Leverage and the low-carbon transition in Europe *

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Abstract

Using data on verified carbon emissions from the EU emissions trading system, this paper examines the relationship between leverage and transition performance for highly polluting and mostly non-listed ETS firms over 2013-2019 that are responsible for approximately 20% of total EU emissions. Panel regression analysis indicates that, up to certain point, firms with higher leverage have lower emissions and improved emission efficiency in subsequent years. But beyond that point, greater leverage is associated with worse transition performance. Exploiting a toughening of the emissions regime in 2015 in a difference-in-differences setup, we also identify a group of firms that appear too indebted to transition towards low-carbon technology, even following a steep increase in the cost of their emissions.

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1 Introduction

Drastic reductions in greenhouse gas emissions are essential for mitigating climate change (IPCC, 2021). Firms generally do not internalize the considerable social cost related to the carbon emissions that they generate (Nordhaus, 1991; Common and Stagl, 2005; Perman, Ma, Common, Maddison, and McGilvray, 2011; Nordhaus, 2017). Correcting for this negative externality can be achieved through carbon pricing mechanisms like carbon taxes or cap-and-trade policies such as the EU's emissions trading system (EU ETS).

Faced with such policies, firms are incentivised to direct their corporate investments toward the adoption of greener technologies. But this also requires adequate financing opportunities; indeed, the European Union's 2019 Green Deal acknowledges that financing is central to achieving emission reduction. This is also confirmed by evidence highlighting the important role of equity financing and stock markets in allocating capital to support the low-carbon transition (De Haas and Popov, 2023). But the vast majority of European firms are not listed on the stock market and debt finance – especially in the form of bank lending – is the primary source of their external financing (ECB, 2022). While debt finance may be relatively less well suited for highly risky investments into potential new green technologies (De Haas and Popov, 2023; Philippe, Boneva, Breckenfelder, Laeven, Olovsson, Popov, and Rancoita, 2022), it is still vital in enabling companies to adopt low-carbon technologies that already exist (Polzin and Sanders, 2020). As such, taking on leverage can support green investment and the low carbon transition of European firms. At the same time, when a firm is already highly indebted, it may find it difficult or costly to raise the finance needed to support significant green investment, consistent with debt overhang literature (Myers, 1977; Kalemli-Özcan, Laeven, and Moreno, 2022).

In this paper, we use firm-level data over the period from 2013 to 2019 for companies subject to the EU Emissions Trading System (ETS) to examine how European firms' debt finance relates to changes in their emissions. We find that leverage – as measured by the debt-to-assets ratio – is a double-edged sword. Results from our panel regressions indicate that up to a leverage ratio of around 40%, firms with higher leverage or who increase their leverage have both lower emissions and higher emission efficiency (i.e. revenues per

unit of emission) in subsequent years.[1] But beyond that point, high leverage or further increases in leverage are associated with worse transition performance. We also use a difference-in-differences setup which mitigates possible endogeneity concerns to ascribe some causality to the role of very high leverage in impeding firms' efforts to reduce their emissions. For this analysis, we exploit the legal adoption of the Market Stability Reserve (MSR) of the EU ETS in 2015 that imposed a more stringent cap on emissions and acted as an exogenous shock to carbon prices. In particular, we identify a group of firms that appear too indebted to transition towards low-carbon technology, even following a steep increase in the cost of their emissions. Finally, we assess whether our results may be driven by carbon leakage, whereby firms could invest to relocate emissions outside the scope of the EU ETS, but find limited evidence to support this possibility. Overall, our results highlight the important role of debt finance in facilitating firms to lower their carbon emissions and demonstrate that high leverage can be an impediment to firms' ability to embark on a low-carbon transition even if they are subject to a costly constraint on their emissions.

More specifically, we first construct a novel dataset covering yearly verified emissions of approximately 2400 non-financial firms – comprised mostly of non-listed firms and including a large share of small and medium enterprises (SMEs) – subject to the EU ETS. The EU ETS regulates emissions produced by most fossil-fuel-intensive economic activities in the European Economic Area. Its main goal is to reduce the aggregate level of emissions under the cap-and-trade policy, while its longer-term goal is to foster innovation and the adoption of clean technologies (Martin, Muûls, and Wagner, 2020). For this purpose, each installation subject to the EU ETS is allocated yearly a limited amount of allowances (EUAs) to emit a given amount of greenhouse gases for free. If an installation's yearly emissions exceed its total amount of free EUAs, it has to purchase additional EUAs to cover its excess emissions or otherwise faces a penalty. Conversely, operators with a surplus of EUAs may store them for future years or trade them in a system of auctions with those with a deficit of EUAs.[2]

[1]The 40% threshold is defined by the sample under investigation and may vary from one sample to another. Our main claim is about the inverted U-shape relationship between the level of transition performance of a firm and its leverage, and not specific value of the leverage. See Section 2 for the discussion.

[2]For a history of the EU ETS and further detail on its functioning concerning emissions, allowance prices, the use of offsets, and its overall performance for reducing emissions, see Ellerman, Marcantonini,

The emissions of each installation subject to the EU ETS are verified by a third party; hence they are more reliable than the self-reported or estimated emissions used in much of the green finance literature. These emissions data are published annually on the website of the European Union Transaction Log (EUTL). We identify the firm corresponding to each operator that owns installations within the EUTL and we aggregate the verified ETS emissions at the firm level. The emission data collected therefore only refers to firms that can be attributed as being subject to the cap-and-trade climate policy instrument. The final dataset represents more than 20% of total EU GHG emissions.[3]

We also collect firm-specific financial characteristics, such as leverage, revenues, profitability and age. Only a very limited number of firms in the sample relied on green debt between 2013 and 2019, suggesting that debt financing of ETS active firms has been driven so far foremost by means of traditional debt instruments. We additionally collect firm-specific environmental factors, such as cumulative EUA balances which may either be in surplus or deficit.

We then test our hypotheses about the existence of a non-linear relationship between debt finance and transition performance, assessing the latter in terms of both absolute emissions and emission efficiency. We use both a panel regression over the period 2013 to 2019 and a difference-in-differences approach which provides stronger identification of the impact of very high leverage on transition performance. The period of examination ends prior to the onset of the Covid-19 pandemic which distorted both firms' emissions and their leverage.

Results from the panel regressions indicate that there is an inverted U-shape relationship between the level of firm leverage and its transition performance. Leverage ratios beyond about 40% start to be associated with higher emissions and worse emission efficiency. And increases in leverage for firms which are already highly indebted also worsen their

and Zaklan (2020).

[3]See 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 difficult to compare (e.g. different sets of greenhouse gases, use of different organizational-boundary-setting methodologies, and equity-based approach or control approach — operational control or financial control — in carbon accounting).

transition performance.

To confront endogeneity concerns, we then apply a difference-in-differences setup which exploits the formal adoption of the introduction of the Market Stability Reserve (MSR) in 2015. [4] This quasi-exogenous regulatory shock imposed a more stringent cap on emissions. Although it only came into force in 2019, soon after a reform that further strengthened the MSR and set the ground for phase 4 of EU ETS, and although emission allowance prices only started to increase sharply from late 2017 onwards, there are several reasons why 2015 is likely to be the appropriate year for the policy shock in the difference-in-differences analysis. First, it represents the moment when firms began adjusting their behavior in response to the Market Stability Reserve (MSR) mechanism since firms make capital investment or operational decisions typically as a response to policy certainty rather than policy implementation. Delaying the shock year would overlook the fact that firms had already started adapting in anticipation of the future regulatory landscape. Second, choosing 2015 avoids contamination from later events of the second wave of policy reforms in 2018. Finally, although emission allowances can be carried over into future years, they are traded on spot markets and earn no return. Given the less stringent emission caps during 2015-2018, firms with the capacity to do so were therefore likely to have undertaken green investments to reduce future emissions (or undertaken other profitable investment opportunities) rather than accumulating emission allowances with zero return only in anticipation of a possible future price increase. As such, even though it was understood from 2015 that emission allowances would probably become more valuable from 2018 or 2019 onwards, there were reasons why actual emission spot prices only started to rise materially as implementation became imminent.

While all firms would have been strongly incentivised to invest in low-carbon technology upon the formal adoption of the MSR due to the higher future cost of emissions, only those firms with sufficient financing may have been able to do so in practice. And highly leveraged firms may have found it difficult or expensive to access the necessary

[4]The introduction of the Market Stability Reserve followed a process spanning five years. In 2014, European Commission proposed the MSR to address the surplus of allowances. In 2015, the European Parliament and Council adopted the MSR decision. In 2017, the Commission published the calculation of the total number of allowances in circulation on an annual basis that served as the indicator for determining whether allowances were to be placed in or released from the MSR. In 2018, the MSR was established and further strengthened (e.g., doubling its intake rate from 2019-2023). Finally, in 2019, the MSR became operational, starting to remove surplus allowances from the market.

additional finance. Therefore, our difference-in-differences setup compares the transition performance of highly leveraged firms exposed to the price increase against less leveraged firms also exposed to the price increase. We find that the former group saw worse transition performance subsequently than other firms, whether measured in terms of emissions or emission efficiency. In various robustness exercises, we also find that this result is robust to different ways of partitioning firms by their leverage, the use of matching estimators, alternative measures of indebtedness, and alternative sub-samples with different characteristics (e.g. the sub-sample of SMEs or large firms and the sub-sample of firms with privately held equity). Overall, these findings suggest that high leverage does indeed hamper firms' efforts to cut their carbon emissions in a causal manner.

Our interpretation of these results builds upon the economic mechanisms linking carbon pricing in the EU ETS, green investment and emissions. In particular, the EU ETS may encourage the use of debt to finance investment in green technologies which enable firms to achieve their low-carbon transition, unless firms are highly indebted and potentially constrained. The findings shed light on the existence of a group of firms that are too indebted to transition, despite being subject to a constraint on their emissions and even when such constraints become more binding.

While our results are consistent with the narrative that firms invest in the adoption of green technologies to reduce their emissions, they may also align with the narrative that carbon pricing encourages firms to invest to relocate emissions outside the EU ETS (carbon leakage). To assess this, we exploit a list of firms identified by the European Commission deemed to be at risk of carbon leakage. We find that our main results continue to hold in the sub-sample of firms not deemed to be at risk of carbon leakage as of the beginning of the sample. The latter finding suggests that our results are unlikely to be driven by firms who invest to relocate their plants outside the EU ETS rather than in the adoption of low-carbon technologies to improve their transition performance. While this does not rule out that some firms in our sample may shift their polluting activity outside the EU ETS, the existing literature mitigates such concerns as it provides limited evidence of the materialization of carbon leakage risks in the EU ETS.

Our findings have important policy implications. They highlight that the EU ETS may not be effective as it could be in helping to reduce the emissions of highly leveraged firms.

While highly indebted firms with low growth prospects may have to leave the market to more emission-efficient firms, highly indebted firms with high growth prospects require suitable transition finance solutions to enable them to reduce emissions. This points to the potential value of deepening green bond and green loan markets, for example through greater transparency and international standards, or by making the tax advantages of debt financing only applicable to green debt. Investor appetite for green debt is strong and growing, which gives more highly-leveraged companies the chance to borrow at reasonable premiums for their green investments. Green debt instruments may also allow firms with high leverage to still access finance conditional on committing to use the proceeds to invest in low-carbon technology and measuring the positive real-world outcome of these investments, even if they may struggle to increase borrowing more generally. This is because lenders may be more confident that this type of finance will increase the profitability and resilience of the companies over the medium term.

This paper relates to three strands of the literature: (i) the role of (green) finance and financing opportunities in supporting the investment necessary for the low-carbon transition; (ii) the role of firm-level over-indebtedness and financial constraints in hampering (green) investment; and (iii) the EU ETS and other factors as determinants of firms' emissions reduction and energy efficiency improvement.

Firstly, finance is vital to support all types of investment and essential to transition to a low-carbon economy (ESA, 2024). As such, raising equity and/or taking on more leverage via borrowing is necessary to support the green investment needed to lower carbon emissions (Polzin and Sanders, 2020). Consistent with this, De Haas and Popov (2023) find that at the country-level, equity finance is important in helping to reduce carbon emissions. The literature on debt financing to support the low-carbon transition has primarily focused so far on the role of green bonds.[5] The firm-level evidence on green bonds' role in reducing emissions is inconclusive, with Flammer (2021) and Fatica and Panzica (2021) finding that firms that issue green bonds reduce their GHG emissions, while Ehlers, Mojon, and Packer (2020) find that this is not the case. Empirical research

[5]There is also a broad literature examining whether firms' greenness is priced by banks and capital markets, but this generally does not speak to how finance helps firms to reduce carbon emissions (see, for example, Beyene, De Greiff, Delis, and Ongena (2021); Kacperczyk and Peydró (2021); Degryse, Goncharenko, Theunisz, and Vadasz (2021)).

on green loans is scarce (see e.g., Gilchrist, Yu, and Zhong (2021) for a literature review), partly due to minimal data on green loans.

Secondly, there are also theoretical reasons and strong empirical evidence which suggest that high levels of leverage may constrain firm investment (Myers, 1977; Lang, Ofek, and Stulz, 1996; Hennessy, 2004; Kalemli-Özcan, Laeven, and Moreno, 2022). More specifically, financing constraints can act as a barrier to (green) investment. For example, De Haas, Martin, Muûls, and Schweiger (2022) find that credit constraints may affect a firm's green investment decisions while Howell (2017) shows that relief of financial constraints is associated with more patents, especially for firms in industries related to clean energy and clean production. Kaldorf and Shi (2024) show that credit constraints impair firms' climate policies, namely, firms with tighter credit constraints exhibit a relatively smaller emission reduction after a carbon tax increase. A growing literature further documents that financial constraints lead to more pollution (Xu and Kim (2022), Sfrappini (2024), Fang, Hsu, and Tsou (2024), Bellon and Boualam (2024), Iovino, Martin, and Sauvagnat (2024)). Interestingly Sfrappini (2024) argues that when financially-constrained firms tend to privilege more profitable dirtier projects. However, if funding access is linked to environmental performance, then firms tend to shift to cleaner projects to relax financial constraints thus reducing emission intensity.

The third 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; Colmer, Martin, Muûls, and Wagner, 2024). The literature on clean production documents that clean innovation has increased since the launch of the EU ETS in 2005 (Martin, Muûls, and Wagner, 2020). Furthermore, ETS-regulated firms showed a larger increase in low-carbon patents compared with non–regulated firms (Calel and Dechezleprêtre, 2016), suggesting that carbon pricing is related to an uptick in green innovation (Känzig, 2021; Martin, Muûls, and Wagner, 2013; Borghesi, Cainelli, and Mazzanti, 2015). Colmer,

Martin, Muûls, and Wagner (2024) document that EU ETS induced regulated manufacturing firms to effectively reduce CO2 emissions by 14–16% between 2005 and 2012 via targeted investments to reduce emissions intensity of production and without outsourcing to unregulated firms or markets nor contractions in economic activity firms. Finally, De Jonghe, Mulier, and Schepens, 2020 also exploit the tightening of the EU ETS regulation to show that it improved the emission efficiency of highly polluting firms, with this also being supported by the acquisition of green firms.

Relative to the existing literature, our key contribution is to examine how leverage and debt financing may affect the low-carbon transition of firms subject to an explicit constraint on their emissions in a broad sample which also encompasses unlisted firms and SMEs. In this context, we also move beyond inferred or non-verified measures of emissions to develop a novel firm-level dataset with verified disclosed emissions, reducing the risk that we capture greenwashing or other confounding effects that may characterise self-reported or inferred emissions data (Busch, Johnson, and Pioch, 2020; Kalesnik, Wilkens, and Zink, 2020). By contrast, existing research examining the link between firm-level finance or financial constraints and reductions in emissions typically uses non-verified emissions and focuses on listed or large firms, often including those not subject to an explicit climate policy constraint. And while a small number of other studies do examine firms subject to the EU ETS and exploit changes in the ETS regulation, none of these have focussed on the interplay between transition performance and firms' leverage or financing opportunities. By contrast, our analysis provides robust evidence on the existence of a group of firms that are too indebted to abate their emissions and improve their clean production, even when faced with a significant increase in the cost of emissions. Our results also indicate that the reduction in emissions identified in previous studies examining the EU ETS is likely to be driven by less leveraged firms who have the financial capacity to invest in less polluting technologies. Our findings thereby highlight that while the strengthening of the EU ETS emissions cap is likely to have pushed regulated firms to reduce their emissions, the system alone may not be a sufficient tool to achieve the corporate sector low-carbon transition if not paired with suitable financing opportunities.

The rest of the paper is structured as follows. Section 2 discusses the conceptual back-

ground, our set of hypotheses and our empirical strategy. Section 3 describes the dataset and section 4 discusses our results. Finally, section 5 concludes and discusses policy implications.

2 Conceptual background and empirical specifications

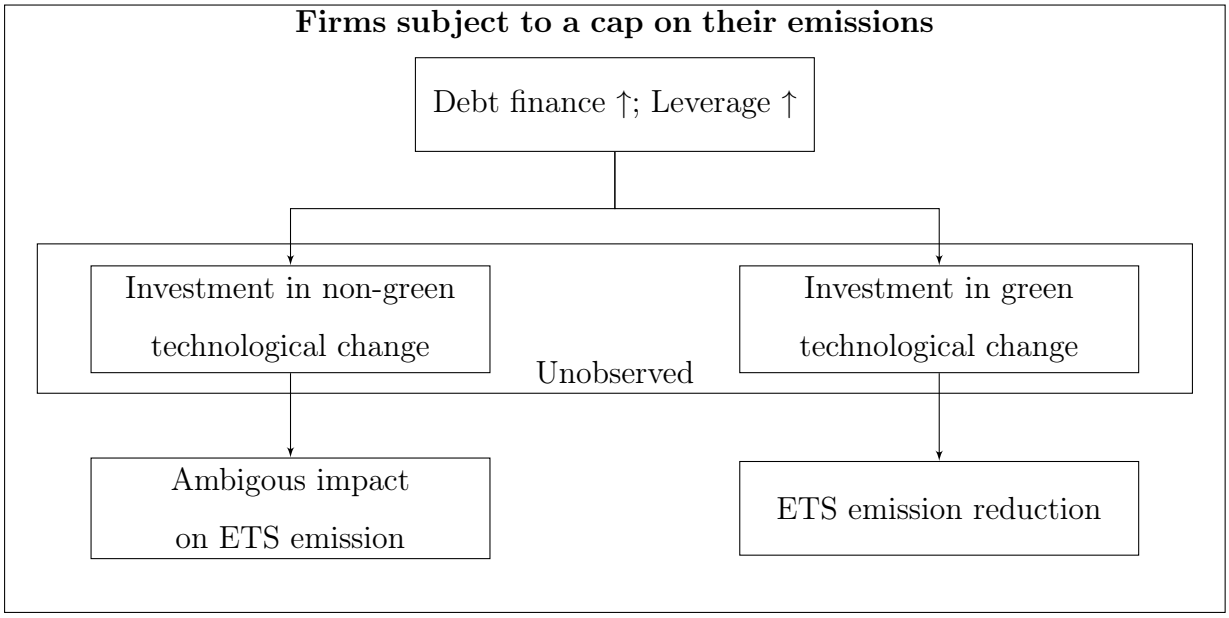
The EU ETS is designed to tackle negative externalities associated with greenhouse gas emissions (Nordhaus, 1991) which would not otherwise be internalised in the decisions of profit-maximising firms (Helbling, 2017). To comply with the EU ETS cap, firms either need to produce less, purchase additional emission allowances, or invest in substituting emissions-intensive technologies with less polluting ones. Finance to support investment is, therefore, central to enabling firms subject to the ETS to invest in cutting their emissions without reducing their economic activity. Debt financing, particularly from banks, is the primary source of external financing for non-financial firms in Europe (ECB, 2022). The ability of firms to borrow and take on additional leverage may, therefore, be important for investment in the adoption of green technologies and reducing emissions.

In a simplified illustration of debt-leverage-investment links (Figure 1), firms subject to an emissions cap may increase their debt financing and leverage either to invest in the adoption of green technologies or for any other purpose (e.g., other types of investment or debt servicing). Investing in green technological change allows firms to approach low-carbon transition goals by decreasing their emissions and increasing their emission efficiency over time. Conversely, borrowing for other purposes has an ambiguous effect on the emissions performance of the firm. And highly indebted firms unable to take on more leverage may also be unable to invest in green technologies and reduce their emissions. This highlights the relevance of exploring the firm-level links between leverage and emissions empirically, also recognising that there are limited data which allow firms' green investments to be distinguished from their other investment, especially historically.[6]

[6] De Haas, Martin, Muûls, and Schweiger (2022) analyses the EBRD-EIB-WB Enterprise Surveys data, which collect information on firm-level green management and green investments in 22 Emerging European countries.

Figure 1: 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.

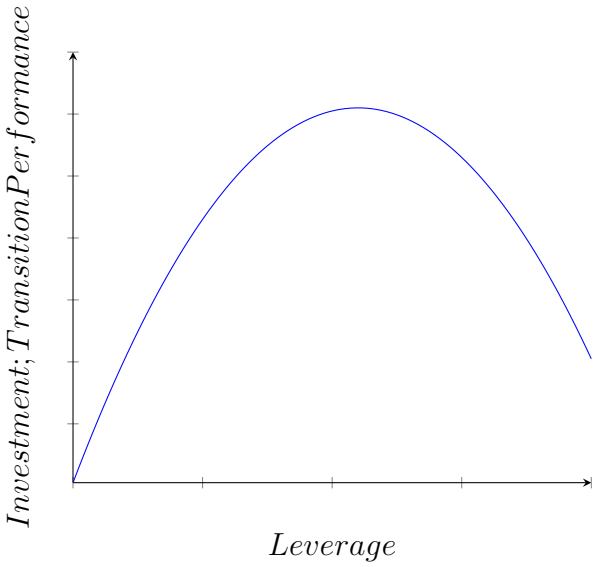


In examining the potential links between leverage and carbon emissions, it is important to recognise that the literature on corporate debt and investment documents two opposing forces that may influence the relationship between leverage and investment. Firms can benefit from corporate debt financing through tax advantages and reduced agency costs (Modigliani and Miller, 1958, 1963; Ross, 1977; Grossman and Hart, 1982). This incentivises firms to take on more debt to finance investment in profitable opportunities. And for firms subject to the ETS, investing in low-carbon technologies is likely to be a profitable strategy over the medium term. At the same time, high levels of existing indebtedness may hold back a firm's investment. This is because highly leveraged firms may find it more difficult or costly to raise new external financing and because they may need to direct a higher share of any debt financing they receive towards covering debt servicing costs (Myers, 1977). Given these two opposing forces, the static trade-off theory on debt and investment suggests an inverted U-shape relationship between leverage and investment (Figure 2). Empirically, Gebauer, Setzer, and Westphal (2018); Mosk, Pietsch, Cappiello, and Kapadia (2023) provide evidence of a concave relationship between debt and investment for European firms. And a wider empirical literature finds that high corporate leverage may adversely affect investment (Hernando and Martínez-Carrascal,

2008; Martinez-Carrascal and Ferrando, 2008; Kalemli-Özcan, Laeven, and Moreno, 2022; Barbiero, Popov, and Wolski, 2020).

Figure 2: Conceptual relationship between leverage and investment of a firm

*Notes:*The figure illustrates the conceptual inverted U-shape relationship between leverage and investment as well as between leverage and transition performance as measured by emission efficiency.



Drawing on these conceptual relationships between leverage, (green) investment and carbon emissions, this paper aims to examine the role of corporate debt in the low-carbon transition. Specifically, we pose that there is a non-linear relationship between ETS firms' leverage and their transition performance (see Figure 2), with the latter measured by a firm's (future) carbon emissions and emissions efficiency, as discussed in more detail below. Our empirical hypothesis is that firms subject to the EU ETS which have relatively low leverage are not financially constrained. Therefore, they can flexibly borrow to invest in adopting the technologies needed to lower their carbon emissions and ultimately display better transition performance as they take on more leverage. However, when firms' leverage is already relatively high, they may not be able to invest as much in low-carbon technologies either because external debt finance is less readily available or more costly, or because they cannot channel as high a share of their borrowing towards investments in green technologies due to other financial commitments. Therefore, beyond a certain point, higher firm leverage may lower transition performance. Implicit in this hypothesis is the assumption that firms do not use investments to shift emissions outside the scope of the ETS cap-and-trade system, an important topic that we return to in Section 4.3.

More precisely, we first test whether a relationship between firms' leverage and transition performance exists along the following two dimensions:

Hypothesis 1. There is an inverted U-shape relationship between the level of transition performance of a firm within the EU ETS and its leverage.

To strengthen identification, we examine the relationship between the two variables in the context of the 2015 introduction of the Market Stability Reserve (MSR).[7] We select 2015 as the policy shock year for the difference-in-differences analysis as it marks the point at which firms plausibly began adjusting their behavior in response to the MSR announcement. Firms typically respond to policy certainty rather than policy implementation, especially when it affects long-term capital investment and operational planning.[8] Delaying the shock year to 2017, 2018 or 2019 would likely miss the anticipatory behavioural changes already underway. In addition, choosing 2015 helps avoid contamination from the second wave of EU ETS reforms introduced in 2018. The MSR's announcement significantly enhanced the credibility of the EU ETS and provides a natural setting to exploit variation in firms' responses to a tightening carbon market. The subsequent rise in the implied cost of carbon increased pressure on firms to reduce emissions, thereby offering a relevant empirical context to study transition behaviour (Ampudia, Bua, Kapp, and Salakhova, 2022).

Hypothesis 2. Highly leveraged firms exposed to rising emission allowance prices after 2015 are unable to reduce their emissions, whereas less leveraged firms successfully do so.

Throughout, we measure firm leverage as total debt divided by total assets (as in Gebauer, Setzer, and Westphal, 2018). As noted above and in line with much of the literature (e.g., Bolton and Kacperczyk, 2021b and De Jonghe, Mulier, and Schepens, 2020), we consider two complementary measures of firm-level transition performance: absolute emissions and emission efficiency, defined as how much revenue a firm generates for each unit of

[7] Decision (EU) 2015/1814, followed by the Directive (EU) 2018/410

[8] While the 2015 Paris Agreement may represent a potential confounding factor, we argue that its impact was largely complementary, reinforcing existing EU climate policy rather than introducing specific, binding mechanisms. The Agreement articulated broad targets, such as limiting global warming to 1.5C - 2C, without detailing enforcement or sector-specific pathways, thereby strengthening the signal from the MSR rather than confounding it.

emissions (the inverse of emission intensity).[9] The two measures reflect different, yet both important, aspects of a firm's low-carbon transition and are consistent with the targeted metrics of the EU ETS: reducing aggregate emissions and improving emission efficiency. Absolute emissions reflect a firm's contribution to the overall, global level of greenhouse gases. Therefore, reducing absolute emissions is what ultimately matters from a societal perspective in tackling global warming. Absolute emissions are also a simpler measure, not subject to being conflated with other factors that may affect revenues. At the same time, holding all else equal, the higher the level of emission efficiency, the cleaner the production technology of the firm. This may be an important dimension because rapidly growing firms that increasingly adopt ever-lower carbon technologies may displace less emissions-efficient competitors, and so may contribute to the overall transition of the economy even if their absolute emissions are increasing as they grow in size.

Our empirical strategy adopts a panel regression to test hypothesis 1 and a difference-in-differences approach for hypothesis 2. We first estimate the following specification to test hypothesis one:

$$Y_{f,t} = \eta_{c,s,t} + \gamma_1 Leverage_{f,t-x} + \gamma_2 Leverage^2_{f,t-x} + \gamma_3' X_{f,t-1} + \mu_{f,t} \tag{1}$$

Where $Y_{f,t}$ is a time varying measure of transition performance, either the total emissions of the firm or its emission efficiency. Equation 1 is quadratic in leverage, following the strategy introduced by Mosk, Pietsch, Cappiello, and Kapadia (2023).[10] This allows for testing the non-linearity of the relationship between leverage and transition performance. In our preferred specification, we fix firms' leverage at their levels before the beginning of the sample period, in 2013. However, we conduct additional analyses employing a time-varying measure of leverage lagged by either 1 or 2 years relative to the baseline. We consider lags of both 1 year and 2 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

[9] Our choice to focus on emission efficiency rather than emissions intensity (i.e., Emissions / Revenues) is in line with the practice in the literature on clean production, e.g., De Jonghe, Mulier, and Schepens (2020). Nevertheless, all of our results can also be interpreted identically for emissions intensity.

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

and may only result in an improvement in transition performance over a longer time horizon (e.g., changing to clean cement production).

$X_{i,t-1}$ is a vector of control variables. Our rich set of control variables includes firm-specific economic variables, firm-specific environmental variables and country-specific environmental variables. The firm-specific economic variables include revenues, profitability and the age of the firm (as in De Jonghe, Mulier, and Schepens, 2020; Bolton and Kacperczyk, 2021a; Xu and Kim, 2022; De Haas, Martin, Muûls, and Schweiger, 2022). Although a firm's market-to-book ratio is also a widely used control, we exclude it as 96% of the firms in our sample are non-listed. Regarding firm-specific environmental controls, we include a firm's cumulative balance of free allowances to emit net of ETS emissions and the number of ETS-regulated installations of a firm, where the latter helps to control for the possibility of our results being driven by carbon leakage (see Section 4.3). We cumulate the EUAs balance of a firm to proxy its total number of EUAs in a given year since firms can bank their EUAs. Together, this set of control variables helps to tackle concerns related to omitted variable bias and confront endogeneity concerns by including common factors that may explain both leverage and transition performance, as documented in the literature (see, for example, Gebauer, Setzer, and Westphal, 2018 for the literature on leverage and De Jonghe, Mulier, and Schepens, 2020 for the literature on transition performance). Lastly, we include $\eta_{c,s,t}$, sector-country-time fixed-effects to control for possible country and sector-specific shocks that may affect the estimates (e.g., country-specific debt financing policies or carbon taxes that specifically affect certain sectors). The choice of country, industry, and time fixed effects is aligned with the wider literature that aims to estimate the determinants of firm-level emissions (see, for example, Bolton and Kacperczyk (2021a)). At aggregate (Figure 5) or sector levels (Figure 10), firm-level emissions do not change much over time but vary substantially across firms. Therefore, as we discuss further in Section 4, the inclusion of firm fixed effects within this panel regression on levels would absorb the effect of leverage, while differences in variability across firms are more systematically related to country and sector.

The coefficients from this specification allow us to compute, for a given set of firms, an implied leverage threshold above which the relationship between leverage and transition

performance inverts, in line with the hypothesis that we aim to test[11]:

$$threshold = \frac{-\gamma_1}{2 \times \gamma_2} \tag{2}$$

Finally, to test hypothesis 2, we proceed in two steps. Firstly, we exploit the following specification in a difference-in-differences approach:

$$Y_{f,t} = \alpha_f + \eta_{s,c,t} + \beta Treatment_f \times Event_t + \gamma' X_{f,t-1} + \epsilon_{f,t} \tag{3}$$

Where $Treatment_f$ is a dummy equal to 1 for firms with an excess of emissions over allowances (i.e., a negative EUA balance) at the beginning of phase 3 of the EU ETS (2013), 0 otherwise. In this first diff-in-diff specification, the coefficient of interest is β, which captures the average relative difference in transition performance after the 2015 event, relative to the previous period, for treated firms relative to control firms. While also firms with an excess of allowances face a higher opportunity cost of allowances when EUA prices rise, firms with a negative EUA balance face higher *direct* costs in these circumstances. These firms are directly exposed to the cap imposed by an increase in allowances' prices observed after 2015, as they face the legal obligation to pay for their excess emissions.

Secondly, we use an interaction term to study the different responses of firms with low or high leverage relative to the implied threshold computed in our baseline panel approach (in Equation 2). Therefore, we exploit the following specification:

$$\begin{aligned} Y_{f,t} =& \alpha_f + \eta_{s,c,t} + \beta_1 Treatment_f \times Event_t + \beta_2 LeverageAbove_f \times Event_t + \\ &+ \beta_3 Treatment_f \times LeverageAbove_f \times Event_t + \gamma' X_{f,t-1} + \epsilon_{f,t} \end{aligned} \tag{4}$$

In our baseline specification, $LeverageAbove_f$ is a dummy equal to 1 for firms with leverage above the implied leverage threshold computed in Equation 2, before the beginning of

[11] Leverage thresholds may depend on the sector and other economic factors. Banks consider the debt-to-assets ratio alongside other financial indicators, such as profitability, cash flow, and market conditions, when making lending decisions. Thus, there is no universally "ideal" debt-to-assets ratio, since acceptable levels depend on industry norms, economic conditions, and individual company circumstances. Our point is not about the existence of a unique leverage threshold but rather about the U-shape relationship between leverage and transition performance.

the sample period, and 0 for other firms. This allows us to capture firms that were both highly indebted and exposed to rising EUA prices when the new policy was introduced. We conduct robustness tests for alternative constructions of the $LeverageAbove_f$ dummy.

3 Data

We construct a firm-level dataset based on the EUTL database on the verified greenhouse gas emissions of installations subject to the European Carbon Market (EU ETS), which, in its entirety, reflects approximately 40% of the EU's CO2 emissions. The EUTL dataset allows mapping installations to their owners through national identification and trade registry numbers. Our mapping approach follows closely De Jonghe, Mulier, and Schepens (2020). Throughout Bureau van Dijk's Orbis database, we identify the non-financial corporations that own most of the installations in the EUTL and we retrieve financial and economic variables that may explain their transition performance. We also obtain further firm and country-level environmental variables 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[12] as explained in Section 3.1. We obtain an unbalanced dataset covering 3,724 firms over the period from 2013 to 2019, and a balanced sample of 2,421 firms, upon which we focus for the majority of our analyses.[13] 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 approximately 20% of the greenhouse gas emissions produced in the EU on average be-

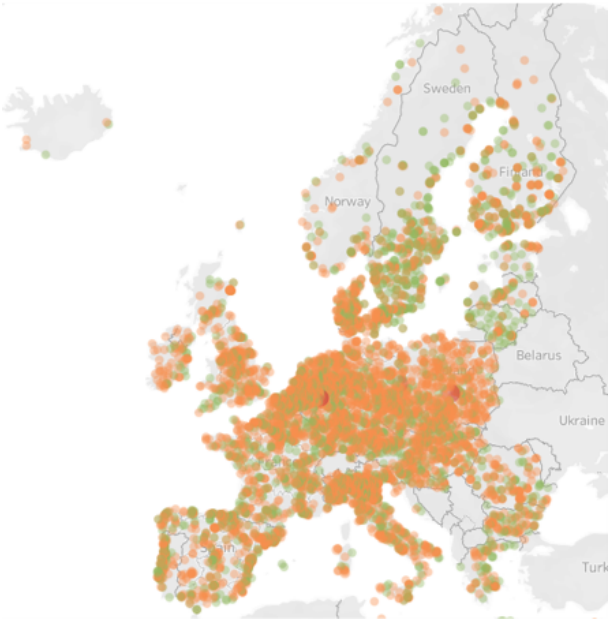
[12]Data on the share revenues that are attributable to ETS emissions are not available. Therefore, to obtain emission efficiency, we divide ETS emissions by the firm's operating revenues from Bureau van Dijk's Orbis.

[13]We favor the balanced sample for the following reasons. First, the seven-year period in our balanced sample allows us to capture the gradual impact of ETS-related policies on firms, especially considering the time it takes for technology adoption. By focusing on firms that remained operational throughout the whole period of the sample, we ensure that the sample reflects firms with (financial) capacity and time to make such investments and remain operational. This observation period further provides enough time to see the full effects of policy changes, ensuring that the analysis reflects the real-world time lag between policy shifts and actual emission reductions through technology adoption. If firms that exited the market were included, it might suggest that some firms failed due to emissions policies (e.g., being unable to afford necessary investments or being acquired due to their emissions profile). This could introduce noise, making it harder to isolate the impact of policy on technology adoption among viable firms. Second, Olley and Pakes (1992) studies dynamics of productivity in the US telecommunication equipment industry. The authors combine theoretical predictions and econometric analysis and argue that the balanced sample gives more consistent results.

tween 2013 and 2019. In Figure 3, we show a map of the installations that are owned by the firms in our sample and that produce verified greenhouse emissions within the EU ETS. In the dataset, most observations describe firms with legal registration in the European Economic Area, particularly Germany, Spain, France, and Poland, and entities in the Nace sectors of manufacturing and electricity, gas, and air conditioning supply, metals, manufacturing, and chemicals. The dataset includes small and medium European enterprises (SMEs), which we identify as entities with total assets below 43 million EUR in the year prior to the beginning of the sample period[14] and represent approximately 40% of firms in our sample. Moreover, most of the dataset consists of non-listed companies. Overall, the sample is representative of the structure of the fossil-fuel-intensive section of the European real economy.

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

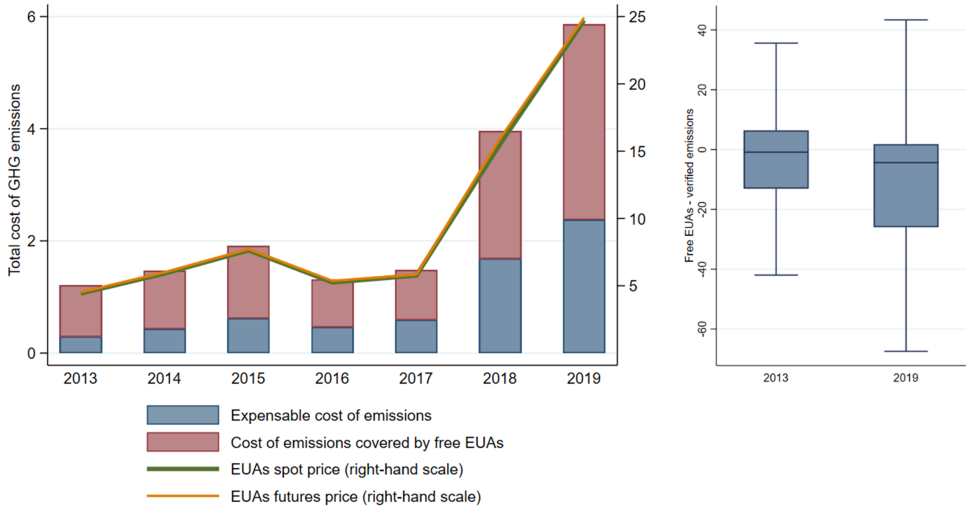
*Notes:*The Figure illustrates the installations owned by the 3724 firms in our EU ETS sample in 2019. Each dot represents one installation. Green dots are installations with free EUAs in excess of their emissions, and vice versa for orange and red dots.



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

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

Notes: Left panel: cost of emissions faced by an average firm in the sample of 3724 firms (in million euros, as shown in the left-hand side scale) and the level of EUA prices over time in phase three of EU ETS trading (in euros, as shown in the right-hand side scales). EUA futures prices reflect 12-month futures' prices. Right panel: distribution of firm-level EUA balance in 2013 and 2019.



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

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

3.1 Measures of transition performance

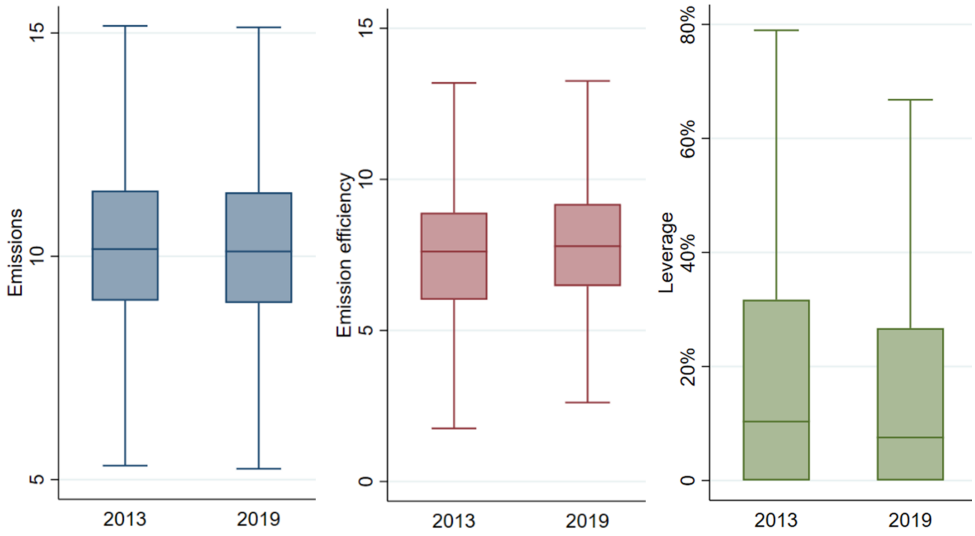
Two measures of transition performance are analyzed. Consistently with the literature on the topic (see e.g., De Jonghe, Mulier, and Schepens, 2020), we rely on firm-level EU ETS verified greenhouse gas emissions and on emission efficiency, which we compute as the ratio of firm-level revenues on verified ETS emissions of their plants subject to the EU ETS[15]. To conduct our empirical analyses, we consider the log transformation of the two measures of transition performance, which allows for decreasing the skew in their distribution. Firm-level ETS emissions are the sum of the ETS emissions of the firm's installations that are subject to the EU ETS. ETS emissions are disclosed by firms at the installation level and verified by a third party. They compare to Scope 1 emissions of a firm as defined under the GHG protocol, albeit excluding methane (European Parliament and the Council, 2003) and excluding non-ETS eligible installations.

During the sample period, the firms in the sample have broadly experienced a limited reduction in the levels of their ETS emissions (Figure 5, left panel). Across the same period, firms have generally experienced an increase in their emission efficiency (Figure 5, middle panel). The average firm in our sample has emissions of the order of 200 thousand tonnes eCO2, emissions efficiency of the order of 500 thousand EUR/eCO2 and leverage of 18%.

[15] 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.

Figure 5: Firm-level ETS emissions, emission efficiency and leverage across time.

Notes: Sample: 2421 firms. 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.



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. The description of the economic variables used in the analysis is found in Table 5. We winsorize all controls at the 1 and 99% levels.

Our main variable of interest is leverage measured as the debt-to-assets ratio. Total assets are equivalent to liabilities and equity, where the latter includes retained earnings; thus, it accounts for other sources of external and internal financing of the firm. We also collect data on whether the firm holds green debt. We find that out of our sample, only a few have taken a green loan or issued green bonds. This is discussed in Section 3.3.
The dataset is enriched with firm-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 compute the cumulative sum of this variable to account for firms' possibil-

ity to store EUAs across years. Relying on the EUTL regulation, we also build a dummy indicating whether a firm is included within the carbon leakage list by the European Commission before and at the beginning of the sample period (European Commission, 2009). These firms are deemed to be at risk of reallocating their production activity outside the EU, area of coverage of the EU ETS (this topic is further explored in Section 4.3).

The description of the firm and country-level environmental variables used in the analysis is in Table 5. Summary statistics of our variables of interest are provided in Tables 1 and 2 for the sample of firms observed every year from 2013 to 2019.

Table 1: Sample composition by year, country and sector

Notes: The table shows the sample composition for firms that appear every year in the sample from 2013 to 2019.

Year	Obs.	Country	Obs.	Sector	Obs.
2013	2,421	Germany	2,436	D 35- Electricity, gas, steam and air conditioning supply	5,068
2014	2,421	Spain	1,890	C 23- Manufacturing of non-metallic mineral products	2,807
2015	2,421	France	1,652	C 17 - Manufacture of paper	1,645
2016	2,421	Poland	1,512	C 20- Manufacture of chemicals	1,358
2017	2,421	Sweden	1,302	C 10- Manufacture of food	1,078
2018	2,421	Other	8,155	C 24- Manufacture of basic metals	847
2019	2,421			Other	4,144
	Obs.				16,947

Table 2: Summary statistics of relevant variables

Notes: The table shows the sample composition for firms that appear every year in the sample from 2013 to 2019.

	Count	Mean	p50	Min	Max	Sd
Log(ETS-Emissions)	16,947	10.37	10.30	0.00	17.44	2.20
Log(Revenues/ETS-Emissions)	16,154	7.64	7.61	-23.61	22.49	2.49
Debt/Assets	16,947	0.18	0.10	0.00	0.89	0.21
Log Revenues	16,240	18.06	18.11	12.99	22.96	2.00
ROA	15,718	3.45	2.87	-31.97	32.35	8.65
Number of ETS-Installations	16,947	1.82	1.00	1.00	13.00	1.90
EUA balance (EUAs-Emissions)	16,947	-0.25	-0.01	-8.62	1.54	1.18
Age	16,937	34.19	23.00	0.00	333.00	29.58
N	16,947					

3.3 Data on green debt

Since 2015, the green debt market has demonstrated fast growth with only the green bonds market exceeding USD 1 trillion in 2020 (Pietsch and Salakhova, 2022) and reaching USD 3 trillion of cumulative issuance worldwide in 2025 (Demski, Dong, McGuire, and Mojon,

2025). Fatica and Panzica (2021), Flammer (2021) and Demski, Dong, McGuire, and Mojon (2025) show that the issuance of green bonds by NFCs is associated with an emission reduction in the following years.

Using data on the issuance of green debt, we find that a negligible number of firms in our sample have relied on green bonds between 2013 and 2019. Only 11 EU ETS firms directly benefited from green debt, while 23 firms have benefited from it through their consolidated group structure[16]. Therefore, we disregard controlling for green debt throughout our analyses.

The EU ETS regulates highly polluting industries, and it is possible that polluting firms may find it difficult to convince investors of the greenness of their projects in the absence of a common regulatory standard for green bonds. 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 the green loans market is still developing. All in all, we conclude that the use of different forms of green debt does not explain firms' transition performance in EU ETS between 2013 and 2019.

4 Results

This section first presents the results of the fixed-effects regression analysis testing hypothesis 1, followed by the main difference-in-differences analysis testing hypothesis 2. We then discuss the robustness of our results. Throughout this section, we consistently show the results for the two chosen metrics of transition performance - emissions and emission efficiency - introduced in section 2.

4.1 Fixed-effects regression results on leverage and transition performance

Table 3 presents results from the specification in Equation 1 which examines the relationship between firms' leverage and transition performance. In columns (1) and (2),

[16]Table 10 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.

we report results for our preferred specification where $Leverage_f$ is kept fixed at levels observed in the year before the beginning of the sample period. In columns (3) and (4), we report results for the specification that employs time-varying leverage with a 1-year lag, while in columns (5) and (6), a 2-year lag in leverage is used. The results in column (1) are consistent with a significant convex relationship between leverage and greenhouse gas emission levels. The coefficients imply that, on average, firms with a leverage ratio below 42% are associated with lower emissions, while firms with levels of leverage above this threshold are associated with higher emissions. The implied leverage threshold of 42% is the minimum of the regression's equation, computed as explained in Equation 2. Results in columns (3) and (5) are aligned with those reported in column (1) showing that the non-linear relationship between leverage and emissions is robust throughout different specifications, although less statistically significant in specification (5). The results on the relationship between leverage and emission efficiency are also aligned with hypothesis 1. The coefficients in column (2) imply that, on average, firms with a leverage ratio below 44% are associated with high emission efficiency, while firms with higher levels of leverage are associated with low emission efficiency. Also in this case, we show that the non-linear relationship between leverage and emission efficiency is robust throughout the different specifications. Indeed, results in columns (4) and (6) are aligned with those reported in column (2). Due to the use of country-by-sector-by-year fixed effects, the regressions' results should be interpreted as resulting from a cross-sectional study. Indeed, the use of firm fixed effects would not only be econometrically unfeasible due to its collinearity with the *Leverage*2012 dummy, but a within-firm estimator would also fail to capture the non-linearity in the relationship between firms' scarcely time-varying leverage and their transition performance.

Throughout the analysis, the coefficients on the controls are broadly stable. Larger firms are associated with higher emission levels, while profitability is negatively correlated with emissions, but positively correlated with emission efficiency. While large firms are almost always mechanically associated with higher emissions due to the size of their economic activity, profitable firms subject to an emission trading system might be able to undertake green investment opportunities to adopt the clean technologies that might enable their transition. Closely related to size, a firm's number of ETS-installations (i.e., installations subject to the EU ETS) is positively correlated with emissions. Moreover, a larger num-

ber of ETS installations is correlated with worse emission efficiency.

Firms with a positive (cumulative) EUA balance benefit from an excess of allowances over their emissions. Within a given sector-year, this might imply that a firm's emissions are low relative to its peers, implying that the firm receives enough allowances to cover a larger part of its emissions, or that its emissions have decreased over time, which allows the firm to bank excess allowances over time. Lastly, a firm's age is not significantly correlated with its emissions, while it is positively correlated with its emission efficiency. For instance, a firm's age might be positively correlated with the length of its relationships with suppliers, banks or investors. The stability of this business environment might ease the firm's low-carbon transition process.

Table 3: Panel regression for transition performance and leverage, from 2013 to 2019

Notes: The table shows the result of the panel regression relevant to hypothesis 1 for the two metrics of transition performance: emissions and emissions efficiency. The relationship between transition performance and leverage is tested for the full balanced data sample covering the period from 2013 to 2019. Results for the unbalanced sample are in Table 11. 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 less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10. All controls are lagged by one year (i.e., taken at time $t-1$) apart from age.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
Leverage 2012	-1.31***	1.78***				
	(0.46)	(0.49)				
Leverage 2012 squared	1.49**	-2.11***				
	(0.72)	(0.76)				
Leverage 1y-lagged			-0.96**	1.35***		
			(0.38)	(0.42)		
Leverage 1y-lagged squared			1.08*	-1.55**		
			(0.61)	(0.65)		
Leverage 2y-lagged					-0.96**	1.29***
					(0.39)	(0.42)
Leverage 2y-lagged squared					0.96	-1.44**
					(0.62)	(0.65)
Size	0.65***		0.65***		0.65***	
	(0.029)		(0.029)		(0.029)	
Profitability	-0.0074**	0.016***	-0.0075**	0.016***	-0.0085***	0.015***
	(0.0031)	(0.0037)	(0.0031)	(0.0038)	(0.0031)	(0.0035)
Number of ETS installations	0.18***	-0.074***	0.18***	-0.074***	0.18***	-0.072***
	(0.024)	(0.023)	(0.024)	(0.024)	(0.024)	(0.024)
EUA balance	-0.40***	0.28***	-0.40***	0.29***	-0.40***	0.28***
	(0.034)	(0.037)	(0.034)	(0.037)	(0.033)	(0.036)
Age	-0.0010	0.0038***	-0.00099	0.0038***	-0.00097	0.0037***
	(0.0012)	(0.0013)	(0.0012)	(0.0013)	(0.0012)	(0.0013)
Constant	-1.54***	7.44***	-1.56***	7.48***	-1.59***	7.52***
	(0.49)	(0.091)	(0.49)	(0.089)	(0.50)	(0.085)
Country-Sector-Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,146	14,033	14,146	14,033	12,112	12,001
R-squared	0.644	0.516	0.643	0.515	0.646	0.531

Standard errors clustered at the firm level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.2 Baseline difference-in-differences approach

The results in Section 4.1 show a non-linear relationship between leverage and transition performance, with high leverage associated with worse transition performance beyond a

certain point. We mitigate omitted variable bias concerns using a rich set of controls and fixed effects, and we mitigate reverse causality concerns using highly lagged leverage levels in our preferred specification. However, further endogeneity concerns may arise, for example, if the relationship observed is determined by firms' preferences for green investments.

To further mitigate potential endogeneity concerns, we adopt a difference-in-differences specification, as described in Equation 4, to test Hypothesis 2 and examine firms' transition performance in response to the announcement and European Parliament approval of the MSR in 2015. Although the MSR was officially implemented in 2019, its announcement in 2015 significantly strengthened the credibility of the EU ETS by introducing a more stringent cap on emissions. Firms often respond to policy certainty rather than to the formal implementation of regulations, especially when such policies have clear long-term implications for investment and operational decisions. Therefore, it is plausible that firms began adjusting their behaviour as early as 2015, in anticipation of the future tightening of the carbon market. We take a conservative stance by selecting 2015 as the event year, thereby also avoiding potential contamination from subsequent policy reforms introduced in 2018. It is worth noting that the steep increase in EUA prices only materialised from late 2017 onwards, while prices remained relatively stable and near pre-reform levels in the intervening years (Ampudia, Bua, Kapp, and Salakhova (2022), see also Figure 8). However, although emission allowances can be carried over into future years, they are traded on spot markets and earn no return. Given the less stringent emission caps during 2015-2018, firms with the capacity to do so were therefore likely to have undertaken green investments to reduce future emissions (or undertaken other profitable investment opportunities) rather than accumulating emission allowances with zero return only in anticipation of a possible future price increase. As such, even though it was understood from 2015 that emission allowances would probably become more valuable from 2018 or 2019 onwards, there were reasons why actual emission spot prices only started to rise materially as implementation became imminent.

Throughout our setup, the treatment group includes firms that in 2013, prior to the event, had leverage of above 40% and a negative cumulative EUA balance, implying that they would need to buy additional EUAs to cover their excess emissions. The control group

includes firms that have an excess of EUAs over their emissions. Firstly, we compare treated and control groups along the dimensions of the chosen covariates. In Table 7, we find that, unconditionally, treated firms show significantly higher emissions compared to control firms, and significantly lower emission efficiency. Moreover, the t-test shows that the treated and control groups differ significantly in their size, profitability, number of ETS installations, EUA balance and age. To address these differences we adopt two approaches. Firstly, we saturate our baseline specification with granular fixed effects and controls. Secondly, we use a matching estimator in our robustness tests which we will discuss in section 4.4.

Figures 6 and 7 report the regression coefficients of interest in a dynamic setup, for emissions and emission efficiency respectively. The Figures show that pre-event trends are not significantly different for our treatment and control groups. Moreover, they show that, while as expected treated firms significantly reduce their emissions relative to the year prior to the event and relative to the control group, they do not significantly improve their emission efficiency (although on average the coefficients after the event are positive). The results of the difference-in-differences regression are formally reported in Table 4.

Figure 6: Visual inspection of validity of parallel trend assumption - emissions

Notes: Impact of the introduction of the first Decision (EU) 2015/1814 addressing the surplus of EUAs in the EU ETS on treated firms' **emissions**—from the beginning of phase 3 of the EU ETS (t=2013) to t.

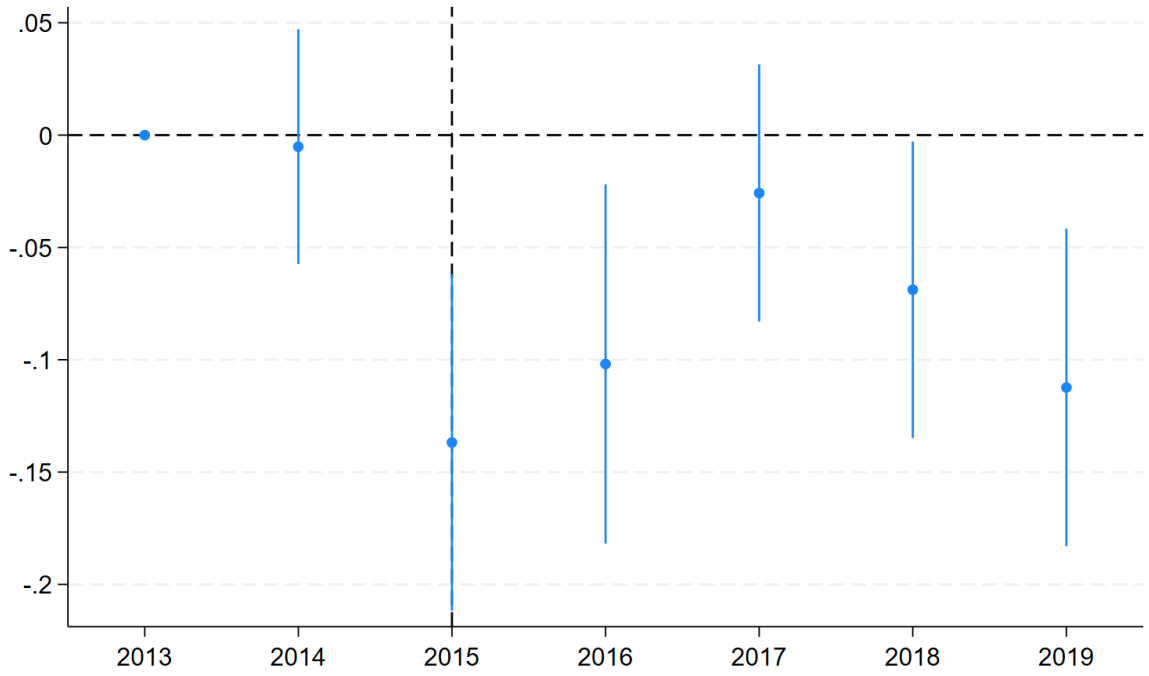
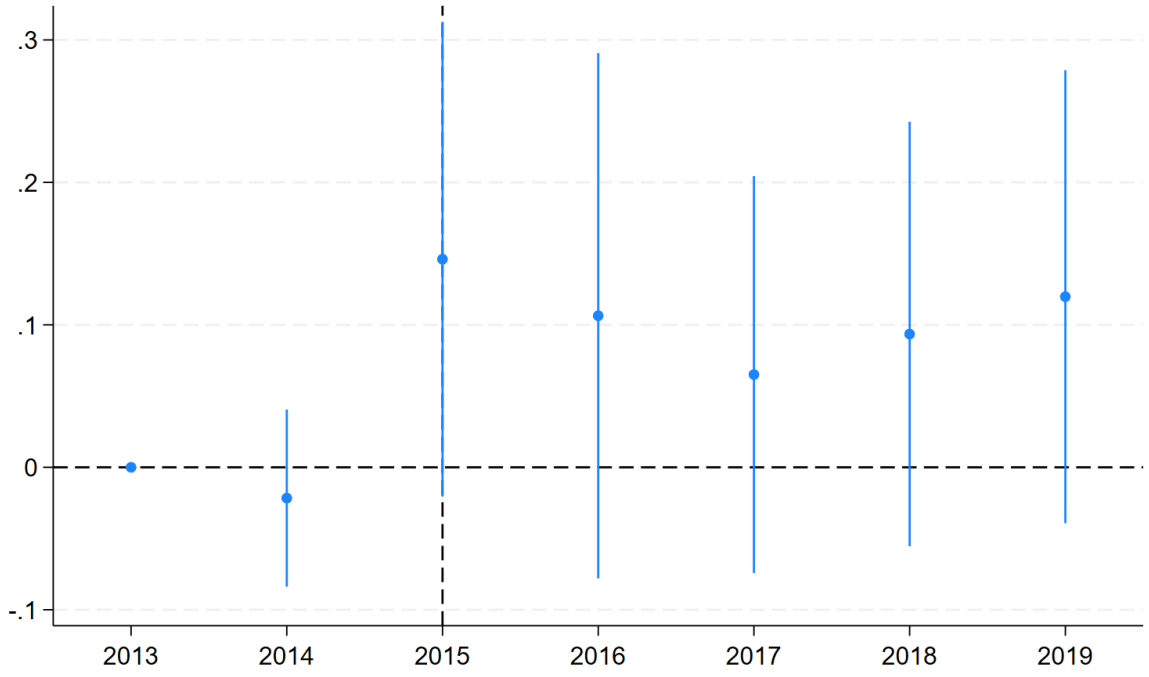


Figure 7: Visual inspection of validity of parallel trend assumption - emission efficiency

Notes: Impact of the introduction of the first Decision (EU) 2015/1814 addressing the surplus of EUAs in the EU ETS on treated firms' **emission efficiency**—from the beginning of phase 3 of the EU ETS (t=2013) to t.



The coefficients in columns (1) and (2) of Table 4 show that the introduction of the more stringent regulation on emissions within the EU ETS is associated with lower emissions for firms exposed to the rising price of EUAs, relative to the years prior to the event and relative to firms that are not directly exposed to the rising constraints imposed by the EU ETS cap. However, they do not successfully improve their emission efficiency, possibly because this might require undertaking significant green investments, that not every firm in the treated group might be able to promptly undertake.

In columns (3) and (4) we report results for our analysis of interest, where we interact our treatment variable with an indebtedness variable that is equal to 1 for firms with a pre-sample leverage above the implied leverage threshold of 40%, and 0 otherwise. These results are aligned with hypothesis 2: while ETS firms, on average, reduced their emissions following the steep increase in the cost of EUAs, highly indebted firms did not experience such a significant reduction in their emissions. Similarly, while ETS firms, on average, improved their emissions efficiency following the steep increase in the cost of EUAs, highly indebted firms did not experience such a significant improvement.

The sign on the coefficients of the control variables is consistent with that obtained in our fixed-effects regression. Larger firms, or a larger number of ETS installations, are correlated with higher emission levels, while firms' profitability is negatively correlated with emissions, but positively correlated with emission efficiency.

Taken together, the set of results suggests that the increased EUA price linked to the event led to worse subsequent transition performance of highly leveraged firms with negative EUA balances, relative to the control group. These results refine the findings of Colmer, Martin, Muûls, and Wagner (2024) by suggesting that reduction in emissions is particularly driven by less leveraged firms who were able to invest in less emitting technologies.

Table 4: 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 balanced sample covering the years 2013 to 2019. Results for the unbalanced sample are in Table 12. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)
Variables	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
Treated × *Event*	-0.086***	0.12	-0.11***	0.16*
	(0.028)	(0.076)	(0.032)	(0.087)
LeverageAbove × *Treated* × *Event*			0.13*	-0.27**
			(0.080)	(0.11)
LeverageAbove × *Event*			-0.12**	0.15*
			(0.055)	(0.078)
Size	0.061***		0.062***	
	(0.020)		(0.020)	
Profitability	-0.0017*	0.0070***	-0.0017*	0.0071***
	(0.0010)	(0.0024)	(0.00100)	(0.0025)
Number of ETS installations	0.16***	-0.094	0.16***	-0.096
	(0.042)	(0.078)	(0.042)	(0.078)
Constant	9.04***	7.70***	9.04***	7.68***
	(0.37)	(0.15)	(0.37)	(0.15)
Firm FE	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes
Observations	14,154	14,041	14,154	14,041
R-squared	0.973	0.882	0.973	0.882

Standard errors clustered at the firm level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.3 Carbon leakage

Carbon pricing via a cap-and-trade system such as the ETS may encourage investment in the adoption of green technologies but may also encourage relocation of emissions outside

the scope of the scheme, which would also reduce measured ETS emissions. Therefore, it is important to assess whether our results are influenced by such potential carbon leakage.

There are two possible types of EU ETS related carbon leakage practices. Firstly, firms could shut down their active plants and relocate them outside the EU ETS, to avoid facing the cost of EUAs. We control for this type of carbon leakage in our setup via the *Installations* variable that controls for the number of EU ETS active plants held by the firms in the sample across time.

Secondly, firms could maintain their existing EU ETS plants, while increasing their economic activity outside the ETS (Martin, Muûls, De Preux, and Wagner, 2014). Our results could be consistent with such forms of regulatory arbitrage. Indeed, the use of debt for investment in the adoption of green technologies is not the only possible interpretation of the non-linear relationship between leverage and transition performance, as debt could also be used to finance carbon leakage practices. A limitation of the available data is that we cannot fully assess this possibility empirically because information on plants that are active outside the coverage of the EU ETS is unavailable.

At the same time, the existing empirical literature tends to find limited evidence of carbon leakage within the EU ETS, instead suggesting that our results do reflect firms' improvement of their transition performance via the adoption of clean technologies. For example, using recent confidential plant-level data, Naegele and Zaklan (2019) show that the emission reduction achieved by French manufacturing firms within the EU ETS is inconsistent with carbon leakage but is rather mainly driven by their investment in facilities that enable clean production, while an earlier study by Naegele and Zaklan (2019) does not find any evidence that the EU ETS induced manufacturing firms to carbon leakage in the initial years of emissions trading.[17]. The one exception is De Beule, Schoubben, and Struyfs (2022) who use foreign direct investment data in their examination of Phase 3 of the EU ETS. They find evidence for a statistically significant risk of shifting economic activities outside the EU ETS for firms deemed to be at risk of carbon leakage by the European Commission, although they do not find any evidence of carbon leakage for firms

[17]The latter study is also consistent with Koch and Mama (2019) who focus on the German manufacturing sector and Branger, Quirion, and Chevallier (2016) who focus on the cement and steel sectors; Dechezleprêtre, Gennaioli, Martin, Muûls, and Stoerk (2022) who focus on multinational firms

not on the carbon leakage list.

Together, this empirical literature suggests that our findings on the relationship between leverage and transition performance are unlikely to be driven by carbon leakage. Therefore, it could be less likely that the results presented in Section 4 capture improved ETS transition performance due to carbon leakage rather than green investment.[18]

To further mitigate the concerns that our results are driven by unobserved carbon leakage, we re-run our main specification on the sub-sample of firms that do not belong to sectors included on the first carbon leakage list (that holds valid at the beginning of our sample period, when we select the treatment and control groups). Results are in Table 13. They are entirely aligned with our main specification, while some coefficients might not be statistically significant due to the smaller sample size reducing statistical power. In conjunction with the existing empirical literature, this suggests that our empirical relationships between leverage and transition performance are likely to be driven by channels operating through green investment rather than by carbon leakage.

4.4 Robustness exercises

4.4.1 Alternative indebtedness dummy

In our baseline analysis, we use the dummy $AboveLeverage_f$ to split the sample into firms with leverage above the implied threshold of 40% and below this threshold. In this robustness test, we repeat the baseline analysis using a dummy that is equal to 1 when leverage is above, or equal to $40\% + \frac{1}{2}\sigma_{leverage}$ and 0 when leverage is below or equal to $40\% - \frac{1}{2}\sigma_{leverage}$, where $\sigma_{leverage}$ is the standard deviation of leverage equal to 20 percentage points. This reduces possible confounding effects attributable to firms with leverage around the implied threshold. Results are reported in Table 14 and show that the coefficients estimated are both economically and statistically aligned with those observed

[18]Recent literature on the Californian cap-and-trade, which differs from the EU ETS along many dimensions including the geographic and the allowance pricing ones, shows that only financially constrained firms are significantly responsible for carbon leakage (Bartram, Hou, and Kim, 2022). While these results cannot be extended to our analysis, they may build an argument for our coefficients constituting a lower bound of the effect of leverage on transition performance. Indeed, were firms with relatively high leverage responsible for carbon leakage, we would observe a reduction in their ETS emissions, in contrast with our results.

for the baseline specification.

4.4.2 Matching estimator

In our baseline analysis, we show that firms in the treated and control groups differ significantly along dimensions of size, profitability, ETS installations, EUA balance and age. We address these differences saturating our main specification with very granular fixed effects and a rich set of controls. In this robustness test, we further control for differences in the two groups using a propensity score matching estimator. We use an exact match on sector, country and equity type (listed or privately held). We use a propensity score weighting approach on size, profitability and ETS installations. The matching entities are selected through the use of an algorithm that selects at least the 3 closest neighbors to each treated firm. Results are reported in Table 15 and show that the coefficients estimated are consistent with those observed for the baseline specification.

4.4.3 Large firms or SMEs

We consider whether our results vary across firm size by comparing large firms with small and medium enterprises (SMEs). Economically, leverage-induced constraints may represent a greater obstacle to the investment needed to achieve low-carbon transition goals for SMEs than for large firms. This could potentially be linked to the broader financing sources available to large firms and, in particular, their ability to raise market-based finance via bond issuance. Due to data constraints, we are, however, unable to distinguish firms in our sample according to their fraction of market-based versus bank-based debt. Therefore, we proxy access to financing using our measure of size. Tables 16 and 17 show that our main results mostly continue to hold for both sub-samples.

4.4.4 Firms with listed or privately held equity

We analyse the differential effect of leverage on transition performance for firms with and without access to the public equity markets. As shown by De Haas and Popov (2023), public equity markets reallocate investment towards less emitting firms and may

push firms to improve their transition performance. Therefore, such firms' adoption of green technologies might be driven by an economic mechanism that differs from the one discussed in Section 2. We conduct the diff-in-diff analysis over the sub-samples of privately held and listed firms separately. In Table 19 we find that results are not statistically significant over the sub-sample of listed firms, while Table 18 shows that they are robust over the sub-sample of privately held firms. While the result has an economic meaning, it might also be driven by the smaller size of the sub-sample of listed firms.

4.4.5 Sectors

Firms in different sectors may have different needs for external financing and the level above which leverage represents a over-indebtedness may also differ across sectors; indeed, previous literature has found that the implications of indebtedness may vary with firms' features and their sector (Rajan and Zingales, 1996). Therefore, we consider our main specifications at the sectoral level. Tables 20, 21 and 22 show that our results are mostly aligned across sectors. Specifically, in Table 20, we show results for the sub-sample of firms in the electricity sector (Nace 2-digits 35). In Table 21 we group firms in highly polluting manufacturing sectors (Nace 2-digits from 19 to 25), while firms in all other sectors are in Table 22.

4.4.6 Alternative normalisation of emissions at the firm level

Section 3.2 discusses our choice to normalise emissions by firm-level revenues for one of our transition performance metrics. Here we assess the robustness of our main results for one alternative: total firm assets over emissions. Appendix Table 23 shows that our main results continue to hold when using assets over emissions as our dependent variable, with even slightly stronger results than our main specification.

5 Conclusion and policy implications

We study the role of debt as a source of transition finance supporting the low-carbon transition of non-financial corporations in Europe. Particularly, we focus on the emissions of firms that are subject to the EU ETS. Using historical data on verified emissions of ETS firms accounting for approximately 20% of the total emissions in the EU, we show that higher debt financing of firms subject to a cap on their emissions contributes to emissions reduction and higher emission efficiency as long as leverage is not above a given threshold. We find that this inverse U-shaped relationship between debt financing and low-carbon transition is especially robust when accounting for the subsample of non-listed firms subject to the EU ETS. Crucially, our study highlights the existence of a group of firms that are too indebted for the transition, although subject to a constraint on their emissions and even when such constraints become more binding. Indeed, we show that on average firms reduced their emissions in response to the first introduction of MSR in 2015, which tightened the ETS emission cap going forward. However, highly indebted firms in the sample did not respond with an emission reduction. Rather, the increased cost of emission allowances that was triggered by the event was followed by a further increase in the emissions produced by such firms. The result is robust to a large set of economic and environmental controls and robustness tests.

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 concern that our results are driven by carbon-leakage firms that are exposed to the risk of relocating their plants outside the EU ETS, rather than investing in the adoption of green technologies to improve their transition performance. While this does not rule out that firms in our sample shift their polluting activity outside the EU ETS, previous literature discards such concerns as it only provides scarce evidence of the materialization of carbon leakage risks in the EU ETS, and in the period analysed.

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

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

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A Appendix

A.1 Additional descriptive statistics

Table 5: List of variables

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

Table 6: Summary statistics of relevant variables

Notes: The table shows the sample composition for the entire (unbalanced) sample of firms.

	Count	Mean	Median	Min	Max	Sd
Log(ETS-Emissions)	23,966	10.11	10.09	0.00	17.98	2.22
Log(Revenues/ETS-Emissions)	22,271	7.71	7.69	-23.61	22.49	2.71
Debt/Assets	23,961	0.18	0.09	0.00	0.89	0.22
Log Revenues	22,825	17.88	18.01	11.01	22.75	2.09
ROA	22,045	2.94	2.59	-38.34	34.15	9.66
Number of ETS-installations	23,966	1.67	1.00	1.00	11.00	1.64
EUA balance (EUAs-Emissions)	23,966	-0.19	-0.00	-7.52	1.13	0.99
Age	23,938	32.16	23.00	0.00	333.00	29.02
N	23,966					

Table 7: T-test of relevant variables

Notes: The table shows the t-test for firms that appear every year in the sample from 2013 to 2019.

	t-test on differences between control and treated groups. (mean of control - mean of treated)
Log(Emissions)	-1.213***
	(-36.94)
Log(Revenues/Emissions)	1.035***
	(26.80)
EUA balance	0.620***
	(35.08)
Size	-0.216***
	(-6.83)
ROA	-0.454**
	(-3.27)
Number of ETS-installations	-0.00979
	(-0.33)
Age	1.214**
	(2.65)
N	16947

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 8: EUA prices over time

Notes: Price of EUAs (spot and futures) over time. .



Figure 9: 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.

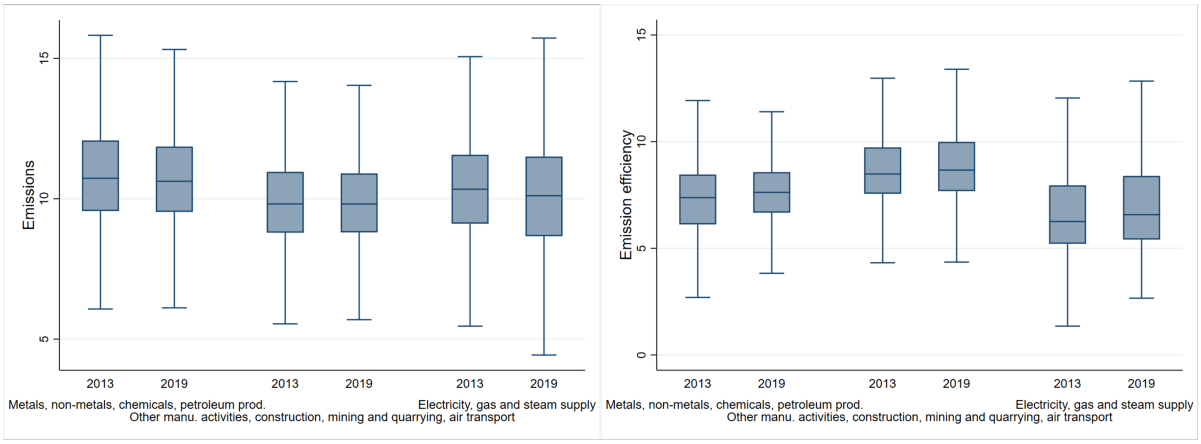


Figure 10: Firm-level leverage across time and industry groups

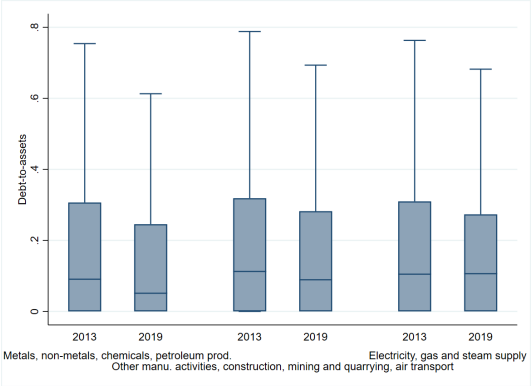


Table 8: Correlations between the variables of interest

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

Table 9: NFCs that have contracted green debt

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

	Green Bonds
NFCs in EU ETS with direct contraction of green debt	11
NFCs in EU ETS with possible indirect contraction of green debt	23
NFCs in Europe	162
NFCs in the World	506

Table 10: Matching estimator performance

Notes: Standardised difference in means for variables used in propensity score matching estimator (size, ROA, number of ETS installations). The exact match is performed on sector, country and equity type.

	Before match			After match		
	Treated	Untreated	StdDif	Treated	Untreated	StdDif
Size	18.06096	17.90833	0.0758249	17.76312	17.47155	0.1448516
ROA	3.117778	1.388919	.1965149	1.953915	2.3492	-0.044931
Number of ETS installations	1.783069	1.881279	-0.0506881	1.806156	1.637247	0.0871771

A.2 Additional results

Table 11: Panel regression for transition performance and leverage: unbalanced sample

Notes: The table shows the result of the panel regression relevant to hypothesis 1 for the two metrics of transition performance: emissions and emissions efficiency. The relationship between transition performance and leverage is tested for the unbalanced data sub-sample of ETS-firms covering the period from 2013 to 2019. Results are both economically and statistically consistent with those observed on the balanced sample, suggesting that the sample selection bias in the estimates is negligible. The implied leverage threshold is also broadly consistent with the one obtained on the balanced sample (40%). 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 less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10. All controls are lagged by one year (i.e., taken at time $t-1$) apart from age.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
Leverage 2012	-1.03**	1.51***				
	(0.41)	(0.46)				
Leverage 2012 squared	1.13*	-1.78**				
	(0.65)	(0.71)				
Leverage 1y-lagged			-1.07***	1.89***		
			(0.30)	(0.38)		
Leverage 1y-lagged squared			1.34***	-2.20***		
			(0.46)	(0.55)		
Leverage 2y-lagged					-1.05***	1.67***
					(0.32)	(0.39)
Leverage 2y-lagged squared					1.29***	-1.98***
					(0.48)	(0.56)
Size	0.59***		0.53***		0.54***	
	(0.026)		(0.023)		(0.025)	
Profitability	-0.0014	0.015***	-0.00056	0.017***	-0.00062	0.014***
	(0.0025)	(0.0031)	(0.0022)	(0.0032)	(0.0023)	(0.0029)
Number of ETS-installations	0.23***	-0.089***	0.26***	-0.092***	0.25***	-0.087***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
EUA balance	-0.49***	0.34***	-0.53***	0.34***	-0.51***	0.34***
	(0.034)	(0.038)	(0.032)	(0.036)	(0.031)	(0.035)
Age	-0.00097	0.0042***	0.00016	0.0036***	0.00034	0.0032***
	(0.0011)	(0.0013)	(0.00099)	(0.0011)	(0.0010)	(0.0012)
Constant	-0.62	7.50***	0.29	7.57***	0.025	7.64***
	(0.44)	(0.082)	(0.40)	(0.083)	(0.43)	(0.081)
Country-Sector-Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16,402	15,983	20,153	19,600	16,501	16,050
R-squared	0.626	0.489	0.594	0.431	0.601	0.453

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

Table 12: Difference-in-differences on emissions and emissions efficiency: unbalanced sample

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on an unbalanced sample covering the years 2013 to 2019. Results on emissions are both economically and statistically consistent with those observed in the same analysis on the balanced sample, suggesting that the sample selection bias in these estimates is negligible. Results on emission efficiency in column (4) show a lower statistical significance than those observed in the baseline analysis on the balanced sample. After the event, some highly indebted firms might drop out of the sample due to bankruptcy. This would be accompanied by a decreasing economic activity, characterized by both low emissions and low revenues resulting in higher emission efficiency for some and lower for other firms, in turn, introducing a confounding effect in the analysis. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.059**	0.021	-0.072***	0.048	-0.12***	0.12
	(0.026)	(0.077)	(0.027)	(0.087)	(0.036)	(0.077)
$Leverageabovethreshold \times Event$			-0.083	0.057		
			(0.051)	(0.075)		
$Leverageabovethreshold \times Treated \times Event$			0.078	-0.17		
			(0.075)	(0.11)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					-0.13*	0.11
					(0.076)	(0.095)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.20*	-0.32**
					(0.10)	(0.13)
Size	0.057***		0.057***		0.072***	1.02***
	(0.014)		(0.014)		(0.020)	(0.16)
Profitability	0.0014	0.0084***	0.0014	0.0085***	0.0020*	-0.0039**
	(0.00089)	(0.0025)	(0.00088)	(0.0025)	(0.0010)	(0.0016)
Number of ETS-installations	0.19***	-0.099	0.19***	-0.100	0.18***	-0.18***
	(0.038)	(0.077)	(0.038)	(0.077)	(0.041)	(0.069)
Constant	8.81***	7.82***	8.81***	7.82***	8.75***	-10.5***
	(0.25)	(0.13)	(0.25)	(0.13)	(0.37)	(2.88)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,968	19,410	19,968	19,410	13,528	13,150
R-squared	0.968	0.848	0.968	0.848	0.968	0.885

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

Table 13: Difference-in-differences on emissions and emissions efficiency: firms that are excluded from the first carbon leakage list

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample covering the years 2013 to 2019, for firms excluded from the first carbon leakage list produced by the European Commission. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
Treated $\times Event$	-0.067**	0.055	-0.087***	0.098**	-0.085***	0.093**
	(0.029)	(0.037)	(0.029)	(0.039)	(0.030)	(0.044)
Leverage above threshold $\times Treated \times Event$			0.12	-0.24**		
			(0.083)	(0.11)		
Leverage above threshold $\times Event$			-0.076	0.19**		
			(0.068)	(0.098)		
Leverage above threshold + $\frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.14	-0.31**
					(0.10)	(0.15)
Leverage above threshold + $\frac{1}{2}\sigma_{leverage} \times Event$					-0.092	0.25*
					(0.090)	(0.14)
Size	0.073*		0.074*		0.065	
	(0.038)		(0.039)		(0.040)	
Profitability	-0.00011	0.0053**	-0.00015	0.0053**	0.0010	0.0043
	(0.0010)	(0.0026)	(0.0010)	(0.0026)	(0.00091)	(0.0030)
Number of ETS-installations	0.12**	-0.099	0.12**	-0.096	0.13**	-0.11
	(0.056)	(0.10)	(0.056)	(0.10)	(0.055)	(0.11)
Constant	8.91***	8.13***	8.91***	8.10***	9.15***	7.99***
	(0.71)	(0.17)	(0.72)	(0.17)	(0.74)	(0.19)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,861	7,787	7,861	7,787	6,340	6,280
R-squared	0.979	0.932	0.979	0.933	0.982	0.923

Standard errors clustered at the firm level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 14: Difference-in-differences on emissions and emissions efficiency: robustness to the use of a different implied leverage threshold measure.

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

Variables	(1) ln(Emissions)	(2) ln(Revenues/Emissions)	(3) ln(Emissions)	(4) ln(Revenues/Emissions)	(5) ln(Emissions)	(6) ln(Revenues/Emissions)
Treated $\times Event$	-0.086***	0.12	-0.11***	0.16*	-0.12***	0.18*
	(0.028)	(0.076)	(0.032)	(0.087)	(0.035)	(0.10)
Leverage above threshold $\times Treated \times Event$			0.13*	-0.27**		
			(0.080)	(0.11)		
Leverage above threshold $\times Event$			-0.12**	0.15*		
			(0.055)	(0.078)		
Leverage above threshold + $\frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.20*	-0.40**
					(0.11)	(0.16)
Leverage above threshold + $\frac{1}{2}\sigma_{leverage} \times Event$					-0.13	0.19*
					(0.079)	(0.11)
Size	0.061***		0.062***		0.045**	
	(0.020)		(0.020)		(0.018)	
Profitability	-0.0017*	0.0070***	-0.0017*	0.0071***	-0.00058	0.0070**
	(0.0010)	(0.0024)	(0.00100)	(0.0025)	(0.00095)	(0.0029)
Number of ETS installations	0.16***	-0.094	0.16***	-0.096	0.17***	-0.10
	(0.042)	(0.078)	(0.042)	(0.078)	(0.044)	(0.088)
Constant	9.04***	7.70***	9.04***	7.68***	9.39***	7.56***
	(0.37)	(0.15)	(0.37)	(0.15)	(0.34)	(0.17)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14,154	14,041	14,154	14,041	11,673	11,583
R-squared	0.973	0.882	0.973	0.882	0.974	0.866

Standard errors clustered at the firm level in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 15: Difference-in-differences on emissions and emissions efficiency: robustness to the use of a matching estimator.

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced and matched sample covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

Variables	(1) ln(Emissions)	(2) ln(Revenues/Emissions)	(3) ln(Emissions)	(4) ln(Revenues/Emissions)	(5) ln(Emissions)	(6) ln(Revenues/Emissions)
Treated $\times Event$	-0.068**	0.14	-0.10***	0.12	-0.10***	0.13
	(0.029)	(0.095)	(0.033)	(0.094)	(0.035)	(0.11)
LeverageAbove $\times Treated \times Event$			0.19**	-0.28**		
			(0.079)	(0.12)		
LeverageAbove $\times Event$			-0.063	0.025		
			(0.054)	(0.076)		
LeverageAbove + $\frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.24**	-0.30**
					(0.11)	(0.15)
LeverageAbove + $\frac{1}{2}\sigma_{leverage} \times Event$					-0.079	-0.0067
					(0.077)	(0.10)
Size	0.048***		0.050***	1.14***	0.044**	1.20***
	(0.018)		(0.018)	(0.26)	(0.017)	(0.27)
Profitability	-0.00079	0.0049*	-0.00089	-0.0031*	-0.00096	-0.0029
	(0.0011)	(0.0029)	(0.0011)	(0.0019)	(0.0011)	(0.0020)
Number of ETS-installations	0.15***	-0.054	0.15***	-0.14*	0.17***	-0.15*
	(0.057)	(0.095)	(0.057)	(0.076)	(0.050)	(0.077)
Constant	9.17***	7.37***	9.15***	-12.5***	9.29***	-13.7***
	(0.33)	(0.18)	(0.33)	(4.53)	(0.32)	(4.84)
Matched sample	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,964	10,891	10,964	10,881	9,181	9,113
R-squared	0.971	0.846	0.971	0.870	0.972	0.859

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

Table 16: Difference-in-differences on emissions and emissions efficiency: sub-sample of SMEs.

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample of SMEs covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1) SMEs	(2) SMEs	(3) SMEs	(4) SMEs	(5) SMEs	(6) SMEs
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.16**	0.41**	-0.19***	0.47**	-0.20**	0.52**
	(0.063)	(0.18)	(0.068)	(0.19)	(0.076)	(0.22)
$Treated \times LeverageAbove \times Event$			0.13	-0.38		
			(0.18)	(0.26)		
$LeverageAbove \times Event$			-0.23*	0.24		
			(0.13)	(0.16)		
$LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Event$					-0.29	0.23
					(0.22)	(0.27)
$Treated \times LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Event$					0.28	-0.55
					(0.24)	(0.38)
Size	0.12**		0.12**		0.068**	
	(0.049)		(0.048)		(0.034)	
ROA	-0.0044	0.013**	-0.0043	0.014**	-0.0022	0.017**
	(0.0028)	(0.0063)	(0.0027)	(0.0064)	(0.0027)	(0.0084)
Number of ETS installations	0.33***	-0.14	0.33***	-0.15	0.36***	-0.16
	(0.12)	(0.25)	(0.12)	(0.25)	(0.12)	(0.27)
Constant	7.01***	6.80***	7.04***	6.77***	7.95***	6.64***
	(0.80)	(0.37)	(0.79)	(0.37)	(0.58)	(0.41)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,833	4,787	4,833	4,787	4,102	4,067
R-squared	0.953	0.804	0.953	0.804	0.954	0.782

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

Table 17: Difference-in-differences on emissions and emissions efficiency: sub-sample of large firms.

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample of large firms covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1) Large	(2) Large	(3) Large	(4) Large	(5) Large	(6) Large
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.068**	-0.00043	-0.092***	0.037	-0.10***	0.045
	(0.030)	(0.092)	(0.034)	(0.11)	(0.038)	(0.12)
$Treated \times LeverageAbove \times Event$			0.12*	-0.19		
			(0.073)	(0.13)		
$LeverageAbove \times Event$			-0.021	0.071		
			(0.045)	(0.096)		
$Treated \times LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Event$					0.18*	-0.35**
					(0.094)	(0.17)
$LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Event$					-0.017	0.13
					(0.056)	(0.13)
Size	0.057***		0.057***		0.058***	
	(0.019)		(0.019)		(0.020)	
ROA	-0.00079	0.0029	-0.00085	0.0029*	-0.00032	0.0018
	(0.00092)	(0.0018)	(0.00092)	(0.0018)	(0.00087)	(0.0020)
Number of ETS installations	0.085**	-0.021	0.084**	-0.021	0.089**	-0.021
	(0.037)	(0.054)	(0.037)	(0.054)	(0.038)	(0.060)
Constant	9.78***	8.04***	9.79***	8.03***	9.84***	7.93***
	(0.36)	(0.11)	(0.36)	(0.11)	(0.38)	(0.13)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,637	8,587	8,637	8,587	6,997	6,956
R-squared	0.979	0.927	0.979	0.927	0.980	0.918

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

Table 18: Difference-in-differences on emissions and emissions efficiency: sub-sample of firms with privately held equity

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
	Private firms	Private firms	Private firms	Private firms	Private firms	Private firms
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.078***	0.11	-0.11***	0.17*	-0.11***	0.18*
	(0.029)	(0.079)	(0.032)	(0.091)	(0.035)	(0.11)
$LeverageAbove \times Treated \times Event$			0.16**	-0.30***		
			(0.075)	(0.11)		
$LeverageAbove \times Event$			-0.11**	0.15*		
			(0.056)	(0.080)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.19*	-0.40**
					(0.11)	(0.16)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					-0.13	0.19
					(0.080)	(0.11)
Size	0.053***		0.054***		0.043**	
	(0.020)		(0.020)		(0.019)	
ROA	-0.0014	0.0069***	-0.0014	0.0070***	-0.00077	0.0072**
	(0.00097)	(0.0025)	(0.00097)	(0.0025)	(0.00098)	(0.0029)
Number of ETS installations	0.17***	-0.12	0.17***	-0.12	0.18***	-0.13
	(0.046)	(0.086)	(0.046)	(0.086)	(0.048)	(0.096)
Constant	9.13***	7.70***	9.13***	7.68***	9.36***	7.57***
	(0.37)	(0.16)	(0.37)	(0.16)	(0.35)	(0.18)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	13,478	13,368	13,478	13,368	11,178	11,089
R-squared	0.974	0.879	0.974	0.879	0.974	0.865

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

Table 19: Difference-in-differences on emissions and emissions efficiency: sub-sample of firms with listed equity

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sample covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
	Listed	Listed	Listed	Listed	Listed	Listed
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.97	1.03*	-1.17*	1.25*	-1.56	1.76
	(0.59)	(0.61)	(0.69)	(0.70)	(1.24)	(1.30)
$LeverageAbove \times Treated \times Event$			1.55**	-1.37**		
			(0.73)	(0.67)		
$LeverageAbove \times Event$			-0.67	0.79		
			(0.57)	(0.50)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.61	-0.87*
					(0.58)	(0.49)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					0.17	0.27
					(0.11)	(0.22)
Size	-0.029		0.034		0.016	
	(0.062)		(0.043)		(0.031)	
ROA	-0.0019	0.017	-0.0022	0.015	-0.0078	0.024
	(0.0068)	(0.014)	(0.0077)	(0.014)	(0.0091)	(0.018)
Number of ETS installations	0.023	0.19	0.036	0.19	0.075**	0.20
	(0.070)	(0.25)	(0.059)	(0.25)	(0.028)	(0.27)
Constant	12.7***	7.18***	11.6***	7.04***	12.5***	6.89***
	(1.37)	(0.88)	(0.97)	(0.91)	(1.10)	(1.23)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	317	311	317	311	211	204
R-squared	0.986	0.978	0.986	0.979	0.980	0.967

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

Table 20: Difference-in-differences on emissions and emissions efficiency: sub-sample of firms in electricity sector

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sub-sample of firms in the electricity sector (NACE 2-digits 35) covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.11	0.24*	-0.15*	0.30**	-0.16**	0.36**
	(0.067)	(0.14)	(0.077)	(0.15)	(0.083)	(0.17)
$LeverageAbove \times Treated \times Event$			0.15	-0.30		
			(0.19)	(0.21)		
$LeverageAbove \times Event$			-0.17	0.20		
			(0.12)	(0.14)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.34	-0.42
					(0.26)	(0.28)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					-0.23	0.21
					(0.18)	(0.21)
Size	0.053		0.055*		0.020	
	(0.034)		(0.034)		(0.023)	
ROA	-0.0019	0.0076	-0.0019	0.0077	-0.00025	0.0095
	(0.0024)	(0.0053)	(0.0024)	(0.0053)	(0.0023)	(0.0063)
Number of ETS installations	0.22***	-0.14	0.22***	-0.15	0.25***	-0.15
	(0.067)	(0.12)	(0.068)	(0.12)	(0.075)	(0.15)
Constant	8.83***	6.94***	8.82***	6.92***	9.44***	6.78***
	(0.58)	(0.32)	(0.58)	(0.32)	(0.43)	(0.37)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,682	4,662	4,682	4,662	3,987	3,970
R-squared	0.966	0.845	0.966	0.845	0.967	0.833

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

Table 21: Difference-in-differences on emissions and emissions efficiency: sub-sample of firms in the sectors of metals, non-metals, chemicals and petroleum products

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sub-sample of firms in the sectors of metals, non-metals, chemicals and petroleum products (NACE 2-digits 19 to 25) covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)	ln(Emissions)	ln(Revenues/Emissions)
$Treated \times Event$	-0.084***	0.058**	-0.099***	0.081***	-0.11***	0.082**
	(0.025)	(0.029)	(0.028)	(0.031)	(0.030)	(0.035)
$LeverageAbove \times Treated \times Event$			0.085	-0.14*		
			(0.056)	(0.074)		
$LeverageAbove \times Event$			-0.026	-0.00056		
			(0.035)	(0.037)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.099	-0.21*
					(0.077)	(0.12)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					-0.059	0.0036
					(0.042)	(0.049)
Size	0.13***		0.13***		0.12***	
	(0.044)		(0.044)		(0.045)	
ROA	0.00078	0.00088	0.00072	0.00096	0.0013	-0.00030
	(0.0010)	(0.0016)	(0.0010)	(0.0016)	(0.00092)	(0.0016)
Number of ETS installations	0.085***	-0.025	0.085***	-0.025	0.095***	-0.037
	(0.029)	(0.024)	(0.029)	(0.024)	(0.029)	(0.025)
Constant	8.55***	7.40***	8.54***	7.40***	8.77***	7.36***
	(0.81)	(0.042)	(0.80)	(0.043)	(0.82)	(0.044)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,179	5,135	5,179	5,135	4,334	4,299
R-squared	0.986	0.972	0.986	0.972	0.985	0.971

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

Table 22: Difference-in-differences on emissions and emissions efficiency: sub-sample of firms with other sectors

Notes: The table shows the result of the difference-in-differences regression. The analysis is performed on a balanced sub-sample of firms in all sectors excluding (NACE 2-digits from 19 to 25 and 35) covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

VARIABLES	(1) ln(Emissions)	(2) ln(Revenues/Emissions)	(3) ln(Emissions)	(4) ln(Revenues/Emissions)	(5) ln(Emissions)	(6) ln(Revenues/Emissions)
$Treated \times Event$	-0.12**	0.21	-0.15***	0.27	-0.15***	0.26
	(0.050)	(0.19)	(0.054)	(0.23)	(0.058)	(0.26)
$LeverageAbove \times Treated \times Event$			0.18*	-0.35		
			(0.11)	(0.25)		
$LeverageAbove \times Event$			-0.23**	0.23		
			(0.10)	(0.18)		
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$					0.097	-0.31
					(0.15)	(0.30)
$Leverageabovethreshold + \frac{1}{2}\sigma_{leverage} \times Event$					-0.22*	0.26
					(0.13)	(0.22)
Size	0.026		0.028		0.023	
	(0.026)		(0.026)		(0.027)	
ROA	-0.0029*	0.013***	-0.0028*	0.013***	-0.0016	0.014**
	(0.0017)	(0.0049)	(0.0017)	(0.0050)	(0.0018)	(0.0057)
Number of ETS installations	0.18***	-0.18	0.17***	-0.18	0.16**	-0.18
	(0.059)	(0.18)	(0.059)	(0.18)	(0.064)	(0.20)
Constant	9.27***	8.89***	9.27***	8.86***	9.48***	8.77***
	(0.48)	(0.30)	(0.48)	(0.31)	(0.50)	(0.35)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,775	4,734	4,775	4,734	3,965	3,932
R-squared	0.965	0.810	0.965	0.811	0.966	0.793

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

Table 23: Difference-in-differences on emissions and emissions efficiency: robustness to an alternative specification of the dependent variable

Notes: The table shows the result of the difference-in-differences regression using an alternative measure for emission efficiency (ln(Assets/Efficiency)). The analysis is performed on a fully balanced sample of ETS firms covering the years 2013 to 2019. Standard errors are clustered at the firm level, they are indicated in parentheses. All controls are lagged by 1 year. Due to the firm fixed effects the age control drops from the analysis. The statistical significance of the estimated parameters is indicated by *** for a p-value of less than 0.01, ** for a p-value of less than 0.05, and * for a p-value of less than 0.10.

VARIABLES	(1) ln(Assets/Emissions)	(2) ln(Assets/Emissions)	(3) ln(Assets/Emissions)
$Treated \times Event$	0.17***	0.19***	0.21***
	(0.035)	(0.039)	(0.044)
$Treated \times LeverageAbove \times Event$		-0.14	
		(0.087)	
$LeverageAbove \times Event$		0.018	
		(0.059)	
$LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Treated \times Event$			-0.25**
			(0.12)
$LeverageAbove + \frac{1}{2}\sigma_{leverage} \times Event$			0.018
			(0.083)
ROA	0.0038***	0.0039***	0.0033**
	(0.0013)	(0.0013)	(0.0015)
Number of ETS installations	-0.097**	-0.098**	-0.11**
	(0.049)	(0.049)	(0.052)
Constant	7.93***	7.92***	7.84***
	(0.091)	(0.091)	(0.098)
Firm FE	Yes	Yes	Yes
Country-Sector-Year FE	Yes	Yes	Yes
Observations	14,471	14,471	11,926
R-squared	0.956	0.956	0.956

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