
23	0.068311	0.666278	49	0.217173	0.245055
17	0.051996	0.421105	41	0.211364	0.26217
13	0.000256	0.024673	52	0.20007	0.199811
29	-0.00237	0.067877	27	0.193572	0.248683
27	-0.0045	0.011569	30	0.182865	0.19496
21	-0.00785	0.036276	10	0.175988	0.192521
42	-0.00975	0.011594	29	0.168496	0.254737
25	-0.01457	0.025125	51	0.164848	0.234659
8	-0.01575	0.367163	42	0.163602	0.219974
11	-0.02474	0.119527	28	0.160651	0.229842
30	-0.02545	0.068756	25	0.159355	0.185883
22	-0.03172	0.279757	11	0.158787	0.211718
52	-0.05155	0.113645	24	0.158379	0.184731
28	-0.06376	0.164722	23	0.156238	0.197578
10	-0.0657	0.172397	9	0.155043	0.185393
20	-0.09701	0.988374	19	0.154957	0.187069
41	-0.10001	0.089956	17	0.143169	0.190495
9	-0.31993	0.758995	8	0.142049	0.172235
49	-0.45347	0.599301	21	0.140887	0.188181
51	-0.6251	1.429646	20	0.123877	0.18102
6	-0.67733	0.572534	22	0.111191	0.171509
19	-1.45048	2.50127	6	0.080321	0.18364

Table 8: First-differences regression for alternative specification, from 2013 to 2019

Notes: The table shows the result of the first-differences regression relevant for H2. The relationship between transition performance and leverage is tested for the full data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. *Leverage level* is equal to one if the leverage ratio in time $t-2$ is above 55% in column (1), while it is equal to one if the leverage ratio in time $t-2$ is above 45% in column (2).

VARIABLES	(1) fdln(Emissions)	(2) fdln(Rev./Em.)
d(Leverage > 55%) X fdDebt-to-assets	0.22**	
	(0.091)	
d(Leverage > 45%) X fdDebt-to-assets		-0.21*
		(0.12)
d(Leverage > 55%)	-0.016	
	(0.019)	
d(Leverage > 45%)		0.00012
		(0.016)
fdDebt-to-assets	-0.072*	0.19***
	(0.041)	(0.064)
Controls	Y	Y
Time FE	Y	Y
Observations	17,056	17,056
R-squared	0.027	0.006

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Panel regressions on sub-samples for firms on carbon leakage list

Notes: The table shows the result of the fixed effect regression relevant for H1, pointing at the differential effect of leverage changes on transition performance changes for firms on or excluded from the carbon leakage list. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) On carbon leakage list ln(Emissions)	(2) Not on list ln(Emissions)	(3) On list ln(Rev./Em.)	(4) Not on list ln(Rev./Em.)
Debt-to-assets	-1.15***	-1.26***	1.92***	2.80***
	(0.38)	(0.41)	(0.41)	(0.49)
Debt-to-assets^2	0.98*	1.15*	-1.85***	-3.27***
	(0.56)	(0.60)	(0.57)	(0.66)
Controls	Y	Y	Y	Y
Sector-Time FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Observations	9,083	11,795	9,083	11,795
R-squared	0.421	0.401	0.325	0.329

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 10: Difference-in-differences for firms that are not on the carbon leakage list

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a sample covering the years 2016 to 2019. Column (1) shows results for the sub-sample of firms that are on the carbon leakage list, while column (2) shows results for the sub-sample of firms that are not on the carbon leakage list. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) On carbon leakage list ln(Emissions)	(2) Not on list ln(Emissions)	(3) On carbon leakage list ln(Rev./Em.)	(4) Not on list ln(Rev./Em.)
D3(Treated) X Post	0.042	0.20**	-0.16**	-0.23
	(0.045)	(0.091)	(0.066)	(0.17)
Controls	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Observations	1,706	2,991	1,706	2,991
R-squared	0.990	0.987	0.982	0.825

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 6: Visual inspection of validity of parallel trend assumption

Notes: The figure shows the treatment effect of the regression on emissions (coefficients, 90% and 95% confidence bands) for each period. 2017 is the omitted base level, one year prior to the event. Left: treatment D1 is a dummy equal to 1 for firms with leverage $>$ 50% and negative EUA balance (cum.); equal to 0 for all other firms. Middle: treatment D2 is a dummy equal to 1 for firms with leverage $>$ 50% and negative EUA balance (cum.); equal to 0 for all other firms with negative EUA balance. Right: treatment D3 is a dummy equal to 1 for firms with leverage $\geq$ 75% and negative EUA balance (cum.); and equal to 0 for all other firms with negative EUA balance and leverage $\leq$ 25%.

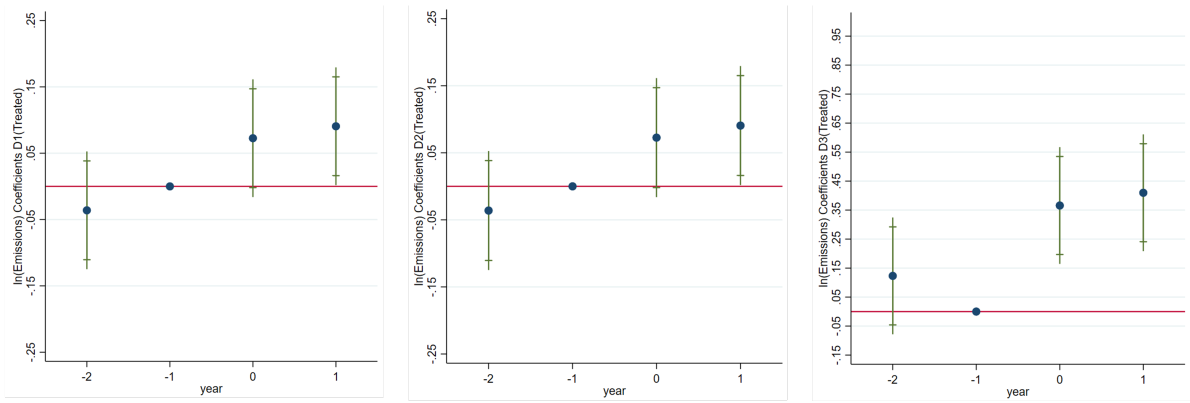


Figure 7: Visual inspection of validity of parallel trend assumption

Notes: The figure shows the treatment effect of the regression on emission efficiency (coefficients, 90% and 95% confidence bands) for each period. 2017 is the omitted base level, one year prior to the event. Left: treatment D1 is a dummy equal to 1 for firms with leverage > 50% and negative EUA balance (cum.); equal to 0 for all other firms. Middle: treatment D2 is a dummy equal to 1 for firms with leverage > 50% and negative EUA balance (cum.); equal to 0 for all other firms with negative EUA balance. Right: treatment D3 is a dummy equal to 1 for firms with leverage ≥ 75% and negative EUA balance (cum.); and equal to 0 for all other firms with negative EUA balance and leverage ≤ 25%.

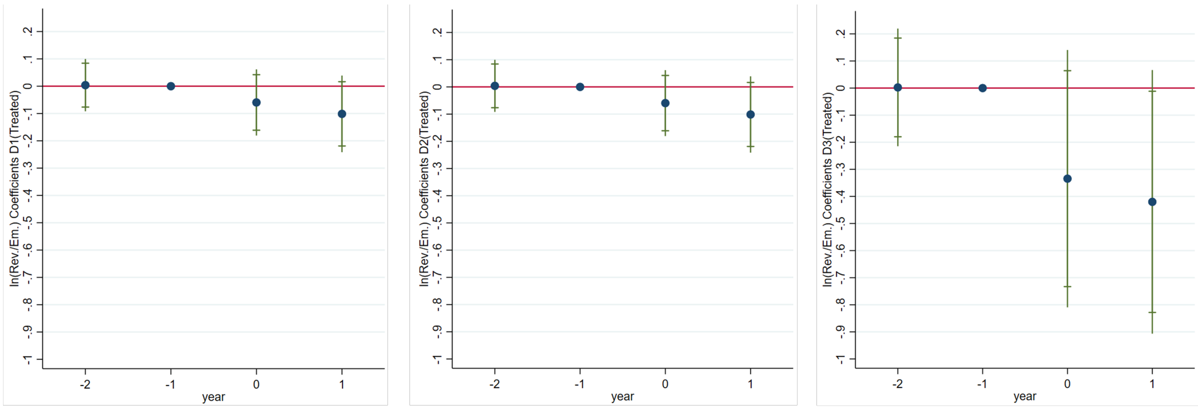


Table 11: Pre-trend analysis

Notes: The table shows the results of the pre-trend analysis. D1: dummy equal to 1 for firms with leverage > 50% and negative EUA balance (cum.); and equal to 0 for other firms. D2: dummy equal to 1 for firms with leverage > 50% and negative EUA balance (cum.); and equal to 0 for other firms with negative EUA balance. D3: dummy equal to 1 for firms with leverage ≥ 75% and negative EUA balance (cum.); and equal to 0 for firms with negative EUA balance and leverage ≤ 25%. Pretrend is a variable equal to 1 in 2016, 2 in 2017, and constant at 3 afterward. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) ln(Emissions)	(2) ln(Emissions)	(3) ln(Emissions)	(4) ln(Rev./Em.)	(5) ln(Rev./Em.)	(6) ln(Rev./Em.)
D1(Treated) X Post	0.12*			-0.087		
	(0.069)			(0.079)		
D1(Treated) X Pretrend	0.031			0.0007		
	(0.049)			(0.049)		
D2(Treated) X Post		0.11*			-0.10	
		(0.065)			(0.078)	
D2(Treated) X Pretrend		0.026			-0.012	
		(0.052)			(0.051)	
D3(Treated) X Post			0.15			-0.30*
			(0.111)			(0.18)
D3(Treated) X Pretrend			-0.15*			0.018
			(0.089)			(0.11)
Controls	Y	Y	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	10,464	6,472	4,725	10,472	6,232	4,725
R-squared	0.982	0.986	0.989	0.913	0.913	0.902

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12: Placebo test around 2017

Notes: The table shows the results of the placebo test on the difference-in-differences analysis. The relationship is tested for the period from 2015 to 2018, therefore, the length of the time interval tested (4 years) is the same as the one used in the main difference-in-differences regression. The event date is 2017. D1: dummy equal to 1 for firms with leverage $>$ 50% and negative EUA balance (cum.); and equal to 0 for other firms. D2: dummy equal to 1 for firms with leverage $>$ 50% and negative EUA balance (cum.); and equal to 0 for other firms with negative EUA balance. D3: dummy equal to 1 for firms with leverage $\geq$ 75% and negative EUA balance (cum.); and equal to 0 for firms with negative EUA balance and leverage $\leq$ 25%. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) ln(Emissions)	(2) ln(Emissions)	(3) ln(Emissions)	(4) ln(Rev./Em.)	(5) ln(Rev./Em.)	(6) ln(Rev./Em.)
D1(Treated) X Post	-0.057			0.058		
	(0.044)			(0.055)		
D2(Treated) X Post		-0.036			0.039	
		(0.045)			(0.061)	
D3(Treated) X Post			-0.208			0.148
			(0.13)			(0.14)
Controls	Y	Y	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	10,464	6,472	4,725	10,472	6,232	4,725
R-squared	0.972	0.980	0.980	0.880	0.900	0.890

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13: Panel and first-differences regression for transition performance and leverage, from 2013 to 2019 using a 3-years lag

Notes: In columns (1) and (2), the table shows the result of the panel regression relevant for H1. The relationship between transition performance and leverage is tested for the full data sample covering the period from 2013 to 2019. In columns (3) and (4), the table shows the result of the first-differences regression relevant for H2. The relationship between transition performance changes and leverage changes is tested for the full data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. All independent variables are lagged by one year (i.e., taken at time $t-3$, apart from $ln(Revenues)$ which is taken at time t.

VARIABLES	(1) ln(Emissions)	(2) ln(Rev./Em.)	(3) fdln(Emissions)	(4) fdln(Rev./Em.)
Debt-to-assets	-1.22***	2.16***		
	(0.33)	(0.36)		
(Debt-to-assets)^2	1.09**	-2.40***		
	(0.49)	(0.51)		
d(Leverage>50%) X fd(Debt-to-assets)			0.0017	-0.26
			(0.069)	(0.17)
d(Leverage $\leq$ 50%) X fdDebt-to-assets			0.023	0.30**
			(0.050)	(0.12)
d(Leverage>50%)			-0.032**	-0.040
			(0.015)	(0.033)
Controls	Y	Y	Y	Y
Sector-Time FE	Y	Y	N	N
Country FE	Y	Y	N	N
Time FE	N	N	Y	Y
Observations	19,103	19,103	15,831	15,831
R-squared	0.415	0.331	0.020	0.008

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: Panel regressions on sub-samples for different sectors

Notes: The table shows the result of the fixed effect regression relevant for H1, pointing at the differential effect of leverage on transition performance in different sectors. The relationship between transition performance and leverage is tested for the data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
		Metals	Other manu.		Metals	Other manu.
		Non-metals	Construction		Non-metals	Construction
		Chemicals	Mining		Chemicals	Mining
	Electr.	Petroleum prod.	Air transport	Electr.	Petroleum prod.	Air transport
VARIABLES	ln(Em.)	ln(Em.)	ln(Em.)	ln(Rev./Em.)	ln(Rev./Em.)	ln(Rev./Em.)
Debt-to-assets	-2.04***	-0.90**	-1.15**	2.96***	1.62***	2.51***
	(0.67)	(0.43)	(0.51)	(0.76)	(0.46)	(0.68)
Debt-to-assets^2	2.50**	1.11*	0.75	-3.76***	-1.77***	-2.96***
	(0.99)	(0.62)	(0.73)	(1.06)	(0.66)	(0.86)
Controls	Y	Y	Y	Y	Y	Y
Sector-Time FE	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y	Y
Observations	5,881	7,729	6,879	5,881	7,729	6,879
R-squared	0.449	0.484	0.398	0.294	0.293	0.264

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15: Difference-in-differences with sector interaction

Notes: The table shows the result of the difference-in-differences analysis relevant for H3. The table is based on a triple diff-in-diff with the interaction between the treatment dummy variable, the time variable, and the sector of each firm (with Nace 1 level granularity). The treatment dummy is equal to 1 for firms with debt-to-assets above 50% and a negative EUAs balance. The relationship between transition performance and leverage is tested for the data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

	(1)	(2)
VARIABLES	ln(Em.)	ln(Rev./Em.)
D1(Treated) X Post X Mining	0.33***	-0.29
	(0.11)	(0.18)
D1(Treated) X Post X Manuf.	0.23**	-0.45***
	(0.099)	(0.14)
D1(Treated) X Post X Electr.	0.25**	-0.47***
	(0.10)	(0.14)
D1(Treated) X Post X Water S.	0.42***	-0.71**
	(0.14)	(0.32)
D1(Treated) X Post X Construction	0.56***	-0.75***
	(0.089)	(0.16)
D1(Treated) X Post X Trade	0.33***	-1.12**
	(0.076)	(0.50)
D1(Treated) X Post X Transport	0.56***	-0.77***
	(0.21)	(0.22)
D1(Treated) X Post X Real Estate	0.26**	-0.38***
	(0.12)	(0.13)
Controls	Y	Y
Time FE	Y	Y
Firm FE	Y	Y
Observations	10,516	10,516
R-squared	0.981	0.913

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 16: Results for alternative specification of the dependent variable

Notes: The table shows the baseline results on the full data sample. Emission efficiency is measured as the ratio of total assets or sales on emissions. Standard errors are indicated in parentheses, they are clustered at the firm level. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. In columns (2) and (4) $d(Leverage)$ is equal to one if the leverage ratio in time $t-2$ is above 50%. The treatment effect in the DiD model is equal to 1 for firms with leverage above 50% and negative EUA balance cumul., and 0 for firms with leverage below 50% and negative EUA balance cumul.

VARIABLES	(1) ln(Assets/Em.)	(2) fdln(Assets/Em.)	(3) ln(Sales/Em.)	(4) ln(Sales/Em.)
Debt-to-assets	2.32***		2.01***	
	(0.33)		(0.55)	
Debt-to-assets^2	-1.99***		-2.65***	
	(0.50)		(0.76)	
d(Leverage $>$ 50%) X fdDebt-to-assets		-0.67***		-0.19
		(0.13)		(0.12)
d(Leverage $\leq$ 50%) X fdDebt-to-assets		0.61***		0.027
		(0.093)		(0.027)
d(Leverage $>$ 50%)		-0.021		0.23
		(0.016)		(0.16)
Controls	Y	Y	Y	Y
Time FE	N	Y	N	Y
Sector-time FE	Y	N	Y	N
Country FE	Y	N	Y	N
Observations	20,903	17,056	6,021	5,558
R-squared	0.359	0.029	0.392	0.024

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 17: Diff-in-diff results for alternative specification of the dependent variable

Notes: The table shows the difference-in-differences results tested for the full data sample. Emission efficiency is measured as the ratio of total assets or sales on emissions. Standard errors are indicated in parentheses, they are clustered at the firm level. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) ln(Asset/Em.)	(2) ln(Asset/Em.)	(3) ln(Asset/Em.)	(4) ln(Sale/Em.)	(5) ln(Sale/Em.)	(6) ln(Sale/Em.)
D1(Treated) X Post	-0.10			0.038		
	(0.067)			(0.054)		
D2(Treated) X Post		-0.13**			0.034	
		(0.062)			(0.055)	
D3(Treated) X Post			-0.36***			0.030
			(0.12)			(0.11)
Controls	Y	Y	Y	Y	Y	Y
Sector-time FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	10,056	6,224	4,720	3,262	2,099	1,432
R-squared	0.970	0.975	0.977	0.984	0.984	0.987

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 18: Robustness test on sub-samples of firms excluding high-low emitters

Notes: The table shows the result of the panel regression relevant for H1. The relationship between transition performance and leverage is tested for the full data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10. High emitters are firms with total verified emissions above 75% of the sample, while low emitters are firms with total verified emissions below 75% of the sample.

VARIABLES	(1) Excl. High Em. ln(Emissions)	(2) Excl. Low Em. ln(Emissions)	(3) Excl. High Em. ln(Rev./Em.)	(4) Excl. Low Em. ln(Rev./Em.)
Debt-to-assets	-0.79***	-1.15***	2.51***	2.62***
	(0.30)	(0.26)	(0.39)	(0.36)
(Debt-to-assets)^2	0.47	1.45***	-2.65***	-3.10***
	(0.45)	(0.37)	(0.53)	(0.46)
Controls	Y	Y	Y	Y
Sector-Time FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Observations	16,010	15,377	16,031	15,377
R-squared	0.290	0.398	0.342	0.335

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 19: Robustness test on large versus small and medium enterprises

Notes: The table shows the result of the fixed effects regression relevant for H1, pointing at the differential effect of leverage on transition performance for firms with different size. The relationship between transition performance and leverage is tested for the data sample covering the period from 2013 to 2019. Standard errors are indicated in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

VARIABLES	(1) Large ln(Emissions)	(2) SME ln(Emissions)	(3) Large ln(Rev./Em.)	(4) SME ln(Rev./Em.)
Debt-to-assets	-0.90**	-1.54***	1.20***	3.62***
	(0.40)	(0.45)	(0.42)	(0.55)
(Debt-to-assets)^2	0.92	1.13*	-1.61***	-3.76***
	(0.61)	(0.68)	(0.62)	(0.73)
Controls	Y	Y	Y	Y
Sector-Time FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Observations	12,688	8,121	12,688	8,121
R-squared	0.422	0.364	0.348	0.299

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

B Online Appendix

B.1 Logic for measurement of transition performance

To support the low-carbon transition, a corporate firm has on one hand to reduce its overall level of emissions and on the other hand, remain economically sound. Generally, a firm would do so by reducing its overall level of emissions while increasing its emission efficiency. This logic applies also to firms active in fossil fuel production, e.g. coal, oil, and gas, albeit acknowledging that such business models shall become stranded in the long run and, even if emission efficiency can be improved, emission reduction in these activities shall be ultimately achieved through a pivotal reduction in activity. Generalizing this rationale: a firm can reduce its emissions either (i) by producing in a cleaner way by changing its "brown" technology to "green" technology and / or (ii) by reducing its economic activity. Conceptually, Table B1 shows four cases of combinations between changes in emissions and changes in emission efficiency that are observable in the real economy and how these relate to the potential absolute and relative targets in emissions of a firm as well as to the economy-wide absolute target[15].

Table B1: Mechanism of changes in emissions and in changes in emission efficiency

#	Transition performance	Contribution to emissions target and to EU target	Contribution to emissions intensity target (clean prod.)	Obs.
1	Emissions ↓, Em. efficiency ↑	Yes	Yes	13 %
2	Emissions ↓, Em. efficiency ↓	Yes	No	40 %
3	Emissions ↑, Em. efficiency ↑	No	Yes	32 %
4	Emissions ↑, Em. efficiency ↓	No	No	15 %

In case 1, emissions are reduced and emission efficiency is improved. The firm contributes both to the low-carbon transition and to the cleaner production goal. In case 2, emissions are reduced and emission efficiency deteriorates. The firm contributes to the low-carbon

[15] Measuring a firm's progress on the low-carbon transition path is further done from the perspective of the targets set by the firm in terms of either absolute targets and / or relative targets. Whereas absolute targets imply a reduction in the absolute level of emissions of a firm, relative targets imply a reduction in the emissions intensity and equivalently an improvement in the emission efficiency of the firm.

transition goal but fails to produce in a cleaner way. In case 3, emissions and emission efficiency increase as the firm's revenues increased by more than its emissions. The firm does not contribute to the low-carbon transition goal, yet it achieves the cleaner production goal. Finally, in case 4, the firm increases its emissions and its emission efficiency deteriorates, indicating that the firm fails to contribute to both goals. Empirically, the last column of Table B1 shows for each of these cases the share of observations in our sample. Furthermore, we take the example of three firms considering their ETS emissions: Shell Deutschland, active in the manufacturing of petroleum products (Nace 2-digits code 19), Enel Produzione, active in the electricity generation (Nace 2-digits code 35), and Saint Gobain Construction, active in the manufacturing of non-metal minerals (Nace 2-digits code 23) as shown in Table B2. From 2013 to 2019, Saint Gobain Construction displays an improvement in emission efficiency, albeit the emissions of the firm increased, i.e. implying higher pollution. This illustrates that incentivizing and monitoring alone an improvement in emission efficiency may not lead to a reduction of emissions in absolute terms. Between 2013 and 2019, Shell Deutschland experienced a decrease in ETS emissions of 0.5 million eCO2 tonnes. At the same time, in 2019 the firm had an emission efficiency of 5,750 EUR/eCO2 tonne and in 2013 – of 7,293, indicating a decrease in emission efficiency. The emission reduction observed is likely due to a reduction in economic activity, as revenues decreased, rather than due to a change in technology for cleaner production. Conversely, Enel Produzione also reduced its ETS emissions from 2019 to 2013 but increased its emission efficiency. The reduction in ETS emissions was stronger than the reduction in revenues observed during this period. An increase in emission efficiency is observed along with an overall emissions reduction implying that the firm likely reduced its emissions by making a change in technology for cleaner production.

Table B2: Example of changes in emissions and in changes in emission efficiency

Firm	ETS-Emissions 2013	ETS-Emissions 2019	Change in emissions	Change in em. efficiency
Saint Gobain Const.	34,429	36,453	2024	4939
Shell Deutschland	3,996,923	3,420,906	-576,017	-1,543
Enel Produzione	34,555,574	17,069,982	-17,485,592	101

Considering the above complementary differences between emissions and emission efficiency, we adopt a common empirical framework for both metrics of a firm's transition to the low-carbon economy.

B.2 Additional descriptive statistics

Table B3: Correlations between the variables of interest

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. ln(Emissions)	1.00											
2. ln(Rev./Em.)	-0.49	1.00										
3. Debt-to-assets	-0.08	0.09	1.00									
4. (Debt-to-assets)^2	-0.09	0.06	0.93	1.00								
5. ln(Revenues)	0.37	0.63	0.02	-0.01	1.00							
6. ROA	0.03	0.07	-0.17	-0.18	0.10	1.00						
7. Carbon tax flag	-0.12	0.03	-0.01	0.01	-0.07	0.04	1.00					
8. EUA balance	-0.25	0.11	0.01	0.01	-0.11	0.02	0.04	1.00				
9. Fossil fuel subsidies	0.03	-0.18	-0.10	-0.09	-0.16	-0.01	-0.10	-0.05	1.00			
10. Age	0.08	0.13	-0.01	-0.04	0.21	0.04	0.03	0.01	-0.03	1.00		
11. Installations	0.26	-0.04	0.00	-0.01	0.20	0.01	0.05	-0.20	-0.05	0.11	1.00	
12. ln(Total assets)	0.44	0.38	0.06	0.03	0.80	0.06	-0.08	-0.15	-0.19	0.25	0.30	1.00

Table B4: Sample composition by year, country and sector

Notes: The table shows the sample composition for observations with available economic and environmental variables.

Year	Obs.	Country	Obs.	Sector	Obs.
2013	2,761	France	2,850	B - Mining and quarrying	473
2014	3,153	Germany	1,732	C - Chemicals	2,014
2015	3,071	Poland	1,991	C - Food	1,634
2016	3,047	Spain	2,924	C - Metals	1,396
2017	3,020	Sweden	1,479	C - Non-metals	4,167
2018	3,022	Other	10,014	C - Paper	2,056
2019	2,916			C - Manufacturing other	2,756
				D - Electricity, gas, steam and air conditioning supply	5,735
				H - Transportation and storage	694
				Other	1645
Obs.	20,990	Obs.	20,990	Obs.	20,990
Firms	3,724	Firms	3,724	Firms	3,724

Table B5: Summary statistics of relevant variables

	N	Mean	Median	St. D.	Min.	Max.
ln(Emissions)	20,990	10.12	10.12	2.23	0.00	17.44
ln(Rev./Em.)	20,990	7.70	7.67	2.67	-23.61	22.49
Debt-to-assets	20,990	0.18	0.10	0.21	0.00	0.89
(Debt-to-assets)^2	20,990	0.08	0.01	0.14	0.00	0.80
ln(Revenues)	20,990	17.82	17.98	2.51	-9.21	25.46
ln(Total assets)	20,990	18.08	18.07	2.00	5.18	26.05
ROA	20,990	2.91	2.58	11.10	-99.81	97.27
Age	20,990	31.51	23.00	27.54	0.00	333.00
Installations	20,990	1.72	1.00	2.21	1.00	46.00
EUA balance	20,990	-0.09	0.00	0.84	-37.52	4.75
Fossil fuel subsidies	20,990	0.03	0.02	0.03	0.00	0.37
Carbon tax flag	20,990	0.51	1.00	0.50	0.00	1.00
fdln(Emissions)	20,990	-5177.04	-44.50	232,976	-16,500,000	7,278,483
fdln(Rev./Em.)	20,990	18,840	8.54	57,800,000	-5,650,000,000	5,600,000,000
fdDebt-to-assets	20,990	-0.01	0.00	0.11	-0.89	0.89

Figure B1: Firm-level ETS emissions, emission efficiency across time and industry groups

Notes: Emissions represent the natural logarithm of verified greenhouse gas emissions of firms, measured in CO2 equivalent tonnes. Emission efficiency is computed as the natural logarithm of the ratio of revenues on verified greenhouse gas emissions.

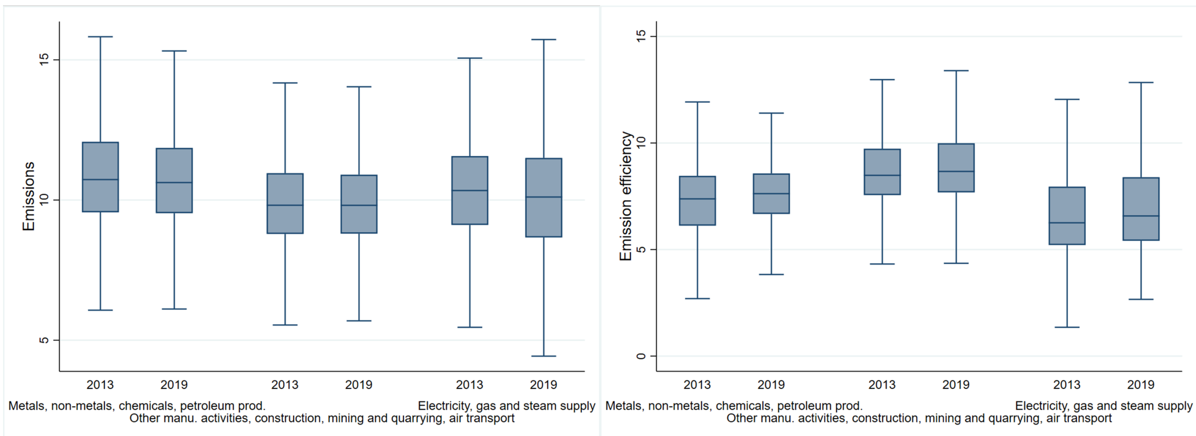


Figure B2: Firm-level leverage across time and industry groups

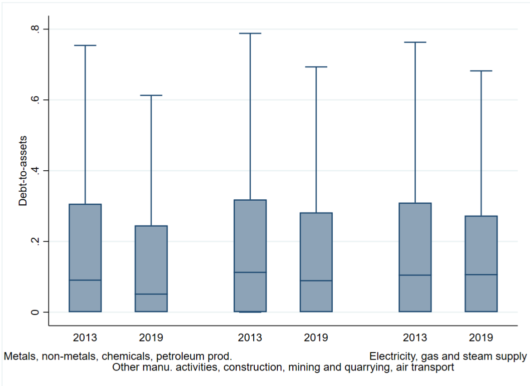


Figure B3: Firm-level ETS emissions, emission efficiency and leverage across time.

Notes: Emissions represent the natural logarithm of verified greenhouse gas emissions of firms, measured in CO2 equivalent tonnes. Emission efficiency is computed as the natural logarithm of the ratio of revenues on verified greenhouse gas emissions. Leverage is computed as debt-to-assets ratio.

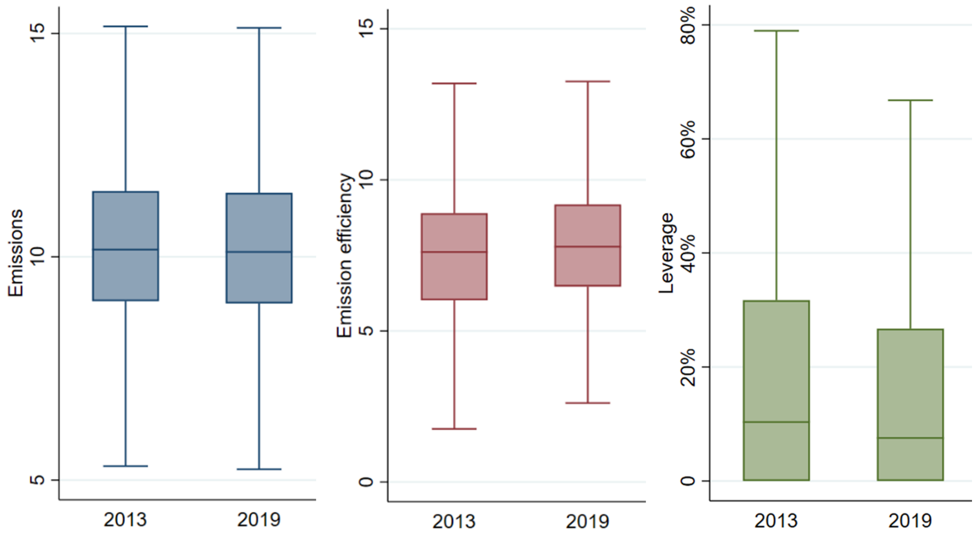


Table B6: Summary statistics of ratio of NFCs market-based debt on total debt by country

	Mean	Std. dev.
Austria	0.119	0.012
Belgium	0.085	0.003
Bulgaria	0.038	0.004
Croatia	0.041	0.005
Czech Republic	0.118	0.003
Denmark	0.066	0.012
Estonia	0.065	0.012
Finland	0.116	0.009
France	0.178	0.003
Germany	0.088	0.007
Hungary	0.021	0.005
Ireland	0.032	0.006
Italy	0.119	0.007
Latvia	0.015	0.005
Netherlands	0.098	0.005
Poland	0.117	0.018
Portugal	0.126	0.006
Romania	0.002	0.001
Slovakia	0.121	0.007
Total	0.109	0.046

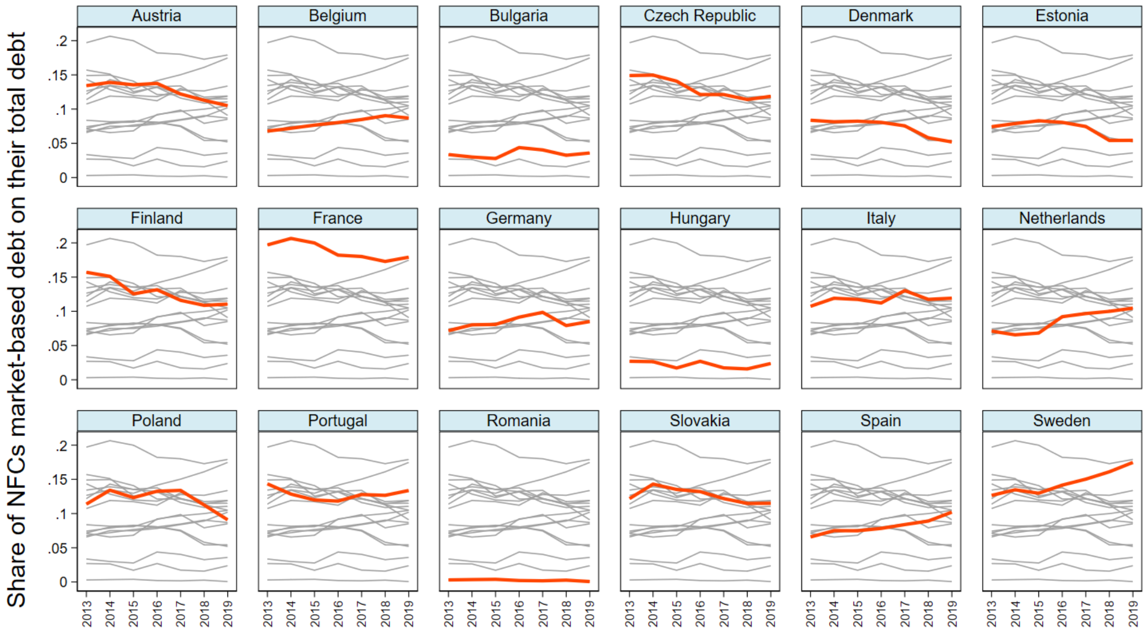
Table B7: NFCs that have contracted green debt

Notes: Unique number of NFCs that have either issued a green bond or taken a green loan in our sample between 2013 and 2019. We make a distinction between NFCs that have directly contracted green debt and NFCs that have potentially benefited from green debt because a subsidiary or the head of their corporate group has contracted green debt.

	Green Bonds	Green Loans	Green Debt
NFCs in EU ETS with direct contraction of green debt	11	9	18
NFCs in EU ETS with possible indirect contraction of green debt	23	20	37
NFCs in Europe	162	636	739
NFCs in the World	506	1767	2238

Figure B4: NFCs debt financing by country across years

Notes: Ratio of total NFCs market-based debt divided by their total debt by NFCs' country of registration and by year. In each figure, the highlighted line shows the dynamics of the variable for the country specified in the light-blue note, while the grey lines represent all other countries for comparison. The countries with most observations in our sample are: France, Germany, Poland, Spain, and Sweden.



Acknowledgements

The authors thank Winta Beyene, Calogero Brancatelli, Martin Brown, Laura Capota, Juliette Desloires, Elias Einiö, Emilia Garcia, Sofia Gori, Daniel Kapp, Jean-Stéphance Mésonnier, Benjamin Mosk, Steven Ongena, Melina Papoutsi, Loriana Pelizzon, Allegra Pietsch, Alexander A. Popov, Maria Alsina Pujols, Glenn Schepens, Danilo Vassallo, Ivo Vehviläien, Christian Weistroffer, Soh Young In for their helpful comments as well as conference and seminar participants at the European Central Bank, the Helsinki Graduate School of Economics, the Helsinki Graduate School of Finance, the Leibniz Institute for Financial Research SAFE, the School of Finance of the University of St. Gallen, the 2022 RiskLab/BoF/ESRB Conference on Systemic Risk Analytics, the International Journal of Central Banking (IJCB) 2022 Conference, the 2022 GRASFI Conference, the 2022 Annual Research Conference of the European Commission, the Sustainable Finance Initiative Seminar of the Stanford Precourt Institute for Energy, the 11th Annual Research Workshop of the European Banking Authority, the 2023 Energy Finance Italia Conference, the 2023 Young Swiss Economist Meeting.

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PDF ISBN 978-92-899-6076-2 ISSN 1725-2806 doi:10.2866/354356 QB-AR-23-050-EN-N