Climate-related transition risk in the European CDS market*

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The European low-carbon transition started in the last decades and is accelerating to reach net-zero by 2050. This paper analyses how the climate-related transition indicators of a European large corporate firm relate to its CDS-implied credit risk for different time horizons. Findings show that firms with higher GHG emissions have higher CDS spreads at all tenors, even at the 30-year horizon, particularly after the 2015 Paris Agreement and in salient industries, such as Electricity, Gas, and Mining. Results suggest that the European CDS market is already pricing to some extent, albeit small, the exposure to transition risk of a firm at different time horizons, but ignores a firm's transition risk management efforts and its exposure to the European Union Emissions Trading Scheme.

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"Climate change is the Tragedy of the *Horizon*." Marc Carney (2015)[1]

1 Introduction

Limiting global warming requires reducing substantially the greenhouse gases that economies emit. Transitioning to a lower-carbon economy involves extensive policy, legal, technology, and market changes. Financial risks that could result from the process of adjustment towards a lower-carbon economy are referred to as transition risk and represents one of the channels through which climate change can affect credit risk and financial stability (Carney, 2015).[2] Climate action and emission reduction are not a new phenomenon in Europe by comparison with other advanced economies such as the US, yet reaching net-zero by 2050 will require more efforts than the ones observed historically (see Figure 1). The European Union has been gradually reducing its level of greenhouse gases (GHG) by over 20% in 2020 since its 1990 levels. This emission reduction was to a large extent achieved due to public policies such as the creation in 2005 of the first carbon market worldwide, the EU Emissions Trading Scheme (ETS). The EU net-zero target for 2050, which was enforced in 2019, is accompanied by a set of policies aimed to foster the low-carbon transition and by evolving market sentiment of investors (e.g., fossil fuel divestment, clean energy investment). However, concerns over climate-related financial risks only recently became more prevalent in the financial sector. This is partly due to the very long horizon of the low-carbon transition, i.e., 30 years, which goes beyond the time horizon of standard credit metrics, i.e. 2-3 year time horizon for credit ratings.

In this paper, we aim at assessing how the European market of credit default swaps reflects the relation between climate-related transition indicators[3] and credit risk at different time horizons. We construct a dataset covering firm-level greenhouse gas emissions and transition management indicators to proxy a firm's transition risk, alongside standard determinants of CDS-market-implied credit risk. Given the very long time horizon of the low-carbon transition, the metrics of CDS-market-implied credit risk that we collect are the 1, 5, 10, and 30-year CDS spread. The data covers European large corporate firms over the time period 2010 − 2021. All the data sources used in this study are either from

[1] Quote from the speech "Breaking the tragedy of the horizon - climate change and financial stability" given by the former Governor of the Bank of England and Chairman of the Financial Stability Board - see Carney (2015)

[2] See for instance BCBS (2021) and Alogoskoufis et al. (2021) for an outline of the transmission channel.

[3] The choice of the term "indicators of firm's transition risk" follows the terminology employed for instance in FSB (2021) and ECB (2021a).

commercial data providers that are widely used by financial institutions or public data. For instance, the CDS data is collected from IHS Markit and the transition risk indicators are collected from Bloomberg, Refinitiv, the Carbon Disclosure Project, and the EU Transaction Log. The choice of these data sources is deliberate to approach as much as possible the environment of data sources available to CDS market participants.

We apply a panel regression and a difference-in-differences approach to assess how climate-related transition indicators relate to CDS-implied credit risk. Our findings show that firms with higher GHG emissions have higher CDS spreads at the 5, 10, and 30-year tenor, which reflect medium, long, and very-long-term credit risk time horizons, respectively. The relation appears to be causal as confirmed in a differences-in-difference analysis around the Paris Agreement that signalled a shift in climate-related policies and market sentiment. Following this event, high polluting European firms display higher CDS spreads than other European firms in the sample. This result is mainly driven by high emitters in salient industries, such as Electricity, Gas, and Mining. When considering a firm's efforts to mitigate their exposure to transition risk, findings show that CDS market participants do not appear to consider mitigation based on indicators of a firm's transition management efforts such as emission reduction targets, climate policies, remuneration, and / or risk management related to the energy transition. Finally, the results on the carbon market suggest no differential treatment by the CDS market of GHG emissions (Scope 1) depending on the fact whether the firm is subject to the carbon market, i.e. ETS, and herewith directly exposed to emissions costs or not. Also, CDS market participants are likely not considering in their assessment of a firm's credit risk positive ETS-related cash flows derived from a surplus of free allowances. Overall, the results in this paper suggest that the European CDS market is already pricing to some extent, albeit small, the GHG emissions (Scope 1) of a firm, but much of the readily available information on other climate-related transition indicators is not yet embedded by CDS market participants.

This paper is related to the wide and emerging literature on the pricing of climate-related transition risk in the financial system and more broadly to the literature on climate economics (see for instance the seminal work of Nordhaus, 1991). The first studies in the literature on the pricing of climate-related transition risk inspected the link to the CDS market using third-party corporate social responsibility scores, ESG scores, and/or environmental scores as proxies for climate-related transition risk (Höck et al., 2020; Truong and Kim, 2019; Gao et al., 2021; Drago et al., 2019). Yet, such scores were shown later to have many shortcomings that discard them as an adequate proxy of transition risk (see for instance Boffo and Patalano, 2020). Due primarily to large discretion in enviromental score methodology, such scores are often inconsistent over time, incomparable across firms and sectors, at times unreliable, and display a very low correlation when compared across different providers (Berg et al., 2019; Billio et al., 2021; Schnabel, 2020). By comparison with environmental scores, GHG emissions are a better proxy of transition risk and exploitable under informed methodological choices that acknowledge and address caveats on availability, reliability, and comparability of such data (see for instance Busch et al., 2020; Kalesnik et al., 2020). Nevertheless, existing caveats should not prevent from better leveraging already available data sources and approaches (NGFS, 2021; Elderson, 2021). Instead of environmental scores, recent work has been focusing on firm-level GHG emissions. For instance, several studies explore the link between firm-specific GHG emissions and stock returns (Bolton and Kacperczyk, 2020, 2021b), while the empirical literature pertaining to the European carbon market study in addition the link between carbon certificates and stock returns (Oestreich and Tsiakas, 2015; Brouwers et al., 2016). Another stream of literature investigates how the bond market, the syndicated loan market, and ratings relate to firm-level emissions.[4] However, GHG emissions taken alone do not reflect a firm's adaptation and mitigation efforts, which are necessary to assess a firm's transition risk in its entirety (see for instance EBA, 2021).

We contribute to the above literature in three ways. First, thanks to the CDS term structure, we assess the relation between climate-related transition risk and credit risk for a variety of maturities, ranging from short-term to very-long-term credit risk. This provides a comprehensive picture of the time horizon of transition priced by the CDS market. Second, we evaluate transition risk in its whole by considering both GHG emissions and a firm's efforts to reduce emissions as well as a firm's exposure to the carbon market. Third, financial risks posed by climate change, i.e. physical and transition risks, are considered so unprecedented that very little reliance can be placed upon historical data to assess their magnitude (BCBS, 2021). However, in geographies were the transition already started decades ago, one can learn from historical data about the initial magnitude of the effect of climate-related transition risk on credit risk. This initial magnitude can partially inform the set of possible future values of magnitude of the effect of climate-related transition risk on credit risk. We obtain such estimates of magnitude by exploiting the unique setup of the

[4] See for instance, Carbone et al. (2022); Kabir et al. (2021); Capasso et al. (2020); Seltzer et al. (2020); Safiullah et al. (2021); Ehlers et al. (2021); Kacperczyk and Peydró (2021)

European low-carbon transition, where - by comparison with other advanced economies such as the US - an up-and-running carbon market and actual emission reduction have been already observed over the past decade.

The remainder of this paper is organized as follows. Section 2 explains the background and outlines the hypotheses explored in this paper. Section 3 describes the dataset while 4 describes the research design. Section 5 presents and discusses the results for each hypothesis. Finally, Section 6 concludes.

2 CDS-implied risk and tested hypotheses

In this section, we present the economic mechanism pertaining to CDS-implied credit risk and transition risk and outline the set of hypotheses that we test empirically.

A single name CDS is a credit derivative, where the buyer of a single name CDS pays to the seller a periodic amount over the tenor of the contract. In exchange for these payments, she gets protection against the occurrence of a credit event (e.g., default of the reference firm). If the credit event occurs, then the seller of the CDS contract compensates the buyer for the difference between the par value and the market value of the reference bond. Clearly, a higher spread for the CDS indicates greater perceived credit risk for the reference entity.

The CDS term structure reflects the shape of future losses (expected and unexpected) associated with the reference entity over different time horizons (i.e., 1, 5, 10, and 30 years). Its slope reflects the relative movement between short-run and long-run credit risk. The dynamic and trading activity of CDS spreads can be driven by name or sector-specific news events; for instance, the 2015 emissions scandal saw a significant increase in activity in Volkswagen's CDS (Q3-Q4 2015), while the 2015 drop in oil prices (oil price falls to 11-year low in December 2015) prompted increased trading volumes in energy sector names (i.e., Glencore).

Transition risks to a low-carbon economy might also affect CDS spreads depending on their timing and speed. These include changes in public sector policies (e.g., net-zero policies), technological innovation and changes in the affordability of existing technologies (e.g., electric cars), and changes in market sentiment of investors (e.g., ESG or clean energy investment, fossil fuel divestment), as well as of consumers (e.g., air travel). An acceleration in these drivers may increase a firm's exposure to transition risk.

A key variable for assessing a firm's exposure to transition risk is the level of its GHG emissions. Under the GHG protocol, these emissions are categorized under three *Scopes* for accounting and reporting purposes:

- *Scope 1.* It corresponds to the direct emissions of the firm from owned or controlled sources.
- *Scope 2.* It relates to the emissions associated with the firm's consumption of purchased energy.
- *Scope 3.* It includes all emissions that occur in the value chain of the firm, excluding Scope 2.[5]

The historical data availability on firm-specific GHG emissions reflects a fragmented landscape of disclosure requirements. The disclosure of emissions from owned or controlled sources (Scope 1) has been mandatory in some European countries but not in all (i.e., the UK starting from 2013). Also, where a firm does report its GHG emissions under Scope 1, it might not necessarily report the ones under Scope 2 and/or Scope 3. The resulting data landscape of firm-specific GHG emissions of listed companies is a relatively good coverage for self-reported GHG emissions under Scope 1, a somewhat lower coverage for Scope 2 and a very low coverage for Scope 3, which is affected by severe measurement challenges (Busch et al., 2020; Kalesnik et al., 2020). Recent emerging literature explores firm-specific self-reported and/or inferred GHG emissions data (see among others, Safiullah et al., 2021; Ehlers et al., 2021; Bolton and Kacperczyk, 2021a). The majority of these studies find a significant relation for Scope 1 GHG emissions and the financial variable of interest while evidence for Scope 2 and Scope 3 GHG emissions is ambiguous.

In the light of the above considerations, this study focuses on firm-specific self-reported GHG emissions under Scope 1 as an indicator of a firm's exposure to transition risk and the transmission mechanism to credit risk through the production costs channel described below.

2.1 Transition risk and credit risk time horizon

The transition to a low-carbon economy requires a long time horizon. The European Union's target for achieving net-zero is 2050 with an intermediate target of achieving a

[5]Generally, Scope 3 represents the highest emissions' category as it includes, among others, the emissions stemming from the usage of products sold by the firm (downstream emissions) as well as emissions stemming from the suppliers manufacturing the inputs (upstream emissions).

GHG reduction of 55% by 2030 (compared to its 1990 level of GHG emissions). Exposure to transition risk may affect the credit risk of a firm through higher operating costs, lower revenues, higher debt, and stranded assets. In the transmission mechanism through the production costs channel, operating costs may be affected by the government climate policy on carbon price and energy price. Carbon prices e.g., EUA price[6], may increase a firm's production costs proportionally to their Scope 1 emissions that are subject to the carbon market (e.g., EU ETS). Moreover, where a carbon tax raises the cost of purchasing goods whose consumption emits greenhouse gases, firms' revenues may be negatively affected, especially if they operate in high polluting sectors. To minimize the downside impact and remain competitive, firms need to adapt their business models. Analogously, firm's leverage may increase given that firms would have to raise additional capital to finance the change of their existing GHG-intensive production processes to more sustainable ones. Firms which have already a high leverage profile may encounter a financing constraint to leverage additional capital.

Finally, as one of the transition drivers is innovation, it is important to consider possible competition-related market pressures on the business models and ultimately future revenues of firms failing to adapt. For instance, competition with new green technologies may create pressure on the revenues of incumbents and increase their credit risk (see, for instance, Alogoskoufis et al., 2021; BCBS, 2021; Maurin et al., 2021).[7] If transition drivers significantly increase a firm's costs, reduce its revenues, and ultimately reduce its ability to repay and service debt, the credit risk associated with this firm increases. Therefore, uncertainties surrounding the timing and speed of the transition represent a source of risk for a firm with high GHG emissions. We develop the following hypothesis:

H1. The European single name CDS market reflects a positive relationship between a firm's exposure to transition risk and the CDS-implied credit risk term structure.

Accordingly, the assessment of transition risk includes information disclosed by the firm on its exposure to this risk and on the firm's strategy how to deal with it. We assess the firm's management of transition risk through a set of climate-transition-related indicators

[6] The carbon certificate under the EU ETS is the European Union Allowance (EUA). One EUA gives the holder the right to emit one tonne of carbon dioxide (CO2), or the equivalent amount of nitrous oxide (N2O) or perfluorocarbons (PFCs).

[7] On January 27, 2021, the Guardian was writing "Rating agency S&P warns 13 oil and gas companies they risk downgrades as renewables pick up steam" - https://www.theguardian.com/business/2021/jan/27/rating-agency-sp-warns-13-oil-and-gas-companies-they-risk-downgrades-as-renewables|-pick-up-steam

covering targets, climate-related internal governance (policies and remuneration), and risk management practices (e.g., internal CO2 pricing). These practices reflect the firm's effort in the transition to a low carbon economy and should be associated with lower credit risk. Hence, we formulate the second hypothesis:

H2. The European single name CDS market reflects a negative relationship between a firm's efforts to manage its exposure to climate-related transition risk and the CDS-implied credit risk term structure.

Regardless the self-reported GHG emissions, a firm is required to report emissions on certain activities that are subject to the Emission Trading System (EU ETS). The EU ETS was launched in 2005 as the first carbon market worldwide, which is to date still the world's biggest carbon market and represents a fundamental element in the EU's policy on climate change, as it is a key tool for reducing greenhouse gas emissions cost-effectively in European countries.[8] It operates on the principle of cap-and-trade, where an overall emissions cap is set for the whole system. Under such a scheme, the basic principle states that whether a firm emits more than the amount of carbon certificates that it holds, it must buy additional certificates from firms that are polluting less. Conversely, if a firm emits less than the amount of carbon certificates that it holds, the firm can sell the excess carbon certificates to firms that are polluting more. The carbon certificate under the EU ETS is the European Union Allowance (EUA): one EUA gives the holder the right to emit one tonne of carbon dioxide (CO2), or the equivalent amount of nitrous oxide (N2O) or perfluorocarbons (PFCs).[9] EUAs are either allocated to firms for free or they are auctioned. The allocation rules are established for each trading period (or phase). Since its launch in 2005, EU ETS run three trading periods (2005-2007, 2008-2012, 2013-2020) and is currently in its fourth phase (2021-2030). The price of an EUA was relatively law since the launch of the ETS in 2005, yet during phase 3 (2013-2020) it increased from EUR 4.43 per tonne eCO2 to 48.25, i.e., an increase of over 1000%, particularly steep since 2017. Hence, the EU ETS a carbon market that puts an explicit price on the emissions of a firm resulting from economic activities subject to the EU ETS, while such an explicit price does

[8] The United Kingdom was part of the EU ETS until it established its own carbon market in May 2021.

[9] The EU ETS does not cover all types of greenhouse gases. Particularly, methane (CH4), which is the type of greenhouse gas with the highest coefficient of global warming, is not included in EU ETS. The EU accounts for 2.3% of global methane emissions and represents a small share in comparison with the Russian Federation and the United States being responsible for 15% and 14% of global emissions, respectively. Yet, the EU is the largest buyer of natural gas on the international market – having a 46% share - buying mainly from the Russian Federation, Norway, Algeria, Nigeria, Qatar, and the United States.

not exist for firms with activities not subject to the EU ETS. Against this background, we develop the following hypothesis:

H3a. The European single name CDS market reflects a different relationship between a firm's exposure to transition risk and the CDS implied credit risk depending on the fact whether the firm is subject to the carbon market, EU ETS, or not.

The allocation of free EUAs to firms is primarily done based on the carbon leakage concept where firms in carbon-intensive and trade-exposed industries are given compensation to prevent those firms from relocating. This concept has been disputed since it may overly compensate firms for the risk of relocation as shown by Martin et al. (2014). Over time, the market experienced several reforms addressing shortcomings of the original design.[10]

The "Market Stability Reserve" (MSR) reform of the EU ETS Carbon Market was confirmed in February 2017 by the EU Parliament and the EU Council. The reform focused on how to absorb the structural oversupply of EUA and make the total supply of emission allowances more flexible, and hence intended to make carbon emissions more expensive for firms.[11] These proposals have been transposed into legislation in November 2017 and the MSR has been operationalised in January 2019 to remove the excess supply of EUA from the market and store the excess in a reserve.[12] Firms with an EUA surplus are expected to have additional liquidity that they can tap in, by comparison with firms with an EUA deficit, which have to engage resources to compensate for the deficit.

Hence, this mechanism may affect a firm's credit risk. Oestreich and Tsiakas (2015) show based on a sample of German firms that receiving free EUAs is associated with higher stock returns, which may be attributable to higher cash flows for the firm. Brouwers et al. (2016) show that disclosure of a shortfall of allowances appears to be relevant for returns if carbon price is high and the scarcity of EUA is anticipated and particularly for firms less able to pass through environmental costs. Therefore, we state the following hypothesis for the carbon-related transition risk:

H3b. The European single name CDS market reflects a negative relationship between a firm's positive cash flows derived from EUA surplus and a firm's CDS-implied credit risk.

[10] One of the main issues was the surplus of allowances that accumulated in the EU ETS that has led to lower carbon prices and thus a weaker incentive of firms to reduce emissions. Another important issue is that firms pass through the costs of their emissions over to consumers in the product prices that they charge, e.g., electricity companies.

[11] More information on the MSR may be found on https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets/market-stability-reserve_en

[12] In 2019, the number of EUA allocated for free and auctioned has been the lowest ever observed since the initiation of the EU ETS in 2005.

2.2 Shift in market awareness after the Paris Agreement in 2015

In December 2015, a group of 195 countries agreed in Paris on the adoption of an international treaty to limit global warming below 2 degrees Celsius, preferably to 1.5 degrees, compared to preindustrial levels. To achieve this goal, the involved countries aim at reducing GHG emissions to net-zero by 2050.

The Paris Agreement was reached during the 21st Conference of the Parties (COP 21), a yearly meeting of the United Nations Framework Convention on Climate Change (UNFCCC). The COP 21 stands out for several reasons in the history of yearly COP negotiations that have been conducted since 1995. First, it is the first-ever legally binding global agreement on climate change. It implies that if countries do not respect their emission reduction commitments, the signatory states may be sued by society. For instance, climate change-related litigation against governments (e.g., France and the Netherlands) and companies (e.g., Royal Dutch Shell and RWE) grew significantly since the Paris Agreement (Setzer and Byrnes, 2020), carrying financial and reputational consequences for the involved parties. Second, since large-scale investments are fundamental to reduce emissions significantly, the COP 21 emphasized the role of climate finance and saw large private investors joining new private and public investments in "clean energy".[13] Third, the Financial Stability Board (FSB) established the task force on Climate-related financial disclosures to provide recommendations for a disclosure framework considering physical, liability, and transition risks associated with climate change.[14] Access to high-quality financial information allows market participants and policymakers to understand and better manage those risks, which are likely to grow with time.[15] In the view of a low-carbon economy in which fossil fuel is phased out, an expectation for businesses to prepare to answer "What's your strategy for 'net zero'?" has been set out.[16]

Therefore, we exploit the Paris Agreement to test a possible causal relationship between

[13]On November 30, 2015, Financial Times was writing "COP21 Paris climate talks: billionaires join forces in energy push. Gates, Bezos, Ma, Ambani, Zuckerberg and Branson among those eyeing low-emission technology". https://www.ft.com/content/1fcae3aa-96f5-11e5-9228-87e603d47bdc. See also the report of the Institutional Investors Group on Climate Change "How the investor voice shaped COP21. Into the post-Paris climate era". https://www.nordea.com/en/doc/iigcc-post-paris-cop21-report.pdf

[14]Speaking at the COP21 Mark Carney, the chair of the FSB, said "The FSB is asking the Task Force on Climate-related Financial Disclosures to make recommendations for consistent company disclosures that will help financial market participants understand their climate-related risks".

[15]Official announcement of the TCFD on December 4, 2015 - https://www.fsb.org/2015/12/fsb-to-establish-task-force-on-climate-related-financial-disclosures/

[16]On December 4, 2015, Financial Times wrote "COP21 Paris talks: Carney weighs in on fossil fuel pollution. Bank of England governor presses business on climate strategy" - https://www.ft.com/content/012e37c4-9a99-11e5-be4f-0abd1978acaa

CDS-implied credit risk and GHG emissions:

H4. In the aftermath of the Paris Agreement in December 2015, European top-polluters receive higher CDS-implied credit risk by comparison with other European firms.

Overall, the Paris Agreement increased the awareness of financial markets of possible implications of the low-carbon transition, including both opportunities, e.g., green investments, and risks, e.g., transition risk. Related empirical evidence has been provided by the studies of Monasterolo and De Angelis (2020) and Bolton and Kacperczyk (2021a), who used the Paris Agreement as an instrument to identify a shift in the pricing of carbon risk in the stock market.

3 Data and variables

We consider European non-financial firms since the determinants of credit risk are different in nature than those of financial firms. The sample is constructed based on four blocks of data describing the activity of a set of European firms: i) CDS-specific data - described in section 3.1; ii) Traditional determinants of CDS-implied credit risk - described in section 3.2; iii) Indicators of exposure to and management of climate-related transition risk - described in section 3.3; and iv) Indicators of carbon market related exposure and management - described in section 3.4.

The timespan of the sample is February 2010 to April 2021 at a monthly frequency. The resulting panel dataset is composed of 20,031 firm-month observations that correspond to the CDS contracts of 210 non-financial firms. Table 1 presents the composition of the resulting sample by year, country, and industry. The number of uniquely observed firms in each year is in the range of 136 to 174 unique firms over the 11 years of the sample. Most observations relate to UK, French, and German-incorporated firms, constituting circa 60% of the total number of observations as well as of total number of firms. The most represented sector in the sample is manufacturing, including GHG-intensive activities (e.g., manufacture of coke and refined petroleum products) as well as other non-GHG-intensive manufacturing activities. The second most represented sector by number of firms is information and communication (with predominantly communication firms), and the third is electricity, gas, steam, and air conditioning supply (with predominantly electricity firms).

3.1 CDS-implied credit risk

The CDS contracts are all single name, denominated in euro, with tier "senior unsecured debt", and document clause "modified-modified restructuring". Each single name CDS in the final sample has a spread quoted for a tenor of 1 year, 5 years, 10 years, and 30 years, respectively. CDS spreads are observed as per end-of-month and have been downloaded from IHS Markit.[17]

Following Augustin and Izhakian (2020), we winsorize the CDS spreads at the 99% levels and use the natural logarithm of CDS spreads to exclude the possibility of any results being driven by outliers. In addition, we construct the end-of-month CDS slope (*lnSlope(5y-1y), lnSlope(10y-1y), lnSlope(30y-1y)*).

The description of variables employed for capturing the CDS-implied credit risk of a reference firm are reported in the online Appendix (Tables A1 and A2) along with the summary statistics (Table A3). The majority of firms in the sample are large corporate firms, as indicated by the market capitalization above 10 billion euros. The mean of the CDS spread is indicative of the CDS-implied credit risk in terms of implied expected and unexpected losses: 0.51% for 1-year maturity, 1.28% for 5-year maturity, 1.63% for 10-year maturity, and 1.73% for 30-year maturity. Assuming a loss given default of 45% in line with the Basel Framework for credit risk estimates[18], the implied probability of default of the average firm in the sample is: 1.13% for 1-year maturity, 2.84% for 5-year maturity, 3.62% for 10-year maturity, and 3.84% for 30-year maturity, corresponding approximately to the profile of a corporate firm with an S&P-rating BB (Tasche, 2013).

Finally, Figure 4 shows the time series of the main CDS variables: the natural logarithm of spread and the natural logarithm of slope at different time horizons. The longer the time horizon of the CDS contract, the higher the CDS spread and the CDS-implied credit risk.

[17] Where a single-name CDS for a specific reference entity is not available for each of these four tenors concomitantly, such entities are excluded. The reason for excluding such records is to ensure validity of results across four different tenors, i.e., corresponding to different credit risk time horizons, for the same set of firms. Furthermore, given the nature of these contracts and of the market, a quote for a CDS contract with a specific tenor for a specific reference firm is not continuously available throughout time, unlike for the stock of a specific firm. We exclude records where the single-name CDS for a specific reference firm has a spread observation for less than 12 consecutive months.

[18] See paragraph 32.5 "Under the foundation approach, senior claims on corporates, sovereigns and banks not secured by recognised collateral will be assigned a 45% LGD.". https://www.bis.org/basel_framework/chapter/CRE/32.htm

3.2 Firm-specific reference and financial data

We select a set of traditional determinants of CDS-implied credit risk based on prior literature on CDS. Particularly, we explore separately the determinants as per the model of Augustin and Izhakian (2020) and the determinants as per the model of Galil et al. (2014).

Both studies consider credit ratings as a determinant of CDS spread. Long-term issuer credit ratings in class A are typically associated with low credit risk (negative relationship), while ratings in class B are associated with moderate credit risk (negative relationship for investment grade BBB, positive relationship for speculative grade BB/B), and ratings in class C are associated with high credit risk (positive relationship). Given that close to half of the firm-month observations in the sample of this study do not have a rating, we follow Galil et al. (2014) and specify a set of rating-related dummies: i) unrated for firms that do not have a rating; ii) investment grade class A rating; iii) investment grade class B rating; and iv) speculative grade class B and C rating. The rating considered is the one issued by S&P or Moody's for the reference firm. Whereas half of the sample is unrated, the remaining half has an average rating of 13, corresponding to a B-class investment grade on S&P's and Moody's rating scales.

The other variables included in the model of Augustin and Izhakian (2020) are:

- *Leverage.* It is proxied by the ratio between the sum of short-term and long-term debt and total assets. More leveraged firms are typically associated with higher credit risk, i.e., higher spreads (positive relationship).
- *Liquidity.* It is proxied by the composite depth of the 5-year CDS. Liquidity is usually associated with lower credit risk, as companies covered by more dealers tend to have lower CDS spreads (negative relationship). Yet in certain market circumstances specific to the single name CDS market, liquidity increases with credit risk as in the case of the Volkswagen emission scandal in 2015 (positive relationship).
- *Firm size.* It is proxied by market capitalization. The larger the size of the firm, the better its ability to repay debt in normal as well as adverse conditions (negative relationship).

The variables included in the model of Galil et al. (2014) are:

- *Stock return.* It is a proxy of changes in a firm's market value of equity. Merton (1974) suggests a negative relation between a firm's market value of equity and its probability of default. As higher stock returns increase a firm's value, then theoretically CDS spreads, as a proxy of credit risk, are expected to decrease (negative relationship).

- *Historical volatility of the stock.* It is a proxy of firm's asset volatility. In line with Merton (1974), it is expected to lead to greater credit risk, i.e., higher CDS spread (positive relationship).

The data are collected from IHS Markit, Refinitiv, Datastream, and Bloomberg. The detailed description of the variables are provided in the online appendix (Table A4) along with summary statistics (Table A5).

To select the baseline model, we evaluate the specifications proposed by Augustin and Izhakian (2020) and Galil et al. (2014). When comparing the results obtained with the two alternative specifications, the results appear to be comparable based on the sign of the relationship and statistical significance. Given the similar results, the set of controls used follows the specification from the most recent contribution of Augustin and Izhakian (2020). Result are presented in Appendix B.

3.3 Indicators of exposure and management to climate-related transition risk

Given the different coverage of firms by different data providers, we collect scope 1 data from three different sources: Refinitiv, Bloomberg, and the Carbon Disclosure Project (CDP). Upon comparing the distribution of emissions across the three data providers, the distributions appear to be similar for the set of considered firms coherently with Busch et al. (2020) and Bolton and Kacperczyk (2021a). Therefore, we construct the variable *Scope1* by taking the maximum value reported as scope 1 for a specific firm among the three data providers. The sample mean of the distribution of observations of Scope 1 emissions is 9.54 million tonnes eCO2, while the median is 0.4 million tonnes eCO2. Furthermore, we construct additional metrics allowing an assessment of the emission intensity of the firm. A higher Scope 1 emission intensity indicates a less efficient production technology employed by the firm for each unit of revenue (*Scope1Rev*) or for each unit of total assets (*Scope1TA*). The sample mean of the distribution of observations of Scope 1 emissions intensity by revenue is 0.27, while the median is 0.03 million tonnes eCO2 / billion EUR. For the considered firms, the GHG emissions under Scope 1 have on average decreased between 2010-2021, both in absolute as well as in relative terms as captured by intensities (see Figure 3).

Given the documented use of environmental scores by market participants in investment strategies (Boffo and Patalano, 2020), we collect the score for the environmental pillar (*E-score*) of Refinitiv's ESG score. The average of the distribution of E-score observations employed in this study is 72.97. The type of business activity that the firm performs is related to greenhouse gases that the firm emits in the course of operating its activity. Firms that have business activities relating to a GHG-intensive sector (NACE sector) are likelier to have higher firm-level greenhouse gases than firms in other sectors. Finally, the country of the firm (*country*) may codetermine the level of emissions through the channel of country-specific environmental policies and the country's overall sentiment for environmental matters (Baiardi and Morana, 2021). The detailed description of the variables are provided in the online appendix (Table A6) along with summary statistics (Table A7).

The set of qualitative variables employed in this study for assessing the firm's management of climate-related transition risk includes indicators on: (i) internal policies, (ii) target setting, (iii) emissions trading, and (iv) internal carbon pricing. Also in this case, the data is retrieved from Refinitiv, Bloomberg, and CDP.

These indicators are qualitative in nature and widely used in the empirical literature on corporate social responsibility and ESG. Dedicated dummy variables indicate whether the firm has set a target to reduce GHG emissions (*Target*) or to increase its energy efficiency (*EETarget*). The 49% of observations in the sample indicate an existing target to reduce greenhouse gas emissions in the reference firm and 33% of observations in the sample indicate an existing energy efficiency target. Most firms started setting up transition-risk-related targets after the Paris Agreement in 2015 as shown in Figure 5. Firms that commit to a target are expected to manage their exposure to transition risk (Bolton and Kacperczyk, 2021c). Whether a firm has linked its climate-related targets to its management remuneration is captured by the dummy *TargetIncentives*, which takes the value 1 for 83% of observations in the sample. This variable allows assessing further the degree of commitment of the firm for reducing emissions. The existence of internal policies on climate-related matters is reflected through the dummies *ClimatePolicy*, *GHGPolicy*, and *EEPolicy*. Firms engaging in the trading of GHG certificates are captured through the dummy *GHGTrading* and constitute 54% of the observations in the sample. Internal carbon pricing is a practice voluntarily adopted by firms to embed the climate footprint in their operations and business models (Bento and Gianfrate, 2020) and can be seen as an internal risk management tool (Gollier, 2020; Breidenich et al., 2021). Firms that have an internal carbon pricing framework are captured through the dummy *CO2InternalPrice*. The 93% of observations in the sample indicate an existing internal carbon pricing in the reference firm. The detailed description of the variables are provided in the online appendix (Table A8) along with summary statistics (Table A9).

3.4 Indicators of carbon market related exposure

The set of indicators employed for assessing a firm's exposure to and management of transition risk through the European carbon market (EU ETS) are collected from the EU Transaction Log for the Phase 3 (2013 - 2020). Under the EU ETS, stationary installations and airlines are required to report their verified emissions for the previous year by end of March and to hand in a corresponding number of allowances (EUA) by end of April. The data on verified emissions, free allowances, and surrendered allowances, is made publicly available in May. Against this background, all ETS related indicators are therefore lagged by 5 months in the analysis in this paper.

Firms having at least one installation under the European Union's EU ETS are identified through the dummy *ETS*. The 34% of observations relate to firms that conduct activities that are subject to the EU ETS. Whereas almost a quarter of observations shows a surplus of free allowances (*EUAexcess*), the vast majority of observations show a deficit of free allowances and hence a need for the firm to buy additional EUA to compensate for its actual ETS-related greenhouse gas emissions (*EUAdeficit*). The data on free allowances (*ETS-EUA*) and ETS-related GHG emissions (*ETS-GHG*) for installations subject to the ETS is retrieved from the publicly available EU Transaction Log. The stationary installations and airlines are mapped to an owner firm using Bureau van Dijk Orbis database.

In total, we identify 70 firms in the sample that hold at least one ETS installation either directly or indirectly through one or more of their undertakings. The NACE1-sectors of these 70 firms (not limited to C-Manufacturing and D-Electrictiy, Gas, and Air Conditioning Supply) are varied and representative of the full sample.The detailed description of the variables are provided in the online appendix (Table A10) along with summary statistics (Table A11).

4 Identification strategy

In the following, we describe our identification strategies for the specified hypotheses that rely on a panel regression methodology and a DiD approach.

4.1 Panel regressions for transition risk and credit risk horizon

The empirical specification employed for the test of hypothesis *H1* focuses on the direction and the significance of the relationship between transition risk and credit risk at different time horizons. Therefore, we estimate the following model:

$$\begin{aligned} \textit{CDS-tenor}_{i,t} = & \alpha + \beta_1 \textit{ExposureTR}_{i,t} + \\ & \Sigma_{j=1}^{N} \gamma_j \textit{Controls}_{j,i,t} + \rho \textit{FirmFE}_i + \tau \textit{TimeFE}_t + \varepsilon_{i,t}, \end{aligned} \tag{1}$$

where the dependent variable $\textit{CDS-tenor}_{i,t}$ is the measure of firm CDS-implied credit risk at tenor 1, 5, 10, or 30 years, corresponding to $\textit{lnCDS}\text{-}1y_{i,t}$, $\textit{lnCDS}\text{-}5y_{i,t}$, $\textit{lnCDS}\text{-}10y_{i,t}$, $\textit{lnCDS}\text{-}30y_{i,t}$, respectively.

The independent variable $\textit{ExposureTR}_{i,t}$ corresponding to GHG absolute emissions under Scope 1, i.e. $\textit{Scope1}_{i,t}$, or Scope 1 GHG emissions relative to total assets, i.e., $\textit{Scope1TA}_{i,t}$, or relative to revenues, i.e., $\textit{Scope1Rev}_{i,t}$, described in the section 3.3.

The vector $\textit{Controls}_{j,i,t}$ includes the control variables described as traditional determinants of CDS-implied credit risk in the section 3.2 and is common throughout the different specifications in this section.

Unobserved variation at firm and time level are captured through firm fixed-effects $\textit{FirmFE}_i$ and time fixed-effects $\textit{TimeFE}_t$. Firm fixed effects are included to absorb unobserved and time-invariant firm-specific characteristics while time fixed effects are included to account for unobservable macroeconomic factors that may affect credit spreads over time. All regressions are clustered on both the time and firm dimensions to account for cross-sectional and serial correlation in error terms.

Analogously, we test hypothesis *H2* on the direction and the significance of the relationship among firm's management of transition risk and credit risk at different time horizons.

Thus, we specify the following model:

$$\begin{aligned} CDS\text{-}tenor_{i,t} = & \alpha + \beta_1 ManagementTR_{k,i,t} + \\ & \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \varepsilon_{i,t}, \end{aligned} \tag{2}$$

where the vector $ManagementTR_{i,t}$ includes the variables used to proxy for a firm's management of transition risk $Target_{i,t}$, $EETarget_{i,t}$, $TargetIncentives_{i,t}$, $ClimatePolicy_{i,t}$, $GHGPolicy_{i,t}$, $EEPolicy_{i,t}$, $GHGTrading_{i,t}$, $CO2InternalPrice_{i,t}$, described in Section 3.3.

Furthermore, we test whether management activities have a mitigating effect for exposure to transition risks and credit risk with a full specification:

$$\begin{aligned} CDS\text{-}tenor_{i,t} = & \alpha + \beta_1 ExposureTR_{i,t} + \beta_2 ManagementTR_{k,i,t} + \\ & \beta_3 \left(ExposureTR_{i,t} \times ManagementTR_{i,t} \right) + \\ & \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \varepsilon_{i,t}, \end{aligned} \tag{3}$$

Finally, we test the hypotheses *H3a-b*. Hypothesis *H3a* relates to the relationship between a firm's exposure to carbon-related transition risk and the CDS-implied credit risk. Therefore, we estimate the following model:

$$\begin{aligned} CDS\text{-}tenor_{i,t} = & \alpha + \beta_1 ExposureETS_{i,t} \times ExposureTR_{i,t} + \\ & \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \varepsilon_{i,t}, \end{aligned} \tag{4}$$

The independent variable $ExposureETS_{i,t}$ corresponds to a dummy variable indicating firms that are subject to the EU ETS and firms that are not subject to the EU ETS.

Hypothesis *H3b* tests the relationship between a firm's positive cash flows derived from EUA surplus and a firm's CDS-implied credit risk:

$$\begin{aligned} CDS\text{-}tenor_{i,t} = & \alpha + \beta_1 ExposureTR_{i,t} + \beta_2 EUA\text{-}GHG_{i,t} + \\ & \Sigma_{j=1}^{N} \gamma_j Controls_{j,i,t} + \rho FirmFE_i + \tau TimeFE_t + \varepsilon_{i,t}. \end{aligned} \tag{5}$$

The independent variables *EUA-GHG* corresponds to a firm's free allowances minus ETS emissions, expressed in million tonnes.

In an alternative specification, we replicate the analyses on the slopes of the CDS term structure, lnSlope(5y-1y)$_{i,t}$, lnSlope(10y-1y)$_{i,t}$, lnSlope(30y-1y)$_{i,t}$, which is a measure of a firm's CDS term structure at term 5, 10, or 30 years relative to 1 year, respectively.

4.2 DiD approach to measure the shift in market awareness after the Paris Agreement

In order to test hypothesis *H4*, we employ a difference-in-differences (DiD) design, which is a quasi-experimental identification strategy that allows estimating causal effects. We use such a framework to investigate whether there have been changes in CDS spread for European high polluting firms versus other European firms, before and after the Paris Agreement. This rational is linked to the study of Bolton and Kacperczyk (2021a) that find a strong and positive effect on returns for high polluting firms defined based on Scope 1 emissions:

$$\begin{aligned} \textit{CDS-tenor}_{i,t} =& \alpha + \beta_0 \textit{Treatment}_i \times \textit{postParis}_t + \\ & \Sigma_{j=1}^{N} \gamma_j \textit{Controls}_{j,i,t} + \rho \textit{FirmFE}_i + \tau \textit{TimeFE}_t + \varepsilon_{i,t}. \end{aligned} \tag{6}$$

The indicator variable $\textit{Treatment}_i$ is defined for each firm i similar to the specification used by Bolton and Kacperczyk (2021a): brown firms are identified as those that belong to the top quartile of GHG emissions $\textit{Scope1}_{i,t}$. In our case, the quartiles are determined based on the values as of November-2015, i.e., the period just before the Paris Agreement.

The indicator variable $\textit{postParis}_t$ takes the value 1 for the period when the shock occurs, i.e., December 2015, and for the four month-periods following the shock, and the value 0 for the four month-periods preceding the shock. The treatment (control) group includes the firms for which the indicator variable $\textit{Treatment}_i$ takes the value 1 (0). β_0 is the difference-in-differences coefficient of interest. The set of controls is described in the section 3.2 as well as firm and time fixed effects.

For robustness, we employ three alternative specifications for defining brown firms: (i) firms in the top quartile of GHG intensity, calculated based on $\textit{Scope1TA}_{i,t}$; (ii) firms in the top quartile of GHG intensity, calculated based on $\textit{Scope1Rev}_{i,t}$; (iii) firms in the bottom quartile of environmental score based on $\textit{E-score}_{i,t}$.

As an additional analysis, we inspect the effect of the Paris Agreement on the CDS-market-implied credit risk of low polluting firms, instead of high polluting firms. The later rational is linked to the study of Monasterolo and De Angelis (2020) suggesting that after the Paris Agreement stock market investors have started globally to consider low-carbon assets as an appealing investment opportunity. Green firms are identified as those that belong to the bottom quartile of GHG emissions $\textit{Scope1}_{i,t}$. For robustness, we employ three alternative specifications for identifying green firms: (i) firms in the bottom quartile of GHG intensity based on $\mathit{Scope1TA}_{i,t}$; (ii) firms in the bottom quartile of GHG intensity, calculated based on $\mathit{Scope1Rev}_{i,t}$; (iii) firms in the top quartile of environmental score based on $\mathit{E\text{-}score}_{i,t}$.

Finally, by the means of a triple difference-in-differences, we separately investigate on a dedicated subsample whether following the Paris Agreement the CDS market assesses differently high polluting firms operating in high polluting industries, which are exposed to public scrutiny, by comparison with high polluting firms in low polluting industries. High polluting industries, such as Electricity, gas, steam and air conditioning supply and Mining of metal ores, have been exposed to more scrutiny by the public (e.g., activists and NGOs) than low polluting industries, affecting market sentiment. Furthermore, market participants at times make use of aggregate industry-level emissions data rather than of granular firm-level emissions data. Given the major oil price decline throughout 2015-2016, this analysis is conducted on a subsample of data excluding firms active in Oil and Basic Metals sectors, to rule out the possibility that the results of changes in CDS-implied credit risk are driven by the oil price decline.

The hypothesis is tested with the following equation:

$$\begin{aligned} \mathit{CDS\text{-}tenor}_{i,t} = & \alpha + \beta_0 \mathit{Treatment}_i \times \mathit{Scrutiny}_i \times \mathit{postParis}_t + \\ & \beta_1 \mathit{Treatment}_i \times \mathit{postParis}_t + \\ & \beta_2 \mathit{Scrutiny}_i \times \mathit{postParis}_t + \\ & \Sigma_{j=1}^{N} \gamma_j \mathit{Controls}_{j,i,t} + \rho \mathit{FirmFE}_i + \tau \mathit{TimeFE}_t + \varepsilon_{i,t} \end{aligned} \tag{7}$$

where the indicator variable $\mathit{Scrutiny}_i$ is equal to 1 for firms in high polluting sectors and $\mathit{Treatment}_i$ is equal to 1 for firms in the top quartile of GHG emissions $\mathit{Scope1}_{i,t}$.

5 Results

In this section, we present the results of the regression analyses on the panel model specification including proxies for exposure to transition risk (hypothesis H1). Next, we illustrate the results of the panel regression analyses on the model specification including proxies for the management of transition risk (hypothesis H2). Furthermore, we present the results for the carbon market related exposure (hypotheses H3a-b). Finally, we discuss the results of the DiD analysis on the relationship between low-carbon-transition indicators and

CDS-implied credit risk (hypothesis H4).

5.1 Exposure to Transition Risk and CDS-implied credit risk

The regression results of Equation 1 testing the relation between CDS spread and the exposure to transition risk as proxied by Scope 1 are presented in Table 2, Panel A. Estimates are reported consecutively without fixed effects, with country-sector-time fixed effects, and with firm-time fixed effects. The Scope 1 emissions of a firm from owned or controlled sources are positively associated with a firm 1, 5, and 10-year natural logarithm of CDS spread as shown in columns 3, 6, 9, and 12. The sign of the coefficient is stable for all tenors and the relation is statistically significant at a 5% level for the 1 and 5-year CDS spreads and at 10% level for the 10-year CDS spread. The regression coefficient of Scope 1 on the natural logarithm of 30-year CDS spread is statistically significant in the specification with country-firm-time fixed effects. When expanding to firm-time fixed effects, the standard errors increase, by comparison with country-sector-time fixed effects, suggesting a decrease in the accuracy of measurement when expanding to firm-time fixed effects. This further suggests that the lack of statistical significance of this coefficient in the specification with firm-time fixed effects occurs solely because of no sufficient within-firm variation. The magnitude of the coefficient for Scope 1 indicates that an increase in one unit of Scope 1 is associated with a 0.47% increase in the 1-year CDS spread, 0.37% in the 5-year CDS spread, 0.24% in the 10-year CDS spread, and 0.23% in the 30-year CDS spread. Given that the average 5-year CDS spread for the sample of this study is 127 bps, this implies that, on average, an increase of 1 million tonnes eCO2 in Scope 1[19] is associated with a spread that is 0.47 bps higher. Similarly, given that the average 30-year CDS spread is 173 bps, this implies that, on average, an increase of 1 million tonnes eCO2 in Scope 1 emissions results in a spread that is 0.40 bps higher, by comparison with 0.47 bps higher for the 5-year CDS spread.

In addition to the panel regression results for scope 1 in absolute terms *Scope1*, Table 2 shows the results for two alternative specifications: scope 1 relative to revenues *Scope1Rev* and scope 1 relative to total assets *Scope1TA*. The results are shown for the full sample, i.e., February 2010 to April 2021 (Panel A) as well as for the post-Paris subsample, i.e. January 2016 to April 2021 (Panel B). Over the full period, i.e., February 2010 to April

[19] For an indicative reference of the order of magnitude, the sample mean of the distribution of observations of Scope 1 emissions is 9.54 million tonnes eCO2, while the median is 0.4 million tonnes eCO2.

2021, only Scope 1 in absolute terms displays a significant positive relationship with the CDS spread at certain tenors, but not Scope 1 in relative terms, i.e. intensities.

The second panel shows that over the period post Paris Agreement, all three alternative specifications of Scope 1 display a positive relationship with the CDS spread at all tenors. Furthermore, we evaluate the relation between Scope 1 and the natural logarithm of 5-year CDS spread in each year of the sample by the means of a cross-sectional regression. The marginal effect of a one unit increase in Scope 1 on the natural logarithm of the 5-year CDS spread are presented in Figure 6. The positive sign of the relationship is remarkably stable over all years of the sample. Where the relation is statistically significant, the magnitude of the yearly marginal effect of Scope 1 on the natural logarithm of 5-year CDS spread is in the range (0.27%; 0.47%).

Finally, we evaluate the marginal effect of a one unit increase in Scope 1 for each industry group to determine for which industry groups the relation between the CDS spread is positive and statistically significant. The results are presented in Table 3 for the major NACE1 sectors with the following breakdown: top-GHG polluting manufacturing activities (category C-topghg including NACE2 19, 20, 23, 24), manufacturing of cars (category C-car including NACE2 29), other manufacturing activities (category C), electricity, gas, and air conditioning supply (NACE1 D), information and communication (NACE1 J), transportation and storage (NACE1 H, which includes the high emitting air travel sector), and all other activities (category Rest). The relation between Scope 1 and the spread is positive and statistically significant for the industry groups electricity, gas, and air conditioning supply, as well as for transportation and storage. Higher Scope 1 emissions in firms active in these sectors are associated with higher CDS spreads across all maturities of the CDS term structure. Interestingly, the estimate coefficient for firms in top polluting manufacturing activities is negative, albeit not statistically significant across the CDS term structure.

To support the regression results on CDS spread and Scope 1 GHG emissions, we report in the online Appendix the results on CDS slope and Scope 1 GHG emissions (Table C1).[20] Furthermore, we repeat the analysis using the natural logarithm of Scope

[20]Table C1 shows that the level of Scope 1 emissions of a firm is significantly positively associated with the natural logarithm of the slope 5y-1y, which is the difference between the 5-year and the 1-year CDS spread. The sign of the coefficients in the specifications on the slope 10y-1y and 30y-1y is also positive, albeit not statistically significant because of insufficient within-firm variation, as indicated by the increasing standard errors for the coefficients in the firm-time fixed effects specification by comparison with those in the country-sector-time fixed effects specification. The results on hypothesis 1 show that there is a positive relationship between a firm's exposure to transition risk, as proxied by the firm's Scope 1 emissions, and

1, instead of Scope 1 (Table C2) and also for the CDS slope (Table C3). The conclusions regarding H1 are qualitatively unaffected.

5.2 Management of Transition Risk and CDS-implied credit risk

The regression results of Equation 2 on CDS spread and a firm's efforts of managing transition risk are presented in Table 4. The act of disclosing an emission reduction target (*Target*) and the act of trading emissions certificates (*GHGTrading*) are both significantly negatively associated with the natural logarithm of the 1, 5, 10, and 30-year CDS spread. Furthermore, the act of linking the emission reduction target to the remuneration of the management of the firm (*TargetIncentives*) is significantly associated with a lower 30-year CDS spread. The results on the transition management indicators *EETarget*, *ClimatePolicy*, *GHGPolicy*, *EEPolicy*, and *CO2InternalPolicy* do not suggest that related transition management efforts are associated with lower CDS spreads (i.e. lower CDS-implied credit risk).[21]

Next, by interacting transition-management-related dummies (*Target*, *GHGTrading*, *TargetIncentives*) with the variable Scope 1 (*Scope1*), we test whether such activities have a mitigating effect for Scope 1 on the CDS spread as per Equation 3. The regression results are included in Table 5 and show that where the firm discloses an emission reduction target, the marginal effect of Scope 1 emissions on the CDS spread is reduced at all tenors, i.e., 1, 5, 10, and 30 years. Particularly, the marginal effect of a one unit increase in Scope 1 results in a 0.44% increase in the natural logarithm of the 5-year CDS spread for a firm that does not disclose a target versus a 0.28% increase in the natural logarithm of the 5-year CDS spread for a firm that discloses a target. This result suggests that the CDS market considers firm's commitments to reduce emissions as a factor reducing the magnitude of the effect of Scope 1 on the perceived credit risk. However, this result is ambiguous as it may be driven by the massive adoption of targets in the aftermath of the Paris Agreement as shown in Figure 5. Finally, the act of trading emission certificates does not appear to have a mitigating effect.[22]

In the online Appendix, we report the results on CDS slope and such indicators (Table

the firm's CDS-implied credit risk, particularly for the tenor 1 and 5 years, i.e., short and medium term.

[21] The results are stable in a robustness specification where each of these dummy variables are tested separately.

[22] The results hold when controlling in addition for Refinitiv's environmental score, suggesting that the interaction between the exposure and the management of transition is an information that is not captured by the environmental score.

C4). The act of disclosing an emission reduction target is significantly negatively associated with the slope 5y-1y while the act of trading emissions certificates is associated negatively with the slope 5y-1y and 10y-1y and significant at 10% level. However, in interaction with Scope 1 as per Equation 1, these variables do not show a significant relationship with the CDS slope (Table C5 in the online Appendix). The results on qualitative indicators of management do not suggest that these are accounted for in the CDS market. Particularly, the act of disclosing an emission reduction target is associated with lower CDS spread and CDS slope, however this result is not conclusive in the light of the fact that a big wave of firms in our sample disclosed targets just after the Paris Agreement.[23]

5.3 Transition Risk and the European carbon market

CDS spreads may be more sensitive to changes in transition risk for firms that pursue an activity which is subject to the EU ETS, since the carbon market puts a price on ETS-related emissions. Against this background, we verify as reported in Equation 4 whether the estimated coefficients of Scope 1 for firms subject to the ETS are stronger and significantly different from the estimated coefficients on non-ETS firms. Table 6 shows the results of eventual differential effects of perceived transition risk exposure, as proxied by Scope 1, across firms that are subject to the EU ETS and firms that are not subject to the EU ETS. The results are shown on two samples: the full sample covering EU ETS Phase 3 (2013-2020) and the subsample starting 2017 when the CO2 price, i.e. EUA spot price, started increasing at a faster pace. Regarding the full sample, all findings indicate a positive relationship albeit not statistically significant. However, the results on the subsample 2017-2021 show a positive and statistically significant relationship between Scope 1 and the CDS spread across all maturities for both ETS-firms and non-ETS firms. The post-estimation test fails to reject the hypothesis that the estimated coefficients for ETS differ in a statistically significant manner from the estimates for non-ETS firms. Overall, these results suggest that CDS market participants do not consider whether a firm's emissions are subject to the EU ETS or not. On the other hand, CDS market participants became potentially overall more sensitive to firm-level emissions information once the carbon price started rising steadily from 2017 on-wards.

In the EU ETS framework, the emissions-related costs are given by the amount of veri-

[23]While we cannot disentangle distinctly the consideration of emission reduction targets by CDS market participants in our sample, other existing studies provide suggestive evidence that such targets are being considered by credit rating agencies and stock market participants.

fied emissions minus allowances that a firm received for free. Where a firm has a shortfall of allowances, the firm shall acquire the amount of missing allowances on the carbon market. A positive balance indicates an excess of free allowances and hence cash for the firm that may reduce credit risk. A negative balance indicates a shortfall and hence a cost for the firm that may lead to higher credit risk. Following Equation 5, Table 7 shows the results on CDS spread of Scope 1 and of the balance of allowances for the subsample of ETS-exposed firms. The estimated coefficient for *EUA-GHG* suggests that a higher balance is associated with a lower 1-year CDS spread. Yet, the estimate is not statistically significant. For the remaining maturities, the estimates are positive, contrary to the expected sign. When repeating the analysis for *EUA-GHGeur*, which is the monetary balance of allowances minus emissions upon applying the carbon price, the obtained estimates have different signs across maturities and are not statistically significant. These results suggest that CDS market participants are likely not considering ETS-related cash flows in their estimates of credit risk of a firm.

5.4 Emissions and CDS-implied credit risk after the Paris Agreement

For the purpose of the DiD on the Paris Agreement, we construct a subsample that includes only firms who have a quote for a CDS spread continuously for 9 months in a row around the Paris Agreement.

Figure 7 shows the evolution of the CDS spread for the tenor 5, 10, and 30 years of the treatment and control groups over the 9 months around the date of the Paris Agreement, i.e., December 2015. The observed CDS spread of the treatment group (high polluting firms) was below the CDS spread of the control group (all other firms) before the event. Interestingly, the relation inverted in the months immediately after the event and the effect lasted for several months. The CDS spread of the treatment group was again below the one of the control group four months after the event for tenors 5, 10, and 30 years, and two months after the event for tenor 1 year.

The results of the difference-in-differences regressions on CDS spread for "brown" firms are shown in Table 8. Estimates are presented for each of the four tenors of the CDS spread (1, 5, 10, and 30 years respectively), showing first the estimate DiD coefficients for a basic difference-in-differences specification, followed by estimates for a DiD specification with firm-time fixed effects, and thirdly for a DiD specification with controls and with firm-time fixed effects as per Equation 6. The DiD estimates for the treatment (*TreatScope1Q4*

× *PostEvent*) have all a positive sign, indicating that after the Paris Agreement the CDS spreads increased for the treatment group more than for the control group. The coefficients are statistically significant for the 5, 10, and 30-year CDS spreads. Regarding the DiD estimated coefficient for the 1-year CDS spread, it is statistically significant in the basic difference-in-differences specification and in the specification with firm-time fixed effects, but not once controls are added, although the positive sign is still as expected. These results highlight that following the Paris Agreement European high polluting firms get higher spreads, i.e., higher CDS-implied credit risk. The increase is by an additional 0.082, 0.068, and 0.077 units relative to the change in the natural logarithm of the spread for the control group.

The DiD approach assumes the existence of a common trend among both treatment and control groups, i.e., CDS spread for the treatment and control group would have developed similarly after the event as before the event in case there would have been no Paris Agreement. This assumption ensures that any difference between both groups results from the event itself and can be tested by comparing the evolution of the CDS spread of the treatment and control groups before the event. If treatment and control groups evolve similarly over time, the common trend assumption is likely to hold.

Figure 8 shows the point estimates for each period from a regression following closely the Equation 6, but where the variable *Treatment* is interacted with yearly dummies, instead of the *postParis* dummy. The pre-treatment coefficients are nearly zero in their point estimate. Moreover, the standard errors of the estimates are very small, suggesting that these are very precisely estimated near-zero differences between firms in the treatment and control group prior to the Paris Agreement.

5.4.1 Robustness and additional analysis

To check the robustness of our findings, we run alternative robustness analyses. We also report results of additional analysis.

The oil price decline in 2015-2016

Low oil prices affect negatively the revenues of oil companies. Oil companies have two broad groups of activities: (i) upstream activities that include locating, testing, and setting up drilling sites for oil extraction, (ii) downstream activities that include refining and distributing of oil-related products, e.g., gasoline. Upstream activities heavily rely on industrial manufacturing companies, e.g., steel and heavy machines for the supply of materials necessary for oil drilling operations. While declining oil prices directly affect oil companies, a related contraction in upstream activities of these firms may negatively affect the supplying manufacturing sectors.

With this background, we construct a subsample that excludes firms active in the oil and basic metal sectors and run the DiD regressions on this subsample. The results are shown in the online Appendix (Table C6) and are quantitatively similar to the results on the full sample. This robustness check rules out the possibility that the DiD results are driven by the oil price decline observed in 2015-2016.

Alternative definitions of the treatment

In the following, we use alternative definitions of the treatment. First, we consider Scope 1 emission intensity by revenues and emission intensity by total assets. We report in the online Appendix (Tables C7 and C8) the DiD results. As expected, all DiD coefficients have a positive sign for all tenors, albeit not statistically significant, with the exception of the point estimate for the 30-year CDS spread using emission intensity by total assets.

Second, the treatment definition is based on the bottom quartile of the E-score distribution (Table C9 in the online Appendix). The DiD coefficients have a negative sign, suggesting a decrease in credit risk for firms with bad environmental scores following the Paris Agreement. The results are statistically significant at 10% level for the 5, 10, and 30 years CDS spread. This outcome suggests that the E-score does not allow differentiating between high emitting firms and other firms in a non-ambiguous manner.

Alternative definitions of the dependent variable

In an alternative specification, we use as dependent variable the natural logarithm of the CDS slope, instead of the CDS spread (Table C10 in the online Appendix). The DiD estimates for the treatment ($\mathit{TreatScope1Q4} \times \mathit{PostEvent}$) have all a positive sign, indicating that after the Paris agreement the CDS slope increased for the treatment group more than for the control group. The DiD estimated coefficients are statistically significant for all terms of the slope, i.e., 5y-1y, 10y-1y, and 30y-1y. The increase in the natural logarithm of the 5y-1y, 10y-1y, and 30y-1y CDS slope is by an additional 0.086, 0.061, and 0.071 units, respectively, relative to the change in the natural logarithm of the corresponding CDS slope for the control group. This suggests that CDS market participants expect the short, medium and long term credit risk of these firms to be higher than that for firms in the control group.

Figure C1 in the online Appendix shows the point estimates for each of the 9 periods of the observation window from a regression following Equation 6, but where the variable *Treatment* is interacted with yearly dummies, instead of the *postParis* dummy. Similar as in the DiD analysis on CDS spread, the pre-treatment coefficients are nearly zero in their point estimate. Moreover, the standard errors of the estimates are very small, suggesting that these are very precisely estimated near-zero differences between firms in the treatment and control group prior to the Paris Agreement.

Temporariness of the effect

To inspect whether the effect of the Paris Agreement on the market sentiment of European CDS market participants was only momentary, we extend the observation window around the event from 9 months to 49 months (2 years before and 2 years after). The results are included in Table 9. Albeit none of the results are statistically significant in the specification with controls and firm-time fixed effects, the DiD coefficients have a positive sign for the 5, 10, and 30-year CDS spread. A possible explanation for the observed variation is that in June 2016 and the subsequent months the European CDS market was affected by the Brexit vote.[24]

Additional analysis on low-emitting firms

Whereas the above analysis is looking at high-emitting firms relative to other firms, we ask in an alternative specification whether the Paris Agreement had a positive effect on the CDS-implied credit risk of low emitting firms relative to other firms. The unreported results of this additional analysis are more ambiguous and do not allow answering this question.[25]

5.4.2 High polluting firms operating in high polluting industries

Finally, Table 10 shows the results of the triple difference-in-differences regressions on the natural logarithm of CDS spread of "brown" firms in scrutinized industries as per Equation 7. The results are presented for the natural logarithm of the 5, 10, and 30-year CDS spread, respectively, showing first the estimated DiD coefficients for a DiD specification with firm-time fixed effects, and then for a DiD specification with controls and with firm-time fixed effects. The triple DiD estimated coefficient for high polluting firms in scrutinized industries ($Treatsc1Q4 \times Scrutiny \times PostEvent$) has a positive sign

[24] IHS Markit was writing on June 24 "A shock result in yesterday's UK referendum has seen wild reaction in the credit market". https://ihsmarkit.com/research-analysis/24062016-credit-credit-markets-in-freefall-after-shock-brexit-result.html

[25] Results are available upon request for interested readers.

and is statistically significant at 1% level, indicating that after the Paris Agreement the 5, 10, and 30-year CDS spreads increased particularly for high polluting firms in scrutinized industries by comparison with the control group. The increase in the 5, 10, and 30-year natural logarithm of the CDS spread for these firms is by an additional 0.13, 0.014, and 0.13 units, respectively, relative to the change in the natural logarithm of the spread for the control group. The estimated coefficient for *Scrutiny* × *PostEvent* is negative and statistically significant at 1% level, indicating that post Paris non-top-polluting firms that are active in scrutinized sectors have experienced a decrease in CDS spreads.

For robustness, similarly as reported for CDS spread, Table 11 shows the results of the triple DiD regressions on the natural logarithm of the CDS slope of "brown" firms in scrutinized industries. The triple DiD estimated coefficient is positive for all three terms, i.e., 5y-1y, 10y-1y, and 30y-1y, albeit not statistically significant.

Overall, the results on the *H4* confirm that following the Paris Agreement European high polluting firms get higher CDS spreads and slopes, i.e., higher CDS-implied credit risk for medium, long, and very long term. The results on the parallel trend assumption in conjunction with the DiD results suggest the existence of a potential causal relationship between a firm's exposure to transition risk, as proxied by Scope 1 emissions, and medium, long, and very long term credit risk, as proxied by CDS spread and slope. These DiD results on the 2015 Paris Agreement are robust to the oil price decline observed in 2015-2016. Finally, following the Paris Agreement, the CDS spread of high polluting firms, which are active in scrutinized industries, increased more than the CDS spread of high polluting firms in non-scrutinized industries, suggesting that the scrutiny of the industry plays a role in the CDS market's assessment of a firm's exposure to transition risk.

6 Conclusion

The European low-carbon transition started in the last decades and is accelerating for reaching the EU's next GHG reduction target by 2030 and net-zero by 2050. In this paper, we study how in Europe a firm's climate-related transition risk, as proxied by disclosed GHG emissions and transition management indicators, relates to the firm's CDS-implied short, medium, long, and very-long-term credit risk. As proxies for the time horizon of the effect of climate-related transition risk on credit risk, we use the 1, 5, 10, and 30-year CDS spread. Based on a sample composed of over 200 European large corporate firms, we find that firms with higher Scope 1 GHG emissions have higher CDS-implied credit risk and the relation appears to be causal as confirmed in a difference-in-differences analysis around the Paris Agreement. Particularly, after the Paris Agreement, the relation between Scope 1 emissions and CDS spreads is reflected at all time horizons of the CDS term structure. This result is mainly driven by high emitters in salient industries, such as Electricity, Gas, and Mining. When looking at transition management, CDS market participants do not appear to price the mitigation effects of qualitative indicators of transition management such as targets, policies, remuneration, and / or risk management. Moreover, the results suggest no differential treatment of the Scope 1 GHG emissions based on the fact whether the firm is subject to the EU ETS and herewith exposed to emissions costs or not. Finally, CDS market participants are likely not considering ETS-related cash flows gained from a surplus of free allowances in their assessment of a firm's credit risk.

Overall, the results in this paper suggest that the European CDS market is already pricing to some extent, albeit small, the information of Scope 1 emissions of a firm, but much of the readily available information on other climate-related transition indicators - whether on transition management efforts or carbon market exposure - is not reflected. For instance, banks and investment firms are the main type of market participants on the European CDS market as well as on the European regulated carbon markets, e.g., EEX, ICE Endex and Nasdaq Oslo, where emissions allowances and derivatives thereof are traded (see for instance ESMA (2021) regarding carbon markets). The results of this analysis suggest however that the information on emissions allowances is not reflected by CDS market participants. A possible explanation is that while the information is available within the part of the financial institution covering the carbon markets, it is not considered by the part of the institution covering the credit risk assessment for single-name corporate CDS market.

This study contributes to the wider discussion on the data needs of financial institutions for assessing the climate related transition risk of non-financial corporations to which they are exposed (Elderson, 2021; ECB, 2021b; NGFS, 2021) by highlighting what is already available yet not used. A wide range of climate-related transition risk indicators are available in data sources such as Bloomberg and Refinitiv, which most financial institutions use in day-to-day business, as well as in publicly available sources, such as the EU Transaction Log run by the European Commission.

While this paper analysis whether and to which extent climate-related transition indicators are priced into credit risk, future research shall assess what would be the just level of the impact of the climate-related transition risk on credit risk to be priced in and how the just level compares to the current level. Moreover, future work shall consider the estimation of shadow climate-related transition CDS spreads, where climate-related transition indicators of a firm are evaluated in standardized transition scenarios that offer a forward-looking assessment of losses related to a particular firm at different time horizons.

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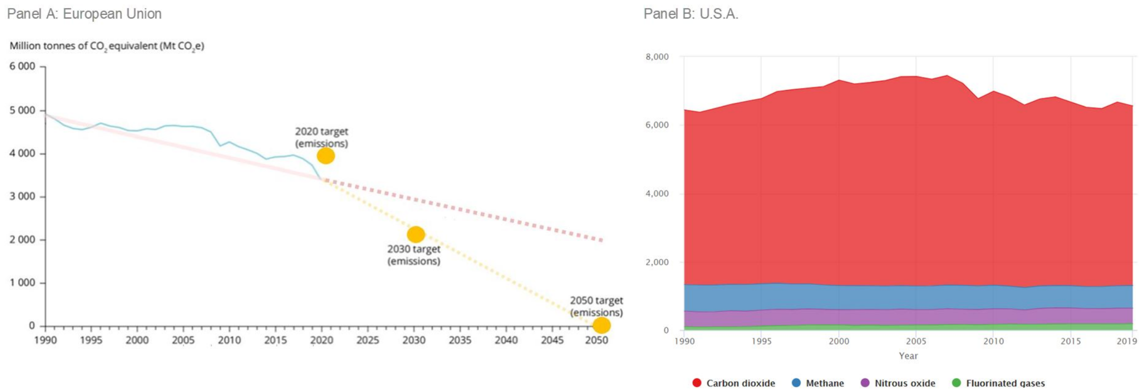
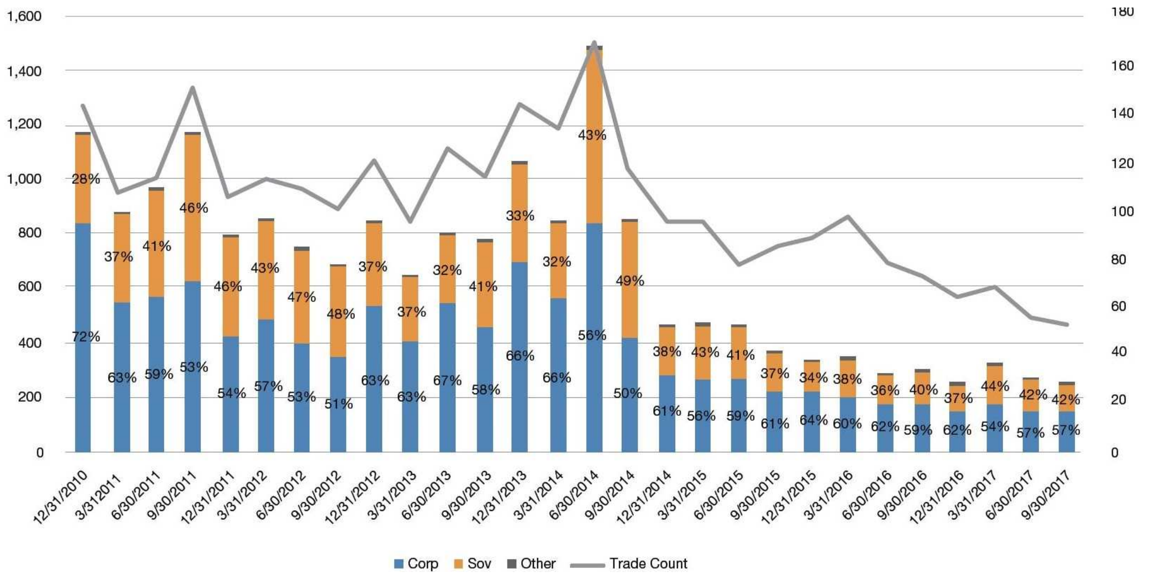
Figure 1: EU Greenhouse Gas (GHG) in the European Union and in the United States.



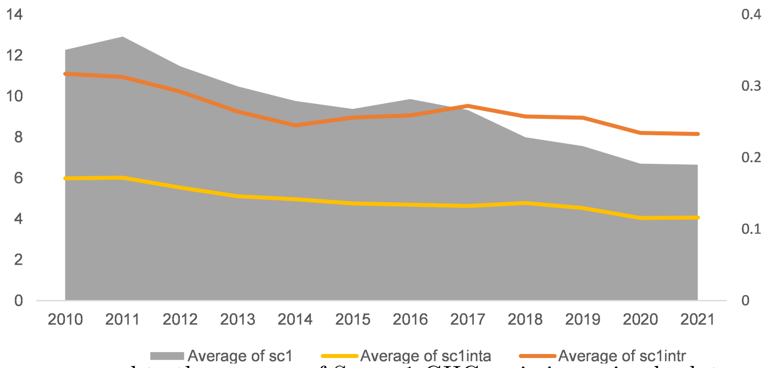
Notes: Panel A: Historical GHG emissions (blue line) of European Union's member states, historical trend (red line) and future trend based on targets (yellow line). Source: European Environmental Agency and authors' adaptation https://www.eea.europa.eu/data-and-maps/figures/greenhouse-gas-emission-trend-projections. Panel B: Historical GHG emissions of United States. Y-axis: Million tonnes eCO2. X-axis: Time period 1990 - 2019 in years. Source: United States Environmental Protection Agency https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. Y-axis: Million tonnes eCO2. X-axis: Time in years.

Figure 2: Time series of European Single Name CDS Notional Traded and Trade Count



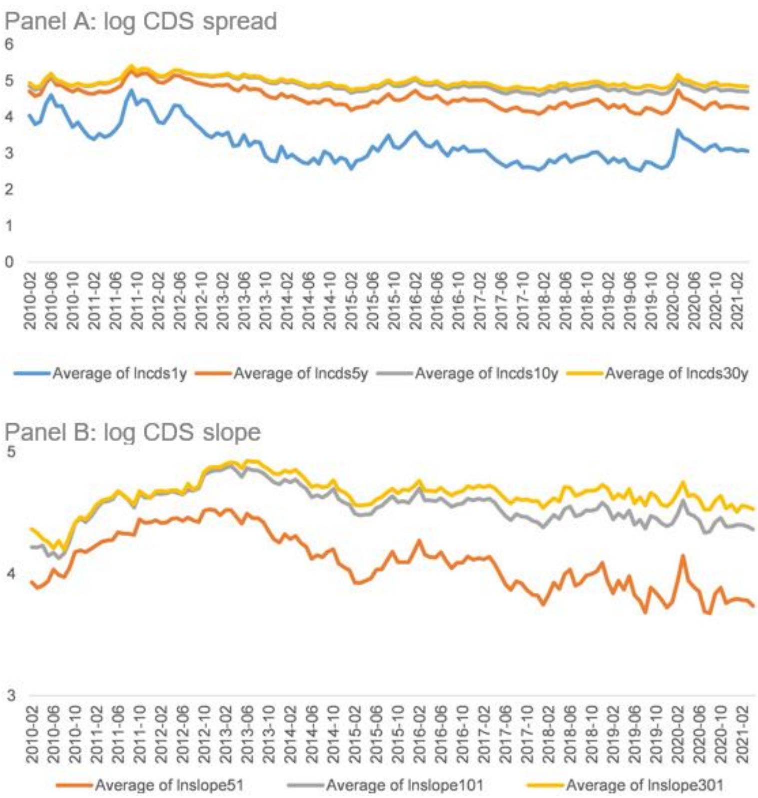
Notes: Left axis: Traded notional in USD (Billions). Right axis: Number of contracts in (Thousands). Time period Dec. 2010 - Sep. 2017. Source: ICMA (2018)

Figure 3: Time series of the Scope 1 GHG emissions and corresponding emissions intensity



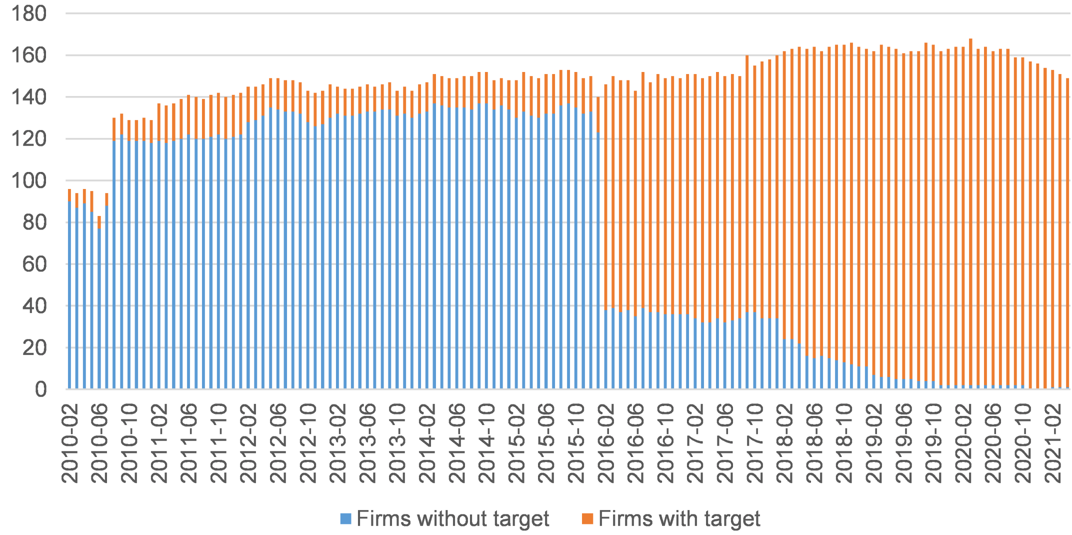
Notes: The values correspond to the average of Scope 1 GHG emissions - in absolute and relative terms - observed in the sample. Left-axis: million tonnes eCO2. Right-axis: million tonnes eCO2 by billion euros. X-axis: Time in years. Time period Feb. 2010 - Apr. 2021.

Figure 4: Time series of the natural logarithm of CDS spread and CDS slope



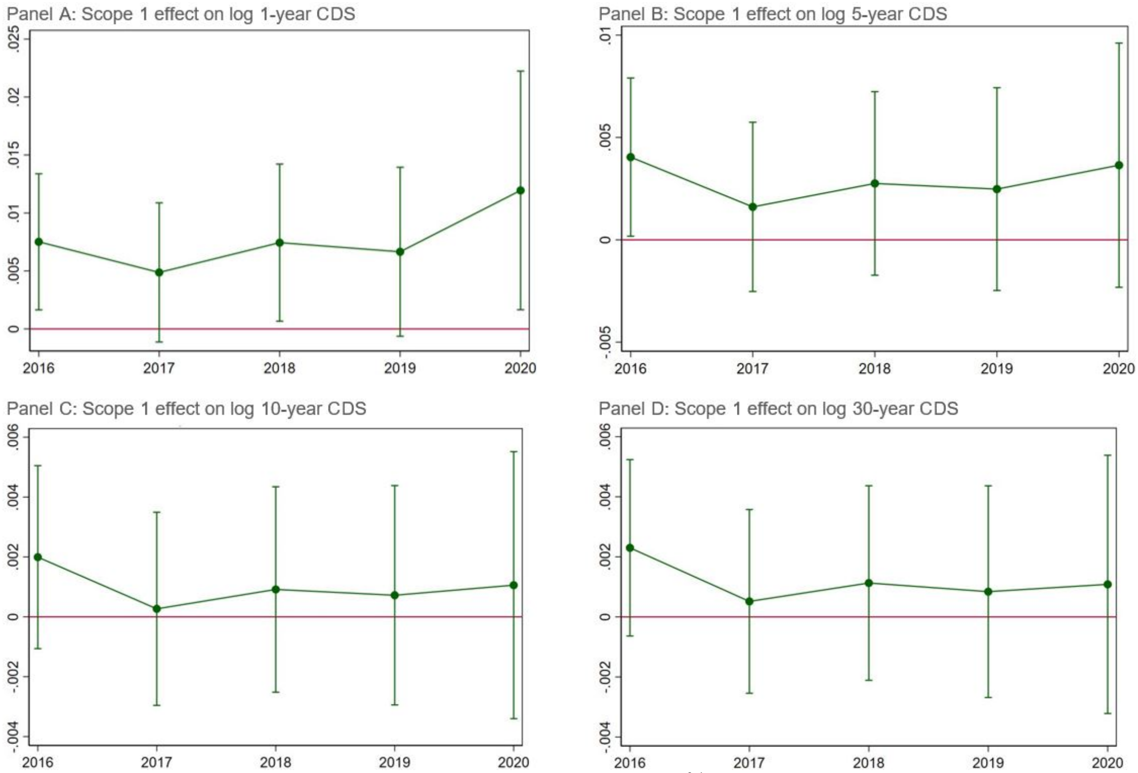
Notes: The values correspond to the average end-of-month natural logarithm of CDS spread (Panel A) and CDS slope (Panel B) observed in the sample. Panel A, Y-axis: Natural logarithm of CDS spread. Panel B, Y-axis: Natural logarithm of CDS slope. X-axis: Time in month-periods. Time period Feb. 2010 - Apr. 2021.

Figure 5: Evolution of number of CDS-reference firms with and without an emission reduction target



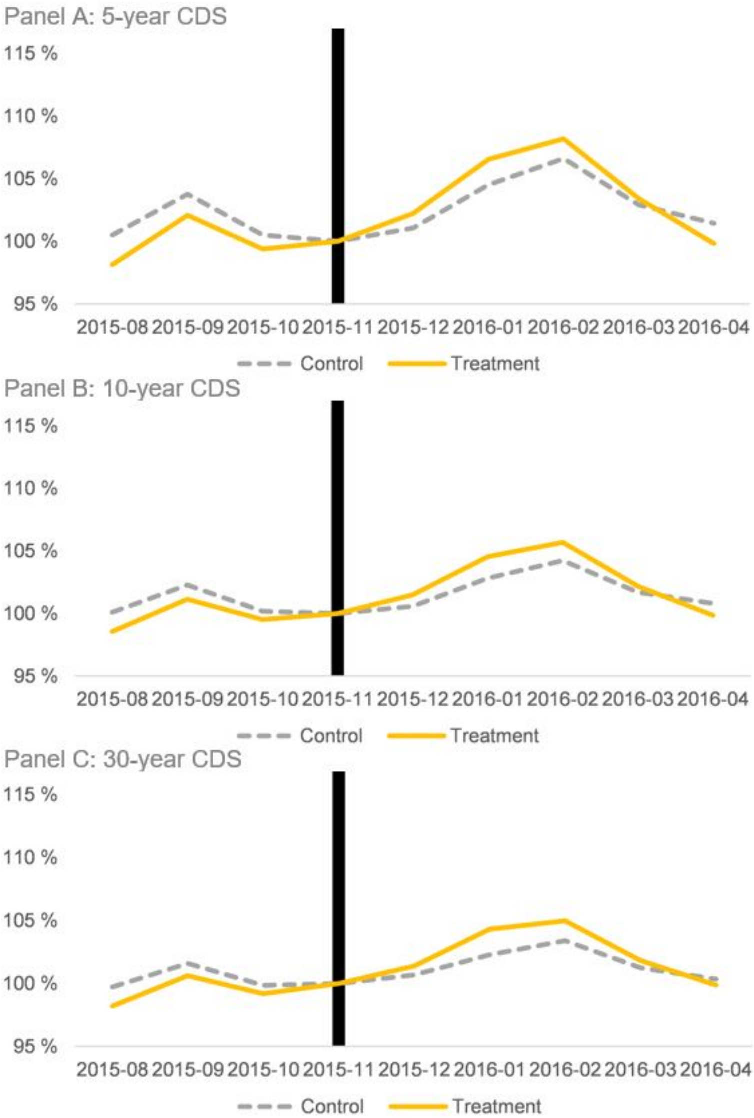
Notes: The values correspond to the number of firms observed in the sample with and without an emission reduction target. Y-axis: Number of CDS-reference firms with an observed CDS quote for tenor 1, 5, 10, and 30 years. X-axis: Time in month-periods. Time period Feb. 2010 - Apr. 2021.

Figure 6: Average marginal effect of Scope 1 on the natural logarithm of CDS spread



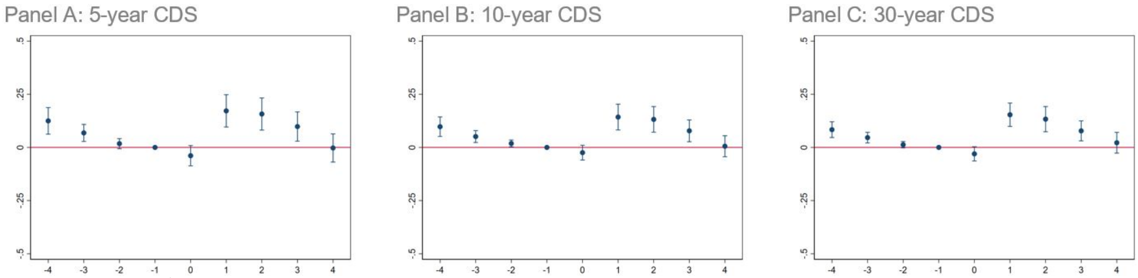
Notes: Panels A, B, C, D show the marginal effect with 95% confidence interval of Scope 1 on the natural logarithm of the 1, 5, 10, and 30-year CDS spread respectively . For a firm who is average on all characteristics, the marginal change of a 1-unit increase in Scope 1 indicates the corresponding percentage increase in the natural logarithm of the CDS spread in the respective year. The underlying sample contains firms that have a continuous CDS quote throughout the period Jan. 2016 - Dec. 2020. Y-axis: Average marginal effect. X-axis: Time in years.

Figure 7: Time series of the natural logarithm of CDS spread around the Paris Agreement



Notes: Panels A, B, C show the evolution of the 5, 10, and 30-year CDS spread, respectively, of two groups of firms. The treatment group includes firms in the top quartile of the Scope 1 emissions distribution as of 2015-11. The control group includes all other firms. Observations are scaled at 100 for the period November 2015, i.e period just before the event. Y-axis: Value of the natural logarithm of the CDS spread relative to the value as of 2015-11. X-axis: Time in month-periods.

Figure 8: Treatment effect for each period of the event window for the DiD results around the Paris Agreement on the natural logarithm of CDS spread



Notes: Panels A, B, C show the treatment effect for each period of the event window for the DiD results around 2015-12 on the natural logarithm of 5, 10, and 30-year CDS spread, respectively. The treatment group includes firms in the top quartile of the Scope 1 emissions distribution as of 2015-11. The control group includes all other firms. Y-axis: Value of the natural logarithm of the CDS spread relative to the value as of 2015-11. X-axis: Time in month-periods.

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Table 1: Sample composition by year, country, and sector

Year	N#	F#	Country	N#	F#	Sector (NACE1)	N#	F#
2010	1208	136	Austria	192	3	B-Mining and quarrying	305	4
2011	1662	151	Belgium	500	6	C-other-Manufacturing other	6723	67
2012	1747	154	Czech Rep.	97	1	C-topghg-Manufacturing top emitting	2720	27
2013	1739	156	Denmark	480	6	D-Electricity, gas, steam, air con.	2276	24
2014	1793	161	Finland	917	8	E-Water supply	309	3
2015	1806	164	France	4479	41	F-Construction	602	8
2016	1773	164	Germany	3366	37	G-Wholesale and retail trade	1351	16
2017	1834	172	Greece	238	2	H-Transportation and storage	1039	12
2018	1962	174	Hungary	99	1	I-Accommodation and food service	618	6
2019	1958	172	Ireland	21	1	J-Information and communication	2724	26
2020	1942	170	Italy	1144	16	M-Professional, scientific, technical act.	495	6
2021	607	156	Luxembourg	270	2	N-Administrative and support services	624	7
			Netherlands	1251	12	Q-Human health and social work	149	2
			Poland	87	1	R-Arts, entertainment and recreation	96	2
			Portugal	260	3			
			Spain	967	11			
			Sweden	1371	14			
			UK	4292	45			
Obs.	20031	210	Obs.	20031	210	Obs.	20031	210

Notes: The table shows the number of observations in the resulting sample by year, country, and sector (NACE1 classification). Where a NACE1 class includes - among other sectors - high-polluting sectors, these sectors are defined in a separate class. The class C-topghg includes the following activities: (C) 19 - Manufacture of coke and refined petroleum products, (C) 20 - Manufacture of chemicals and chemical products, (C) 23 - Manufacture of basic metals (C) 24 - Manufacture of other non-metallic mineral products. The class D includes (D) 35 - Electricity, gas, steam and air conditioning supply activities. The class H includes (H) 51 - Air transport activities. The timespan of the sample is February 2010 to April 2021.

Table 2: Scope 1 emissions in absolute and relative terms and CDS spread

VARIABLES	lnCDS-1y	lnCDS-1y	lnCDS-1y	lnCDS-5y	lnCDS-5y	lnCDS-5y	lnCDS-10y	lnCDS-10y	lnCDS-10y	lnCDS-30y	lnCDS-30y	lnCDS-30y
Scope1	0.0047**			0.0037**			0.0024*			0.0023		
	(0.0023)			(0.0016)			(0.0014)			(0.0014)		
ScopeRev		0.038			0.18			0.15			0.15	
		(0.30)			(0.20)			(0.15)			(0.13)	
Scope1TA			0.26			0.46			0.29			0.24
			(0.54)			(0.37)			(0.27)			(0.24)
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firms	210	193	208	210	193	208	210	193	208	210	193	208
Observations	20,031	18,074	19,769	20,031	18,074	19,769	20,031	18,074	19,769	20,031	18,074	19,769
R-squared	0.787	0.790	0.788	0.827	0.832	0.829	0.837	0.843	0.840	0.835	0.840	0.837

VARIABLES	lnCDS-1y	lnCDS-1y	lnCDS-1y	lnCDS-5y	lnCDS-5y	lnCDS-5y	lnCDS-10y	lnCDS-10y	lnCDS-10y	lnCDS-30y	lnCDS-30y	lnCDS-30y
Scope1	0.0043**			0.0040***			0.0025**			0.0028**		
	(0.0019)			(0.0014)			(0.0012)			(0.0011)		
Scope1Rev		0.41**			0.25**			0.20**			0.21***	
		(0.19)			(0.12)			(0.085)			(0.074)	
Scope1TA			0.87**			0.71**			0.49**			0.51**
			(0.34)			(0.30)			(0.23)			(0.22)
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firms	195	181	193	195	181	193	195	181	193	195	181	193
Observations	10,075	9,314	9,949	10,075	9,314	9,949	10,075	9,314	9,949	10,075	9,314	9,949
R-squared	0.840	0.845	0.842	0.879	0.882	0.880	0.893	0.895	0.894	0.895	0.896	0.895

Notes: The dependent variable is the natural logarithm of CDS spread for the tenor 1 year, 5 years, 10 years, and 30 years, respectively. Panel A shows the results for the full sample period Feb. 2010 to Apr. 2021. Panel B shows the panel regression results for the sample period Jan 2016 to Apr. 2021, which is following the Paris Agreement (Dec. 2015).The definition of all variables is given in tables A1 and A6. All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 3: Scope 1 emissions by sector and CDS spread

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
C×Scope1	0.023	-0.048	-0.043	-0.055
	(0.098)	(0.076)	(0.060)	(0.052)
C-car×Scope1	0.47	0.39	0.47	0.34
	(0.41)	(0.31)	(0.29)	(0.26)
C-topghg×Scope1	-0.018	-0.012*	-0.0076	-0.0064
	(0.014)	(0.0066)	(0.0049)	(0.0043)
D×Scope1	0.0048***	0.0046***	0.0029***	0.0031***
	(0.0016)	(0.0012)	(0.00099)	(0.00098)
J×Scope1	0.65	1.84	1.23	0.77
	(2.60)	(1.51)	(1.12)	(1.00)
H×Scope1	0.13***	0.084***	0.059**	0.055**
	(0.050)	(0.025)	(0.022)	(0.024)
Rest×Scope1	0.036	-0.010	-0.020	-0.0063
	(0.076)	(0.058)	(0.050)	(0.041)
Controls	Y	Y	Y	Y
Sector F.E.	Y	Y	Y	Y
Country F.E.	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Firms	195	195	195	195
Observations	10,075	10,075	10,075	10,075
R-squared	0.842	0.880	0.894	0.895

Notes: The dependent variable is the the natural logarithm of CDS spread for the tenor 1 year, 5 years, 10 years, and 30 years, respectively. The panel regression results are shown on the subsample period January 2016 to April 2021, which is following the Paris Agreement (December 2015). The definition of all variables is given in tables A1 and A6. The class C-topghg includes the following GHG-intensive activities: 19 - Manufacture of coke and refined petroleum products, 20 - Manufacture of chemicals and chemical products, 23 - Manufacture of basic metals 24 - Manufacture of other non-metallic mineral products. The class Manufacturing other includes all manufacturing firms except Manufacturing of cars and Manufacturing topghg. All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 4: Exposure management and CDS spread

VARIABLES	lnCDS-1y	lnCDS-1y	lnCDS-1y	lnCDS-5y	lnCDS-5y	lnCDS-5y	lnCDS-10y	lnCDS-10y	lnCDS-10y	lnCDS-30y	lnCDS-30y	lnCDS-30y
Target	-0.34***	-0.10	-0.14**	-0.25***	-0.058	-0.079**	-0.14***	-0.040	-0.063**	-0.079***	-0.034	-0.057**
	(0.014)	(0.075)	(0.054)	(0.0092)	(0.059)	(0.036)	(0.0075)	(0.050)	(0.028)	(0.0071)	(0.048)	(0.028)
EETarget	-0.0083	-0.032	0.035	0.028***	-0.0039	0.017	0.042***	-0.00041	0.014	0.047***	0.00070	-0.0028
	(0.014)	(0.062)	(0.063)	(0.0090)	(0.048)	(0.045)	(0.0073)	(0.040)	(0.037)	(0.0070)	(0.039)	(0.035)
TargetIncentives	-0.29***	-0.17*	-0.11	-0.19***	-0.15**	-0.070	-0.13***	-0.14**	-0.064	-0.12***	-0.13**	-0.072*
	(0.021)	(0.094)	(0.079)	(0.013)	(0.075)	(0.049)	(0.011)	(0.063)	(0.039)	(0.011)	(0.059)	(0.038)
ClimatePolicy	0.20***	0.063	0.0097	0.10***	0.020	-0.0052	0.10***	0.015	-0.010	0.11***	0.016	-0.016
	(0.019)	(0.077)	(0.073)	(0.012)	(0.060)	(0.048)	(0.010)	(0.050)	(0.037)	(0.0098)	(0.047)	(0.036)
GHGPolicy	0.41***	0.32	0.0035	0.22***	0.12	-0.10	0.17***	0.10	-0.067	0.14***	0.094	-0.049
	(0.059)	(0.20)	(0.094)	(0.044)	(0.15)	(0.064)	(0.037)	(0.14)	(0.049)	(0.035)	(0.13)	(0.047)
EEPolicy	-0.31***	-0.21	0.12	-0.31***	-0.19*	0.074	-0.26***	-0.15	0.038	-0.25***	-0.15	0.022
	(0.034)	(0.13)	(0.13)	(0.023)	(0.10)	(0.064)	(0.019)	(0.093)	(0.052)	(0.019)	(0.091)	(0.050)
GHGTrading	-0.22***	-0.072	-0.14**	-0.17***	-0.087	-0.11**	-0.15***	-0.097**	-0.080**	-0.14***	-0.095**	-0.065*
	(0.014)	(0.071)	(0.066)	(0.0090)	(0.053)	(0.046)	(0.0074)	(0.045)	(0.037)	(0.0070)	(0.043)	(0.034)
CO2InternalPrice	-0.036	-0.052	0.10	0.012	-0.013	0.082	-0.042***	-0.042	0.030	-0.076***	-0.058	0.011
	(0.024)	(0.11)	(0.099)	(0.018)	(0.078)	(0.072)	(0.015)	(0.063)	(0.056)	(0.014)	(0.059)	(0.052)
Controls	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sector F.E.	N	Y	N	N	Y	N	N	Y	N	N	Y	N
Country F.E.	N	Y	N	N	Y	N	N	Y	N	N	Y	N
Time F.E.	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Firm F.E.	N	N	Y	N	N	Y	N	N	Y	N	N	Y
Cluster firm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firms	210	210	210	210	210	210	210	210	210	210	210	210
Observations	20,031	20,031	20,031	20,031	20,031	20,031	20,031	20,031	20,031	20,031	20,031	20,031
R-squared	0.290	0.586	0.789	0.388	0.602	0.829	0.399	0.595	0.839	0.392	0.585	0.836

Notes: The dependent variable is the percentage change of the natural logarithm of CDS spread for the tenor 1 year, 5 years, 10 years, and 30 years, respectively ($lnCDS\text{-}1y\Delta^{\%}$, $lnCDS\text{-}5y\Delta^{\%}$, $lnCDS\text{-}10y\Delta^{\%}$, $lnCDS\text{-}30y\Delta^{\%}$). The interacted variables correspond to the interaction between sector-group dummies (C, C-topghg, D, J, Other), where each group has more than 2000 observations, and Scope 1 percentage changes. The independent variables are percentile change of Leverage, percentile change of size, percentile change of liquidity, and dummies corresponding to the rating class or to unrated. The definition of all variables is given in tables A1 and A4. The results for each type of tenor-specific dependent variable are presented for an OLS regression, regression with country - sector - time fixed effects, and regression with firm - time fixed effects. All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 5: The mitigating effect of proxies of management on Scope 1 in relation with the natural logarithm of CDS spread

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
Scope1	0.0047*	0.0037**	0.0021	0
	(0.0025)	(0.0018)	(0)	(0.0017)
Target	-0.11**	-0.067*	-0.054*	-0.048*
	(0.055)	(0.036)	(0.029)	(0.028)
Target×Scope1	-0.0026***	-0.0017**	-0.0012*	-0.0013**
	(0.00089)	(0.00077)	(0.00061)	(0.00058)
GHGTrading	-0.13*	-0.10**	-0.083**	-0.073**
	(0.072)	(0.049)	(0.038)	(0.036)
GHGTrading×Scope1	0.0021	0.0014	0.0021	0.0027
	(0.0028)	(0.0024)	(0.0019)	(0.0021)
Controls	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Firms	210	210	210	210
Observations	20,031	20,031	20,031	20,031
R-squared	0.789	0.829	0.839	0.837

Notes: The dependent variable is the natural logarithm of the spread in basis points for the tenor 1, 5, 10, and 30 years(*lnCDS-1y*, *lnCDS-5y*, *lnCDS-10y*, *lnCDS-30y*). The independent variables are Scope 1 emissions of the firm (*Scope1*), the act of disclosing an emission reduction target (*Target*), and the act of trading emissions certificates (*GHGTrading*). The definition of all variables is given in tables A1, A6, and A8. The results are presented for a regression with firm - time fixed effects. All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 6: Transition risk through the ETS and CDS spread

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
Scope1				
- ETS	0.0030	0.0029	0.0013	0.0014
	(0.0023)	(0.0018)	(0.0015)	(0.0015)
- non-ETS	0.0035	0.0036**	0.0018	0.0020
	(0.0023)	(0.0017)	(0.0015)	(0.0015)
Controls	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Observations	13,527	13,527	13,527	13,527
R-squared	0.790	0.847	0.866	0.867

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
Scope1				
- ETS	0.011**	0.0086**	0.0062**	0.0065**
	(0.0049)	(0.0039)	(0.0026)	(0.0026)
- non-ETS	0.0072***	0.0061***	0.0041***	0.0039***
	(0.0023)	(0.0014)	(0.0011)	(0.0011)
Controls	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Observations	8,299	8,299	8,299	8,299
R-squared	0.862	0.897	0.911	0.913

Notes: The table shows the results of an OLS regression with firm - time fixed effects for each type of tenor-specific dependent variable. The top panel shows the results on the ETS Phase 3 period, while the bottom panel shows the results on the subsample 2017- 2021.

Table 7: Transition risk of ETS-exposed firms and CDS spread

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
Scope1	0.0089***	0.0069***	0.0049***	0.0047***
	(0.0028)	(0.0017)	(0.0013)	(0.0013)
EUA-GHG	-0.0020	0.0076	0.0095	0.012**
	(0.017)	(0.0083)	(0.0065)	(0.0058)
Controls	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Observations	2,915	2,915	2,915	2,915
R-squared	0.839	0.900	0.913	0.914

VARIABLES	lnCDS-1y	lnCDS-5y	lnCDS-10y	lnCDS-30y
Scope1	0.0086***	0.0064***	0.0043***	0.0040***
	(0.0028)	(0.0017)	(0.0013)	(0.0013)
EUA-GHGeur	0.00040	0.000055	-0.000034	-0.000076
	(0.00060)	(0.00033)	(0.00026)	(0.00026)
Controls	Y	Y	Y	Y
Time F.E.	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y
Cluster time	Y	Y	Y	Y
Observations	2,915	2,915	2,915	2,915
R-squared	0.839	0.900	0.913	0.914

Notes: The table shows the results of an OLS regression with firm - time fixed effects for each type of tenor-specific dependent variable for the subsample 2017-2021 and only for ETS-exposed firms. The top panel shows the results of the balance of allowances and emissions in million tonnes eCO2 (*EUA-GHG*), while the bottom panel shows the results of the monetary balance of allowances and emissions in million EUR after having applied the carbon price (*EUA-GHGeur*).

Table 8: Difference-in-Differences on CDS spread around the Paris Agreement in December 2015 and treated firms in top quartile of Scope 1 distribution

VARIABLES	lnCDS-1y	lnCDS-1y	lnCDS-1y	lnCDS-5y	lnCDS-5y	lnCDS-5y	lnCDS-10y	lnCDS-10y	lnCDS-10y	lnCDS-30y	lnCDS-30y	lnCDS-30y
TreatScope1Q4×PostEvent	0.079*	0.079*	0.051	0.098***	0.098***	0.082***	0.080***	0.080***	0.068***	0.087***	0.087***	0.077***
	(0.046)	(0.046)	(0.045)	(0.030)	(0.030)	(0.029)	(0.024)	(0.024)	(0.022)	(0.023)	(0.023)	(0.022)
PostEvent	0.15***	-0.034	-0.016	0.091***	0.024	0.033	0.066***	0.021	0.027*	0.063***	0.022	0.026*
	(0.029)	(0.042)	(0.042)	(0.014)	(0.022)	(0.020)	(0.010)	(0.016)	(0.015)	(0.011)	(0.016)	(0.015)
TreatScope1Q4	0.19			0.19			0.17			0.16		
	(0.16)			(0.13)			(0.12)			(0.11)		
Controls	N	N	Y	N	N	Y	N	N	Y	N	N	Y
Time F.E.	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Firm F.E.	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firms	128	128	128	128	128	128	128	128	128	128	128	128
Observations	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152	1,152
R-squared	0.027	0.343	0.381	0.037	0.410	0.459	0.035	0.401	0.454	0.036	0.356	0.398

Notes: All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 9: Difference-in-Differences on Paris Agreement for a 49-months-event-window and treated firms in top quartile of scope 1 distribution

VARIABLES	lnCDS-1y	lnCDS-1y	lnCDS-1y	lnCDS-5y	lnCDS-5y	lnCDS-5y	lnCDS-10y	lnCDS-10y	lnCDS-10y	lnCDS-30y	lnCDS-30y	lnCDS-30y
TreatScope1Q4×PostEvent	-0.0041	-0.0048	-0.069	0.069	0.069	0.013	0.068*	0.068*	0.024	0.068*	0.068*	0.028
	(0.067)	(0.067)	(0.057)	(0.048)	(0.049)	(0.040)	(0.040)	(0.040)	(0.033)	(0.039)	(0.039)	(0.033)
PostEvent	0.091*	-0.48*	-0.29	-0.031	-0.52***	-0.37**	-0.043*	-0.41***	-0.29***	-0.0061	-0.33***	-0.22**
	(0.046)	(0.27)	(0.26)	(0.031)	(0.16)	(0.15)	(0.024)	(0.11)	(0.11)	(0.023)	(0.10)	(0.100)
TreatScope1Q4	0.076			0.064			0.077			0.083		
	(0.13)			(0.12)			(0.11)			(0.10)		
Controls	N	N	Y	N	N	Y	N	N	Y	N	N	Y
Time F.E.	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Firm F.E.	N	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Firms	113	113	113	113	113	113	113	113	113	113	113	113
Observations	5,537	5,537	5,537	5,537	5,537	5,537	5,537	5,537	5,537	5,537	5,537	5,537
R-squared	0.006	0.372	0.433	0.007	0.330	0.447	0.012	0.299	0.432	0.013	0.236	0.368

Notes: All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 10: Triple difference-in-differences for changes in CDS spread around the Paris Agreement in December 2015 and differentiating between scrutinized and other sectors

VARIABLES	lnCDS-5y	lnCDS-10y	lnCDS-30y	lnCDS-5y	lnCDS-10y	lnCDS-30y
TreatScope1Q4×Scrutiny×PostEvent	0.15***	0.16***	0.15***	0.13**	0.14***	0.13***
	(0.054)	(0.042)	(0.038)	(0.051)	(0.038)	(0.035)
TreatScope1Q4×PostEvent	0.044	0.026	0.037	0.045	0.027	0.038*
	(0.038)	(0.028)	(0.026)	(0.033)	(0.024)	(0.023)
TreatScope1Q4×Scrutiny	-0.14	0.030	0.11			
	(0.23)	(0.20)	(0.20)			
Scrutiny×PostEvent	-0.10***	-0.11***	-0.11***	-0.098***	-0.11***	-0.099***
	(0.015)	(0.011)	(0.011)	(0.020)	(0.014)	(0.014)
TreatScope1Q4	0.017	0.034	0.022			
	(0.18)	(0.16)	(0.16)			
Scrutiny	0.28***	0.074	0.0072			
	(0.061)	(0.053)	(0.052)			
PostEvent	0.090***	0.066***	0.061***	0.038*	0.032**	0.029*
	(0.015)	(0.011)	(0.011)	(0.021)	(0.015)	(0.016)
Controls	N	N	N	Y	Y	Y
Time F.E.	Y	Y	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y
Firms	120	120	120	120	120	120
Observations	1,080	1,080	1,080	1,080	1,080	1,080
R-squared	0.1218	0.1234	0.1302	0.437	0.434	0.375

Notes: All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.

Table 11: Triple difference-in-differences for changes in CDS slope around the Dec. 2015 Paris Agreement and differentiating between scrutinized and other sectors.

VARIABLES	lnSlope(5y-1y)	lnSlope(10y-1y)	lnSlope(30y-1y)	lnSlope(5y-1y)	lnSlope(10y-1y)	lnSlope(30y-1y)
TreatScope1Q4×Scrutiny×PostEvent	0.082	0.11**	0.10**	0.00011	0.051	0.041
	(0.055)	(0.047)	(0.046)	(0.062)	(0.049)	(0.048)
TreatScope1Q4×PostEvent	0.049	0.031	0.045*	0.053	0.034	0.048**
	(0.038)	(0.027)	(0.024)	(0.034)	(0.025)	(0.023)
Scrutiny×PostEvent	-0.065***	-0.099***	-0.093***	0.0071	-0.045**	-0.037*
	(0.016)	(0.013)	(0.014)	(0.035)	(0.021)	(0.021)
TreatScope1Q4×PostEvent	0.049	0.031	0.045*	0.053	0.034	0.048**
	(0.038)	(0.027)	(0.024)	(0.034)	(0.025)	(0.023)
PostEvent	0.061***	0.037***	0.033**	0.055**	0.037**	0.033*
	(0.016)	(0.013)	(0.014)	(0.022)	(0.017)	(0.018)
TreatScope1Q4	0.031	0.055	0.040			
	(0.19)	(0.16)	(0.16)			
Scrutiny	0.055	-0.14***	-0.22***			
	(0.056)	(0.048)	(0.048)			
Controls	N	N	N	Y	Y	Y
Time F.E.	Y	Y	Y	Y	Y	Y
Firm F.E.	Y	Y	Y	Y	Y	Y
Cluster firm	Y	Y	Y	Y	Y	Y
Firms	120	120	120	120	120	120
Observations	1,080	1,080	1,080	1,080	1,080	1,080
R-squared	0.0655	0.0364	0.0369	0.217	0.132	0.091

Notes: All regressions are clustered on both the time and firm dimension to account for cross-sectional and serial correlation in the error terms. Robust standard errors are reported in parentheses. The statistical significance of the estimated parameters is indicated by *** for a p-value of 0.01, ** for a p-value of 0.05, and * for a p-value of 0.10.