Financing the low-carbon transition in Europe *

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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 are exposed to the steeply increasing cost of their emissions. Furthermore, we provide evidence that firm-specific and country-specific environmental factors, such as fossil fuel subsidies, affect firms' ability to reduce emissions; while we document that only a very limited number of carbon-intensive firms have used green debt instruments in the time frame analysed.

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Non-technical summary

With its *Fit for 55* plan, 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 towards the path of the low-carbon transition, the EU has introduced an economic mechanism of carbon pricing consisting of 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 the transition by reducing the cap every year since its introduction in 2005 and imposing a price on tradable emissions. Firms subject to such 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 for 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 reach carbon neutrality.

We rely on evidence from a sample of almost 4000 firms subject to the EU emission trading system that are responsible for approximately one third of EU's greenhouse gas emissions. We find that firms' leverage matters for their ability to reduce their emissions and achieve the low-carbon transition. Firms with higher leverage produce significantly lower emissions without constraining their economic activity. In fact, they reduce their carbon footprint throughout 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 throughout 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 the introduction of a more stringent regulatory framework within the EU emission trading system. We find that highly indebted firms did not reduce their emissions even when exposed to such 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 points at debt financing as a valid channel to enable the low-carbon transition of firms subject to the EU emission trading system, while sustaining their economic activity. The findings indicate that the availability of adequate debt financing opportunities is key to ensure the effectiveness of the EU emission trading system. 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 emission trading system is not a sufficient tool to push firms on the path of the low-carbon transition, if they are excessively indebted.
At the same time, we document that firms subject to the system generally do not rely on green debt financing. Therefore, we pose that the development of such debt markets could ultimately allow highly indebted firms in Europe to obtain financing opportunities 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 firms' negative externalities 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 towards the adoption of cleaner technologies. The European Union's 2019 *Green Deal* acknowledges that financing is central for 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, 2018; Bolton and Kacperczyk, 2021b). However, in the EU, most firms are not fully exposed to the stock market as an emission reduction driver. Indeed, debt finance, rather than equity, is the primary source of non-financial corporations' external financing and the vast majority of European firms are non-listed[2]. Given the relevance of debt finance in Europe, leverage represents an important factor that can 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 EU's cap-and-trade policy instrument, we study how European firms' debt finance relates to changes in emission. Our sample covers especially 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.

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

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

The EU ETS regulates emissions produced by most fossil-fuel intensive economic activities. The main goal of the EU ETS is to reduce the aggregate level of emissions under the cap-and-trade policy, while the longer-term aim is to foster innovation and adoption of clean technologies (Martin, Muûls, and Wagner, 2020). For the purpose, each installation subject to the EU ETS is allocated yearly a limited amount of allowances (EUAs) to emit for free. If its yearly emissions exceed its total amount of free EUAs, it will have to purchase enough EUAs to cover for its excess of emissions. This can be achieved through a system of auctions, where operators with a surplus of EUAs are enabled to store them or trade them with those having a deficit of EUAs. Where a firm fails to provide EUA covering the amount of its verified emissions for the past year, it has to pay a penalty[3].

We find that a firm's leverage matters for the its ability to reduce its emissions, when it is subject to the EU ETS. 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. Interestingly, 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 in turn leading to steeply rising emission allowances prices. Highly indebted firms exposed to such prices did not succeed in reducing their emissions, while other firms successfully did so. We build 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. 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 a cleaner production. While our results are consistent with firms investing in the adoption of green technologies to reduce their emissions, a possibility is that

[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.

they would also be aligned with carbon pricing encouraging 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, age, but also firm-specific environmental factors, such as number of plants with carbon-intensive activities, and country-specific environmental factors, such as fossil fuel subsidies, as these likely affect firms' ability to reduce emissions. Instead, when examining the use of green finance, we find that only a very limited number of carbon-intensive firms took a green loan or issued a green bond in the timeframe 2013 – 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.

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. We address potential endogeneity concerns 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 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 — in carbon accounting).

This paper contributes to different 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 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, 2012). 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 is not a sufficient tool to achieve the transition if not paired with adequate financing opportunities because financial constraints can impede the transition of firms subject to the EU ETS.

The literature on the role of firms' financial structure, financing opportunities and financial constrains in the low-carbon transition is still in its infancy. Macroeconomic literature suggest that economies that are relatively more equity-funded are greener (De Haas and Popov, 2018). 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 a relief of a 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 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 this literature showing that debt financing is a determinant of the transition of European non-listed firms subject to the EU ETS cap on emissions. Secondly, we also highlight the existence of a group of firms that are too indebted to abate their emissions and improve their clean production. These might face the risk of being left out of the transition even though they are subject to increasingly stringent constraints on their ETS 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, 2021a), 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.

Moreover, relative to this literature, our analysis provides insights on a wide sample of carbon-intensive firms that is still mostly unexplored. First, we analyse 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.

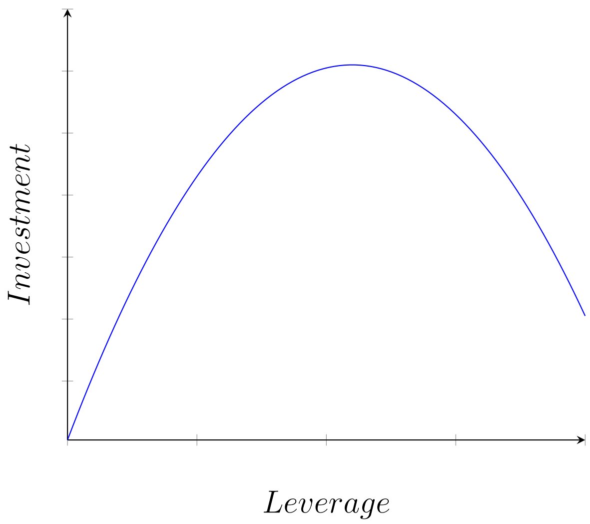
The rest of the paper is organized as follows. Section 2 presents the theoretical background and the set of hypotheses as well as the empirical strategy. Section 3 describes the dataset and presents stylized facts. Section 4 discusses the main results including robustness tests. Section 5 concludes and 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. On one hand, firms can benefit from corporate debt financing due to the tax advantages and reduced agency costs it brings about (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. On the other hand, high indebtedness holds back investment as firms face higher barriers to raise new external financing and direct a higher share of their debt financing towards the coverage of rising servicing costs (Myers, 1977). Given the two opposing forces, 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 too 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: Shape of the function describing the relationship between leverage, i.e. debt-to-assets, and investment.

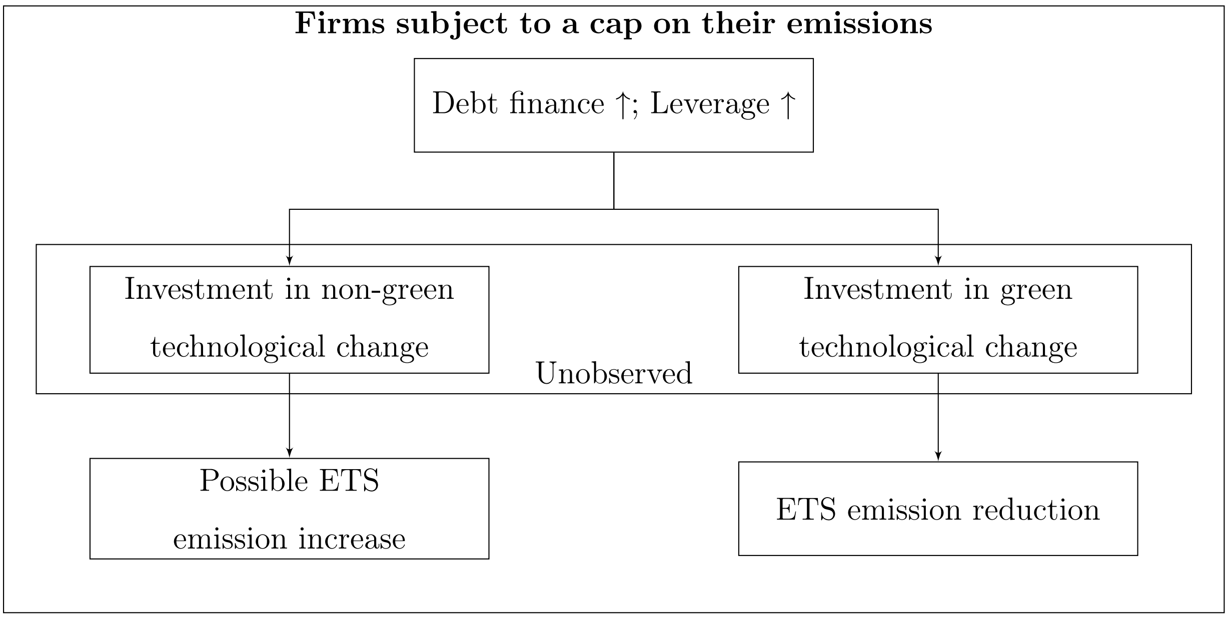


Building on this economic mechanism, we connect the literature on corporate debt financing and investments to the literature on green finance to disentangle the role of corporate debt in financing firms' investments in the technological change needed to achieve the low-carbon transition. The literature on environmental economics clarifies that greenhouse gas emissions are a negative externality (see the seminal work of Nordhaus, 1991). However, the decision making of a firm is primarily based on financial gains and does not include considerations related to the externalities or indirect costs of the available projects (Helbling, 2017). As such, greater economic activity can imply higher GHG emissions. In this paradigm, to emit less, a firm would need to produce less and / or invest in changing its emissions-intensive technology to a cleaner technology, which generates fewer emissions for each unit of output. Therefore, financing is central to enable firms subject to a cap on their emissions to invest in their low-carbon transition, without reducing their economic activity. Debt finance is the primary source of external financing of non-financial firms in Europe. 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." (Alogoskoufis, Dunz, Emambakhsh, Hennig, Kaijser, Kouratzoglou, Muñoz, Parisi, and Salleo, 2021). Generally, in a simplified illustration of debt-investment links, firms that are subject to a cap on their emissions may use their debt financing to pay for their debt servicing and to finance investment in the adoption of either non-green technologies or green technologies (as illustrated in Figure 2). An investment in non-green technological change shall not improve the transition performance of the firm, such that firm's emissions shall increase or at best remain constant while emission efficiency shall decrease or remain constant. In other words, firms that are active within the EU ETS rely primarily on debt to finance to increase in their economic activity without integrating negative externalities on the environment in their decision-making. Conversely, an investment in green technological change shall improve the transition performance of the firm, such that the firm's emissions shall decrease and emission efficiency increase. 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.

The assumption of our analysis is that firms do not use investments to shift emissions outside the cap-and-trade system. We discuss the robustness of our analysis to this assumption in Section 4.4.

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

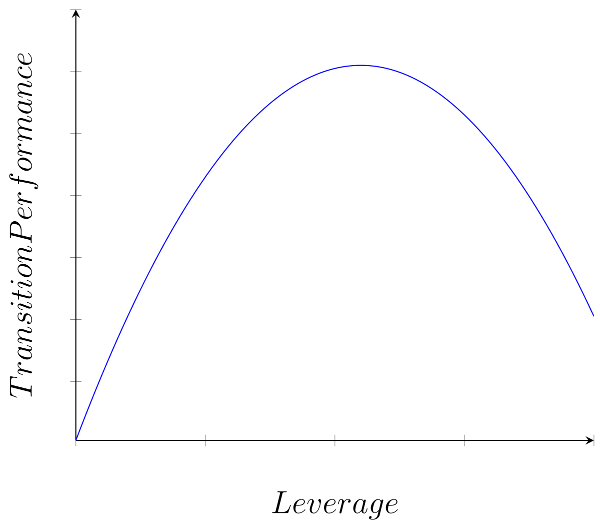
Notes: the Figure illustrates the theoretical link between external financing, investments and emissions for firms subject to the EU ETS.



To study how debt finance relates to a firm's emissions, we outline a set of underlying questions and hypotheses. Building upon the theoretical 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 firms' leverage and their transition performance (see Figure 3). Firms that are subject to the EU ETS and have a relatively low leverage ratio, i.e. low debt-to-assets, 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.

Figure 3: Theoretical relation between leverage and transition performance of a corporate firm

Notes: Shape of the function describing the relationship between leverage, i.e. debt-to-assets, and transition performance.



The economic mechanisms outlined require to test the following hypothesis:

H1. There is a non-linear relationship between the level of transition performance of a firm within the EU ETS and its leverage, such that up to a certain level of leverage higher leverage is associated with better transition performance.

Furthermore, we examine how a temporal variation in debt finance, controlling for other potential drivers, relates to the change in transition performance of a firm within the EU ETS. We pose that:

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

Finally, having observed the relationship between leverage and transition performance, we examine the relationship between the two variables in the context of the entry into force of the March 2018 EU ETS Directive[5] that accompanied the steep increase in EUAs prices[6]. The event is considered as the reason for the strengthened credibility of the EU ETS (Ampudia, Bua, Kapp, and Salakhova, 2022).

H3. While the increased price of EUAs creates a pressure on firms' emission reduction efforts, highly leveraged firms exposed to such rising price are unable to reduce their emissions. Instead, other firms successfully do so.

To test our main hypotheses, we outline both a panel regression and a difference-in-differences approach. We consider two possible measures of transition performance for a given firm: emissions and emission efficiency (alike in De Jonghe, Mulier, and Schepens, 2020). The two measures reflect different yet both important and complementary aspects of a firms' low-carbon transition and are consistent with the targeted metrics of the EU ETS: reducing the aggregate emissions and improving emission efficiency. A firm's level of emissions reflects the firm's overall 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 is the production technology of the firm. Appendix A.1 provides technical input supporting this rational. We measure leverage using total debt divided by total assets (alike in Gebauer, Setzer, and Westphal, 2018).

Controlling for country and sector-year fixed effects and country and firm-level determi-

[5]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).

[6]We acknowledge further events occurring in February 2017 such as the announcement of the MSR reform and its operationalisation in January 2019.

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

nants of emissions, the following equation is exploited to test hypothesis one:

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

Equation 1 is quadratic in $Debt-to-assets$. This allows to test the non-linearity of the relation between leverage and transition performance. $X_{i,t-1}$ is the vector of controls, including fixed effects.

The coefficients resulting from Equation 1 allow 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. Setting the first derivative of Equation 1 with respect to $Debt-to-assets$ to zero we obtain:

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

For the test of hypothesis two, the following equation is exploited by the means of panel regressions with first difference estimation. Equation 3 explores the differential effect of a temporal variation in leverage depending on firm's initial leverage being below or above the threshold (computed in Equation 2).

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

Where $\Delta X_{i,t-1}$ is the vector of the first-differences of the time-varying controls, including the time fixed effect. When transition performance is measured through emissions, the estimate is expected to be negative when leverage is below the threshold and positive or not significant when leverage is above the threshold computed in Equation 2; vice versa holds for the expectations related tothe regression that employs emissions efficiency as a dependent variable.

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

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

In Equation 4 the coefficient of interest is β_1 which captures the average relative differnce in emissions after the event for the treated firms. The treatment dummy is equal to 1 for firms with a leverage above the implied leverage threshold (computed in Equation 2) and with an EUA balance below zero, i.e., they need to purchase additional EUAs to cover for their excess emissions, in the year prior the event (2017). The variable allows to capture the sub-sample firms that are highly indebted and exposed to rising EUAs prices. The dummy is equal to 0 for the remaining firms in the sample. In another exercise we set the treatment dummy equal to zero for firms that are not highly indebted, but similarly exposed to rising EUAs prices. The time dummy *postevent* is equal to 1 in the year of and after the event (i.e., 2018 and 2019) and it is equal to 0 before (i.e., 2016 and 2017)

In our empirical strategy, we use the following set of controls: (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 to address 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).

Table 1 gives a detailed overview of the expected sign for each of these variables in relation to transition performance.

Table 1: Expected signs of the relation between independent variables, control variables and the dependent variable

Variable name	Time	$ln(Emissions)$	$ln(Revenues/Emissions)$
Debt-to-assets	t-1	-	+
$(\text{Debt-to-assets})^2$	t-1	+	-
ln(Revenues)	t	+	
ROA	t-1	-	+
Age	t-1	-	+
Installations	t-1	+	-
EUA balance	t-1	-	+
Fossil fuel subsidies	t-1	+	-
Carbon tax flag	t-1	-	+

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 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 through 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 6, 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 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, following analogous approaches in the green finance literature that relies on difference-in-differences methods (see e.g., De Haas, Martin, Muûls, and Schweiger, 2022 among others).

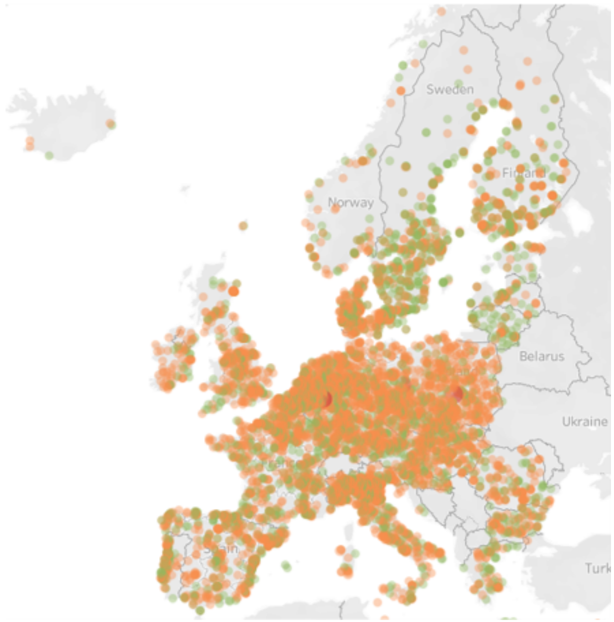
We conduct additional robustness tests in Section 4.5.

3 Data

We construct a firm-level dataset based on observations of the EUTL on the verified greenhouse gas emissions of installations subject to European Carbon Market (EU ETS), which reflects approximately 40% of the EU's CO2 emissions. The EUTL dataset allows to map 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.

Figure 4: 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.



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 in the EU on average. In Figure 4, 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. 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 for the structure of the fossil-fuel intensive section of the European real economy.

[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).

The sample composition by year, country and Nace 1-digit sector is shown in Table 2.

Table 2: Sample composition by year, country and sector

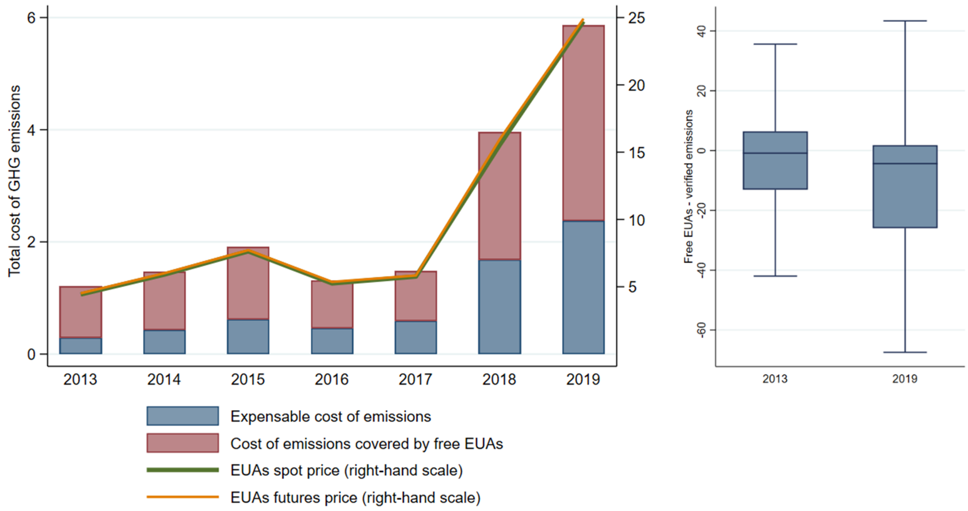
Notes: The table shows the sample composition for observations with available economic and environmental variables.

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

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 5 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 5 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 suggests that the framework of our study is an increasing constraint on firms' emissions from the ETS.

Figure 5: Average cost of ETS emissions, EUA prices and distribution of EUA balance over time.

Notes: Left panel: The chart shows the 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-months futures' prices. Right panel: The chart shows the distribution of firm-level EUA balance in 2013 and 2019.



In the following sections 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 analysed. 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 to decrease 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

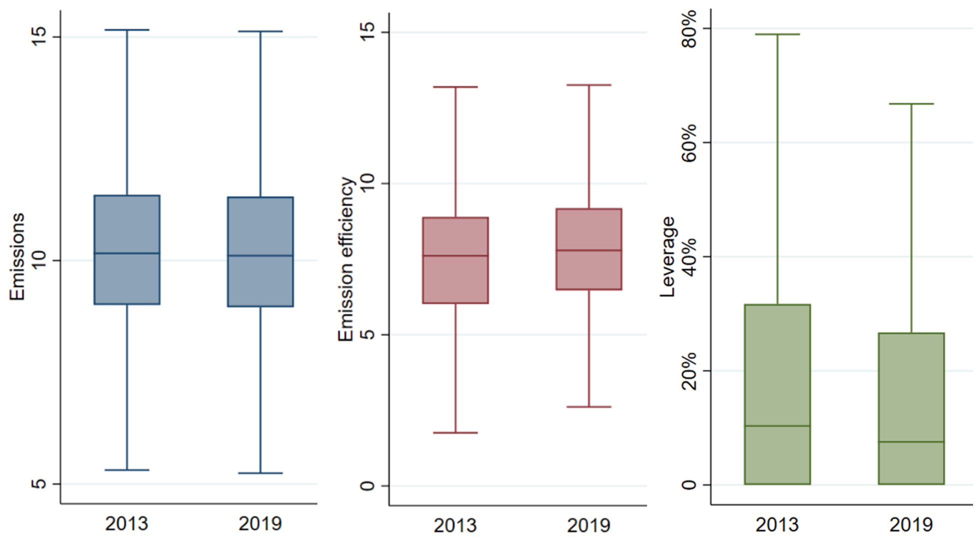
[10] An ideal metric would be revenues generated by the ETS plants relative to their ETS emissions, but plant-level financial data is not disclosed as ETS plants are not a legal entity, but an asset.

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 6, left panel). Across the same period, firms have generally experienced an increase in their emission efficiency (Figure 6, middle panel).

Figure 6: 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.



Box plots describing firm-level ETS emissions, emission efficiency and leverage across time and across sector groups are in Appendix A.2.

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 3.

Table 3: Firm-specific economic variables

Variable	Description	Source
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

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. Figure 6 right panel shows that the leverage ratio of firms in our sample decreased across time. We also collect data on whether the firm holds green debt. We find that out of our sample of almost 4000 firms, only few have taken a green loan or issued green bonds. This is discussed in Section 3.4.

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 excell allowances 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.

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 backwards 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 4.

Table 4: Firm and country-specific environmental variables

Variable	Description	Source
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 Descriptive statistics

Summary statistics of our variables of interest are provided in Table 5. Correlations of main variables are shown in the Appendix in Table 15. The 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.

Table 5: Summary statistics of relevant variables

Note: Descriptive statistics based on sample of firms covering period 2013 to 2019 for the y variables and 2012 to 2018 for the x variables. Variables description is given in Table 3 and Table 4.

	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

3.4 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 (2021a) and Flammer (2021) show that issuance of green bonds by non-financial corporations is associated with reduction in carbon emissions in the following years, particularly if a company issues certified green bonds. However, they argue that the size of the market is still too small to finance green projects, rather issuance of green bonds serves as a signal of firm's commitment to climate objectives and attracts new investors.

In our analysis we are interested in testing if the use of green debt determines firm's transition performance. Using data on the issuance of green bonds and the use of green loans by non-financial firms, we find that a negligible number of firms have benefited from any form of green debt. Table 6 shows the number of firms that have contracted green debt: a very limited number of firms active in the EU ETS, 18 in total, directly benefited from green debt, while only 37 firms might have benefited from it through their consolidated group structure.[11] EU ETS covers the most polluting industries, and it is possible that polluting firms may find it difficult to convince investors of the greenness of

[11]Table 6 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.

their projects in the absence of a common regulatory standard for green bonds. Findings by Pietsch and Salakhova (2022) and Fatica and Panzica (2021b) hint in this direction, as they show that only green bonds from credible investors trade at a greenium, i.e. at a lower spread than conventional bonds from the same issuer and with similar risk profile. Higher demand and thus cheaper funding for firms via green bonds can be considered as a sign of trust from investors. Credible investors are defined as firms in renewable energy sectors, and their green bonds trade at a statistically and economically significant greenium of about 26 bps over the analysed period, 2019-2021 (Pietsch and Salakhova, 2022). 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.

Based on these insights, we rule out the improvement in the transition performance of ETS-constrained firms has been due to the rise of green financing.

Table 6: NFCs that have contracted green debt

Notes: The table shows the unique number of NFCs that have either issued a green bond or taken a green loan in our EU ETS-based sample, overall in Europe and in the world in the timeframe 2013-2019. 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 the 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

4 Results

First, we present the baseline results of the regression analysis on the hypothesis 1 and hypothesis 2. Afterwards, building on such results, we present our key difference-in-differences analysis on hypothesis 3.

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. The latter is measured though verified greenhouse gas emissions in columns (1) and (3) and emission efficiency (i.e., the natural logarithm of total revenues to greenhouse gas emission) in columns (2) and (4) of Table 7. We winsorize the debt-to-assets ratio to remove the effect of outliers above the 99th percentile. Excluding $ln(Revenues)$, which controls for the size of the firm at time t, all other independent variables are lagged by one year relative to the dependent variable. Columns (1) and (2) include sector by time fixed effects and country fixed effects. Vice versa, columns (3) and (4) include firm fixed effects, rather than country fixed effects, and sector by time fixed effects. As shown in Figure 6, firm-level emissions change little over time—also due to the short length of the time series of only 7 years—but they vary substantially across firms—also due to the large cross section of almost 4000 firms. Henceforth, we will focus on the results in columns (1) and (2), which do not include firm fixed effects. Indeed, Table 7 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 global minimum of the regression's equation, computed taking its first derivative and setting it to zero (as explained throughout 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 highlight the non-linear relationship between leverage and emissions and support hypothesis 1.

Table 7: Panel regression for transition performance and leverage, from 2013 to 2019

*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. 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

Firm level financial data are used as controls. Larger firms, whose size is measured through their revenues, are associated with higher emission levels. Higher profitability, measured through firms' return on assets, is associated with lower emission levels and higher emission efficiency. Differently, the coefficients on firms' age are both positive, albeit only significant for emission efficiency. We also include firm-specific environmental controls. Firms that own a higher number of installations that are active within the EU ETS are associated with higher emissions and lower emission efficiency. Moreover, firms with a more positive balance of free allowances in excess of their verified emissions are associated with significantly lower emission levels and higher emission efficiency. An excess of allowances is indicative of lower costs of emissions for firms active within the EU ETS. The firms that benefit from the lower costs are observed to have lower emission levels and higher emission efficiency. This points at these firms' potentially higher availability of funds to finance the technological change needed to accomplish the low-carbon transition.

Lastly, we include country-specific environmental controls. Higher fossil fuel subsidies, relative to the country's GDP, are associated with firms with significantly higher emissions and lower emission efficiency. Firms registered in countries that have introduced a carbon tax of any kind are associated with lower emissions and higher emission efficiency, albeit not significant.

We analyse 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 (2018), 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 we argue for in Section 2. In Table 8 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 and a similar share of the European economy.

Table 8: 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, pointing at the differential effect of leverage changes on transition performance changes for sub-samples of listed or non-listed firms. 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)
	Listed	Non-listed	Listed	Non-listed
VARIABLES	ln(Emissions)	ln(Emissions)	ln(Rev./Em.)	ln(Rev./Em.)
Debt-to-assets	0.71	-1.45***	1.23	2.61***
	(1.76)	(0.33)	(1.94)	(0.37)
$(\text{Debt-to-assets})^2$	-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 and controlling for the level of leverage of the firms. The results are descriptive of the economic mechanism that links changes in leverage to changes in transition performance at firm level for different levels of the firm's leverage, as described in Equation 3. In Table 9, *Leverage* is a dummy equal to one if the firm is highly indebted at time $t-2$, i.e., when the leverage ratio in time

$t-2$ is above the average of the implied leverage thresholds computed in Table 7, which is then used as an interaction term to control for the non-linearity of the relationship between leverage changes and emission or emission efficiency changes. Substituting the coefficients obtained in Equation 2, we obtain an implied leverage threshold of 55%—computed in Table 7, column (1)—and the second implied threshold of 45%—computed in Table 7, column (2). Henceforth, firstly, in columns (1) and (2) of Table 9, we use 50% as an implied threshold that results from the average between the first and second implied thresholds. A possible concern with our first differences results reported in columns (1) and (2) 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 excluding firms with leverage ratio between 25% (approximately one standard deviation below the implied threshold) and 75% (approximately one standard deviation above the implied threshold) from our the first-differences analysis.

Table 9: 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) Leverage 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

The results in Table 9 suggest that there is a non-linear relationship between leverage changes and transition performance changes. When firms with a debt-to-assets ratio below 50% increase their leverage, they are significantly associated with an emission reduction and an emission efficiency increase. However, this is not the case for firms that have a debt-to-assets ratio above 50% and increase it further. Results in Table 9 show that the non-linear effect of debt-to-assets on transition performance remains robust to this specification. Interestingly, when removing the noisy effect of firms with a leverage that is too close to the implied threshold, we obtain that only firms with debt-to-assets below 25% show significantly lower emissions and higher emission efficiency when leverage grows. 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 22.

4.2 Difference-in-differences approach

In the analyses so far, we have showed a non-linear relationship between leverage and transition performance. High leverage is associated with relatively low ETS emissions as long as it is below an implied threshold of approximately 50% (Table 7). An increase in leverage is associated with a reduction in emissions as long as it is below the same implied threshold (Table 9). A possible concern is that firms' transition performance is endogenously determined by their preferences for green investments. Therefore, we investigate firms' emissions following the introduction of March 2018 amendment of the EU ETS Directive[12] that set the ground for phase 4 of the ETS (2021 to 2030)[13]. 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 (Ampudia, Bua, Kapp, and Salakhova, 2022). Specifically, this set of results uses the specification presented in Equation 4 to test hypothesis 3 through a difference-in-differences approach.

The treatment group includes firms, which prior the event (2017) have a leverage above 50%, i.e. firms that are highly indebted according to our previous findings, and a cu-

[12] 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).

[13] We acknowledge further events occurring in February 2017 such as the announcement of the MSR reform and its operationalisation in January 2019.

mulative EUA balance below 0, i.e., firms that have a deficit of EUAs and need to buy additional EUAs to cover for their emissions. In columns (1) and (4) of Table 10 the control group includes all other firms (treatment dummy $D1$), while in columns (2) and (5) it includes all other firms that have a cumulative EUA balance below 0, but a debt-to-asset ratio below 50% (treatment dummy $D2$). The analysis is performed on a sample covering the years 2016 to 2019.

The results are in Table 10. They rely on the sample of firms that are active in the EU ETS in every year observed (two years before the event, i.e., 2016 and 2017 and two years after, i.e., 2018 and 2019). 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, with regards to all other firms (in column (1), where the treatment dummy is $D1$) as well as with regards to firms that are not highly indebted, but similarly exposed to rising EUA prices (in column (2), where the treatment dummy is $D2$). While firms subject to a constraint on their emissions use debt to finance their low-carbon transition, highly indebted firms are not observed to do so in response to higher EUA prices. The results on emission efficiency in columns (4) and (5) are not as significant, hinting at the possibility that highly indebted firms experienced an increase in their revenues in the years following the event, that might have driven the increased emissions production. However, there are possible concerns with the results reported in columns (1), (2), (4) and (5) 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 excluding firms with leverage ratio between 25% (approximately one standard deviation below the implied threshold) and 75% (approximately one standard deviation above the implied threshold) from the sample. This defines the treatment dummy $D3$.

Table 10: 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	0.094*			-0.090		
	(0.054)			(0.065)		
D2(Treated) X Post		0.082*			-0.093	
		(0.047)			(0.061)	
D3(Treated) X Post			0.21**			-0.29**
			(0.10)			(0.15)
Controls	Y	Y	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y	Y	Y
Country FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	10,464	6,904	4,912	10,464	6,904	4,912
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

The results of this analysis are aligned with our hypothesis and suggest that the rise in the EUA price has led to a different behaviour in transition performance of treated firms following 2018. Interestingly, results are particularly significant when excluding the confounding effect of firms with leverage close to the implied threshold of 50%. They are consistent with the idea that a more stringent cap on emission pushes firms that are not highly indebted to invest in green technologies to reduce their emissions; while this is not possible for highly indebted firms. In turn, this highlights the existence of a sub-sample of firms that are too indebted for the low-carbon transition.

4.3 Economic significance

In the previous section, we have documented the relationship between leverage and transition performance. We now aim to provide quantitative indications on the magnitude and economic significance of the estimated coefficients. Particularly, we are interested in what is the magnitude of the change in transition performance given a change in the leverage of the firm in the previous year. As our regression results indicate that the relation between transition performance and leverage is different for firms with leverage below 50% and above 50%, we study the magnitude separately for each of these two groups of firms. To do so, formally, we compute the percentage change in transition performance (TP) as follows:

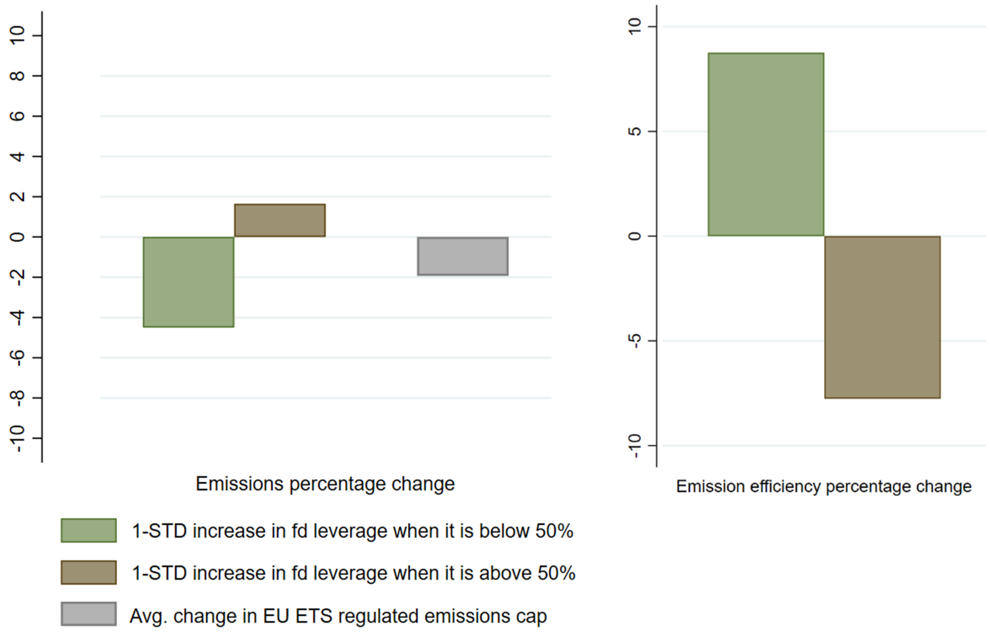
$$\%TransitionPerformance_s = \frac{TP(MED(debttoassets)_s) - TP(MED(debttoassets)_s + \Delta)}{TP(MED(debttoassets)_s)} \tag{5}$$

$TP(MED(debttoassets)_s)$ 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 coefficients obtained for the variables of $debt - to - assets$ and $(Debt - to - assets)^2$ in Table 7. $MED(debttoassets)_s + \Delta$ is the median leverage of sample s considering an increase in leverage. The increase is set to equal one standard-deviation of the first-difference of leverage observed for the median firm in the sample. In a second specification we use the median absolute change instead. In a third specification we use the mean absolute change. 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 standard deviation of the first difference of debt-to-assets is 4.0% for firms with leverage below 50% and it is 7.7% for firms with leverage above this threshold.

The results are presented in Figure 7.

Figure 7: Magnitude of the impact of an increase in leverage on transition performance

Notes: The Figure illustrates the impact of 1-STD increase in the first-differences of leverage of the median firm on its transition performance vis-a-vis the yearly average reduction in the emissions' cap imposed by the EU ETS.



When leverage is below 50%, one standard deviation increase in the first-differences of debt-to-assets of the median firm is associated with an average reduction in emissions by 4.5% in the following year. For the average firm in our sample with ETS emissions of 252,159 eCO2 tonnes, this implies a reduction of 11,347 eCO2 tonnes. When leverage is above 50%, one standard deviation increase in the first-differences of debt-to-assets of the median firm is associated with an average increase in emissions by 1.6% in the following year. For the average firm in our sample with ETS emissions of 252,159 eCO2 tonnes, this implies an increase of 4,035 eCO2 tonnes. The economic impact of one standard deviation increase in the first-differences of debt-to-assets of the median firm on emissions is larger for firms with leverage below 50%. This suggests that the median firm with leverage below 50% is able to reduce emissions by investing in technological change, without reducing production/economic activity. Indeed, it experiences a 8.8% improvement in emission efficiency following an increase in leverage by one standard deviation of the first-differences of debt-to-assets. For the average firm in our sample with ETS emission efficiency of 543,658 EUR / eCO2 tonnes, this implies an increase of 47,842 EUR / eCO2 tonnes.

As an additional exercise, we observe the economic magnitude of the relationship between leverage and transition performance when the leverage of the median firm increases by the mean of the absolute first-differences of its debt-to-assets across time. In this case, the mean of the absolute first-differences of debt-to-assets 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 such 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. Moreover, we observe the economic magnitude of the effect when the leverage of the median firm increases by the median of the absolute first-differences of its debt-to-assets across time. In this case, the median of the absolute first-differences of debt-to-assets 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 such 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. This represents a lower boundary for the economic magnitude of the average effect of leverage on transition performance.

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. Firstly, firms could shut down their EU ETS 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 captures the number of EU ETS active plants held by the firms in the sample. Secondly, firms could maintain their EU ETS plants without expanding them, 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. A limitation of the available data is that we can not fully mitigate these concerns throughout empirical analyses because information on plants that are active outside the coverage of the EU ETS is unavailable. However, as currently available empirical research has not been able to confirm the findings of ex-ante theoretical models that predict a high risk of carbon leakage associated with the implementation of the EU ETS, we argue that the economic mechanism that we capture in Section 4 describes firms' improvement of their low-carbon transition performance throughout the adoption of green 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 (these findings are aligned 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, and Dechezleprêtre, Gennaioli, Martin, Muûls, and Stoerk, 2022; whose focus are multinational firs). 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) propose the only currently available empirical study on carbon leakage that focuses fully on the period 2013-2020 of emissions trading (Phase 3 of EU ETS). Using foreign direct investment data on firms covering 50% of the emissions capped by the EU ETS, 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 (European Commission, 2009). While these firms receive relatively more free EUAs, this does not seem to be sufficient to encourage them to fully maintain their economic activity within the EU ETS between 2013 and 2020 (De Beule, Schoubben, and Struyfs, 2022). Instead, the authors do not find evidence of carbon leakage for firms that are not on the carbon leakage list.

Empirical literature on EU ETS carbon leakage 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 by the European Commission (European Commission, 2009). 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 Table 11, we test hypothesis 1 on a sub-sample of firms that belong to sectors included or excluded by the carbon leakage list. Results are significant and aligned with hypothesis 1. 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 are close to 50%.

Table 11: 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. 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) 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

We repeat the exercise to test our difference-in-differences results.

Table 12: 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	0.039	0.21**	-0.16**	-0.23
	(0.044)	(0.091)	(0.066)	(0.17)
Controls	Y	Y	Y	Y
Sector-year FE	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y
Observations	1,824	3,068	1,824	3,068
R-squared	0.991	0.988	0.983	0.882

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

Similarly to the results provided in Section 4.2, the event is the March 2018 amendment of the EU ETS Directive that set the ground for phase 4 of the ETS. In column (1) of Table 12, the treatment group includes firms that are on the carbon leakage list, which prior the event (2017) have a 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 including and below 25% (as in treatment dummy $D3$ defined in Section **??**). In column (2) of Table 12, the treatment group is selected similarly, but including firms that are not on the carbon leakage list prior the event (2017). As mentioned in Section 4.2, this allows to remove the noisy effect of firms with a 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 11. The results of this analysis suggest that the rise in the EUA price has led to a different behaviour in transition performance of treated firms following 2018, when looking at firms that are in the carbon-leakage list. They are consistent with the idea that a more stringent cap on emission pushes firms that are not highly indebted to invest in green technologies to reduce their emissions; while this is not possible for highly indebted firms. Moreover, subject to such cap, highly indebted firms that are on the carbon leakage list worsen their emission efficiency performance, meaning that they have experienced a reduction of their economic activity without reducing their emissions; while the effect is similar, but not significant for firms that are not on the carbon leakage list.

4.5 Additional robustness tests

We conduct the following set of robustness tests on the difference-in-differences analysis: firstly, we test the parallel assumption (central in the context of difference-in-differences analyses Bertrand, Duflo, and Mullainathan (2004)). Our tests, in Table 24 show that prior to the event treated and non-treated firms are non-distinguishable. Secondly, we conduct placebo tests shifting the event date to 2017. The relationship between the variables is not significant (Table 25).

A potential concern of the regression specifications used in Section 4.1 is that they account for a 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 analyze the relationship between transition performance and leverage, and their changes, where independent variables are observed in their three-years lag. The results are in Table 16. 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 9, showing that a leverage increase is not associated with significantly lower emissions after three-years for firms that are initially not highly leveraged, nor higher emissions for firms that are highly leveraged. Instead, while a leverage increase for firms with debt-to-assets below 50% is associated with improved emission efficiency, this is not observed for firms with higher debt-to-assets.

Additionally, we observe that 76% of the observations in our sample refer to firms that subsidiaries of a corporate group. To reflect the possibility that firm-level observations could especially concentrate across firms that are part of the same group, we repeat our analysis clustering standard errors at the group level. Table 17 shows that results of our panel regressions and difference-in-differences regression are robust to the use of standard errors clustered at the group level.

A further concern is that firms producing very high or very low 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 mostly robust to the sub-sample analysis.

Following the same logic, we examine the differential effect of 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 (Rajan and Zingales, 1996). 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. Leverage induced constraints are not biting for large firms, while they represent an obstacle towards the achievement of low-carbon transition goals for highly indebted SMEs.

Lastly, we test whether the relationship between leverage and transition performance levels of Equation 1 is driven firms that are active within a specific sector; acknowledging that the difference in need for external financing as well as the level above which leverage represents a financial constraint may differ across sectors. For the purpose, we use the empirical strategy outlined in relation to hypothesis 1. In Table 20, 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 sector 35) and manufacturing of metals, non-metals, chemicals and petroleum products (Nace 2-digits sectors 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 sector C, excluding Nace 2-digits sectors 19 to 25, Nace 1-digits sectors B, F, G and H), albeit only the coefficient on the linear term of leverage is significant. Therefore, the relationship between leverage and transition performance is mostly consistent across sectors. Moreover, in Table 21 we repeat the difference-in-differences analysis for hypothesis 3 employing a specification with a triple moderation term as follows:

$$\Delta Emissions_{i,t} = \alpha + \beta_1 treatmentXposteventXsector + \beta_2' \Delta X_{i,t-1} + \epsilon_{i,t} \tag{6}$$

Where $X_{i,t-1}$ is a vector of controls including fixed effects and interaction terms between *postevent* and *sector*, *postevent* and *treatment*, and *sector* and *treatment*. This specification allows to discern how the treated firms react to the increase in EUAs prices by sector. Sectors are defined at the Nace 1 level. The results observed in Table 21 are robust to this specification and aligned with those osberved in Section 4. Lastly, all analyses that rely on the variable emission efficiency specified as the ratio of revenues on emissions are repeated for the ratio of total assets on emissions. As shown in Table 23, the results are unchanged.

5 Conclusion and policy relevance

Using historical data on verified emissions of close to 4000 firms and accounting for 26% of the total emissions in the EU, this paper sheds light on the role of debt finance in supporting the low-carbon transition of non-financial corporations in Europe. Particularly, we study the emissions of regulated firms that are subject to Europe's cap-and-trade policy, i.e. the EU ETS, covering fossil-fuel intensive activities such as power and heat generation, energy-intensive manufacturing, and civil aviation. Using two metrics of transition performance (emissions and emission efficiency), our analysis shows that higher debt financing of firms subject to a constraint on their emissions contributes to emissions reduction and cleaner production as long as leverage does not represent a financial constraint. In fact, this relationship is non-linear such that higher leverage is associated with higher transition performance as long as leverage is below 50% and the relation is inverse for levels of leverage above this threshold. Similarly, our analysis on temporal variation in leverage shows that an increase in leverage is associated with an improvement in the transition performance of the firm in the next years when the firm is not highly indebted. When disentangling the effect, we find strong suggestive evidence that improvement in transition performance is achieved through improving emission efficiency by actually reducing emissions and not merely by reducing economic activity, i.e. reducing revenues.
Most firms in Europe and in our sample are not subject to the pressure of stock markets pushing towards the low-carbon transition, but they are subject to s cap on their emissions enforced throughout the EU ETS. Through our differential analyses, we show that debt financing is especially important for the transition of these non-listed firms. However, our study also highlights 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. Indeed, our difference-in-differences analysis shows that firms reduced their emissions on average in response to the steep increase in EUA prices triggered by the introduction of the EU ETS Directive in March 2018. However, this is not observed for highly indebted firms that were exposed to rising EUA prices.

Our analyses show that the non-linear leverage-emissions relation holds true for the subsample of firms that are not at risk of carbon leakage. This mitigates the risk 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 exclude that our analysis not only captures firms' choice to channel debt towards the adoption of green technologies, but also their decision to finance carbon-leakage strategies to shift their economic activity outside the EU ETS, previous literature discards such concerns as it only provides scarce evidence of the materialization of carbon leakage risks.

Due to the absence of granular plant-level and firm-level data on disclosed emissions, we can not fully assess whether firms use debt to finance the shift of production outside the system. While the findings of previous literature have proven that carbon-leakage risks are limited, they highlight that firm level emissions data is a prerequisite to assess transition funding opportunities and climate-related transition risk (Elderson, 2021; NGFS, 2021). Albeit traditional and specialized data providers (e.g. CDP, Bloomberg, Refinitiv, Urgentem) are increasingly making available disclosed data on firm-level emissions, data on the firm-level emissions of firms that own installations that are subject to the EU ETS are not assimilated by data providers, even though such firms are fossil-fuel intensive and form the most hard to abate segment of emissions[14]. Therefore, to improve research on the financing-emissions nexus, an improvement of the firm-level disclosure framework on GHG emissions is needed. Particularly, the obligation to report GHG emissions should be extended to include all non-listed firms.

Our results are relevant for several other policy discussions. Firstly, 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 has proven its ability to encourage firms with adequate leverage

[14] We observe disclosed firm-level GHG Scope 1 data for only 55 firms, which are mostly listed, leaving unobserved the emissions activity of over 99% of NFCs in our sample.

to reduce emissions. Therefore, to achieve emissions reduction in Europe at a more sustained pace, strengthening the mechanism is indispensable.
Secondly, while acknowledging the role of equity markets for emissions reduction (De Haas and Popov, 2018), we show that also debt financing plays a crucial role for acquiring and implementing green technologies when firms are not highly indebted and subject to a constraint on their emissions. In this context, the development of green and sustainable debt markets is key[15]. The development of such debt markets, and in particular of the market for green loans, might be particularly important for European NFCs that are currently too indebted for the transition. By the means of these instruments, such firms could still obtain financing opportunities by committing to a green use of proceeds.

In our empirical analysis, green investment is an unobserved factor. As new data emerge, future work may consider the assessment of mobilization efforts of the firms such as green capital expenditure, clean energy investment, and green equity.

[15]See e.g., Born, Giuzio, Lambert, Salakhova, Schölermann, and Tamburrini (2021)

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A Appendix

A.1 Logic for measurement of transition performance

The target of the European Union was to achieve by 2020 an emission reduction of -20% compared to its 1990 level. The next target is to achieve by 2030 an emission reduction of -55% compared to its 1990 level (EU's *Fit for 55* plan). 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 the fossil fuel production, e.g. coal, oil, 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 pivotal reduction in activity. Generalizing this rational: 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.
Measuring a firm's progress on the low-carbon transition path is further done from the perspective of the targets envisaged by the firm. Emissions-related targets are typically defined by firms 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.

Conceptually, Table 13 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 absolute and relative targets in emissions of a firm as well as to the economy-wide absolute target.

Table 13: 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 the case 1, emissions are reduced and emission efficiency improved, such that the firm contributes both to the low-carbon transition goal and to the cleaner production goal. In case 2, emissions are reduced and emission efficiency deteriorates, such that the firm contributes to the low-carbon transition goal but fails to produce in a cleaner way. In case 3, a firm's emissions increase and firm emission efficiency also increases, reflecting that the firm's revenues increased by more than its emissions. In this case, the firm does not contribute to the economy-wide low-carbon transition goal, yet 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 the economy-wide low-carbon transition goal and fails to achieve the cleaner production goal. Empirically, the last column of Table 13 shows for each of these cases the share of observations in a sample of firms with emissions-intensive activities observed throughout 2013 – 2019. 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 the manufacturing of non-metal minerals (Nace 2-digits code 23) as shown in Table 14. 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. Such cases illustrate that incentivizing and monitoring alone an improvement in emission efficiency may not lead to a reduction of emissions in absolute terms. In 2019 Shell Deutschland had ETS-emissions of 3.4 million eCO2 tonnes, while in 2013 – 3.9 million eCO2 tonnes, indicating 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. This implies that the reduction observed in the overall level of emissions was likely due to a reduction in economic activity (revenues passed from EUR 29 billion in 2013 to 20 billion in 2019) and unlikely 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 14: 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.

A.2 Additional descriptive statistics

Table 15: 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

Figure 8: 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.

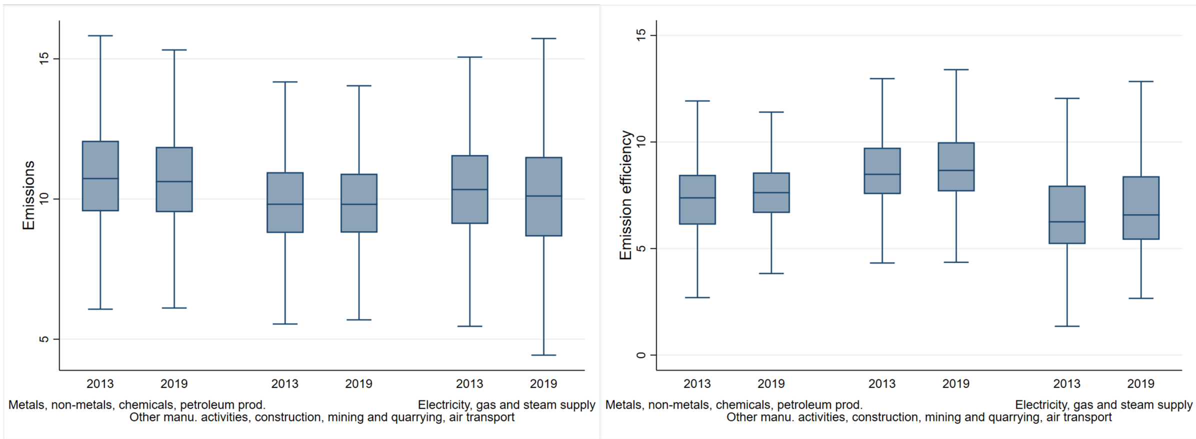
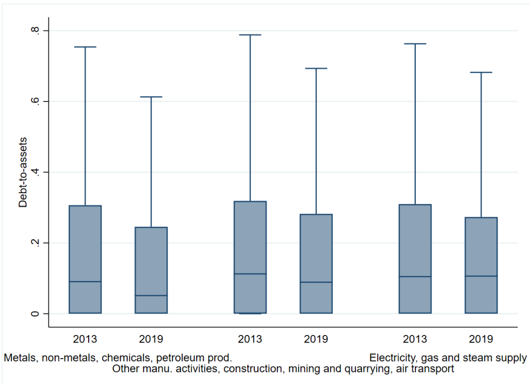


Figure 9: Firm-level leverage across time and industry groups

Notes: Leverage is computed as debt-to-assets ratio.



A.3 Additional robustness tests

Table 16: 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)		
$(\text{Debt-to-assets})^2$	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 17: Regressions clustering errors at the corporate group level

Notes: The table shows the result of the panel regression relevant for H1 and H2 and the difference-in-differences regression relevant for H3. The treatment effect in the DiD model is equal to 1 for firms with leverage above 75% and negative EUA balance cumul., and 0 for firms with leverage below 25% and negative EUA balance cumul. Standard errors are clustered at the group level and 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. D/A stands for debt-to-assets.

VARIABLES	(1) ln(Em.)	(2) ln(Rev./Em.)	(3) fdln(Em.)	(4) fdln(Rev./Em.)	(5) ln(Em.)	(6) ln(Rev./Em.)
D/A	-1.34***	2.60***				
	(0.34)	(0.43)				
$(D/A)^2$	1.13**	-2.86***				
	(0.50)	(0.54)				
D(Lev. $\leq$ 25%) X fdD/A			-0.097*	0.21**		
			(0.055)	(0.084)		
D(Lev. $\geq$ 75%) X fdD/A			0.28**	-0.15		
			(0.14)	(0.23)		
D(Lev. $\geq$ 75%)			-0.012	0.0071		
			(0.036)	(0.045)		
D3(Treated) X Post					0.21**	-0.29*
					(0.10)	(0.16)
Controls	Y	Y	Y	Y	Y	Y
Time FE	N	N	Y	Y	N	N
Sector-time FE	Y	Y	N	N	Y	Y
Country FE	Y	Y	N	N	Y	Y
Firm FE	N	N	N	N	Y	Y
Observations	20,945	20,903	12,203	12,203	4,912	4,912
R-squared	0.391	0.310	0.023	0.007	0.989	0.902

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

Table 18: Panel regression for transition performance and leverage, from 2013 to 2019 - 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)
$(\text{Debt-to-assets})^2$	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: Panel regressions on sub-samples for 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)
$(\text{Debt-to-assets})^2$	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

Table 20: 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.

VARIABLES	(1) Electr. ln(Em.)	(2) Metals Non-metals Chemicals Petroleum prod. ln(Em.)	(3) Other manu. Construction Mining Air transport ln(Em.)	(4) Electr. ln(Rev./Em.)	(5) Metals Non-metals Chemicals Petroleum prod. ln(Rev./Em.)	(6) Other manu. Construction Mining Air transport 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 21: 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 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.*

VARIABLES	(1) ln(Em.)	(2) 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
Country 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 22: 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 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 23: Results for alternative specification of the variable of emission efficiency.

*Notes: The table shows the baseline results and difference-in-differences results. The relationship between emission efficiency and leverage is tested for the full data sample covering the period from 2013 to 2019. Emission efficiency is measured as the ratio of total assets 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 column (2) Leverage level 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(Assets/Em.)
Debt-to-assets	2.32***		
	(0.33)		
Debt-to-assets^2	-1.99***		
	(0.50)		
d(Leverage > 50%) X fdDebt-to-assets		-0.67***	
		(0.13)	
d(Leverage $\leq$ 50%) X fdDebt-to-assets		0.61***	
		(0.093)	
d(Leverage > 50%)		-0.021	
		(0.016)	
D1(Treated) X Post			-0.10
			(0.064)
Controls	Y	Y	Y
Time FE	N	Y	N
Sector-time FE	Y	N	Y
Country FE	Y	N	Y
Firm FE	N	N	Y
Observations	20,903	17,056	10,516
R-squared	0.359	0.029	0.969

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

Table 24: Test of parallel trend assumption

*Notes: The table shows the results of the test of the parallel trend assumption. The relationship is tested for the same data sample used within the difference-in-differences analysis covering the period from 2016 to 2019. The year prior to the event (2017) is set to a dummy equal to 0. 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(Rev./Em.)
D1(Treated) X Year2016	-0.031	0.0026
	(0.032)	(0.046)
D1(Treated) X Year2018	0.067**	-0.058
	(0.033)	(0.041)
D1(Treated) X Year2019	0.090**	-0.12**
	(0.034)	(0.049)
Controls	Y	Y
Firm FE	Y	Y
Sector-time FE	Y	Y
Country FE	Y	Y
Observations	10,472	10,472
R-squared	0.982	0.913

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

Table 25: 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. 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(Rev./Em.)
D1(Treated) X Post	-0.044	0.043
	(0.040)	(0.039)
Controls	Y	Y
Firm FE	Y	Y
Sector-time FE	Y	Y
Country FE	Y	Y
Observations	10,620	10,620
R-squared	0.980	0.916

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